University of Michigan

Xebra Electric-Hydraulic Vehicle Redesign for Accessibility and Maintainability

ME450 Winter 2010 Team 10 Final Report

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Executive Summary

The U.S. Environment Protection Agency (EPA) is developing a hydraulic hybrid car by retrofitting a Xebra® electric car. The vehicle uses electricity as its primary power source and is capable of utilizing a regenerative braking system that can store kinetic energy usually lost during braking in the form of pressurized hydraulic fluid. This hydraulic regenerative braking system has been proven to improve the efficiency of conventional (electric) regenerative braking by up to 40%. Previous ME 450 teams were able to improve the performance of the car but the disjointedness of these projects increased the system's complexity. The sponsor requirements for our team were to improve the maintainability, serviceability and simplicity of the vehicle while maintaining the vehicle's performance.

Through the use of a quality function deployment (QFD), we were able to clearly define the goals of the project. A complete QFD can be found in Appendix IV. With our goals set, we began generating concepts for five different aspects of the design: 1) accessibility of the batteries 2) accessibility of the hydraulics 3) accessibility of the electrics 4) improving the overall simplicity and 5) safety. Using a feasibility chart (Appendix VIII) and Pugh charts (Appendix IX), we filtered out the impractical concepts and were left with three to four concepts aimed at improving each aspect. Many combinations of concepts were considered in creating possible final designs. A final comparison of proposed final designs was performed and our Alpha Design was created. Minor refinements were made to the Alpha Design to create our Final Design. A complete list of the concepts included in our design can be found below.

Primary stage	Secondary stage
Fix recirculation valve	Color code the wires
Replace the motor controller	Include a electronic circuit diagram
Create a manifold for the valves	Bundle the wires
Redesign the overhead space of batteries	Change the base of the controller board
LP Reservoir changes	Clear define the duty of the auxiliary battery
Manufacture Mounting Mechanisms	Redesign the controller board
Change the critical hydraulic connections	
Color code the hydraulic connections	
Detailed Maintenance Procedures	

As of April 18th, all objectives (both primary and secondary) have been completed and implemented on the Xebra vehicle. The custom manifold was generously donated by RHM Fluid Power and, in conjunction with our other hydraulic simplifications, allowed for battery overhead space to be achieved. Updated circuit diagrams of both the electrical and hydraulic systems have been created, the transferability for future semesters has been dramatically improved. Consequently, the troubleshooting times for both systems will be greatly improved.

Validation of the main electrical drive of the Xebra vehicle has been successfully performed with a 24% observed improvement in vehicle acceleration as a result of the updated motor controller components. Unfortunately, the hydraulic launch assist of the vehicle was not able to be validated due to unavoidable appointment cancelations by the Hose Doctor as well as a lack of testing resources (parking lot and dynamometer unavailable). We have confirmed proper operation of the hydraulic logic valves and are confident that the system is fundamentally ready for operation. The serviceability of the vehicle (specifically time to change the batteries) was dramatically improved from 2 working days to approximately 40 minutes.

For future semesters, we recommend first testing the functionality of the hydraulic launch assist system after finalizing the mounting mechanisms and replacing the hydraulic motor dump line (see summary for more detailed instructions). After the performance is validated, future improvements include further simplification of the high side hydraulics as well as an in-depth overhaul of the electrical system.

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Introduction

Over the past few years, the Environmental Protection Agency (EPA) has been involved in developing a hybrid hydraulic-electric vehicle. Previous modifications of the vehicle included installing the initial hydraulics and improving the performance. The previous work has proven the concept behind a hydraulic-electric vehicle to be feasible. The motivation behind this project is to improve the serviceability of the overall system as a step toward mass production. The outcome of this project will be a greatly simplified Xebra car in which the accessibility of critical components will be significantly improved.

Our sponsors at the EPA, Andrew Moskalik and David Swain, assigned our team with the goal of redesigning the current Xebra car for improved serviceability. The Xebra car was purchased as a purely electric vehicle in 2007 for the purpose of implementing a hybrid system that utilizes hydraulics to improve the efficiency of the car during acceleration [3]. This concept was previously applied to a bicycle where the hydraulic system was successfully implemented. The regenerative braking on the bicycle stored the energy during braking and released this energy to theoretically achieve a speed of 27 km/h without pedaling. [2]. Applying this same concept to an electric car will greatly improve the performance, efficiency, and range of a car such as the Xebra.

Previous design teams were successful in installing the hydraulic system to aid in the acceleration process through the use of regenerative braking energy [2]. The system at this point was able to achieve a range of approximately 20 miles with a top speed of 35mph [3]. After the concept of hydraulic assisted acceleration was proved, the next design team was assigned to improve the performance of the car; specifically to achieve 45mph as a top speed. Changes were made to the capacity of accumulators and gear train characteristics to achieve this top speed. With these changes the Xebra car was capable of reaching 43mph, but the shortcomings were thought to be due to a faulty motor controller and malfunctioning recirculation valve [6]. Initial troubleshooting of the problem was performed at the end of last semester but the problem was not able to be identified definitively. Resolving this issue will be the first change to the Xebra this semester; completed approximately by mid-March. While the achievements of previous teams were impressive, the overall design of the complete system is far from optimized. Mainly, access to the battery pack (consisting of 6 lead-acid batteries) requires disassembly of the entire hydraulic circuitry; a process that takes two days to safely accomplish. Other accessibility issues of certain critical components also exist and need to be addressed.

Seeing this as the one of the few main downfalls of the design, an innovative and efficient process of accessing the battery pack must be developed. With the ultimate goal of mass production, consumers will require a relatively quick and efficient method of changing the batteries. Simplifying both the electric and hydraulic circuitry along with developing this battery change method will provide great strides toward achieving mass production.

Project Requirements and Engineering Specifications

Development of Engineering Specifications

Our sponsor at EPA placed the emphasis of this term's project on the improvement of serviceability and maintainability of the car batteries. We still need to maintain the same level of performance and safety standards that the previous teams have achieved. A summary of the key customer requirements are listed below:

1. Enhance serviceability and maintainability
2. Maintain previous performance
3. Ensure stability and safety
4. Pursue simplicity and aesthetics

During the creation of our Quality Function Deployment (QFD) chart, which is included in Appendix IV, we determined the key engineering specification parameters that we want to achieve in this term, as shown below in Table 1.The target values of each performance and safety parameter were adopted from the most recent Xebra report in order to maintain the most recent performance and safety achievements. We identified the problems of the current design, which impede serviceability of key components and complicate the hydraulic system, and quantified these problem areas as our engineering parameters. Improving the serviceability and maintainability of the vehicle is synonymous with reducing the time and effort necessary to access and service parts of the vehicle. The engineering parameters associated with Serviceability, Maintainability and Simplicity were determined using the information gathered from interviewing our correspondents and obtaining their input on appropriate parameters and target values.

Customer requirements	Engineering parameter	Previous value*	Target value
Serviceability and maintainability	Number of steps to chance batteries	N/A	10
	Time to change battery	> 1 day	< 3 hour
	Electrical system trouble shoot time	N/A	< 2 hour
Performance	Top speed	> 70 km/h	> 70 km/h
	Time to reach top speed	< 140 s	< 140 s
	Mass of the vehicle	< 1100 kg	< 1100 kg
	Range of the vehicle	> 26 km	> 26 km
Safety	Location of center of gravity**	< 0.8 m	< 0.8 m
	Temperature of electric system	< 135 °C	< 135 °C
	Maximum accumulator pressure	< 25 MPa	< 25 MPa
Simplicity	Number of hydraulic fittings	≈ 85	< 75
	Total length of the wire	≈ 50 m	< 45 m

* Fall 09 ME450 Team ** From rear axle

Table 1. Key engineering specification parameters

Our design is pioneering in terms of integrating a hydraulic system with an existing electric system. There are other products commercially available utilizing the hybrid concept but with different power generation methods. For example, the Toyota Prius and Honda Civic both use a combination of gasoline and electric power. However, no data on a hydraulic-electric vehicle is readily available for comparison.

The main problem of the previous team's design is that the hydraulic system parts are on top of the electric system, making it difficult to access and maintain the batteries, the electric motor, the motor controller and the battery charger. Our sponsor regarded the ease of changing the batteries and troubleshooting the circuit as the key parameters to determine the quality of our design. This is largely because accessibility of the batteries would entail simplification of the hydraulic system on top of the batteries and because the batteries are a key component that needs to be serviced, although not as often as the hydraulic system. From the interview with Ben Hagan (a previous Xebra team member), the current time to change the battery is about two working days. The time to troubleshoot the electric system was not given because of the complexity of the layout and the previous team's focus on the dynamic systems of the vehicle. From our own experiences in changing car batteries and interviews with local mechanics, the average time of changing a battery of a conventional car is about one hour and it usually only takes about three to six major steps. Since the hydraulic system is on top of the electrical system, access to the batteries of the Xebra hybrid is more complicated and will inherently require more time and steps than for a conventional car. Taking this into account, we set our target time to change the batteries to be less than three hours and restricted the procedures to accomplish this task to be within ten steps which is a marked improvement over the previous design but still an attainable goal.

Currently the electrical system that controls the hydraulics requires an inefficient amount of time to troubleshoot because the electrical system is difficult to understand and the connections are difficult to distinguish from one another. We do not have a benchmark value from the previous team on the time to troubleshoot the electrical system. However, in discussions with Alex Duggan (a previous Xebra team member), he estimated the time to map the electrical system with a multimeter to be 24 hours.

Considering the basic operation of the electrical logic circuit and making a judgment on an acceptable amount of troubleshoot time to fully understand the system, a value of less than two hours was assigned. We realize that quantifying 'accessibility and maintainability' is an unconventional task and our methods may seem as such, but all proposed values were considered reasonable by our sponsors.

Because we decided to maintain the same performance that had been achieved by the previous team, the performance parameters stay the same in our engineering specifications. The previous team has also reached a relatively high safety level, with a safety factor of three for the supporting structure. We also use the same key specification of their safety design in our project to ensure the same standard of safety, shown in Table 1 above.

The additional requirements of our customer are simplicity and aesthetics. We decided to restrict the number of parts and connections and reduce the length of the wires to meet this requirement. We interviewed Ben Hagen, who is a graduate student that worked on this project in previous semesters. He gave us the estimate of the total length of the wire to be 50 meters and the number of hydraulic connections to be 85. Considering the hydraulic system as a whole, and taking into account that our final design does not directly address this measurable, we have assigned approximately a 10% reduction in the number of hydraulic connections. This improvement may have a much higher impact if we are only analyzing the modified sections of the hydraulic circuit. Similarly, there is not much known about the current arrangement of the electrical wiring. It appears that the wiring was very poorly planned and a number of excess wires can be eliminated, but information on the specific system remains unknown. Due to this fact, a modest improvement of 10% on the length of wire was assigned but may dramatically improve once more information is known regarding the electrical system.

Formulation of Quality Function Deployment Chart

This section discusses the background, formulation, use, and results of QFD chart.

Background

The formation of the QFD chart followed the standard steps of correlating quantifiable engineering specifications from the customer requirements developed earlier in the process. An associated importance (or 'weight') was assigned to each of the given customer requirements. The customer requirements were then listed in the upper columns. The central importance matrix was discussed and filled in as a team. The matrix was assigned a value (0, 1, 3, or 9) depending on the strength of relation between the customer requirement and the engineering specification. A value of 9 indicated a strong relation and 0 indicated zero relation. After finishing the central importance matrix a relative weight was assigned to each of the engineering specifications to aid in our importance rankings. In conjunction with this result, the correlations between each engineering specification also need to be considered.

Formulation and Use

The weights assigned to each of sponsor requirements were derived after repeated discussions between our team and our sponsors. As seen in our QFD, the most important goal for our team is to improve the maintainability/ serviceability of the vehicle and to improve the accessibility of the batteries while maintaining the previous performance. As stated earlier the emphasis on access to the batteries is because the batteries require service second only to the hydraulic system. Other important sponsor requirements include making the vehicle transferable to future semesters, ensuring safety, simplifying the layout, and improving accessibility to the hydraulic and electrical system. These sponsor requirements are weighed less than the previously discussed requirements because they are not the focus of our project. Safety is very important to our project because we are working with a heavy vehicle, high pressure accumulators, an electric system with high voltages and high concentrations of energy. We will be focused on ensuring the safety of our team and those in the machine shop by carefully planning safety procedures before we work with the vehicle. Making the vehicle transferable to future semesters, simplifying the layout, improving accessibility to the hydraulic and electrical system, and maintaining the present range of the vehicle are incorporated into our project's focus and are the sponsor requirements with the highest weights. Improving the transferability, simplicity, accessibility and the maintainability are interdependent goals that will be addressed in such a way to promote a synergistic effect on one another. This is not necessarily going to always be the case; however, we plan to address the issues such that this synergistic effect is achieved. Maintaining the performance of the vehicle is an important requirement to remain conscious of. The serviceability of the vehicle was sacrificed for performance by previous teams. We cannot sacrifice performance for improved serviceability because then the project would be regressive. Improving the reliability and aesthetics are refinements to the prototype and are not necessary to improve the vehicle's functionality and serviceability. This is why these requirements hold the least weight.

Results and Correlations

The properties of the accumulators have a strong correlation to the time to reach the top speed. Larger accumulators and a higher maximum accumulator pressure will decrease the time for the vehicle to reach top speed. However, larger accumulators and a higher maximum accumulator pressure will increase the mass of the vehicle. Increasing the mass of the vehicle is not desirable as that will increase the amount of time for the vehicle to reach its top speed. Furthermore the volume of the accumulators is limited by the space under the truck bed. Changing or rearranging the mass of the vehicle may also cause the location of the center of gravity to change causing safety concerns.

The number of steps to change the batteries and the number of hydraulic connections are correlated to the time to change the batteries of the vehicle. If we can reduce the number of steps that are necessary to access the batteries it follows that the time to access the batteries will be reduced. Simplifying the hydraulic system and reducing the number of hydraulic connections that we will need to disassemble and reassemble will also reduce the time to change the batteries. Reducing the time to change the batteries has added benefit because of the batteries and the Xebra's original electrical system are both underneath the hydraulic system. Reducing the time to access the batteries will also reduce the time to troubleshoot the Xebra's original electrical system because both require simplifying the hydraulic system. Reducing the length of electrical wire will also reduce the time to troubleshoot the electrical controller board because it will simplify the layout and prevent confusion. Excess wire will inherently cause confusion to a potential maintenance personnel through the presence of unnecessary and misleading wires.

We concluded that the 'Time to Change Batteries' was by far the most important engineering specification due to its relative weight and strong dependence on other critical engineering specifications. We also realized that this parameter is positively related to other criterions of judging the serviceability and maintainability. So we will be able to focus on it without sacrificing the target values of other key specifications.

Concept Generation

This section of the report will explain our concept generation process and the general reasoning behind these concepts. Prior to beginning our formal concept generation process, we needed to fully understand the design problems at hand. To ensure that we had a thorough understanding of the design problem, we completed a functional decomposition of the current Xebra car in relation to serviceability and accessibility (Appendix V). Considering serviceability as the goal of our project, we analyzed the current car with this in mind.

Functional Decomposition

Decomposition of the Xebra car is an important step to ensure problem definition oversights are avoided. Because our project focuses on the maintainability of the vehicle and accessibility of its components, our functional decomposition focused on the functions that are necessary for regular maintenance of the vehicle. Assuming a faulty Xebra car is the main input to the system, we considered the functions that need to be accomplished to repair the faulty vehicle. The functional decomposition is divided into two main processes: gaining access to various components and the reconstruction of the system to restore the Xebra car to its operational status. The horizontal flow in the functional decomposition maps the functions necessary to gain access to various defective parts of the Xebra vehicle. The vertical flow (on the right) of the functional decomposition focuses on the reconstruction and replacement of parts in order to make the Xebra operational.

The functional decomposition illustrates how different areas of the vehicle's systems are interrelated. When servicing the hydraulics, all of the functions in our diagram are not necessary. For example, if the filter needs to be serviced, the deconstruction of the hydraulic system is not necessary and the electrical system does not need to be exposed. Alternatively, the functional decomposition also illustrates how access to the batteries and the electrical system on the current Xebra requires the most effort as deconstruction of the hydraulic system is necessary before these components can be reached. This is shown in the functional diagram; the optical signal that the electrical system is exposed is a necessary input before the operator can apply human force to guide the movements of or service the electrical components. Another example of the interdependence of the functions is that before the hydraulic system can be removed or repaired, the high pressure accumulators need to be depressurized and the hydraulic fluid has to be removed from the hydraulic system. Additionally, before the hydraulic system can be serviced in any way the truck bed needs to be removed to expose the hydraulic system.

With our knowledge of the problem and further analyses of the functional decomposition, we concluded that the most time consuming function that delays the service of the batteries is the reconstruction of the hydraulic system. According to Alexander Duggan, a former student that worked on the Xebra project, removal of the hydraulic system can be accomplished in roughly three to five hours while the reconstruction of a functional vehicle requires two days. This is due to the fact that reconstruction of the hydraulic system is a more involved process; the valves, fittings, tubing and other hydraulic components need to be installed in a specific direction with a specified torque amount. After each function was identified, possible simplifications to address each were considered. A detailed functional decomposition diagram can be found in Appendix V.

We have also included a functional decomposition in Appendix V that could theoretically be accomplished if the accessibility of the batteries was not as obstructed as it is in the present design. This functional decomposition essentially shows that the replacement of the batteries could be an independent procedure from the hydraulic system. These two functional decompositions were both taken into account when brainstorming concepts.

Brainstorming

After the functional decomposition was successfully used to breakdown the design problem, a brainstorming discussion was performed to develop concepts that addressed some of the most important customer requirements. Subcategories under the overarching requirement of serviceability and accessibility were identified as: Batteries, Hydraulics, Electrical, Simplicity, and Safety.

The first four subcategories (serviceability of the batteries, hydraulics, electronics, and simplicity of the overall system) will all include concepts that address the customer requirement of serviceability and accessibility while the final subcategory contains concepts that aim to improve the always important safety consideration. Additional concepts were generated that aimed to improve some of the other customer requirements. Below are brief descriptions of the most promising concepts generated. A detailed classification tree with every concept considered is included in Appendix VII.

Battery Access

Redesign for Overhead: There are several hydraulic components that are currently located directly over the batteries. This concept would redesign the current hydraulic system layout such that the area over the batteries would be clear for access. The improvements associated with this change would involve improving battery access and condensing the hydraulic circuitry simultaneously.

Partially Modular System: Allowing for a portion of the hydraulics to be removable would also achieve improved battery access. Two variations of this concept would be a full or partial modular system. The full system would encompass the entire hydraulic system including the high pressure accumulators and would require 3-4 people to remove. The partial system would include only the critical components directly above the batteries and would require only 1-2 people to successfully remove.

Hydraulic Access

Create Valve Manifold: To improve the maintainability of the hydraulic system, a central manifold system that would include all relevant valves would be installed. This would greatly simplify the hydraulic circuitry by making all valves available in an easily accessible location. The concept does not directly address the battery access issue but would decrease the complexity of troubleshooting and maintaining the hydraulic system.

Move Valves to Surface: The idea behind this concept is that it is difficult to reach some of the valves because they are obstructed by other hydraulic valves and tubing. This concept is to have a design such that all the critical valves are on the bounding surface of the hydraulic system so that a maintenance personnel could easily access them, thus improving the hydraulic systems serviceability.

Electrical Access

Color-code and Bundle Wires: There is a lot of uncertainty regarding the current status of the electric components of the Xebra. Determining the correct electrical circuitry and color-coding/bundling wires according to the system would clarify the way in which the controls operate. Having a clearer electrical circuitry would simplify the overall complexity of the vehicle and enable future students to understand the system faster and more efficiently.

Electric Circuit Diagram: After organizing the electrical system, a detailed circuit diagram would be placed somewhere in the vehicle for reference. This concept would be implemented in conjunction with color-coding/bundling.

Simplicity

Update Present Hydrulic Flow meter: Eliminating unnecessary tubing in the system would improve the overall simplicity of the Xebra car. One area in which this could be improved is the flow meter. Currently, a large and bulky flow meter is used with a lot of excess hydraulic tubing. Purchasing a more advanced (and smaller) flow meter would allow for the possibility of shortening some of the hydraulic tubing behind the driver.

Redesign Controller Box: Another aspect of the electrical system that is complicated is the actual controller box. It is believed that there are a number of unnecessary wires and relays that should be removed or condensed for simplicity. Again, this would greatly simplify the electrical system.

Safety

Change the diameter of Critical Connections: Currently, there are locations in the hydraulic circuitry that will potentially see high volumes of high pressure fluid and do not have the most suitable piping. Ideally a larger and more ductile alternative should be installed in these locations to handle the high volumes/pressures. This would eliminate a number of potential safety issues that exist in the Xebra.

Color-Code High Pressure Lines: Along the same lines, color-coding the high pressure fittings and lines of the hydraulic circuitry would eliminate potential issues with maintenance on the hydraulics. Clearly labeling the locations where dangerous high pressure hydraulic fluid exists will improve the overall safety of the car. Considerations associated with people who are color-blind need to be taken into account (e.g. – tactile/symbol indicator).

Concept Selection

After generating these concepts for different aspects of our design, we filtered these ideas though our concept selection stage. In this stage, our primary tools were the Feasibility Assessment Chart and the Pugh Chart.

Feasibility Assessment Chart

After the brainstorming process, we have all our raw concepts ready. Before doing any quantitative analysis, we first used the Feasibility Assessment Chart to determine the concepts we had were able to be implemented in our design. We used this chart to process all our designs and below are the examples from the entire chart in Appendix VIII.

Readiness parameter	Valve diagnostic system	Wire color-coding
Mature	Yes	Yes
Manufacturable	No	Yes
Knowledge of the Technology	No	Yes
Response in operating environment	Yes	Yes
Failure modes identified	No	Yes

Table 2. Sample feasibility assessment chart

The feasibility assessment chart checked whether the technology involved in the concept was mature, whether the devices needed to implement the concept were manufacturable, whether we had enough knowledge to create a detailed design of the concept, whether the system components involved in the concept would have normal response in operating environment and whether we were fully aware of the possible consequences if the deployed devices failed.

For example, the diagnostic system for the valves was relatively mature because similar systems had already applied to automobiles and other complex machines. However, the system would be hard to install because we would have to attach sensors to each valve and we lacked the knowledge for programming the system. Even though the operating environment of our Xebra car would allow the use of a diagnostic system and we believe the devices of the diagnostic system would be able to function, we could not identify the exact failure modes of such a system because of its complexity. The learning curve of understanding such a system could be overcome, but making this improvement would not address the primary customer requirements of accessibility/serviceability of the batteries. A more effective allotment of our time should be pursued.

By contrast, the technology is very mature for the concept of color coding the electric wires. We can easily purchase colorful wires online or in local stores. We only need to replace the old wires with the new wires, so we don't need much manufacturing. The knowledge of the technology was well understood and in the normal operating environment of the Xebra car, the system would be able to work as designed. At last, we identified three possible failure modes: the driver could be color-blind, the color could become worn out and the light could be too dim making it hard to distinguish colors. The first two modes were addressed by the idea of supplementing labels with words on the wire and the last mode can be solved by maintaining the vehicle in a well lit area.

Through this process, it was obvious for us that the concept of installing a diagnostic system for the valves was impractical and the concept of color-coding the wires would be easily implemented. Followed the same procedure, we analyzed all the other concepts and filtered out the unfeasible concepts. The reasoning for each concept failing the feasibility test are stated below. The remaining concepts that passed our feasibility test are listed in Table 3 on page 15.

Feasibility Test Failures

Battery Access
Relocation of Batteries to Passenger Seat & Relocation to the Side: Relocation of the batteries to the passenger seat or to the sides of the vehicle did not pass our feasibility test. Although these concepts are theoretically possible and would improve the accessibility and maintainability of the batteries, these concepts complicate the electrical system. We considered these concepts non-manufacturable because our team members do not have a strong background with electrical systems and we did not want to risk making the original electrical system of the Xebra nonoperational. Relocation of the batteries to the passenger would affect the center of mass for the vehicle which could cause the vehicle to roll over while turning. We are also unsure of other failure modes for the electrical system associated with relocating the batteries to either the passenger seat or to the sides. Relocating the batteries to these locations would move the batteries further from the electric motor and could cause failure modes from the wiring or other electrical components. Also, relocation of the batteries to the side of the vehicle would decrease the safety of the vehicle if something collided into the side of the vehicle. The batteries contain lead acid which is a highly caustic liquid that we should prevent any spillage of. With all these concerns considered, the underlying justification for deeming this infeasible is at the request of our sponsors at the EPA.

Drawer Mechanism & Bottom Battery Access: A drawer mechanism or an opening underneath the batteries seemed to be promising concepts at first. They would greatly improve the accessibility of the batteries and reduce the time to replace the batteries from two days to a few hours. However creating these mechanisms would require modifying the frame of the vehicle and could damage the structural integrity of the vehicle's frame. Modification of the frame could cause the frame to fail while the vehicle was moving. In addition, this concept did not meet the requirements of the sponsor because the parallel hydraulic system should supplement the original electrical system. The parallel hydraulic hybrid concept is attractive because it can be retrofitted to original systems. Modification of the Xebra car's frame was considered too intrusive to demonstrate the full benefits of adding a parallel hydraulic hybrid system.

Simplicity
Hydraulic Motor / Pump Combine: Our concept of reducing the parts of the hydraulic system by combining the hydraulic motor and the hydraulic pump proved to be unfeasible. This concept was intended to simplify the system but would actually complicate the hydraulic motor greatly. This is because the hydraulic motor is connected to the axle that drives the rear wheels of the car. In order for this motor to serve a double purpose as a pump to pressurize the hydraulic fluid (that powers the hydraulic motor) this theoretical motor would have to turn in the reverse direction. Turning the motor in the reverse direction is not possible because the motor is attached to the rear wheels. For this concept to work Xebra car would have to move in reverse to pressurize the accumulators.

Slow fill Pump Power Source: The concept of using the main electrical motor from the original Xebra to drive the slow fill pump also failed our feasibility test. This concept would require modifying the original electric motor to power the slow fill pump. This would end up complicating the system although it could eliminate the need for the slow fill pump to have an additional motor inside of it. Changing the motor of the slow fill pump would provide little benefit and would complicate the overall system. Although it could reduce the amount of parts in the hydraulic system it would complicate the electrical system.

Combine Accumulators: Combining the accumulators did not pass our feasibility test because this concept would not be manufacturable. In order to combine the accumulators while maintaining the performance of the vehicle, the accumulators would have to increase in size. The accumulators do not have enough room to increase in size because our sponsors told us that the truck bed could not be moved higher and the original frame of the vehicle should not be modified. The high pressure accumulators are already highly pressurized and increasing them even more would cause safety concerns and require different specifications for hydraulic parts. The costs in the areas of safety and financial commitment greatly outweigh the benefits of simplicity for this concept.

New Batteries: Upgrading the batteries for the Xebra car could increase the range of the vehicle but this is not the focus of our project. Upgrading the batteries while keeping the same performance values would create more space for other components and improve the ease of access to the batteries; however modifications to the original electrical system of the Xebra are not the focus of our project either. We are also unsure of how changing the batteries could affect the circuitry of the electric system.

Safety

Protect the Driver From the Hydraulic Parts : Installing a protective wall to protect the driver from errant hydraulic parts that can fail due to the high levels of pressure in the system would be a consideration for a consumer version of the vehicle. This concept is out of the scope of our project because the project focuses on improving the maintainability of the prototype. There are safety relief valves that we will preserve in our design to ensure that catastrophic failure will not occur when driving the vehicle. The benefits of fabricating a protective wall are not great and are heavily outweighed by the amount of time it would require.

Separation Layer between Hydraulics and Electronics: A separation layer between the hydraulic system and the electronic system could prevent damage to the electric system in the case of the hydraulic system failing but this layer would be detrimental to our project's goal of improving the vehicle's maintainability. This layer would be difficult to fabricate as it would have to allow various components to pass through it while preventing hydraulic fluid to spill through. Creating a layer that obstructs the components we are trying to access (e.g. – main drive batteries) is counterproductive to the primary customer requirements.

Diagnostic Device for Valve Operation: A diagnostic device to notify the driver if the high pressure valves need inspection is not a feasible concept. Such a device would increase the complexity of the vehicle and is outside the scope of our project. Also, there are safety relief valves already in place that will prevent catastrophic failure of high pressure components. We will retain these safety relief valves in our design and ensure that catastrophic failure will not occur when driving the vehicle.

Protect Accumulators from Side Collision: Protecting the accumulators from side collision is outside of the scope of our project. A protective frame would increase the complexity of the system and would reduce the accessibility of the hydraulic system and the electrical system. This is the opposite of the goal of our project. Furthermore, there is little space under the truck bed to add a protective frame. This concept would not be a useful way to spend our limited time.

The following table (page16) is the list of the concepts that we found to be realistic using our feasibility assessment chart. Concept descriptions marked with an asterisk can be found in Appendix VI

Safety	Battery serviceability
Cover exposed electric connections*	Full modular system*
Change the material of the controller*	Redesign for overhead
Ensure the safety of the hydraulic fluid*	hydraulic connections quick release*
Color-code the hydraulic connections	Partial modular system
Change the diameter of critical connections	
Move the controller box*	
Require helmet for driver*	

Electrical sys. serviceability	Hydraulic sys. serviceability	Simplicity
Include circuit diagram	Manifold for valves	Replace flow meter
Color-code wires	Lay valves in surface	Redesign controller board
Bundle wires	Effective hydraulic pipe spacing*	Define AUX battery duty*
Quick release for batteries*	Replace hard pipes to soft ones*	

Table 3. Remained concepts after feasibility assessment

Pugh Chart

For the remaining feasible concepts, according to their different categories, we used Pugh Chart to sort the concepts based on the customer requirements. On the next page is a Pugh Chart for the concepts of electrical system accessibility. It is an example of the Pugh Charts that we have generated for the five categories of our ideas (battery access, hydraulic system access, electrical system access, simplicity, and safety.) All other Pugh Charts can be found in Appendix IX

		Circuit Diagram		**Color-Code Wires**		**Bundle Wires**		**Battery Quick Release**	
Criteria	Weight	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Maintain Performance	0.09	3.00	0.27	3.00	0.27	3.00	0.27	3.00	0.27
Accessibility (hydraulics)	0.09	3.20	0.29	3.00	0.27	3.20	0.29	3.00	0.27
Accessibility (batteries)	0.11	3.20	0.35	3.00	0.33	3.00	0.33	3.50	0.39
Accessibility (electronics)	0.10	3.50	0.35	3.50	0.35	3.00	0.30	3.20	0.32
Transferable	0.09	4.00	0.36	4.00	0.36	3.50	0.32	3.00	0.27
Maintainability	0.10	3.50	0.35	3.50	0.35	3.50	0.35	3.50	0.35
Safety	0.12	3.50	0.42	3.20	0.38	3.00	0.36	3.50	0.42
Simplicity of Layout	0.07	4.00	0.28	3.20	0.22	3.50	0.25	3.20	0.22
Reliability	0.10	3.00	0.30	3.00	0.30	3.00	0.30	3.50	0.35
Aesthetics	0.04	4.00	0.16	4.00	0.16	4.00	0.16	3.00	0.12
Implementation	0.09	3.00	0.27	3.00	0.27	3.00	0.27	3.00	0.27
	Total	**3.40**		3.27		3.19		3.25	
	Rank	**1**		**2**		**4**		**3**	

Table 4. Pugh Chart for the concepts for electrical system serviceability

The first two columns of the Pugh Chart are the customer requirements and their relative weights which came from our quality deployment diagram (QFD, Appendix IV.)The reasoning behind the relative weights are discussed in the Project Requirements and Engineering Specifications section. The first horizontal rows displayed the four different concepts that we have generated for serviceability. Each concept was then rated according to their ability to satisfy each customer requirement on a 1.00 to 5.00 scale. For example, color coding the wires improves the ability to identify where a wire is connected to thus improving the ability to understand what is malfunctioning and what part may need to be services. Color coding wires also improves the transferability to future teams. This is because someone new to the project will be able to follow where the connections are going and will be less confused by the numerous wires. The utility of the Pugh Chart is that is can identify how concepts generated for one of the customer requirements affects the other customer requirements. The specific number for each rating came from the individual engineering judgment of our team members and group decisions made during our team meeting. A rating of 3.00 signifies that the concept neither has a positive nor a negative impact on the engineering specification. A rating of below three signifies that the concept is actually detrimental to that customer requirement and a rating above three signifies that the concept improves the customer requirement. Ratings are useful for comparing the different amounts of improvements or detriments. For example a circuit diagram will improve the ability to understand the electrical system and will allow someone to perform maintenance more efficiently. Creating a quick release mechanism for the batteries will decrease the amount of time to remove the batteries but only marginally because disconnecting six separate batteries is not a very time consuming process. Each of the concepts was rated in this fashion to establish consistency and scored against the current system as the datum. After rating each concept, we multiplied the rating with the weight of each customer requirement and obtained the weighted score of each concept for each customer requirement. We then took the sum of the weighted scores of each concept and ranked them in descending order, as shown in the last row of the chart.

From this process, we can compare how well each concept satisfies the overall customer requirements. Examining the results of the Pugh Chart rankings we could see which concepts were able to improve the most customer requirements while avoiding making other customer requirements worse. The top four concepts in each category are shown below in Table 5.

Rank	**Battery Access**	**Safety**
1st	Redesign for overhead	Color-code the hydraulic connections
2nd	Hydraulic connections quick release	Require helmet for driver
3rd	Full modular system	Ensure the safety of the hydraulic fluid
4th	Partial modular system	Change the diameter of critical connections

Rank	**Electrical Sys. Access**	**Hydraulic Sys. Access**	**Simplicity**
1st	Include circuit diagram	Manifold for valves	Redesign controller board
2nd	Color-code wires	Lay valves in surface	Replace flow meter
3rd	Battery quick release	Effective pipe spacing	Define AUX battery duty
4th	Bundle wires	Use soft pipes	

Table 5. Top concepts for each category

The top concepts for the five categories are redesigning the overhead space for the batteries, including circuit diagram for the electronic system, creating a manifold for the valves, replacing the current flow meter, and color-coding the hydraulic connections according to their pressure.

The concept of redesigning the overhead of the batteries would save us a lot of time and effort for redesigning the hydraulic circuitry. Because the current hydraulic system is connected with hard connections, it is very hard to make some parts of it movable or change the location of the key hydraulic parts (reservoir, accumulators, hydraulic motor and pump). This concept enabled us to only focus on the hydraulic components right on top of the batteries. The drawback of this concept would be that we need to find out ways to squeeze the hydraulic parts into other components so that we can clear up the space for directly accessing the batteries.

Including the circuit diagram for the electronic system would reduce the time for future students and possible maintenance personnel to understand the circuit, which greatly increased the transferability of the entire system. However, to accomplish this target, we would need to go through the entire circuit of the Xebra car including the circuit for electric power system and hydraulic system.

Creating a manifold to integrate all the critical valves would not only simplify the system, but also enhance the maintainability of the hydraulic system. The disadvantage of this concept was that we will need to change the major part of the hydraulic system to connect the pipes to the manifold and have to find additional space for the manifold.

The current flow meter is very large and takes a lot of space on the top of batteries. The concept of replacing it with a smaller flow meter or even a sensor would greatly reduce the volume of the device and save the space for other designs. However, our sponsors told us that the flow meter was important for checking the conditions of the system and they did need some direct readings from this device. So we would need to find a more compact flow meter with appropriate capability of measurement and direct readings.

We regarded color-coding the hydraulic connections according to their internal pressures would be very important for the safety of maintenance personnel. However, it would take us more time to paint the required components and we would have to handle the components with more care because of the possible degradation of the color coatings.

Concept Combination

After determining which concepts were the most promising through our pugh chart analysis, combination of said concepts into a proposed design must be performed. This was done through a two step process: 1) use a MATLAB code to determine the best combination of single concepts and 2) then use the results from this as a starting point for beginning our objective combination using our engineering judgment. During this process, our knowledge of constraints (budget and time) and customer requirements were the two motivating factors in scoring proposed designs. A detailed description of this two-step series type process follows.

Combination Using MATLAB
After ranking each group of concepts according to the results of the Pugh charts, a MATLAB code was used to determine the optimal combination of positive impact on the Xebra car and ease of implementation. The full MATLAB code can be found in Appendix X. In the following section, 'concept' is used to refer to each idea generated under a give category (e.g. – Simplicity) and 'design' refers to a proposed alpha design which consists of a combination of concepts.

Design Scoring: The logic of the code is very simple; it cycles through each and every possible combination of concepts from each of the five categories (Battery Access, Hydraulics, Electric, Simplicity, and Safety) and sums their individual Pugh chart scores. The result is a combined design score as a measure of the amount of impact the design will have on the Xebra car. Throughout this process, indices were also outputted to track which concepts were used in each design.

Implementation Factor: In addition to calculating the total impact on the Xebra, an 'Implementation Factor' was also calculated for each design. To do this, the indices that were outputted in the Design Scoring portion of the code were used to find the weighted implementation Pugh chart scores and again summed them for a total implantation score.

In the end, a design with large values in both impact and implementation categories to ensure that the design will have a large positive impact on the Xebra car while still being plausible given the time constraints. The output of the code was reviewed and discussed as a team and the highest ranked designs are tabulated below in Table 6.

Rank	Batteries	Hydraulics	Electrical	Simplicity	Safety
1	Redesign for Overhead	Valve Manifold	Circuit Diagram	Redesign Electric Controls	Color-code Hydr. connections
2	Redesign for Overhead	Valve Manifold	Circuit Diagram	Replace Flow Meter	Color-code Hydr. connections
3	Redesign for Overhead	Valve Manifold	Color-Code	Redesign Electric Controls	Color-code Hydr. connections
4	Redesign for Overhead	Valve Manifold	Battery Quick Release	Redesign Electric Controls	Color-code Hydr. connections
5	Redesign for Overhead	Lay valves in surface	Circuit Diagram	Redesign Electric Controls	Color-code Hydr. connections

Table 6. Optimized combination of concepts

Comparison of Final Design Variations

This section gives a detailed description of the final design variations that our Xebra team has developed for comparison. For each, an overview of the changes will be described and the advantages and disadvantages will be discussed. The MATLAB code which outputted the best combination of single concept designs was used as a starting point for developing the alpha design. The MATLAB code was used to determine a 'base' for creating our final design variations in a series (not parallel) manner.

It should be stated that all designs include resolving the issues of the faulty recirculation valve as well as the outdated controller. If any concept listed is unclear, please refer back to 'Brainstorming' section (pg. 12) or Appendix VI which gives a brief description of each concept. The main advantage of this section is to consider the concepts that are not necessarily mutually exclusive and can be accomplished concurrently with each other at minimal increase in time/effort costs.

Design A: The first design is aimed more toward simplifying the electrical components and consists of:

- Quick hydraulic connects
- Effective hydraulic pipe spacing
- Color code and bundle the wires, include circuit diagram, clearly define objectives of AUX battery, and redesign controller box
- Color code high pressure hydraulic connections

The advantages of this proposed design is the fact that the entire electrical system will be overhauled and will be greatly simplified. These changes would dramatically improve the transferability of this project to future semesters. The electrical circuitry in the Xebra is extremely complex and disorganized. In addition, an accurate in-depth circuit diagram does not exist to aid in understanding. Also, the AUX battery and main drive batteries are currently sharing some objectives and this is thought to have caused some issues with the performance of the vehicle as a whole. Redesigning the circuitry will resolve this issue. Another minor improvement of this design is the fact that the safety of the car is improved via the indications of where high pressure fluid exists through the color coding of hydraulic fittings.

The main disadvantage of the design is the fact that the drive batteries still remain relatively inaccessible. Implementing hydraulic quick connects and effective pipe spacing are relatively easy changes to reduce the time required to disassemble the hydraulic system, but this improvement on battery access is almost negligible.

Design B: The second design is geared toward achieving superior safety of the Xebra car as a whole and consists of:

- Replace hard pipes with soft flexible pipes
- Circuit diagram
- Color code hydraulic connections, change diameter of critical connections, relocated controller board

The advantages of this proposed design is the fact that many of the existing safety concerns are resolved through the replacement of poor design choices. Mainly, there are some locations in the hydraulic circuitry that will experience unnecessary stresses when in operation. These stresses that result from either a series of hard connects or small dimensions will have a higher probability of failure when required to handle the high pressure flows of the system. Relocating the controller board away from the high voltage recharging pack will eliminate those safety concerns. Other changes that will improve the safety that have already been discussed are: circuit diagram and color coding hydraulic connections.

The disadvantages of this design are numerous. While safety is a major concern of our design, it does not address any of our customer requirements directly. The batteries and hydraulics remain unchanged, complex, and inaccessible.

Design C: The third design addresses the main objective of accessing the main drive batteries and consists of:

- Redesign for overhead
- Manifold for valves
- Replace or reposition flow meter
- Color code high pressure connections and change the diameters of critical tubing
- Detailed Maintenance Procedures
- Secondary Objectives: Electrical overhaul (similar to Design #1)

The advantage of this design is the fact that it addresses the access to the batteries as the 'design driver.' This design results in a simpler hydraulic circuitry (manifold), improved access to the batteries (overhead) and a safer hydraulic layout (color coding and critical diameters). Seeing as how most of the maintenance occurs with the hydraulics or the batteries, this design resolves both of these issues to some extent.

The disadvantage of the system is the fact that the electrical components may remain unresolved. Depending on whether the Primary objectives are accomplished, the electrical components may remain unchanged. This scenario was viewed as a minimal trade off because the system is still operational with the current circuitry, yet the transferability will still suffer.

*Design D***:** The fourth design is the ideal case where all major customer requirements are addressed in full and consist of:

- Redesign for overhead
- Manifold for valves
- Electrical overhaul
- Critical safety considerations (color code, diameter of connections, etc).

This design has many advantages and very few disadvantages associated with the changes it involves. The access to the batteries is accomplished through the redesign for overhead, while the access to the hydraulics is simplified through the hydraulic manifolds. At the same time, the electrical circuitry is also addressed and will result in a greatly improved transferability to future semesters. Finally, the remaining safety concerns are also addressed through the use of warnings and more thoughtful hardware selection.

The only disadvantage of this proposed design is the required time to complete. Changing both the hydraulic and electric circuitry will most likely require more time than is available due to the fact that there is no accurate circuit diagram for either system.

*Design E***:** The last design addresses the access to the batteries through an alternate method while talking more electrical problems and consists of:

- Full or partial modular system
- Color-code and bundle wires, circuit diagram, redesign controller board and clearly define objectives of AUX battery

The advantage of this design is the fact that the access to the batteries is addressed in a crude manner by allowing for the hydraulic system to be fully removable from the base of the Xebra car. This will be a simpler alternative than the redesign for overhead but will require much more analysis on the added components. The difference between this design and Design C is the fact that the electrical components of the Xebra car can be also addressed.

The disadvantage is the fact that we are not directly addressing the problem of an inefficient hydraulic circuit. We are simply allowing for the user to remove this when necessary. This does not address the access to the hydraulics nor does it allow time for safety or simplicity changes to be implemented.

Criteria	Weight	Design A Rating	Design A Score	Design B Rating	Design B Score	Design C Rating	Design C Score	Design D Rating	Design D Score	Design E Rating	Design E Score
Maintain Performance	0.09	3	0.27	3	0.27	3	0.27	3	0.27	3	0.27
Accessibility (hydraulics)	0.09	3.2	0.288	3.2	0.288	3.8	0.342	3.8	0.342	3	0.27
Accessibility (batteries)	0.11	3.1	0.341	3	0.33	4.5	0.495	4.5	0.495	4.5	0.495
Accessibility (electronics)	0.1	3	0.3	3.1	0.31	3.2	0.32	4	0.4	4	0.4
Transferable	0.09	4	0.36	3	0.27	4	0.36	4.5	0.405	3.5	0.315
Maintainability	0.1	3.1	0.31	3.1	0.31	3.9	0.39	4.1	0.41	3.83	0.383
Safety	0.12	3.5	0.42	5	0.6	3.5	0.42	4	0.48	3	0.36
Simplicity of Layout	0.07	3.5	0.245	3	0.21	4	0.28	4	0.28	3	0.21
Reliability	0.1	3	0.3	3	0.3	3	0.3	3	0.3	3	0.3
Aesthetics	0.04	3.5	0.14	3	0.12	4	0.16	4	0.16	3	0.12
Implementation	0.09	0.5	0.045	2	0.18	3	0.27	0.5	0.045	1	0.09
	Total	3.02		3.19		3.61		3.59		3.21	
	Rank	5		4		2		1		3	

Table 7. Pugh Chart for top 5 designs

Design Finalization

The last stage of concept selection is finalizing the alpha design. To accomplish this, our primary foundation was the result from the above process. We have identified the key concepts that would help us satisfy the customer requirements and the best combination was also determined from the above table. However, we realized that the result of the MATLAB code was not necessarily our final alpha design. The MATLAB code was limited because it did not consider combinations of concepts within each of the five main customer requirement categories. We realized this and used our own knowledge of the system to consider a multitude of combinations left out by the MATLAB code. This is particularly true with improving the accessibility and the maintainability of the electrical system.

A common aspect across all final design variations is the presence of two faulty parts that are currently installed in the Xebra car. So before we make any modifications to the car, we will have to fix these malfunctioning parts of the present design to make it possible for us to maintain the same level of performance. This will also allow us to gain more familiarity with this complex hydraulic system.

As mentioned earlier, we realized that some concepts in the same category are correlated. For example, it would take a lot of time to understand the entire electronic system in order to draw the circuit diagram or color-coding the wires, however, it would be easy for us to draw the circuit diagram after we have already went through the process color-coding the wires. Color coding the wires, bundling the wires and creating a circuit diagram could be done concurrently and do not represent completely differing tasks. By contrast, the concepts for improving the battery access lack this amount of correlation. For example, creating a fully modular hydraulic system cannot work in conjunction with a redesign for the battery overhead space because both of these concepts modify the same components in differing ways. Generally correlating concepts means that for some concepts, little additional effort is needed to implement other related concepts.

Taking these two aspects into consideration, we came up with our alpha design which was Design C in Table 7 above. There were two clear winners out of our final design variations, Design C and Design D. While their pugh chart scores were nearly identical, the ease of implementation of Design C was determined to be the main cause of it receiving the higher score. The concepts that the alpha design (Design C) consists of are shown below in Table 8 (Secondary Stage objectives are defined as 'Electrical Overhaul' in the description for Design C above).

Primary stage	Secondary stage
Fix recirculation valve	Color code the wires
Replace the motor controller	Include a electronic circuit diagram
Create a manifold for the valves	Bundle the wires
Redesign the overhead space of batteries	Change the base of the controller board
Change the critical hydraulic connections	Clear define the duty of the auxiliary battery
Color code the hydraulic connections	Redesign the controller board
Detailed Maintenance Procedures	

Table 8. The concepts in the finalized design

Our alpha design consists of two main stages. All the concepts that are vital to the success of our project were put into the primary stage. We would focus on implementing these concepts for now. If we are able to accomplish these targets and have time before the Design Expo on April 15th, we will try to add the concepts included in the secondary stage to the car.

Selected Concept Description

Primary Objectives

The following section describes in detail the changes that will be made in-order to achieve battery overhead space as well as a simpler and safer hydraulic circuitry.

Major Changes

Figure 1 and 2 (page 24) shows the main structure of the Xebra car before and after our proposed modifications from the first stage. The most notable change is the available space above the batteries. This change will allow for a user to easily access the batteries for replacement or maintenance. We were able to achieve this change by developing a more efficient and condensed hydraulic circuitry.

This hydraulic circuitry simplification consists of:

- Relocation of high pressure/volume 'dump lines'
- Relocation of slow fill pump
- Installation of custom manifold
- Condense secondary components (flow meter and filter)

The details of these above listed changes are discussed in more detail on the next page.

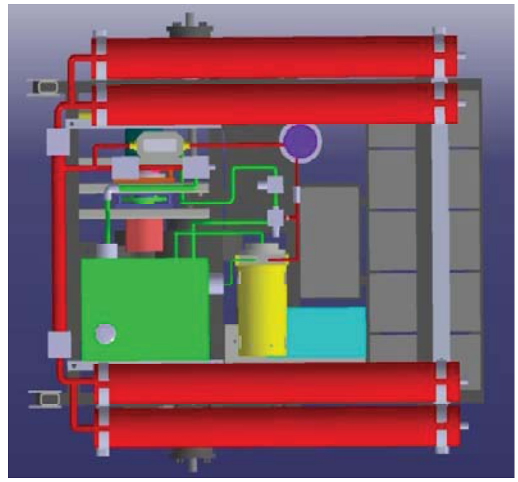


Figure 1. Xebra car before our modification **Figure 2. CAD drawing of proposed alpha design**

In addition to the changes outlined above, there will be a number of alternative mounting mechanisms for the slow-fill pump, custom manifold, and hydraulic filter. The basic design of these components will be presented briefly in the 'Mounting Mechanism' section of this report with a more detailed description of design, manufacturing, and assembly plan provided in the safety report.

During our initial understanding of the current Xebra system, we immediately noticed an area that was occupied a number of fittings and hydraulic piping (immediately exiting the low pressure reservoir). It turns out that this complexity is completely avoidable. Previous teams did not efficiently route certain 'dump lines' and rather plumbed them in such a way which wastes valuable space in the vehicle. The figure on the next page highlights two of the 'dump lines' that will be relocated to a new low pressure inlet.

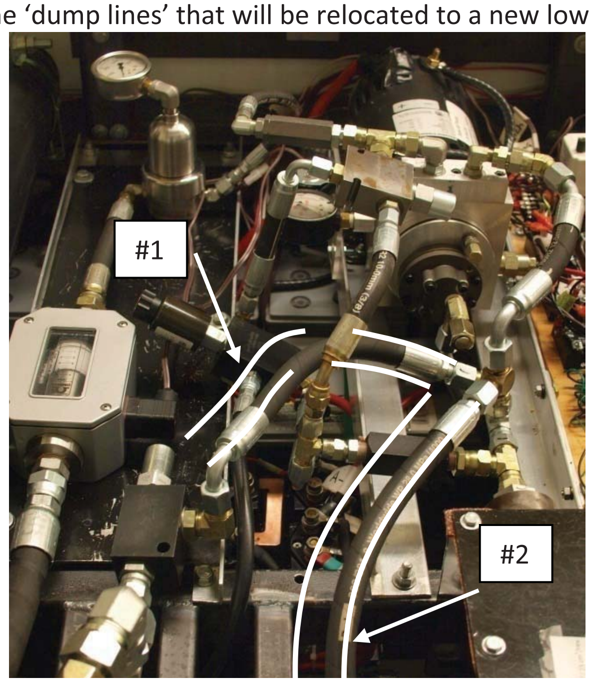


Figure 3. Inefficient location of hydraulic dump lines (highlighted white) labeled #1 and #2

The below CAD model highlights how line #2 will enter the LP reservoir (LPR) without adding complexity to the logic circuit. Also, dump line #1 will combine with this same line coming up directly from the hydraulic motor instead of traversing valuable space to the only LPR inlet (Figure 3).

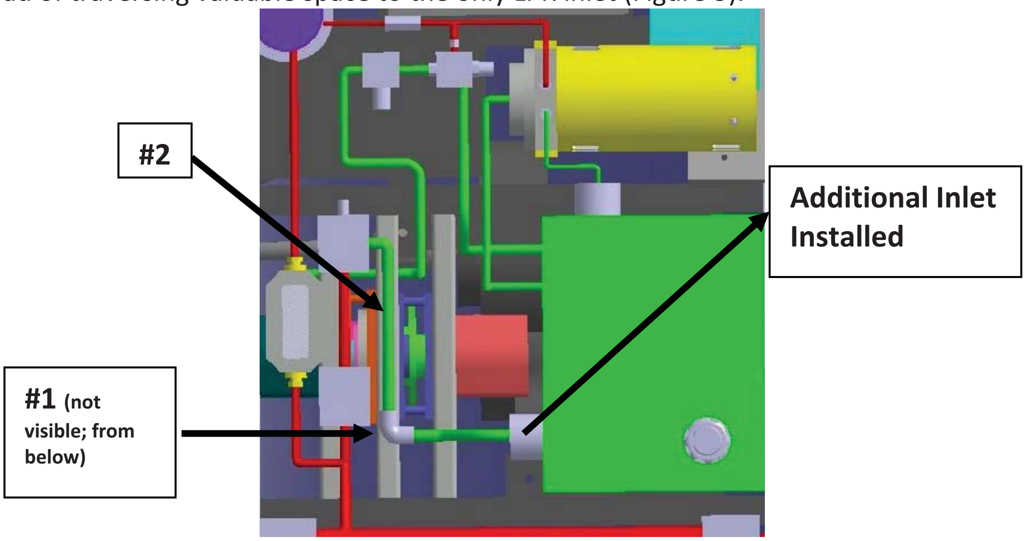


Figure 4. New Low Pressure inlet and relocation of dump lines

After clearing up that space near the low pressure reservoir, the slow-fill pump will be relocated to achieve cleared battery overhead space. The pictures below highlight the changes being made and the resulting CAD model. These changes cannot be performed until the 'dump lines' are relocated clearing space for the slow-fill pump to be installed. As a result, these two changes are directly connected in terms of implementation.

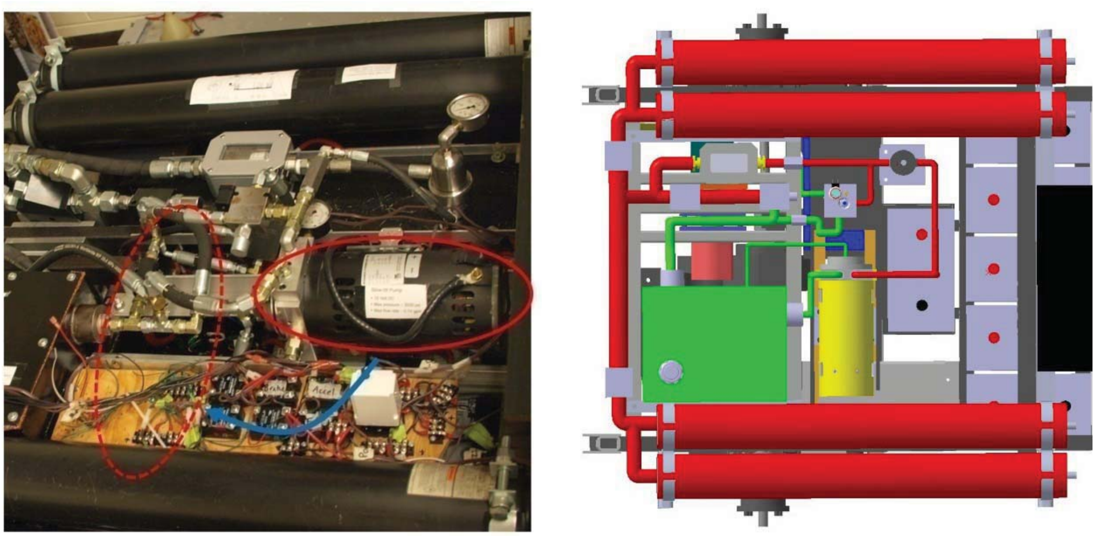


Figure 5. Relocation plan for the slow-fill pump achieving battery overhead space

The next changes were aimed at simplifying the hydraulic circuitry. There exists two hydraulic logic valves in the current system (highlighted in Figure 6 below) which are installed in a very inefficient manner. Relocation is not an option since the input/output relationship between the two valves is critical for proper operation. Our final design will aim to simplify this by installing a single custom-made manifold which will condense the area required by the hydraulic logic circuitry. A schematic of our proposed changes is shown below and detailed drawing files of the custom manifold can be found in Appendix XVI.

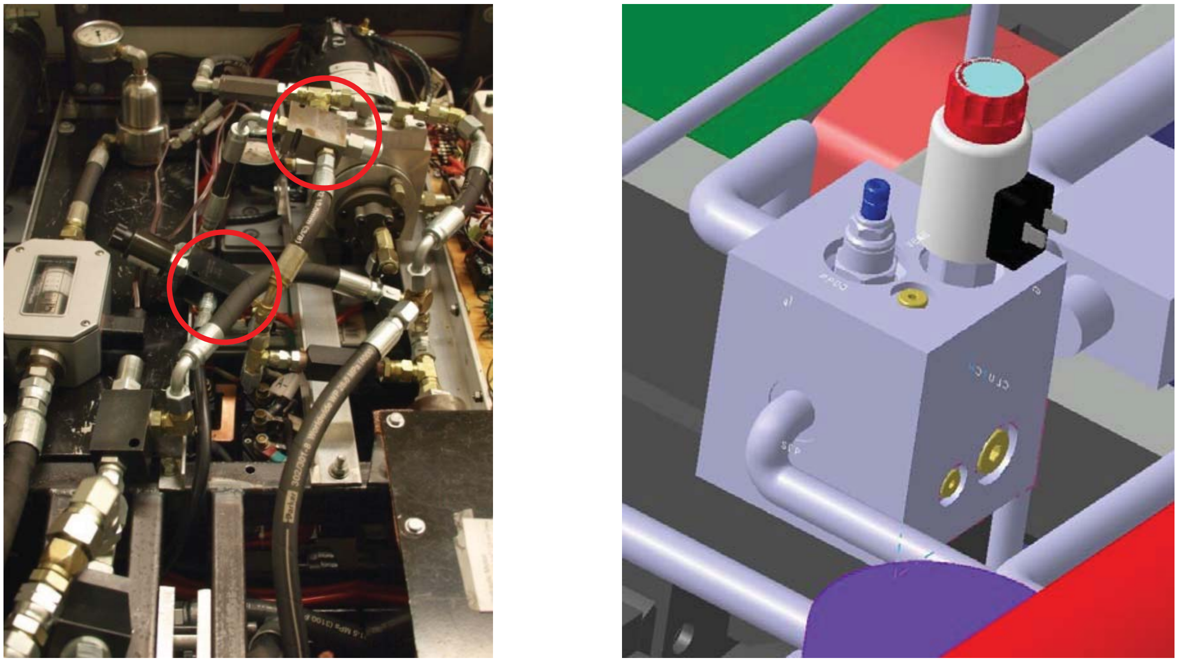


Figure 6. Custom manifold greatly simplifies the logic of the hydraulic circuitry

Our final major proposed change is to condense the flow meter and relocate the hydraulic filter. Condensing the flow meter is a necessary change to create a space efficient final design. Excess piping attached to the flow meter will be eliminated to ensure the most efficient use of available space. The improvements that result from the relocation of the filter are also related to spacing issues. A number of excess piping had been attached to the filter in haste and has resulted in an inefficient design. The flow from the slow-fill pump/filter/flow meter will be condensed in a way that will use the least amount of tubing.

At the request of our sponsors, a detailed maintenance procedure will be created for the many processes that the user may encounter. Mainly, the procedure for replacing the batteries and troubleshooting the hydraulic and electrical systems will greatly reduce the time required to understand the current system. A detailed and comprehensive circuit diagram for the hydraulics (primary) and electronics (secondary) will be a major portion of our ultimate goals toward transferability.

Mounting Mechanisms

The above changes require alternative mounting mechanisms for the slow fill pump, custom manifold, and hydraulic filter. In the current design, there are two sets of aluminum rails that support the above mentioned components. These rails are not only an inefficient mounting method in terms of space, but they are also obstructing the access to the batteries. Our alternative mechanism for mounting is discussed below.

Our initial design for mounting the three components is a combined four rail system. The first set of rails will be mounted to the frame perpendicular to the accumulators such that the slow-fill pump can be mounted to them. Next, another set of rails are attached perpendicular to the first set to allow for the mounting of the custom manifold. The manifold was designed to have predefined mounting holes in the bottom of the piece such that it can be mounted to a rail system such as this. A rough schematic of the proposed mounting mechanism is shown below; final dimensions have yet to be defined and will be implemented in the design once the manifold is finalized and ordered.

Figure 7. Schematic of first-stage mounting mechanism

In addition to the slow-fill pump and custom manifold, the hydraulic filter also needs to be mounted to the system in some way. We propose to mount the filter on the inside of the frame on the driver side of the car. The design takes advantage of the flange that exists on the present filter and includes a redesign of the readout such that it can be visible from the side. The design can be seen in Figure 6 (page 30).

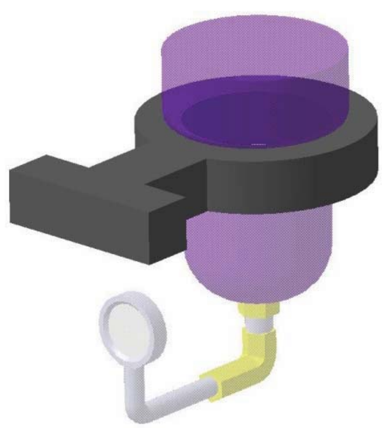
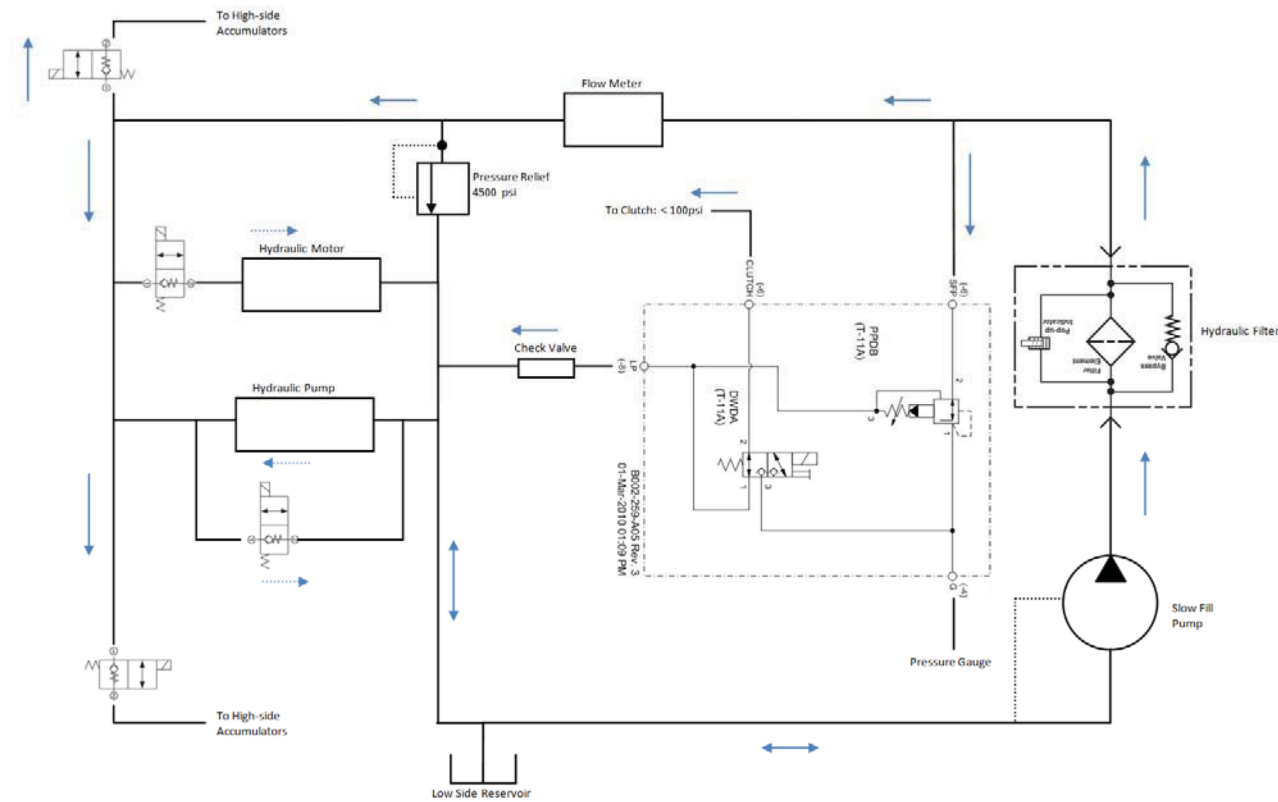


Figure 8. First stage design of filter mounting design

Updated Hydraulic Circuit Diagram

An updated hydraulic circuit diagram has been created to increase the transferability and troubleshooting time required to understand the circuit. The final circuit diagram can be found on the next page. Dashed lines are 'conditional flows' based on logic valve operation.



Controller board

The controller board was used during previous semesters for data acquisition and for controlling the valves for the hydraulic system. The controller board was difficult to understand at first because the wiring was created using brown wires that were only labeled using tags and tape. To increase the transferability of the controller board we color-coded the signal wires from the controller board to the hydraulic valves. We also replaced the wiring between the relays. Although the data acquisition device no longer works, we rewired most of the connections in the controller board for the DAQ system to allow for an easier reinstallation in the future. In its current state the controller board is a simple switch that is activated from buttons on the accelerator and brake inside of the truck's cabin. There is a time-delay for the recirculation valve to allow the fluid to re-circulate around the pump initially with the normally open recirculation valve to allow the clutch to engage before loading in order to reduce wear on the clutch. A diagram of the controller board is included on page 30. The original circuit diagram of the controller board is included in Appendix XX. The wires to the hydraulic valves are color coded according to the table below. Unfortunately, we did not have enough wire or time to color code the wires that go into the cabin of the car. They are currently labeled using tape and electrical wire according to the circuit diagram.

Color Code for Controller board	
E Stop Valve Left	Red
E Stop Valve Right	Yellow
Motor Valve	Green
Manifold/Clutch Valve	Blue
Recirculation Valve	White

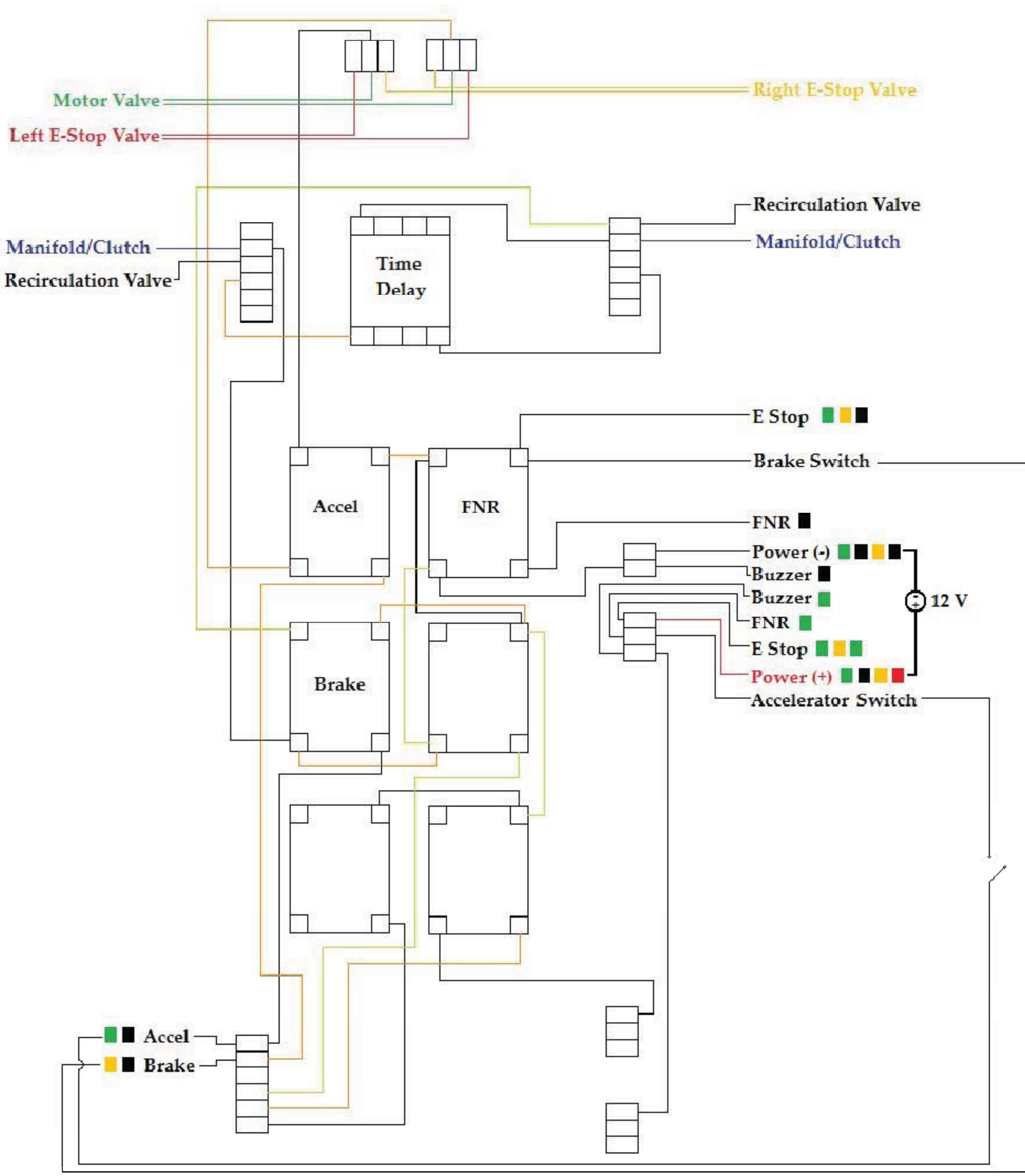


Figure XX. Diagram of Controller Board

Minor Changes

Other changes in the primary stage, including repairing malfunctioning parts, and changes in the secondary stage, primarily changes to the controller board, were not shown in Figure 2 because they are difficult to represent in a CAD drawing. To provide an idea of these concepts through visualization, we included several figures showing the parts or configurations of the concepts that were included in the alpha design. It should be noted that these figures are only for illustration, they do not represent the actual parts that we are going to purchase.

Figure 9. Faulty valve **Figure 10. Elec. Controller** **Figure 11. Critical connection**

Figure 7 and 8 shows the recirculation valve and the electric system controller that are installed in the current Xebra car. They are malfunctioning and will be replaced and reinstalled. Our research of the recirculation valve from the manufacturer's specification sheet [14] and inspection of the part installed in the Xebra car indicate that it is in fact not installed in the reverse direction. Figure 9 shows one of the hydraulic connections in the current hydraulic circuitry. High pressure fluid flows through this particular connection and safety concerns were voiced by Jason Moore. Its diameter is clearly smaller than the rest of the pipe, which generates additional impedance for the hydraulic fluid. This connection and others that may not have been noticed presently will be replaced with new ones that have larger diameters.

Secondary Objectives

http://www.veer.com/

http://tech.icrontic.com/

Figure 12. Color-coded wires **Figure 13. Bundled wires** **Figure 14. Elec. controller board**

As we have mentioned before, besides the primary objectives, we will try to implement the secondary objectives if we have enough time. Figure 10 shows the typical color-coded wires that are widely available. We are going to use this kind of wires to distinguish the electric connections between each subsystem. It also illustrates the general idea of color-coding the hydraulic connections. We will use white to indicate high pressure lines and green for low pressure. We will also include the direction of flow in the indicator strip. Figure 11 shows the idea of bundling wires for simplicity. Figure 12 shows the base of the controller board in the car. This wooden board will be replaced with a plastic board which can provide electric insulation, better strength and improve the aesthetics.

Engineering Design Parameter Analysis

There are a number of design parameters that have been decided upon (e.g. – placement, connection method, materials) throughout the alpha design process without any proper analysis. After making an initial judgment on these decisions without much support, a detailed engineering analysis was carried out to validate our conclusions on a number of design parameters. As a result of these changes, a number of the parameters have changed and are discussed in more detail below.

Head Loss Improvements

The initial design for the dump line relocation and custom manifold has remained the same after an engineering analysis of the potential head loss/gain from our changes. Improving the head loss of the system was not one of our objectives and as a result an in-depth analysis in the level of head losses/gains was not performed. Reducing the number of hydraulic fittings and length of piping was an engineering specification, as a result, a quantifiable improvement in system efficiency (i.e. – head losses) should be captured from this reduction.

The head loss in any system that involves flow is the sum of the major and minor losses. The major losses are associated with friction lost in flow through piping. There is also major head loss with elevation changes, however since we are not making any significant changes to the vertical position of components these losses are neglected. The most significant losses due to losses in potential energy would be associated with the delivery of the high pressure fluid from the accumulators to the hydraulic motor. The circuitry associated with this section of the system will remain unchanged, and so too will the associated losses.

$$h_{total} = \Sigma h_{major} + \Sigma h_{minor}$$

Major head losses associated with friction are dependent on the friction coefficient (λ), length of piping (L), hydraulic diameter (d_h), velocity (v), and gravity (g). The only parameter that is changing is the total length of the piping. As you can see from the following equation, a percentage change in the amount of piping will result in a 1:1 direct change in h_{major}.

$$h_{major} = \lambda \left(\frac{L}{d_h}\right)\left(\frac{v^2}{2g}\right)$$

The same analysis applies to the minor losses associated with the hydraulic fittings. Each type of hydraulic fitting has an associated loss coefficient, K_L, which directly affects the total head loss. The changes that are being implemented will not have a significant impact on the velocity of the fluid. Assuming that the same type of fitting is analyzed (keeping K_L constant), it will have a direct impact on the percentage of minor head losses.

$$h_{minor} = K_L \left(\frac{v^2}{2g}\right)$$

$$P = 0.0981(h\gamma)$$

Due to this 1:1 relationship, a percent decrease in the amount piping/fittings will have the same percentage impact on the head losses. A summary after analyzing the current system in terms of number of hydraulic fittings and length of piping is shown below.

Loss Medium	Reduction [%]
elbow	36
tee (line)	50
tee (branched)	50
length	30

Table 9. Head loss summary: significant improvement in the head losses of the system

Although these head loss improvements may seem significant from the perspective of vehicle performance, it should have a negligible effect on system performance because the circuitry that controls the high pressure fluid is remaining the same.

Access Time

An engineering analysis on the improvement in the time required to access critical components was performed and has validated our choice for the location of critical components. Boothroyd Dewhurst (BD) charts were used to compare our design to the current configuration. BD charts are used by industry, such as Dell Computers and Harley Davidson, to estimate the assembly time and improve the efficiency of a design. By decreasing the assembly time of a design companies can reduce assembly costs which is the main objective. BD charts estimate the assembly time by considering the number of parts, part size, part symmetry, need for tools as well as obstructions and handling difficulties. The BD charts that we used are provided in Appendix XI. Each part is classified by its handling code and the insertion code, which each have their own associated time. The time estimates are used to approximate the time that assembly personnel would require to handle (pick up and maneuver) and insert (fasten or position) a part. A justification for the handling code and insertion code chosen for each part is provided in Appendix XI. One of our team members, Eric, had previous exposure to these BD charts in ME 452 Design for Manufacturing.

Instead of using the BD charts to estimate the assembly time of the entire design, we used the charts to compare the estimated time necessary to access and replace the batteries for the present configuration and for our design. The time estimates are lower than the time a team of students new to the vehicle would require. When applied to the present Xebra configuration, the time required to access the batteries is estimated to be 42 minutes which is much lower than the actual time it required from the Fall 09 Xebra team. The time estimate for our design is 3 minutes, which is much lower than the time we expect. The BD charts were used to obtain a justifiable and quantifiable way to compare our design's capability to increase the serviceability of the batteries in the Xebra vehicle. To allow for an evenhanded comparison we used the BD charts in the same manner for both designs, with the same estimates for similar parts. The BD charts for the present design as well as for our design are presented in Tables X and Y below.

A	B	C	D	E	F	G	
Number of Times the Operation is Carried out	Two Digit Manual Handling Code	Manual Handling Time per Part	Two Digit Manual Insertion Code	Manual Insertion Time Per Part	Operation Time in Seconds A* (C+E)	Operation Cost in Cents 4*G	Part Name
20	3,0	1.95	5,7	13	299	119.6	Hydraulic Fittings
2	1,0	1.5	3,9	8	19	7.6	Slow Fill Pump Cable
1	9,7	5	5,9	12	17	6.8	Slow Fill Pump
2	9,1	3	3,7	9	24	9.6	Mounting for Slow Fill Pump
1	3,0	1.95	3,7	9	10.5	4.2	Filter
1	3,0	1.95	3,7	9	10.95	4.38	Flow Meter
7	3,0	1.95	5,7	13	108.57	43.428	Hydraulic Valves
1	3,0	1.95	3,8	6	7.95	3.18	Controller board
10	1,0	1.5	0,0	1.5	30	12	Electrical Connections
4	9,1	3	5,7	13	64	17.6	Support Beam
1	9,1	3	3,6	8	11	4.4	Flow Meter and Filter Mounting
6	9,9	9	3,8	6	90	36	Batteries
1	9,9	9	3,0	2	11	4.4	Truck Bed
1	na	na	na	na	1800	720	Remove Hydraulic Fluid
					2503.0	1001.2	
					TM	CM	

Table 10. Boothroyd Dewhurst Chart for Present Configuration

A	B	C	D	E	F	G	
Number of Times the Operation is Carried out	Two Digit Manual Handling Code	Manual Handling Time per Part	Two Digit Manual Insertion Code	Manual Insertion Time Per Part	Operation Time in Seconds A* (C+E)	Operation Cost in Cents 4*G	Part Name
4	9,1	3	5,7	13	64	20.8	Support Beams
1	3,0	1.95	3,8	6	7.95	3.18	Controller board
10	1,0	1.5	0,0	1.5	30	12	Electrical Connections
6	9,9	9	3,8	6	90	36	Batteries
1	9,9	9	3,0	2	11	4.4	Truck Bed
2	1,0	1.5	3,9	8	19	7.6	Slow Fill Pump Cables
					221.95	83.78	
					TM	CM	

Table 11. Boothroyd Dewhurst Chart for Our New Design

From the charts, our design will decrease the time to access and change the batteries by 92 percent. The Boothroyd Dewhurst charts do not have an assembly process listed that accounts for the time to remove the hydraulic fluid from the lines and the low pressure reservoir which is a necessary step to access the batteries in the present configuration. So we added a part named 'Remove Hydraulic Fluid.' We estimated the time to remove the hydraulic fluid to be thirty minutes. From our experience, it took an hour to remove the hydraulic fluid from the low pressure reservoir but this time can be reduced by using a better pump to remove the hydraulic fluid. If removal of the hydraulic fluid is not considered, the time to access and change the batteries is reduced by 68 percent. Our new design would avoid having to remove any hydraulic fluid (because the hydraulic system will no longer be above the batteries), 20 Hydraulic fittings (shown in Appendix XI), mounting beams, 7 hydraulic valves, the slow fill pump, the filter and the flow meter.

Filter Implementation

Through initial troubleshooting of the recirculation valve, it was found that the level of filtration in the system was inadequate to ensure proper operation of the valves within the system. The recirculation valve is the most sensitive valve to debris in the hydraulic fluid and requires an 18/16/13 level of filtration defined by the standards of ISO 4406: 1999 and recommended by Morrel Inc, our filter supplier. According to the ISO 4406: 1999 the cleanliness code is assigned on the basis of the number of particles per unit volume (1mL) that are greater than 4 µm / 6 µm / 14 µm respectively. Table 12 shows how cleanliness codes are established.

In contrast, there is no known information about the filter that is presently installed on the vehicle. In conversations with the manufacturer, the filter is not specifically made for hydraulic filtration and either 1) the filter does not meet 18/16/13 requirements or the filter element needs to be replaced. With that said, there appears to be visible metal chips in the bottom of the LP reservoir which obviously should have been filtered out.

A recommended cleanliness code chart developed by Eaton Corporation (a global leader in fluid systems) allowed us to determine which filter should be used in the hydraulic system, and also allowed us to confirm the recommendation made by Morrel Inc. This worksheet takes into account the filter requirements of every single component in the system, as well as operating conditions and type of hydraulic fluid used. The first step in choosing a filter indicates that the component with the cleanest fluid standard has to be identified. It also indicates that the cleanliness standard has to be determined at the highest pressure encountered during a complete cycle of operation. As it is shown in Table 12 the component with the cleanest (lowest) fluid code of 18/16/13 is the fixed gear in the hydraulic pump which operates at a pressure greater than 3000 PSI. The cleanliness code coincides with the recirculation valve code making both components the most susceptible to debris in the fluid.

ISO 4406: 1999
PARTICLE COUNTS/ML

More Than	Up to and Including	Scale Number
1,300,000	2,500,000	28
640,000	1,300,000	27
320,000	640,000	26
160,000	320,000	25
80,000	160,000	24
40,000	80,000	23
20,000	40,000	22
10,000	20,000	21
5,000	10,000	20
2,500	5,000	19
1,300	2,500	18
640	1,300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
3	5	9
1	2.50	8
1	1.3	7
0	0.64	6
0	0.32	5
0	0.16	4
0	0.08	3
0	0.04	2
0	0.02	1
0	0.01	0

Table 12: Definition of ISO 4406: 1999 cleanliness codes

For example, a 1 mL sample that has 1500 particles greater than 4 µm, 500 particles greater 6 µm, and 70 particles greater 14 µm has a 18/16/13 ISO cleanliness code.

PUMPS PRESSURE	<140 BAR <20000 PSI	140 - 210 BAR 2000 - 3000 PSI	210+BAR 3000+PSI
Fixed Gear	20/18/15	19/17/15	18/16/13
Fixed Vane	20/18/15	19/17/14	18/16/13
Fixed Piston	19/17/15	18/16/14	17/15/13
Variable Vane	19/17/15	18/16/14	17/15/13
Variable Piston	18/16/14	17/15/13	16/14/12
VALVES PRESSURE		**<210 BAR <3000 PSI**	**210+BAR 3000+PSI**
Directional (solenoid)		20/18/15	19/17/14
Pressure Control (modulating)		19/17/14	19/17/14
Flow Controls (standard)		19/17/14	19/17/14
Check Valves		20/18/15	20/18/15
Cartridge Valves		20/18/14	19/17/14
Screw-In Valves		18/16/13	17/15/12
Prefill		18/16/13	17/15/12
Load-Sensing Directional Valves		18/16/13	17/15/12
Hydraulic Remote Controls		18/16/13	17/15/12
Proportional Directional (throttle valves)		18/16/13	17/15/12*
Proportional Pressure Controls		18/16/13	17/15/12*
Proportional Cartridge Valves		18/16/13	17/15/12*
Proportional Screw-In Valves		18/16/13	17/15/12
Servo Valves		16-14-11*	15/13/10*
ACTUATORS PRESSURE	**<140 BAR <2000 PSI**	**140 - 210 BAR 2000 - 3000 PSI**	**210+BAR 3000+PSI**
Cylinders	20/18/15	20/18/15	20/18/15
Vane Motors	20/18/15	19/17/14	18/16/13
Axial Piston Motors	19/17/14	18/16/13	17/15/13
Gear Motors	20/19/17	20/18/15	19/17/14
Radial Piston Motors	20/18/14	19/17/13	18/16/13
Swash Plate Design Motors	18/16/14	17/15/13	16/14/12*
HYDROSTATIC TRANSMISSIONS PRESSURE	**<210 BAR <3000 PSI**	**140 - 210 BAR 2000 - 3000 PSI**	**210+BAR 3000+PSI**
Hydrostatic Transmissions (in-loop fluid)	17/15/13	16/14/12*	16/14/11*
BEARINGS			
Fixed Gear	20/18/15	19/17/15	18/16/13
Fixed Vane	20/18/15	19/17/14	18/16/13
Fixed Piston	19/17/15	18/16/14	17/15/13
Variable Vane	19/17/15	18/16/14	17/15/13
Variable Piston	18/16/14	17/15/13	16/14/12

* Requires precise sampling practices to verify cleanliness levels.

Table 13: Recommended Cleanliness Code Chart Eaton Corporation

The second step in setting a target cleanliness level is to determine if the hydraulic fluid is 100 % oil based. In the case it is not, (E.g. water glycol) the target code is to be reduced by one particle size. In our case it would go from 18/16/13 to 17/15/12. Since the hydraulic fluid used in the Xebra is synthetic, and by definition synthetic oils have longer lifetime than oil based fluids this measure is not necessary. The third step suggests reducing the target code one particle size if there are frequent cold starts (-18 ^{o} C), intermittent operations with temperatures greater than 70 ^{o} C, or high vibration or high shock operation. Since the Xebra does not operate at any of these conditions our cleanliness code stays at 18/16/13 for the entire system.

Filter Placement

Eaton Corporation also provides its clients with tables that allow the user to place the filter properly in order to achieve the level of cleanliness previously established. In the Xebra, the pump flow passes once through the filter and the closest cleanliness level in Table 14 to our desired level is 18/16/14. This gives us a code of 05 which is then used in Table 15 to determine how the filter should be connected.

C-Pak System Cleanliness Ratings

CODE	NUMBER OF TIMES PUMP FLOW PASSES THROUGH FILTER(S) (SEE NOTE 1)	TYPICAL ISO 4406 CLEANLINESS LEVEL ACHIEVED (SEE NOTE 2)
03	2.0	14/12/10
	1.5	15/13/11
	1.0	16/14/12
	.5	17/15/13
05	2.0	16/14/12
	1.5	17/15/13
	1.0	18/16/14
	.5	19/17/15
10	2.0	18/16/14
	1.5	19/17/15
	1.0	20/18/15
	.5	21/19/16

Table 14: Code rating according to cleanliness level and number of flow passes through filter

14/12/10		03	03	03		
15/13/11		03	03	05		
16/14/12	03	05	05	05	03	
17/15/13	03	05	05	05 or 10	03	03
18/16/14	05	10	05 or 10	10	05	03
19/17/15	05 or 10	10	10	10	05 or 10	05
Target Cleanliness	Full flow pressure line or return line	Full flow pressure line and return line	Pressure line (or return line) and recirculating loop at 20% of system fluid volume per minute	Pressure line plus return line plus recirculating loop	Recirculating loop at 20% of system volume per minute	Recirculating loop at 10% of system volume per minute
	Recommended filter placements for fixed volume pumps	Recommended filter placements for high ingression systems with fixed volume pumps	Recommended filter placements for systems with variable volume pumps	Recommended filter placements for high ingression systems with variable volume pumps	Recommended filter placements for systems with fixed or variable volume pumps	Recommended filter placements for low ingression systems with fixed or variable volume pumps

Note: All systems need a reservoir with 3 micron air breather filtration.

Table 15: Placement of filter in the hydraulic system

According to Table 15, the filter should be connected to a full flow pressure line or return line. In our proposed design we have decided to connect the full flow pressure line coming from the slow fill pump to the filter which means that our proposed filter placement has been hereby validated.

Filter Maintenance

Finally, Eaton Vickers recommends sampling fluid during first day of running, after one month, and then every four months subsequently. Their fluid analysis kit provides photomicrograph, particle count information, cleanliness code and comparison to target viscosity. It confirms if the target cleanliness level was achieved [15].

SYSTEMS WITH TARGET CLEANLINESS 18/16/13 OR HIGHER

SYSTEM PRESSURE	<140 BAR (2000 PSI)	140 - 210 BAR (2000 - 3000 PSI)	>210 BAR 3000 PSI
8 hours or less operation per day	6 months	4 months	4 months
Over 8 hours of operation per day	4 months	3 months	3 months

Table 16: Recommended System Sampling Frequency Chart

Updated Mounting Mechanism

Previous designs for the various mounting mechanisms required were both separate and more complex than the design that will be discussed in this section. After performing the deflection analysis on a simply supported 1020 steel rail system, it was determined that the new design was superior to the old design in simplicity while maintaining performance. The force required from the beams to support is 97 Newtons. We did a static analysis using this maximum force as a point force in the middle of the beam. This maximum force was used to ensure that the weight of the components could be supported both beams. Because the slow fill pump and manifold are mounted in between the two mounting beams their weight will be distributed among both beams. The flow meter and filter are mounted outside of both beams so the weight of these components will be supported by each beam separately. We determined that the beams, using the dimensions of the actual beams that we have purchased, have a safety factor of 4.6 therefore the beams will not fail in bending.

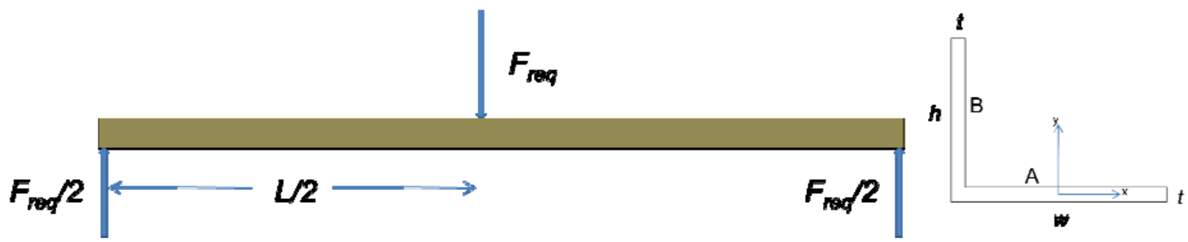


Figure 15: Schematic of static analysis performed on new mounting mechanism

The F_{req} was determined from the total weight of all components that will be supported by the structure. The length and width were constricted by the frame-to-frame distance and slow-fill pump respectively. The required thickness to meet a safety factor of 3 was calculated to be 0.35 cm to ensure safe operation of the mounting mechanism. Detailed calculations can be found in Appendix XII.

The final mounting mechanism consists of a two rail system with a plate that allows for both the filter and manifold to be mounted. This simplified the original design by eliminating an additional mounting mechanism for the filter. In addition to this, having the filter readily available on the mounting plate improves accessibility and maintenance.

Figure 16: Final mounting mechanism for slow fill pump, manifold, and filter

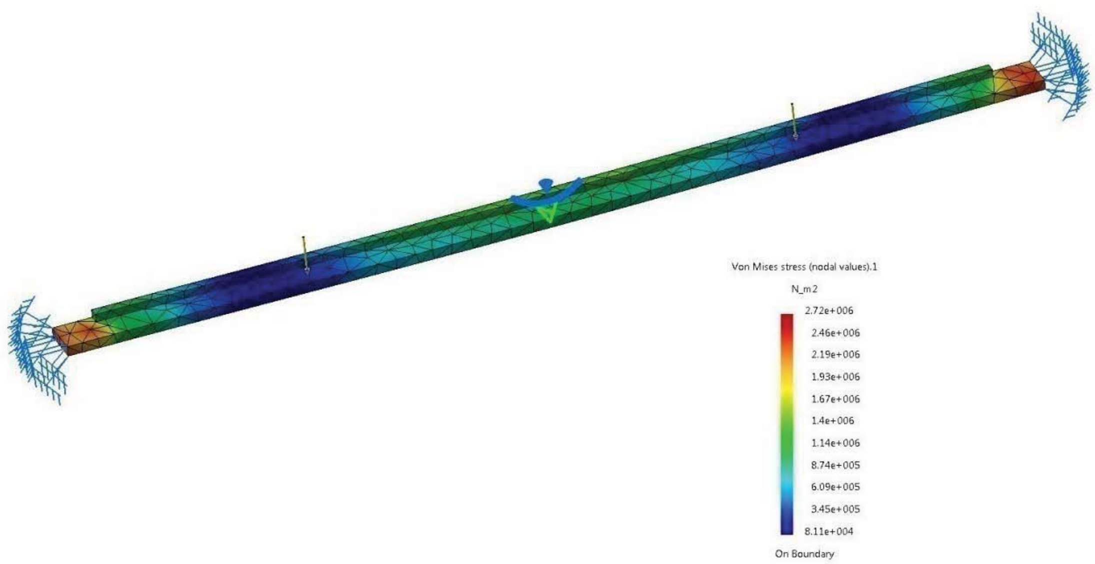


Figure 17: FEA analysis of beam to be used in mounting mechanism, CATIA V5R17.

The beam was secured from the sides preventing any downward displacement during the simulation. A distributed force of 101 N was applied through the steel beam and the parameters of sag and size were adjusted before running the FEA solver. After the computation was completed it can be seen that the beam does not deform, and that the greatest von misses stress present is 2.72 $x10^6$ Pa. Dividing the yield stress of steel (2.5 x 10^8 Pa) by the greatest von misses stress present gives a safety factor of 91.91. The FEA analysis verifies that the beam will not yield much less fail under the loads it will be supporting during operation of the redesigned Xebra vehicle.

Center of Mass (COM)

It was determined from previous reports that the target COM specification defined by previous teams was not met by their design. This fact is unacceptable as it has implications on the stability and safety of the vehicle in operation. An added incentive (outside of the cleared battery overhead area) was the improvement of this engineering specification.

Using the detailed CAD model, and assigning appropriate material properties within the model, an accurate COM calculation was outputted from CATIA V5. The proposed design change has validated the previous specification defined by previous teams. This validation has improved the overall safety of the Xebra car.

In order to calculate the center of mass of the Xebra after, the 3-D CAD model was thoroughly updated taking into account our proposed modifications to the hydraulic system. Steel was applied as the appropriate material to the chassis of the vehicle as well as the accumulators. The hydraulic fluid was accounted for through the selection of the accumulator material. The low side accumulator was redrawn and steel was also applied to the 3-D model. The batteries were also re-drawn and the appropriate density was given to simulate the actual weight of each battery.

Previous teams had modeled the passenger cabin as a 300 lb point force when calculating the center of mass (COM). This approximation led to inaccurate results when calculating the COM. The passenger cabin of the Xebra was modeled accordingly and applied aluminum as the material of the component. The newly added hydraulic lines, hydraulic manifold and slow fill pump were modeled to the exact dimensions and applied to correct material properties as well. Once the 3-D model of the Xebra vehicle was completed, the COM was calculated by using the “measure inertia” function using the same modeling software CATIA V5R17. This function calculated the exact location of the center of mass and made a point in the 3-D model which then allowed us to measure the horizontal and vertical distances from the rear axle. The new coordinates of the COM (0.25 and 0.6m), both fall well below the stated requirement of 0.8 meters.

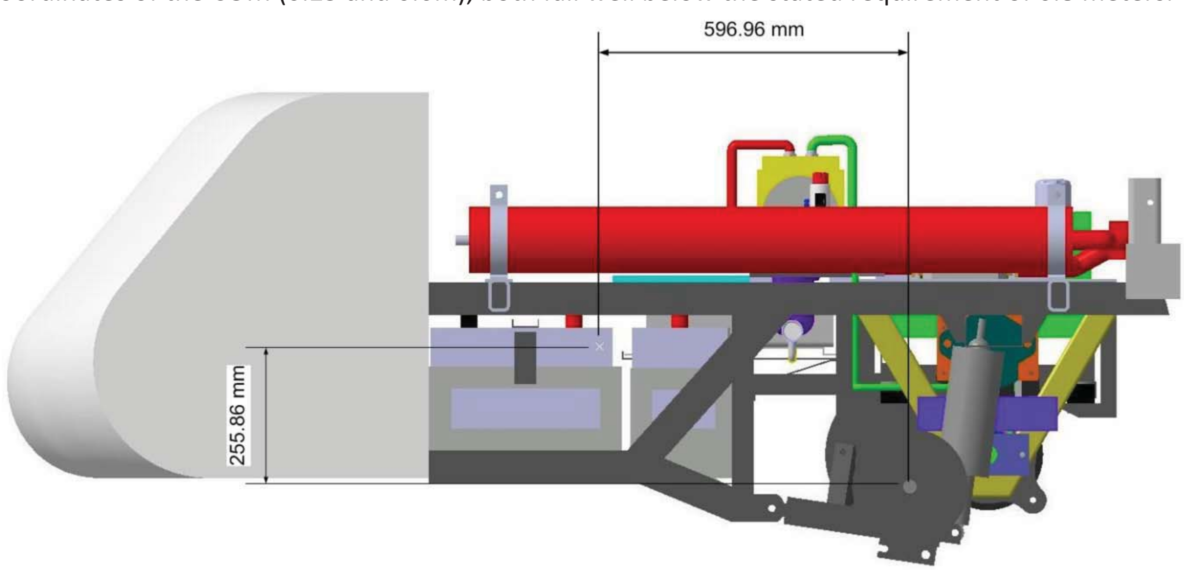


Figure 18. Analysis of center of mass Xebra vehicle

Motor controller Upgrade

The previous performance data provided by past Xebra teams indicated unusual behavior due to 1) a suspected recirculation valve and 2) an out-of-date motor controller. Despite the changes of previous semesters, they were not able to achieve the top speed of 45mph The shortcomings in performance were thought to partly be due to the motor controller not having the ability of supplying the desired current. Upgrading the motor controller will allow the Xebra car to reach its top performance.

A modified model of the vehicle has been created with and without a limitation on the amount of current available. The difference in performance that we observed in the results is justification for implementing these changes. The accuracy of this proposed model was not given precedence as we are not aiming to improve the performance of the vehicle, rather this simple model was used as a tool to measure the potential improvement of upgrading the motor controller.

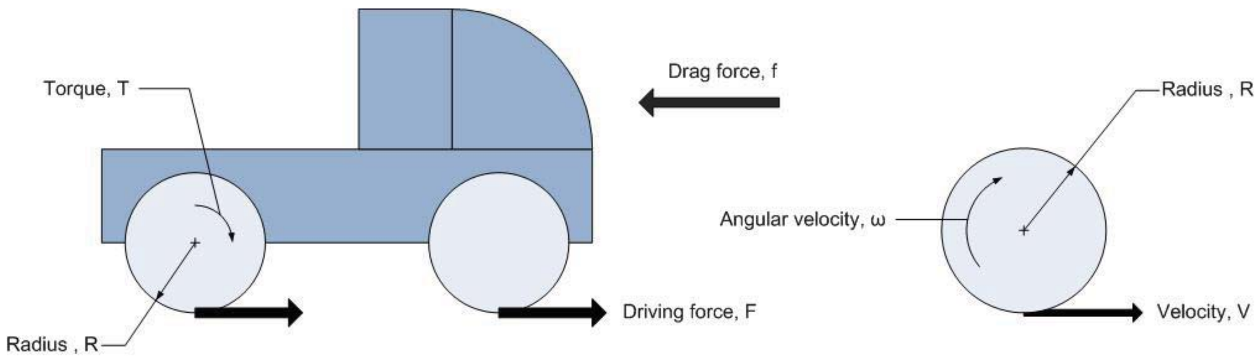


Figure 19. Trivial steady state model showing the performance improvements from controller upgrade

To simplify the entire analysis, we only emphasize the state when the car reaches its top speed. At that state, it is operating at its maximum power and from the force balance, we have:

$$F = f \qquad \text{Eq.1}$$

Where *F* is the driving force and *f* is the drag force, which is mainly the air drag. For each of these forces, we have:

$$f = c \cdot V^2 \qquad \text{Eq.2}$$

$$F = \frac{T}{R} \qquad \text{Eq.3}$$

Where *c* is the drag coefficient of the car, *V* is its velocity, *T* is the torque output and *R* is the radius of the wheels. Furthermore, we have the following relation:

$$V = \omega \cdot R \qquad \text{Eq.4}$$

Where ω is the angular velocity of the wheels. For the electric motor, we have:

$$\eta = \frac{P_m}{P_e} \qquad \text{Eq.5}$$

$$P_m = T \cdot \omega \qquad \text{Eq.6}$$

$$P_e = U \cdot I \qquad \text{Eq.7}$$

Where η is the motor efficiency, P_m is the motor output power, P_e is the motor input power, U is the input voltage and I is the input current. Now collecting Eq.1 to Eq.4,we have:

$$T = c \cdot R^3 \cdot \omega^2 \qquad \text{Eq.8}$$
$$P_m = c \cdot R^3 \cdot \omega^3 = c \cdot V^3 \qquad \text{Eq.9}$$

We have known that the input voltage of the batteries and the radius of the wheel are constant. We also know that the drag coefficient and motor coefficient can be approximated to be constant in normal environment. So we conclude that a 50% increase in the maximum current will result in a 50% increase in the input power and the output power. Then the percentage increase of the top speed will be $\sqrt[3]{1.5}$ -1 = 14%. During the test that was conducted on the dynamometer last semester, the top speed was determined to be 37mph, so our prediction of the new top speed will be 37×1.14 = 42.4mph.

Final Design Description

The following section will describe our proposed solution that is the result of the above design parameter analysis. In short, a detailed description of our final design will be presented with references to the conclusions drawn from the previous section (Engineering Design Parameter Analysis). Resolving the previous two performance issues (recirculation valve and motor controller) are not discussed in this section, however they are included in our final design as improvements.

Manufactured Components

Custom Manifold

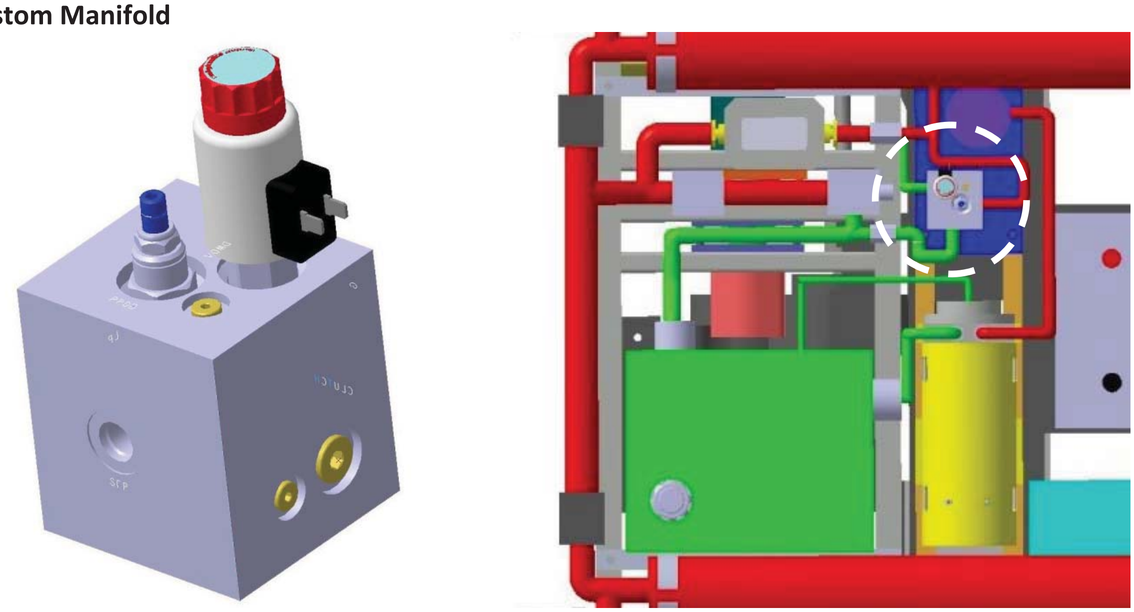


Figure 20. Manifold simplifies hydraulic layout and reduces number of connections

The custom manifold has been manufactured by RHM Fluid Power and consists of a pressure reducing valve (Sun Hydraulics: # PPDB-LBN) and a solenoid operated directional valve (Sun Hydraulics: #DWDA-MAN512) installed in a 6061 Aluminum Alloy housing. Detailed drawings and specifications of this product can be found in Appendix XV.

The custom manifold provided by RHM Fluid Power enables our team to greatly simplify the hydraulic circuitry and to achieve overhead access to the batteries. The manifold houses two logic valves: 1) pressure reducing and 2) 3-way directional valve. The manifold receives high-pressure fluid (max: 3500psi) and is reduced down to 100psi because the hydraulic clutch is not able to handle more than 100-psi. The 100-psi flow is regulated by the directional valve to control when the clutch is engaged. The directional valve receives a voltage signal to activate the solenoid and allow flow to the clutch. When the signal to the directional valve is removed, the flow is relieved to the low pressure reservoir.

The exact same valves that were used in the previous design have been integrated together through this product. This change has reduced the required fittings and hydraulic lines by approximately 50% and as a result, the head losses associated with this section of the hydraulic circuitry is also reduced by that same factor.

Simplified Mounting Mechanism

In the previous section the mounting mechanism has been simplified to result in a basic 'rail system' that will support the slow-fill pump as well as the custom manifold and the hydraulic filter. A detailed engineering drawing of the components that make up this design can be found in Appendix XIV. Through the static load analysis performed in previous sections, the material was chosen to be 1020 steel.

For our material selection process we first created a well defined function for the part. For the mounting beams, the primary function was to support the weight of three vital hydraulic components: the slow fill pump, the manifold and the filter. We used the CES Software created at Cambridge University to aid in our material process selection.

The force required from the mounting beams was calculated from the masses of the slow fill pump (15 kg), manifold (2.5 kg) and filter (2.2 kg). The mounting beam must have adequate yield strength and fracture toughness to prevent failure. The required length of the mounting beam was determined from the distance from the frame of the Xebra vehicle. This required length is constrained because the mounting beams need to be fastened to the frame using bolts. The shape of the mounting beam was also constrained so the slow fill pump, manifold, and filter could be supported by the mounting beams as well as to limit the horizontal movements of the vehicle. The remaining free variable for the mounting beam was the material thickness. The objective of our material selection process was to minimize both the cost of the material as well the environmental impact of the vehicle.

Function	Support beam for mounting the Slow Fill Pump, Manifold and Filter
Constraints	Adequate Strength, Freq = 100 N High Fracture Toughness Length = 0.975 meters Shape
Objective	Minimize cost and Environmental Impact
Free Variables	Material thickness

Table17. Summary of constraints and objective of material selection process

We chose to constrict our materials to metals because they are machinable and strong materials. The free variable of the mounting beam is the thickness. The mounting beam is loaded in bending and the stiffness, length and width are specified. Using the CES Edupack 2, we found that to minimize the cost for a mounting beam with these characteristics, the relationship below must be maximized.

$$\frac{E^{\frac{1}{3}}}{\rho * Cost}$$

We found that the materials that maximize this relationship were aluminum alloys, steels and cast irons. Cast irons were eliminated in the next step of selection process because they are brittle and have low fracture toughness which would allow any cracks in the mounting beam to propagate and cause failure. To minimize the impact on the environment we used SimaPro 6 to compare Aluminum alloys and steel alloys. The specific alloys we compared were age wrought Aluminum alloy, AlSiMgMn 6009 I, and manufacturing steel, 10SPb20 I. Using graphs to compare the two materials, included in Appendix III, we concluded that steel had a much lower impact on the environment. Producing Aluminum requires more resources and it also releases more pollutants than producing steel. Therefore we chose to use steel to manufacture our mounting beams.

Using static analysis on the beam, we determined that with a minimum safety factor of 3, the minimum thickness necessary for the mounting beam was 7.7 mm. This would be a very thin metal sheet that would be difficult to find or manufacture. We will use a mounting beam with a thickness of 10mm in order to ensure that the beam will not fail in bending. The formulas and calculations to find this minimum thickness are included in Appendix XII.

The installation of the mounting rails has also been considered and dimensions for their locations within the Xebra car layout can also be found in Appendix XXI. The design is both simple and effective in supporting the necessary components. As previously stated, this mounting structure will support the slow-fill pump, hydraulic filter, and the custom manifold. The main advantage of this design is an increased level of simplicity in accomplishing the same objective. A description of the previous designs can be found in the 'Selected Concept Description' section of this report.

The slow-fill pump will be mounted directly to the rails through two pairs of nut/bolt connections, while the plate will be secured in a similar manner. The remaining components (custom manifold and hydraulic filter) will be placed on the plate itself. The manifold will be bolted down because it will rarely need to be removed while the hydraulic filter will be set in a hole in the plate for ease of removal/replacement of filter elements. The validation for why this design will succeed included basic static analysis and finite element analysis of the mounting rails with appropriate forces applied (discussed above).

Layout and Relocation of Components

The second major change that we are making to the Xebra car which combines many of the objectives our primary stage goals is the layout and relocation of components. This change includes successful redesign for overhead space, changing the critical hydraulic connections, and color coding the hydraulic connections. An unanticipated change that was discovered in the troubleshooting process of the recirculation valve was the required improvement of the filtration system; this will be discussed at the end of this section. A detailed layout of the system with dimensions can be viewed in Appendix XXI.

Overhead Space

Many of the components were relocated to achieve the required overhead space. These include: 1) slow-fill pump 2) logic valves 3) hydraulic filter 4) flow meter and 5) dump lines. These changes were all necessary for clearing the space above the batteries for ease of access. The cleared space above the batteries will allow faster replacement of those components; a process that previously required two days to complete. To ensure the success of accomplishing this feat, an in-depth and detailed CAD assembly of the entire system was created to model the changes that we proposed.

After the changes, a comparison in access time was attempted using Boothroyd Dewhurst (BD) charts. These charts (which are discussed in more detail in the 'Engineering Parameter Analysis' section) quantify how difficult it will be to accomplish a task by taking into account the characteristics and conditions of assembly. This process was performed on the current design and compared with an identical analysis with our proposed design. The percentage change in access time that was estimated using this method was 92% which would translate to approximately 2.4 hours in real-world access time (which meets our target value).

Layout

The major change in regards to the layout of the system is the relocation of two major dump lines. The previous design had these dump lines traversing unnecessary distances to reach to only inlet to the system. A more efficient design was developed which includes an additional inlet to allow for these dump lines to be more efficiently located.

Other minor relocations that do not warrant a detailed description in this section are the logic valves, hydraulic filter, and flow meter. Excess piping associated with these components were eliminated and efficient usage of available space was emphasized. These relocations were critical in achieving the overhead space that was discussed previously. The validation of these changes as having a practical impact on the efficiency and performance of the car is seen in an improvement in head losses.

Filtration System

As previously mentioned, an improvement in the filtration system on the Xebra was deemed necessary as a result of the ISO standards of particle size for the recirculation valve. The recirculation valve requires a 3µm filtration rating while the current rating is estimated to be 10µm. This estimation is a result of the lack of information on the age of the current filter element. As a result, we are planning on ordering a 3µm filter from Hydac (DFBN/HC30TB3B1.X/12 B6) that not only achieves the necessary filtration requirements, but also comes with a filter element indicator. This indicator will provide a visual display that notifies the user when the filter element needs to be replaced. This will not only improve the maintainability of the Xebra system as a whole, but will also have a positive impact on the transferability to future semesters.

The location of this filter will also be relocated. With the goal of improved maintenance in mind, relocating the existing filter to a position in which filtration will occur before the fluid interacts with any components. In the current design the logic valves are receiving un-filtered hydraulic fluid. Making this change will reduce the frequency of required maintenance of those valves.

Fabrication Process

Manufacturing

Low Pressure Reservoir Redesign

In order to route the hydraulic lines of the Xebra system more efficiently, an additional inlet was created in the left side of the existing low pressure (LP) reservoir. The low pressure reservoir was removed from the main frame of the vehicle and thoroughly cleansed with acetone. We proceeded to use an air pressure rotatory tool to sand the side of the accumulator and remove the paint at the desired location of the collar. A 1-$^{3}/_{8}$ step drill was used to make the hole on the side. The drilling/tapping process done on the collar was performed by the Environmental Protection Agency (EPA) using a SAE O-ring Boss tool which at the time was not available in the ME student shop. The tapping procedure was validated by testing an available JIC-16 fitting .Once the collar was threaded, we proceeded to reduce the thickness of the collar by using the lathe and milling machines. Both components were cleansed once more with acetone before Bob Coury welded the collar onto the LP reservoir in the student shop giving the new inlet a professional finish.

Slow Fill Pump and Manifold Mounting Plate

In order to create overhead space for the batteries, the slow fill pump was relocated closer to the low pressure reservoir and also rotated 90 degrees clockwise from the previous configuration. The original mounting mechanisms of the slow fill pump and filter were disassembled and discarded accordingly. We purchased two AISI 1020 L-shape steel beams (975x40x8 mm), a thin metal plate (343x165x8 mm) and implemented them as the new mounting mechanism for the slow fill pump and the hydraulic manifold. We used the following feed rate and cutting speeds for steel during our manufacturing.

	Feed Rate [mm/rev]	Speed [RPM]
Turning (Lathe)	0.076 – 0.914	325 – 3800
Drilling	0.10 – 0.20	995 – 2060

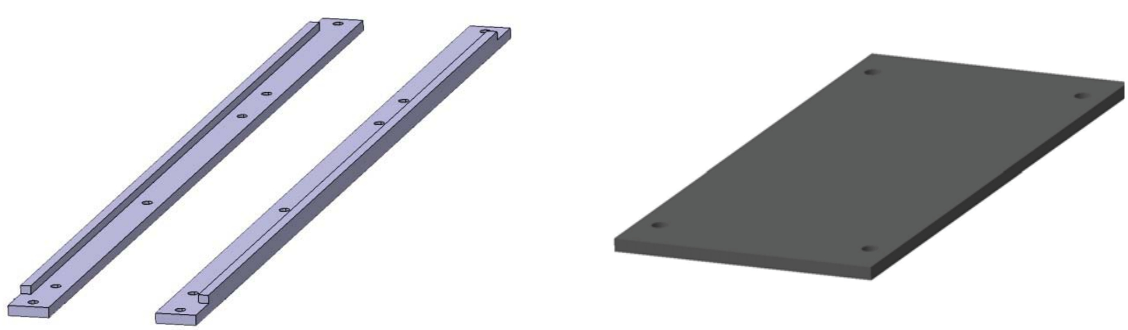


Figure 21. Supporting beams and plate

We measured the width of the main body of the Xebra and determined that the beams had to be 975 mm long. We proceeded to cut the beams and plate to the correct dimensions using the band saw. We also realized that the beams were taller than we expected, and to avoid any interference between the beams and the inner accumulators we cut a portion of the upper side at the ends of each beam accordingly. The beams were filed in order to remove any sharp edges. Using a 3/8 inch (9.525 mm) drill bit we then continued to make the mounting holes for the slow fill pump. The beams were superimposed on the frame of the Xebra and the slow fill pump was mounted. We confirmed the desired new position of the slow fill pump and also discovered that one of the holes in the beam did not align. We went back to the shop and corrected this issue by drilling another hole followed by filing. It proved difficult to be 100 % accurate when drilling holes and this incident presented itself several times. Over the following days we completed the mounting holes on the beams and dismounted the accumulators in order to drill the mounting holes on the frame of the Xebra using a cordless drill. All the components were assembled once again and any hole alignment problems were resolved. In doing so we also realized that there was interference between the beam closest to the low pressure reservoir and one of the check valves. A 1.25" step drill was used to remove material from the side of the beam allowing the cylindrical part of the check valve to pass through. Finally, two mounting holes were drilled in the left top side of other beam which would be used to secure the filter mounting mechanism. All mounting holes were made with a 3/8 inch (9.525 mm) drill bit in the student shop; securing the beam with a clamp and/or using the provided vice and scrap wood. All safety procedures were strictly followed.

Manifold Mounting Plate

The manifold mounting plate was originally made according to the engineering drawings found in Appendix XIV. In the final stages of fabrication, the hydraulic lines were completed by the hose doctor but the manifold was not installed in the predetermined location. An interference arose between the low pressure dumping line of the manifold and the pressure line that connects the (LP) reservoir to the slow fill pump. The manifold was also closer to the slow fill pump and the plate was not long enough anymore. The only solution was to manufacture a new mounting plate long enough to support the manifold in its new position, and to raise the plate to avoid the two hydraulic lines to touch. The new plate would have to have the appropriate shape that would allow it to go through the check valve and the pre-existing bolts from the filter mounting mechanism when raised to the desired height. The mounting holes on the new manifold plate were made based on the holes of the original manifold plate. We set the new plate on top of the old one and traced with a marker the location of the cylindrical interference of the check valve and the bolts form the filter mount. The plate was manufactured onsite and no engineering drawings exist. Even though the manufacturing plate was improvised we made sure the finish was professional allowing enough clearance for all components.

Filter Mounting

Two additional brackets and a mounting plate were the original design that would allow proper mounting of the new filter. Original engineering drawings can be found in Appendix XIV.

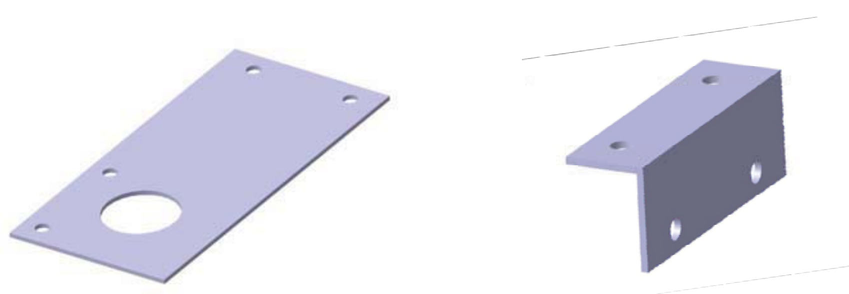


Figure 22. Original Filter mounting components, supporting beams and plate

The following procedure was used in the manufacturing process of the filter mount mechanism.

Brackets

1. Brackets were cut to appropriate lengths according to original engineering drawings.
2. Two pairs of mounting holes were drilled in the brackets using a ¼ inch (6.35mm) drill bit.

Mounting Plate

1. Band saw (100 RPM) was used to cut the plate to appropriate dimensions (Appendix XIV).
2. The filter mounting hole was drilled with outside diameter of 50.8mm.
3. Filter hole required a diameter of 52mm and this was accomplished by using a CNC programmable mill with the assistance of Marv Cressey.

Final Filter mounting

The original mounting was modified after the hydraulic connections were completed by the hose doctor. Such connections forced the filter into a different position and it no longer fit in the space provided the mounting. We proceeded to cut the unnecessary material in the mounting plate almost reducing it to half its size. We also decided that a single beam would be sufficient to provide support.

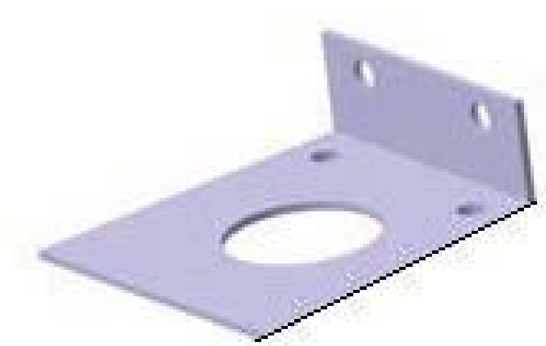


Figure 23. Final filter support mechanism

Flow Meter Mounting

We had not anticipated that a flow meter mounting would be necessary to complete our proposed layout redesign. After partially mounting the components we realized that the flow meter did not fit as it had interference with the inner accumulators and the check valves. An elegant solution was presented by one of our teammates that involved elevating the flow meter __ inches to avoid any interference with aforementioned components. The mounting mechanism (shown in figure 24) consisting of one plate and two support beams was implemented to solve the flow meter interference issues.

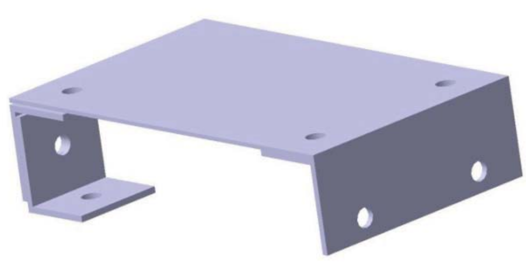


Figure 24. Flow meter support mechanism

The supporting structure for the flow meter was manufactured following the same procedures as with the filter mounting mechanism. A hole center punch was used to mark the position of the desired mounting holes before drilling.

Electronic Control Board
The electronic control board made of wood was replaced. A schematic of the circuit relays was drawn. A plastic board was cut using the band saw and it was given the same dimensions as the original board. The relays of the control board were re-attached in the plastic board by making small holes using a cordless drill and then using screws to secure the components. Following the schematic, the control board was rewired using new color coded wires. The wires were cut to the necessary length, stripped, and electrical connectors were installed using a crimping tool. The electronic control board was finally placed adjacent to the rear end of the passenger cabin.

Assembly

Motor Controller and Contactor
The motor controller and contactor were easily replaced. Access to the supporting bolts was limited, but the new components fit into the existing mounting mechanisms without any modifications. A diode was installed in the contactor, and the main fuse of the electrical system was replaced. The wiring diagrams of the original ZAPcar and Alltrax were used when reconnecting the electrical wires. A troubleshooting session was carried out with the help of Alltrax technicians over the phone as well. A Serial RS-232 to USB adapter was provided by John Hart and the controller was connected to a laptop to confirm it was programmed with the correct settings provided by ZAPcar.

Manufactured components
The assembly process was ongoing and occurred simultaneously with part fabrication. It was the only way to check if the parts actually fit, if the mounting holes did align, and if the bolts fit into the mounting holes without struggle. We partially assembled and disassembled the slow fill pump and manifold mount mechanism several times until all hole misalignment and interference issues were corrected. Once the supporting beams were perfected, we manufactured the filter mount mechanism followed by a trial assembly. The mounting holes of the supporting beam had to be filed until the bolts finally fit. The same trial and error procedure was used in the assembly/correction process for the flow meter mount. It must be pointed out that the accumulators had to be removed to drill the holes on the frame in order to secure the slow fill pump and manifold mounting mechanism using four 3/8 inch bolts, nuts and washers. Such mechanism was also raised using washers to allow clearance between the beams and the end tip of one of the new contactor connections. We encountered a problem in the reassembly of the left side accumulators when a JIC fitting in the pressure line would not bolt correctly. The thread of the elbow fitting was damaged and had to be replaced. After several days of work, all the mounting mechanisms were ready and assembled. The high voltage electric connections were also covered with insulation covers.

Hose doctor
On April 10th, 2010 the hose doctor finally arrived to the X50 lab. He worked 5 hours with an associated cost of $883.01 and was able to complete all the hydraulic connections pertinent to our new layout. He provided all the raw materials and tools as well. The hydraulic manifold, slow fill pump, filter, low pressure reservoir, flow meter and hydraulic motor were all properly connected. As mentioned before, the hydraulic connections forced the manifold and the filter into a new position which forced us to modify the mounting mechanisms for both components. The final manifold plate was raised by using washers between the

supporting components. We also used washers as spacers when installing the filter mounting mechanism. This allowed us to place the mounting mechanism according to the predetermined position of the filter defined by the hydraulic lines. The final position of the mounting mechanism provides support and guides the filter in the correct orientation.

Design Validation

After successfully manufacturing the parts and assembling the vehicle, we performed several tests to gauge how the improvements that we have made satisfy the customer requirements and the engineering specifications. The main tests were the functionality test and the accessibility test.

Functionality Test

After consulting with our sponsors at the EPA, it was determined that the functionality of the Xebra car was to be the only aspect validated. Since our team is not modifying any aspect that directly or significantly affects the performance of the car, testing on the EPA's dynamometer would be ideal but not necessary. Also, because the hose doctor cancelled his appointments twice and left us no time to finish the hydraulic system assembly, we were not able to test the functionality of the hydraulic system. On April 11th, 2010, we carried out the parking lot test for the electric system.

A detailed procedure about the safety concerns involved in moving the car can be found in the attached safety report in Appendix XIII.

We after the test, we measured the average length of a parking space and found that it was about 8'. We also utilized the following equation:

$$a = \frac{2s}{t^2}$$

Where *a* is the acceleration, *s* is the distance traveled (80' in our case) and *t* is the time of travelling. Incorporating these information with the data that we obtained during the test, we were able to calculate the initial acceleration of the vehicle using only electric system to start and add it on top of the data from last semester's team, as shown below in Figure 25.

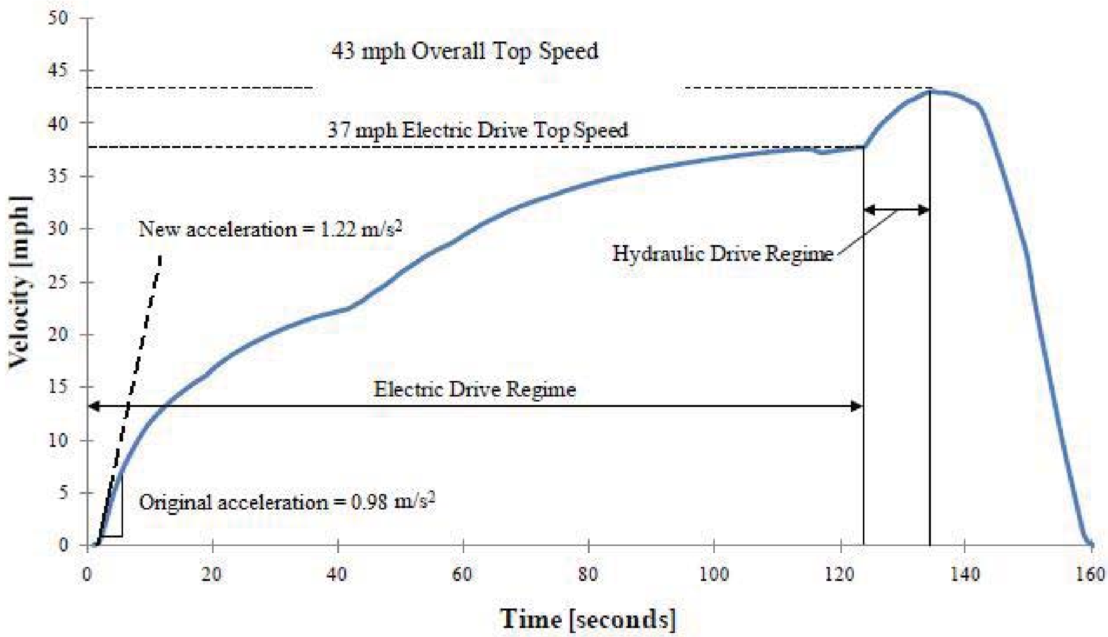


Figure 25. Result of the parking lot test

From the figure we can see that the new initial acceleration of the vehicle was 1.22 m/s^2. This is about 25% increase compared with the last semester's dynamometer test results. We think this is mainly because the updated motor controller was able to provide more current to the motor in this process.

In a conclusion, the test validated that our design not only was able to keep the same level of performance, but also actually improved the electric system performance of the vehicle through the upgrade of the key components.

Accessibility Test

After the functionality test, we further performed an accessibility test of the batteries to test the improvements in the serviceability of the vehicle. A detailed procedure of this test can be found in the safety report in Appendix XIII. The result of the test is shown below in table 18.

Test #	1st	2nd	3rd
Take off (min)	15	14	12
Put back (min)	20	18	16

Table 18. Battery accessibility test result

The result of our test showed that the average time for 3 team members to completely change the batteries was about 30 to 40 minutes. Considering the fact that we did not actually pull all the batteries out for safety concerns and we were quite familiar with vehicle, we further estimated the time for three workers who are new to this vehicle to change the batteries to be about 1.5 hour, which was still better than our engineering specifications.

Project Plan

The preliminary stage of our project began with a sponsor that consisted of the Xebra Team and our two primary EPA contacts, Dr. Moskalik and Dr. Swain. The goal of this meeting was to determine the customer requirements and general direction of our project. After these meetings, we understood that our project would be to enhance the maintainability and accessibility of the vehicle while keeping the same level of performance of the vehicle. We then met one of the former ME450 team members, Alexander Duggan, to determine the current status of the car and asked for suggestions based on his knowledge. After these interviews, we identified the hydraulic system as the main impediments to the serviceability of the vehicle and our project would focus on this aspect. Then we began to translate the customer requirements into engineering specifications. To solidify our plans and clarify the tasks our team would have to accomplish, we created a detailed Gantt chart, shown in Appendix XXIX.

As the hydraulic system is the main emphasis of our project, we interviewed Dr. Jason Moore, a known expert on this subject, to help ourselves better understand the hydraulic system and principles of the functionality of the vehicle. We researched several possible solutions to simplify the hydraulic system and Kevin investigated the idea of installing a central manifold for the hydraulic logic valves.

In preparation for Design Review 2 we went through a thorough concept generation and selection process. We used a functional decomposition diagram as an engineering tool to better our understanding of the problems that our project will address. We outlined the processes necessary for servicing the Xebra vehicle on January 30th. Afterward we brainstormed as a team and generated concepts to address the customer requirements while considering the functions that needed the most improvement. By February 8th, we created a Feasibility Assessment Chart, a Pugh Chart and MATLAB code to aid our concept selection process. We discussed the merits and disadvantages of our best concepts and created our Alpha design. By February 11th, we had a preliminary CAD model of our Alpha design. We met with our sponsors, David Swain on February 12th and Andrew Moskalik on February 16th to discuss our Alpha design and received approval for presenting it.

After getting approval from the section instructor and sponsors during the second design review, we began to refine the design and making CAD models with accurate geometries. The main components that we would need in our alpha design were quoted and specific information was provided to our sponsors for the approval of purchase. We also submitted two preliminary safety reports to the section instructor for our tests of determining the cause of the malfunctioning parts.

By the end of the spring break, we had determined the cause of the failure of the recirculation valve and proposed a replacement of the filtration system. Our custom manifold and the updated electric controller were approved for purchase. We have received both the electric controller and custom manifold on March 18th and March 22nd respectively. With the main components received, we completed preparations for implementation on the Xebra vehicle. These preparations included but ar not limited to completing the necessary safety reports for system investigation, hydraulic disassembly, manufacturing, and assembly. While waiting for approval of these documents, we began a theoretical analysis on the positive impacts that our alpha design may have on the overall system.

On April 1st, our comprehensive safety report was approved and work on the vehicle could begin. Prior to this date, a specific safety report for investigating the recirculation valve was approved on February 26th and a similar report for hydraulic disassembly was approved on March 24th. Separating the safety report into separate documents was very beneficial to the overall success of the project.

The recirculation valve testing began on February 27th and the appropriate components were ordered to resolve the issue. The hydraulic disassembly began immediately on March 24th to discover any potential problems with our original design that might have arisen from not seeing the system in full. The low pressure reservoir was successfully removed and modified by Marth 29th. The motor controller was successfully installed by April 6th while the controller settings were not able to be confirmed until April 13th. By April 7th, everything was in place for the Hose Doctor installation appointment the next day. The Hose Doctor canceled his appointment on April 8th and we rescheduled for April 9th; he proceeded to cancel that appointment as well. Alternative methods for installing the hydraulics were investigated and it was discovered that he was our only viable option given the time constraints. The Hose Doctor offered to come in on that Saturday (April 10th) and completed the work by 2:00pm.

We had previously scheduled a parking lot test on April 11th to test the functionality of both the electrical and hydraulic systems on the Xebra. However, the cancelations by the Hose Doctor eliminated any chance of finalizing the hydraulic fittings for testing. Validation of the electric drive of the car was performed on April 11th only. A problem with the main drive batteries ‘cutting out’ was discovered and experts at EV Drives were contacted on April 14th for possible solutions. Throughout all this time, Eric had been working on the controller board rewiring. His focus was color-coding the signal wires to the hydraulic valves and improving the overall clarity of the system. His work was completed by April 12th.

The Design Expo on April 15th showcased our completed vehicle. After the expo, the motor controller settings were corrected and Parking and Transportation Services were contacted to schedule another parking lot test, but there were no times/locations available. Other work that has been completed after the design expo includes: documenting the final report (April 20th), cleaning up the X50 lab, and delivery of the vehicle to our sponsor before April 27th.

Discussions

Advantages

At the beginning of this semester, we had two main problems to solve in this project: clean up the remained problems from the previous team and implement our own design to enhance the serviceability of vehicle. Now in view of the progress that we have made, we are confident that most of the targets have been met.

The malfunctioning parts mentioned in the previous reports have been identified and repaired/replaced. Additionally, we have updated the critical components (contactor, filter) of the hydraulic and electrical system so that there would not be particles that would clog the hydraulic valves in the system. During testing of the recirculation valve we realized that the valve was not installed in the reverse direction. When comparing the bill of materials between the Fall 08 Xebra report and the Fall 09 Xebra report, there is an inconsistency in the part numbers for the recirculation valve. The Fall 09 team which believed that the recirculation valve was installed in the reverse direction had the part number listed as WS16**Z**R-01-M-SS16-N-12-DS but the part number is actually WS16**Y**R-01-M-SS16-N-12-DS. The recirculation valve was installed correctly but was clogged, which we discovered during testing.

For improvement to the serviceability of the design, our idea of redesigning the hydraulics to create overhead space for the batteries through the implementation of a manifold has proven to be both efficient and effective. With the additional work required for fixing the problems unresolved from previous projects, we were able to finish our main objective on time. This will not be possible if we did not choose to design for the battery overhead. The design saved a lot of time because we did not have to completely redesign the high-pressure components but were able to greatly improve the accessibility of the batteries.

When the batteries need to be replaced in the future, the time to access them will be dramatically decreased. What was once a nearly 2 day process, that causes an inefficient use of time and resources, has been reduced to a process that should take less than an hour with 3 to 4 people.

Disadvantages

With all these good points of our design, we also clearly realized that there are some weak points in the current car. First, due to the time constraints of the class and the focus of our project, we were not able to further simplify the high-pressure circuitry of the system, which would save more space for other components. Also due to time constraints we were not able to change the mountings of the accumulators, and the accumulators are still very hard to remove. So even though we can easily access the batteries, it is still hard to access the motor controller or other electric system components because the mountings of the support beam for the slow fill pump and flow meter are fastened to the frame beneath the accumulators. We thought that a completely modularized hydraulic system may be able to solve the problem, but it will be much more expensive, complex and alternative approaches may be available.

There is one significant error in the hydraulic lines that needs to be fixed before testing the vehicle can begin. The diameter of the hydraulic line going from the hydraulic motor to the low pressure reservoir is too small. The diameter of the output line from the hydraulic motor should be the same as the diameter of the input line into the hydraulic motor to maintain the same volumetric flow rate.

Although the electronic controller board that controls the hydraulics has been improved it still needs refinement. The most important addition to the electronic controller board is a remote data acquisition (DAQ) system. The old DAQ system no longer worked and the addition of a DAQ system was not within the scope of our project. In the future, the addition of a DAQ system will increase the serviceability of the vehicle and will also increase the ease of troubleshooting the hydraulic system. We were able to rewire the controller board and create a clearer schematic to improve the transferability dramatically but some of the wiring remains unchanged. We were unable to finish rewiring the electrical connections to the brake, accelerator, FNR (Forward, Neutral, and Reverse) switch, buzzer, emergency stop button and batteries because we did not have enough time or material left.

Further thoughts

A main issue of the project is the conflict between reaching higher speed and ensuring safety. The original Zebra car was designed to run at a top speed of 35 mph, now the car has been modified and the test result from the last semester showed that it could reach a top speed of 45 mph. The previous team reached this target by adding new accumulators and other components to the system. However, the improvements did not come at no cost – the complexity of the system increased, resulting in increased difficulty of maintenance. More important than that, the main electric driving system had been pushed to the operational limit. In this semester, we have redesigned the system so that most critical components can now be easily accessed; we have also updated the motor controller and its auxiliary parts so that enough power can be delivered to the motor for a 45 mph top speed. However, problems reported from previous semester like occasional overheat and short in circuit were not inspected and solved, which were mainly caused by operating the car at too high speed.

Our main objective of improving the accessibility of the batteries was met, unfortunately we were not able to verify the functionality of the hydraulic system. Due to scheduling conflicts with the hose doctor to finish the hydraulic lines, we were unable to finish assembly of our design before our testing scheduled on April 11th. We have data that shows that the electrical motor is functional and we have correctly reinstalled the repositioned components. However, with such a complex system we are not sure if all the problems have been resolved and validation is a necessary step.

Recommendations

We recommend that future Xebra team look at the following aspect of improving the current vehicle.

1. **Correct the diameter of the hydraulic line leaving the motor:** the diameter of the hydraulic line going from the hydraulic motor to the low pressure reservoir is too small. The diameter of the output line from the hydraulic motor should be the same as the diameter of the input line into the hydraulic motor to maintain the same volumetric flow rate.

2. **Validate the functionality of the hydraulic system:** Due to scheduling conflicts with the hose doctor and time constraints, we were unable to validate the functionality of the hydraulic system. The dynamometer was unavailable before the end of the semester and the parking lot was also unavailable at the time needed. Unfortunately we were unable to test the functionality of the hydraulic system and the regenerative braking.

3. **Further simplify the hydraulic circuitry**: the concept of modularization has been proved to be very effective, the addition of the manifold greatly simplified the logic valve circuitry. Further simplification of the system can be conducted on the high pressure circuitry connecting the accumulators and the hydraulic motor and pump. A similar manifold design with much higher rating would be worth considering. RHM Fluid Power Inc. was extremely helpful in assisting us with our project.

4. **Combine the hydraulic pump and the motor**: to our understanding, the function of the hydraulic pump and the hydraulic motor are basically the same except for the rotating direction. We did not have time to combine them because we realized that a mechanism is needed to transit the rotation of the main shaft with a backward direction to the combined motor/pump to pump the hydraulic fluid into the accumulators. This mechanism can be a gear system with a clutch and can be very beneficial as further simplification.

5. **Connect slow fill pump to the main motor/shaft:** currently the slow fill pump is driven by a separate electric motor. The motor has a very large size and is getting power directly from the main batteries. As we have the main motor providing ample rotational energy to the car, we have an idea about moving the slow fill pump downwards and connect it to the main shaft; in this case, much more space will be saved in the upper surface of the system.

6. **Replace the flow meter:** the current flow meter has a quite large size, and are taking a lot of valuable spaces on the mountings. Future team can investigate the possibility of using a smaller flow meter so that the filter can be moved to the mounting plate and the motor controller can be easily accessed. We were unable to find a smaller flow meter with the same pressure and flow rate specifications but a smaller flow meter may be created in the future.

7. **Add pressure gauge for accumulators:** the main safety issue that we have faced at the beginning of this semester was the potential high pressure in the accumulators. Although it turns out that the accumulators are empty, we were not sure about that at that time because the pressure measurement device was a transducer and no appropriate connectors or instructions were available to us. We think that adding a pressure gauge with a dial reading in series with the existing transducer would be easier for everyone to inspect the pressure of the accumulators.

8. **Electrical system redesign:** Even though we rewired the electronic control board using color coded connections, we believe there is still room for vast improvement in the electrical system of the Xebra. The electrical connections in the cabin are very disorganized and some connections are unreliable and become loose when the vehicle is operated. There are also wires that we believe not connected to anything and serve no purpose. We recommend a complete electrical redesign of the electrical wireframe by a professional electrical engineer. An electrical engineer also needs to address/ troubleshoot the original electrical system of the Xebra in order to discover why the vehicle will not turn back on a full charge unless it is plugged back into an electrical outlet.

9. **Improve mounting mechanisms:** After the hose doctor completed all the hydraulic connections, he moved some of the key components (such as the oil filter and the hydraulic manifold) forcing us to modify our mounting mechanisms very late in the manufacturing stage. We believe that such mounting mechanisms can be perfected assuming that the hydraulic layout of the vehicle remains unchanged. The mounting mechanisms of the high pressure accumulators also desperately need an overhaul. The current mounting configuration makes it very difficult for the user to reattach the accumulators to the frame of the vehicle, and to reconnect the hydraulic lines.

10. **Update speedometer sensor:** The Xebra team of fall 2009 was responsible for increasing the top speed of the Xebra, and in doing so they implemented rear tires of larger diameter without readjusting the speedometer sensor. Due to this modification, the speedometer sensor gives a false reading which is an issue that should be addressed in future semesters.

11. **Contactor Insulation Box:** During the course our assembling stage, we insulated the critical electrical connections that carry high voltage in the Xebra. We think that our preventive efforts against an electrical accident could be taken a step further by covering the contactor using and insulation box. This measure would be very helpful to prevent any bolt or metallic tool to fall in the contactor area and cause a short circuit in the system.

12. **Revise Motor Control settings:** During our parking lot test, the Xebra vehicle cut off and stalled when full throttle was applied. It is possible that the motor control settings given by Zapcar are incorrect causing erratic behavior. We recommend future teams to use the settings recommended by Alltrax and test the vehicle once more to verify the vehicle accelerates smoothly at any operating condition.

13. **Resolve Budget Early:** Due to regulations placed on the EPA, they are unable to pay for the services of a hose doctor to cut and crimp the hydraulic lines. The hose doctor costs upwards of $1,000 which is much greater than the ME 450 budget. Resolve how to pay the hose doctor early in the project lifetime.

Summary and Conclusions

The Xebra project, sponsored by Andrew Moskalik and David Swain of the EPA, has been an ongoing endeavor that has been worked on by four different ME 450 teams from the University of Michigan. After four separate projects aimed at improving the energy efficiency and the utility of the Xebra vehicle, the serviceability of the electric vehicle has been sacrificed. The lack of serviceability was caused by the fragmented nature of the project's lifetime. With each new team and project focus, the Xebra vehicle increased in complexity. The difficulty of our design was integrating the differing focal points of these separate projects into a single vision.

We have performed extensive research into the current system by reading the reports of prior teams, patents and academic research papers to better understand hydraulic systems. We continuously used the expertise of our sponsors and previous team members to aid in our understanding of the vehicle.

Our sponsor at the EPA emphasized that the objective of this project is to redesign the hydraulic system for improved accessibility and maintainability of key parts including the batteries and the electric motor. The maintainability of the design also has to be improved so the vehicle can be considered for mass production. In addition to improving the maintainability, we were asked to maintain the performance levels and safety standards, to refine the electrical wiring and to repair the faulty valve and motor controller. To quantify the improvements asked for, we set a list of engineering specifications as our goals, found on page 3. We aimed to decrease the number of hydraulic connections and the length of wire by ten percent in order to increase the simplicity and maintainability of the hydraulic and electric systems. The reduction in time to change the battery, the time to troubleshoot the electric system, and the number of steps also were derived from our goal of increasing the serviceability of the vehicle. When determining the specific values for our engineering parameters, we accounted for the complexity of the hybrid vehicle in order to arrive at reasonable targets. The translations of the sponsors' requirements into our engineering specifications were approved by Andrew Moskalik and David Swain.

After clearly defining our project objectives through our customer requirements and engineering specifications, we began developing many concepts that addressed at least one of the main customer requirements (Accessibility & Maintenance, Simplicity, and Safety). Through our concept generation process we were able to create a set of primary and secondary objectives aimed at improving these main customer requirements. We completed all of our primary objectives and a majority of the secondary objectives. We were able to identify that the recirculation valve was installed correctly but clogged because the hydraulic fluid was not being adequately filtered. We installed and were able to test an updated motor controller for the vehicle. We cleared the space overhead the batteries, vastly improving their accessibility, by installing a manifold and modifying the low pressure reservoir. We were able to create mounting mechanisms for the hydraulic components and color coded the hydraulic connections. We also created a detailed maintenance procedure for replacing the batteries of the vehicle. Of our secondary objectives, we color coded the wiring from the controller board to the hydraulic valves, included an updated electronic circuit diagram, bundled wires to the frame and changed the base of the controller board. The accessibility of the batteries was vastly improved, the maintenance of the filtration system was improved, and the safety was slightly improved be adding insulation to the motor contactor and motor connections. Although we were able to improve the vehicle, there were still some shortcomings.

The largest shortcoming of our project was our inability to validate the hydraulic system. Although we had reserved 3 days in order to finish the hydraulic connections so we would be prepared to test on April 11^{th}, the hose doctor's scheduling conflicts prevented us from finishing in time to test our design. The lack of hose doctors in the Ann Arbor area is a large liability because the hose doctor's other appointments are out of the team's control. One very important lesson that our team learned from our project was to plan out our finances as soon as possible. Our misconception on the process of paying the hose doctor was a large mistake and led to difficulties. As stated in our recommendations, the process of paying the hose doctor should be resolved as soon as possible because the grant that previous teams used to pay for the hose doctor's services has been expended.

The vehicle has three components that need to be fixed before the vehicle is functional. The diameter of hydraulic line going from the hydraulic motor to the low pressure reservoir is too small and needs to be replaced. The diameter should be the same as the entrance line into the hydraulic motor to ensure that the volumetric flow rate is the same. The wires from the controller board into the cabin and to the auxiliary battery should be replaced and color coded to improve the simplicity of the controller board. The low pressure reservoir needs to be sealed with gasket. The hydraulic fittings need to be tightened; the hydraulic components need to be fastened to their mountings; and hydraulic fluid needs to be added to the vehicle before it is functional.

Acknowledgements

The Winter 2010 Xebra Team would like to thank all of those individuals who generously offered their time and effort and were an integral part of making our project a success:

We would like to thank our sponsors at the U.S. Environmental Protection Agency, Dr. Andrew Moskalik and Mr. David Swain, for being a constant source of information and guidance throughout the semester. Having sponsors who were both understanding and willing to discuss the many problems that arose throughout the semester was very beneficial.

A special thanks is extended to Professor Krauss for having exceptional control of his section and keeping us constantly on task throughout the semester. His close guidance of our project through detailed discussion sections was extremely beneficial to the successful completion of our project.

We would also like to thank Phil Bonkoski for all his help with both the safety reports and being available for after hour access on a number of occasions.

The help of former students Alex Duggan, Ben Hagan, and Jason Moore was especially helpful in learning the intricacies of the Xebra vehicle that was not available through previous reports.

A very special thanks is extended to Hasan Shahid and the executives at RHM Fluid Power for their generous donation of a custom 2-valve manifold. Without this critical component, the redesign for overhead space would not have been possible.

We would also like to thank John Baker for his assistance; particularly with the electrical components of the vehicle.

Thank you, Bob Coury and Marv Cressey, for your answers to our seemingly endless inquiries about various machining processes.

A very special thank you goes out to Dan Phillips for his Hose Doctor service on a Saturday and his understanding with the unique billing issue we were experiencing as a team.

And lastly, a general thank you to the many companies that were involved in our project who provided either valuable components or essential technical support: Hydac, Exotic Automation, Parker Hannifin, Alltrax, ZAP, EV Drives, Sun Hydraulics, and Morrell Inc.

Information Sources

For our initial research we read reports by the previous ME 450 teams and discussed the project with our sponsors from the EPA, Andrew Moskalik and David Swain. From these sources we have obtained a basic understanding of the current hydraulic circuitry and the level of resources committed to the project. We have also met with Alexander Duggan, a member of the Fall 2009 Xebra team, and learned of certain intricacies of the vehicle that would have otherwise gone unnoticed.

Significant information gaps still exist in the understanding of the hydraulic and electric circuitry. A comprehensive circuit diagram of each system was never provided to us in the previous ME 450 reports. As a remedy for this fact, we have scheduled a meeting with Jason Moore, a post-doctoral student who was previously involved with the Xebra project, in which he will explain the current status of the hydraulic system in detail.

We have also done some lateral benchmarking with other electric cars in order to better understand the performance capabilities of electric vehicles. The information on these competitors has been obtained through various company brochures. From these, we have obtained basic knowledge that has enabled us to better gauge the current design against the competition. We established the main benchmarks of the vehicles would be the top speed and overall range. Other characteristics of the cars were obtained, yet were deemed irrelevant to the performance of the car itself. The ZENN car and GEM car were chosen because of their similar weight and shape for comparison with the modified Xebra car. [10,11]. The conclusion of such a comparison was that the Xebra had a better top speed but a lower range.

In addition to the above information sources, we have also referenced various patents and academic research papers for a deeper understanding of the current technological advancements on the topic of hydraulic energy storage. A more in depth modeling strategy was investigated in the paper by Ding et al. Separate models were used for city and highway of their ELPH propulsion system and concluded that with the newly developed propulsion system a car can achieve similar performance and loads when compared to a conventional car but with double the fuel economy [7]. Pourmovahed et al provided a relatively in-depth literature survey of systems with hydraulic energy storage and propulsion. [8]. The information provided in the report was a valuable overview of the applications of hydraulic systems. In another paper, the use of a hydraulic regenerative braking system in the area of anti-lock braking was discussed [9]. The paper provided a unique application of hydraulics that was not directly related to our project, yet enabled a valuable alternative view on hydraulic technology in general. The patents that we investigated discussed the most recent advancements in hydraulic regenerative braking systems. The most applicable patent that was most relevant to the Xebra project was a regenerative braking system implemented in a hydraulic-diesel truck [12].

The sponsors from the EPA and the former project participants are our most valuable sources of information and we will continue to utilize their expertise on the project. After our initial research, we have a clearer understanding of the problems that we will address.

Reference

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<not uploaded to Deep Blue>

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Appendix I

Item/Service	Manufacturer	Serial number	Distributor	Location	Contact name	Contact phone #	Comment	Unit cost	Quantity	Shipping	Tax	Total
Manifold	RHF fluid power	customized	RHF fluid power	Ann Arbor, MI	Hasan Shahid	(734)728-1779	hshahid@rhmfp.com	0.00	1	0.00	0.00	0.00
Electronic controller	Alltrax	AXE- 7245P	EV Drives	Port Townsend WA	Carl	(541)218-8890	carl@evdrives.com	565.00	1	22.30	33.90	621.20
Filter	HYDAC	DF BN/HC30TB 3A1.X12-VB6	Morrell Inc.	Auburn Hills, MI	Brian Hrischuk	248 / 373-1600	bhrischuk@morrellinc.com	262.98	1	25.00	15.78	303.76
Hose doctor	Parker	N/A	Exotic Automation	Farmington hills, MI	N/A	(248) 477-2122		883.01	1	0.00	0.00	883.01
Color wires	CAROL	6P16	Home Depot	Ypsilanti, MI	N/A	N/A	For color coding,five colors	4.69	5	0.00	1.41	24.86
Electric tape	Gardner Bender	GTPC-550	Home Depot	Ypsilanti, MI	N/A	N/A	For labling wires	3.98	1	0.00	0.24	4.22
Bucket	LEAKTITE	NRC0070MIL	Home Depot	Ypsilanti, MI	N/A	N/A	For exessive hydraulic fluid	2.34	2	0.00	0.28	4.96
Lid for the bucket	LEAKTITE	N/A	Home Depot	Ypsilanti, MI	N/A	N/A		0.98	2	0.00	0.12	2.08
Gloves	West Chester	Nitrile (100 count)	Home Depot	Ypsilanti, MI	N/A	N/A		14.97	1	0.00	0.90	15.87
Gasket	FEL-PRO	#3018 (10"x26"x1/16")	AutoZone	Ann Arbor, MI	N/A	N/A	For reservior sealing	4.99	1	0.00	0.30	5.29
Gasket maker	Permatex	#81724(77B)	AutoZone	Ann Arbor, MI	N/A	N/A	Used together with gasket	6.29	1	0.00	0.38	6.67
Steal plate	Alro Metal Plus	24" by 18.5"	Alro Metal Plus	Ann Arbor, MI	N/A	(734)213-2727	For filter mounting	10.27	1	0.00	0.62	10.89
Steal beam	Alro Metal Plus	4' long, 1/8" thick	Alro Metal Plus	Ann Arbor, MI	N/A	(734)213-2727	For filter mounting	8.75	2	0.00	1.05	18.55
Collar	Alro Metal Plus	2.5" diameter, 1.5" height	Alro Metal Plus	Ann Arbor, MI	N/A	(734)213-2727	For reservior inlet mounting	3.68	1	0.00	0.22	3.90
Gauge	WIKA	Mfr. Part # 9768688	Industrial Automation	Cornelius, NC	N/A	N/A	http://www.gaugestore.com/	37.08	1	9.98	0.00	47.06
Wire connectors	N/A	N/A	Home Depot	Ypsilanti, MI	N/A	N/A		13.33	2	0.00	1.60	28.26
Battery terminal caps	N/A	N/A	Auto Parts	Ann Arbor, MI	N/A	N/A		16.00	1	0.00	0.96	16.96
											total	**1,997.52**

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DATE	04/12/2010	TOTAL PAGES	5	INCLUDING COVER
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SUBJECT	SALES ORDER 1586692			

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SHIP TO

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2350 HAYWARD
ANN ARBOR, MI 48109
Phone: 845-558-0906 Fax:

'Hose assemblies, cut material and special ordered items are non-returnable."

ORDER DATE	CONTACT	RELEASE NUMBER	CUSTOMER P/O NUMBER	PAYMENT TERMS
04/12/10	KEVIN			VISA/MASTER CARD
SALES REP: MARK LEFEBVRE			WRITTEN BY: Dan Phillips	SHIP VIA: EXOTIC SALES ASSOCIATE DEL.

PRODUCT/DESCRIPTION	QUANTITY OPEN	QUANTITY PICKED	QUANTITY BACKORDERED	PRICE	U/M	EXTENSION
PHC8 C5OX-S FTG, PARKER, STR THD EL, 90 DEG, 1/2 37 DEG X 3/4-16 SAE **PO Line: 1**	2	2	0	6.6033	EA	13.21
	Exotic Sched Dt: 04/12/10					
PHC8 CTX-S FTG, PARKER, MALE EL, 90 DEG, 1/2 37 DEG FLARE X 3/8 NPT **PO Line: 2**	1	1	0	4.1067	EA	4.11
	Exotic Sched Dt: 04/12/10					
PHC6 F5OX-S FTG, PARKER, STR THD CONN, 3/8 37 DEG FLARE X 9/16 SAE, STEEL **PO Line: 3**	2	2	0	1.4833	EA	2.97
	Exotic Sched Dt: 04/12/10					
PHC12-16 C5OX-S FTG, PARKER, STR THD EL, 3/4 37 DEG FLARE X 1-5/16 SAE **PO Line: 4**	1	1	0	16.2500	EA	16.25
	Exotic Sched Dt: 04/12/10					
PHC12-8 TRTXN-S TUBE END REDUCER 3/4 FEMALE JIC X 1/2 MALE JIC, STEEL **PO Line: 5**	1	1	0	5.7133	EA	5.71
	Exotic Sched Dt: 04/12/10					
PHC8 R6X-S FTG, PARKER, SWIVEL NUT RUN TEE, 1/2 37 DEG FLARE, STEEL **PO Line: 6**	2	2	0	9.5967	EA	19.19
	Exotic Sched Dt: 04/12/10					
PHC4 F5OX-S FTG, PARKER, STR THD CONN, 1/4 37 DEG FLARE X 7/16 SAE, STEEL **PO Line: 7**	1	1	0	1.5367	EA	1.54
	Exotic Sched Dt: 04/12/10					

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MARK LEFEBVRE		Dan Phillips	EXOTIC SALES ASSOCIATE DEL.

PRODUCT/DESCRIPTION	QUANTITY OPEN	QUANTITY PICKED	QUANTITY BACKORDERED	PRICE	U/M	EXTENSION
PHC4 FNTX-S FTG, PARKER, CAP, 1/4 37 DEG FLARE, STEEL **PO Line: 8**	1	1 Exotic Sched Dt: 04/12/10	0	1.2867	EA	1.29
PHC8 HX6-S FTG, PARKER, SWIVEL NUT UNION, 1/2 37 DEG FLARE, STEEL **PO Line: 9**	1	1 Exotic Sched Dt: 04/12/10	0	23.1333	EA	23.13
PHC8 R5OX-S FTG, PARKER, STR THD RUN TEE, 1/2in 37 DEG FLARE X 3/4 SAE **PO Line: 10**	1	1 Exotic Sched Dt: 04/12/10	0	9.4300	EA	9.43
PHC8 F5OX-S FTG, PARKER, STR THD CONN, 1/2 37 DEG MJIC X 1/2 MORB, STEEL **PO Line: 11**	2	2 Exotic Sched Dt: 04/12/10	0	2.1300	EA	4.26
PHCP86014060 PH C820S COLORFLOW CHECK VALVE STEEL **Cust P/N: ALT-P86014060** **PO Line: 12**	1	1 Exotic Sched Dt: 04/12/10	0	29.7500	EA	29.75
PHC16 C6X-S FTG, PARKER, SWIVEL NUT EL, 1in 37 DEG FLARE, STEEL **PO Line: 13**	1	1 Exotic Sched Dt: 04/12/10	0	16.3400	EA	16.34

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PRODUCT/DESCRIPTION	QUANTITY OPEN	QUANTITY PICKED	QUANTITY BACKORDERED	PRICE	U/M	EXTENSION
PHC8 C6X-S FTG, PARKER, SWIVEL NUT EL, 90 DEG, 1/2 37 DEG FLARE **PO Line: 14**	1	1	0	6.2133	EA	6.21
	Exotic Sched Dt: 04/12/10					
PHC CALL OUT FEE AFTER HOUR HOSE DR. SERVICE BILLING CODE 999-999 **PO Line: 15**	5	5	0	90.0000	EA	450.00
	Exotic Sched Dt: 04/12/10					
EXK4W6W612 4 & 6 WIRE HOSE ASSEMBLY, 3/8in TO 3/4in, SEE DESC. **PO Line: 16** **721TC-06-06-16-12-12-1'**	1	1	0	58.5433	EA	58.54
	Exotic Sched Dt: 04/12/10					
EXK1W2W412 1 & 2 WIRE HOSE ASSEMBLY, 1/4in TO 3/4in, SEE DESC. **PO Line: 17** **302-06-37-8-6-6-1'**	1	1	0	16.6501	EA	16.65
	Exotic Sched Dt: 04/12/10					
EXK1W2W412 1 & 2 WIRE HOSE ASSEMBLY, 1/4in TO 3/4in, SEE DESC. **PO Line: 18** **302-06-37-6-4-4-3'**	1	1	0	30.6766	EA	30.68
	Exotic Sched Dt: 04/12/10					
EXK1W2W412 1 & 2 WIRE HOSE ASSEMBLY, 1/4in TO 3/4in, SEE DESC. **PO Line: 19** **302-39-06-8-8-8-1'**	1	1	0	29.9267	EA	29.93
	Exotic Sched Dt: 04/12/10					

Continued

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SALES REP: MARK LEFEBVRE			WRITTEN BY: Dan Phillips	SHIP VIA: EXOTIC SALES ASSOCIATE DEL.

PRODUCT/DESCRIPTION	QUANTITY OPEN	QUANTITY PICKED	QUANTITY BACKORDERED	PRICE	U/M	EXTENSION
EXK1W2W412 1 & 2 WIRE HOSE ASSEMBLY, 1/4in TO 3/4in, SEE DESC. **PO Line: 20** **302-06-37-8-8-8-2'**	1	1 Exotic Sched Dt: 04/12/10	0	32.5600	EA	32.56
EXK1W2W412 1 & 2 WIRE HOSE ASSEMBLY, 1/4in TO 3/4in, SEE DESC. **PO Line: 21** **302-39-06-8-8-8-1'**	1	1 Exotic Sched Dt: 04/12/10	0	29.5100	EA	29.51
EXK1W2W412 1 & 2 WIRE HOSE ASSEMBLY, 1/4in TO 3/4in, SEE DESC. **PO Line: 22** **302-06-06-12-8-8-1'**	1	1 Exotic Sched Dt: 04/12/10	0	28.2267	EA	28.23
EXK1W2W412 1 & 2 WIRE HOSE ASSEMBLY, 1/4in TO 3/4in, SEE DESC. **PO Line: 23** **302-39-39-8-8-8-1'**	1	1 Exotic Sched Dt: 04/12/10	0	35.6100	EA	35.61
PHC4-4 G6X-S FTG, PARKER, SWIVEL NUT FEMALE CONN, #4 SWIV JIC x 1/4 FNPT **PO Line: 24**	2	2 Exotic Sched Dt: 04/12/10	0	6.1400	EA	12.28
PHC4-6 C5OX-S FTG, PARKER, STR THD EL, 1/4 37 DEG FLARE X 9/16 SAE, STEEL **PO Line: 25**	1	1 Exotic Sched Dt: 04/12/10	0	5.6267	EA	5.63

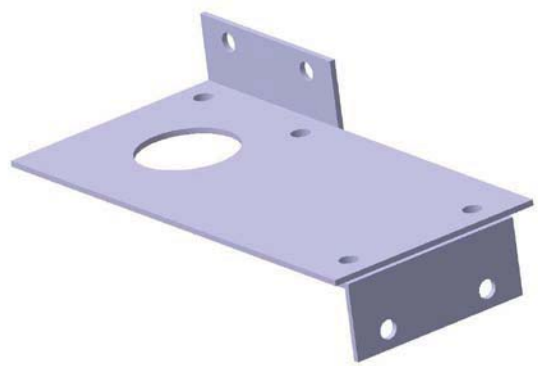
Per Exotic Standard Terms & Conditions

MERCHANDISE TOTAL **883.01**

Appendix II

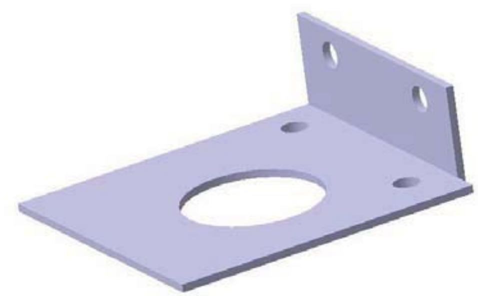
Engineering Change Notice

WAS:



Length of Plate: 343 mm

IS:



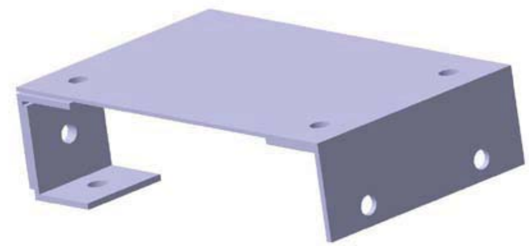
Length of plate: 110 mm

Notes:
Needed to cut plate in order to comply with new orientation of filter.
Washers were added between the mounting bracket and the supporting beam.
Only one mounting bracket was used.

Xebra Team WN 2010	
Project: Xebra Redesign for Maintenance	
Engineer: A. DIAZ	4/20/2010
Proj. Mgr: Professor Krauss	4/20/2010
Mgmt./Sponsor: A. Moskalik, D. Swain	4/20/2010

WAS:

IS:



Notes:
Flow meter mount was made after discovering interference between components.
3/8 nuts and bolts were used to secure the filter mounting mechanism.
Washers were also added.

Xebra Team WN 2010	
Project: Xebra Redesign for Maintenance	
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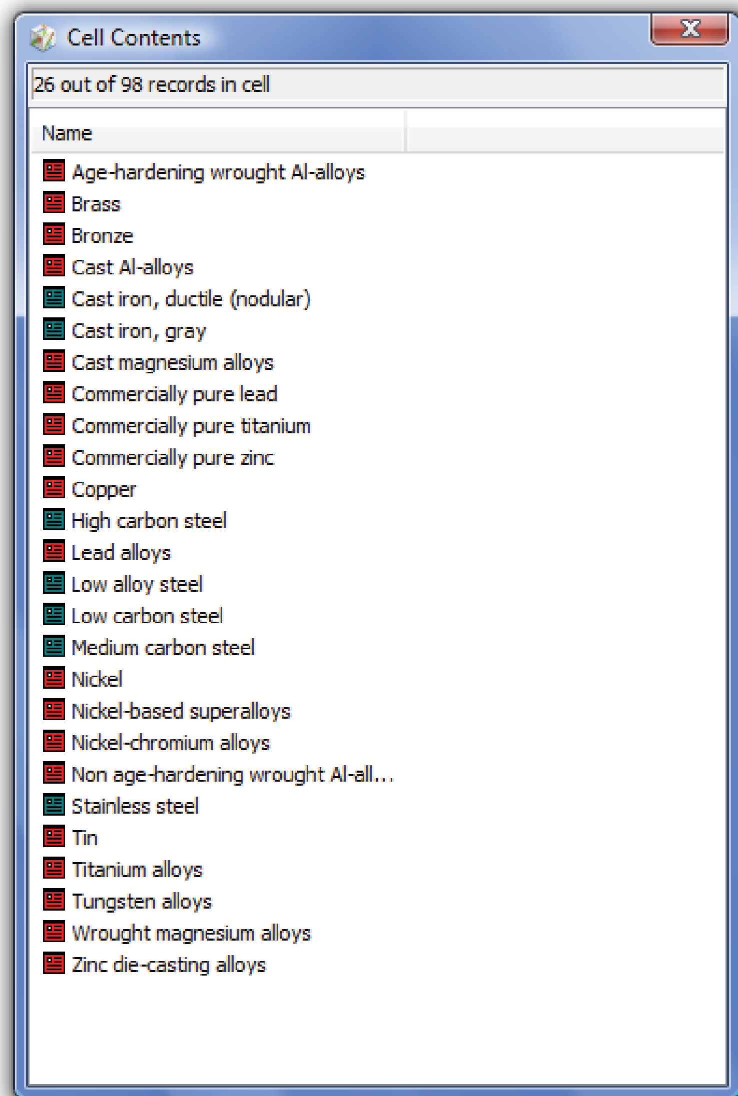
Appendix III : Design Analysis Assignment

Mounting Mechanism Analysis

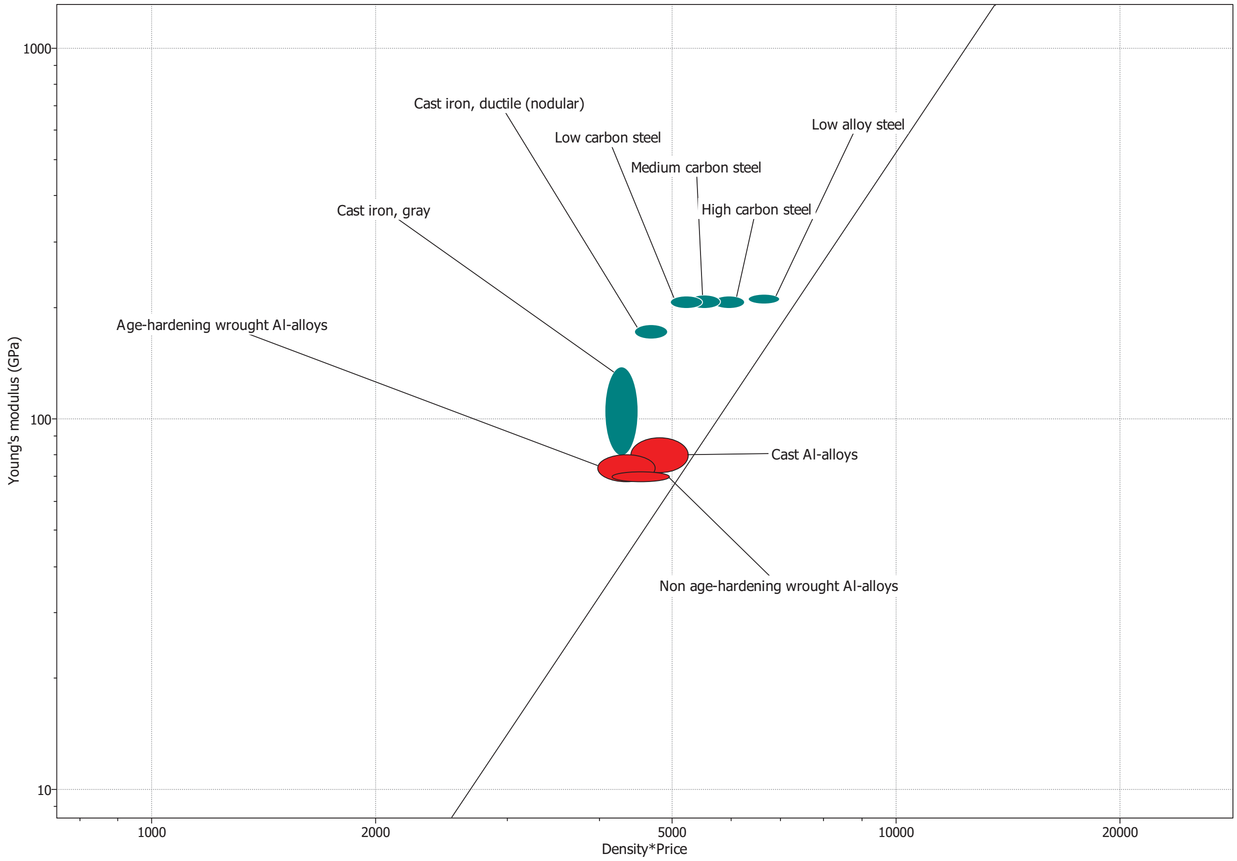
Material Selection

Function	Support beam for mounting the Slow Fill Pump, Manifold and Filter
Constraints	Adequate Strength Freq = 10 N Length = 0.91 meters
Objective	Minimize cost and Environmental Impact
Free Variables	Material thickness

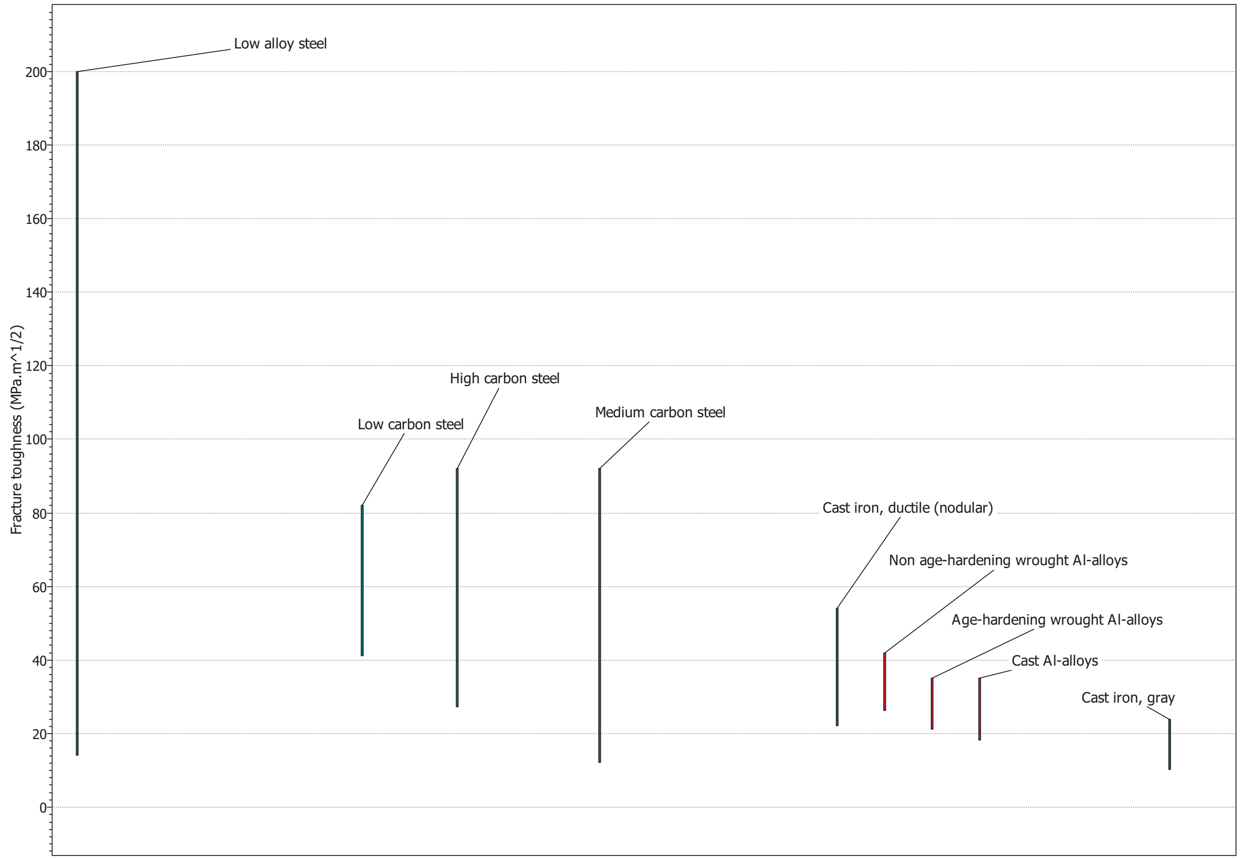
Material Function and Objective



Filter Materials for Metals for Manufacturability and Strength



Maximization of $\frac{Young's Modulus^{1/3}}{Density * Cost\ per\ kg}$

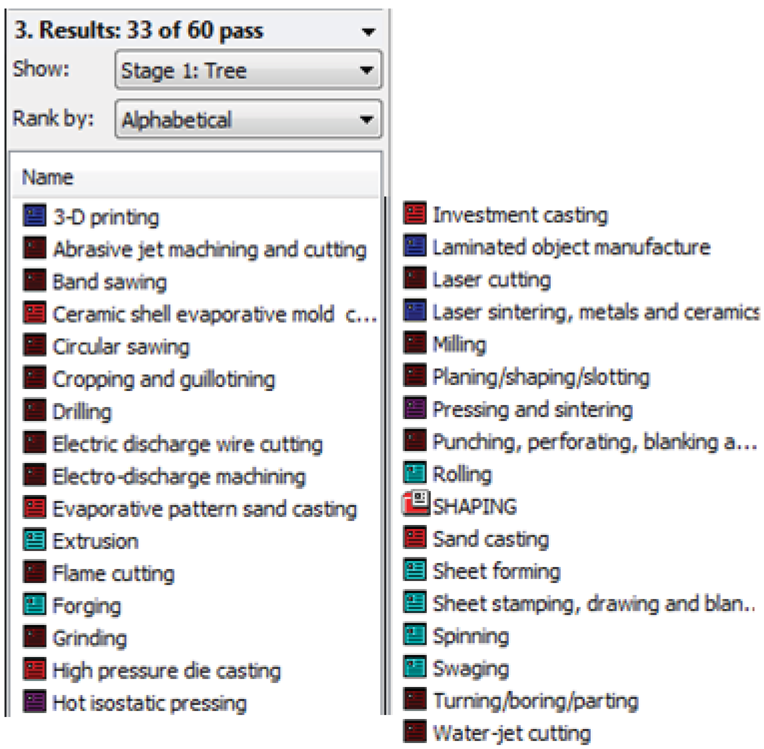


Fracture Toughness Comparisons

Manufacturing Process Selection

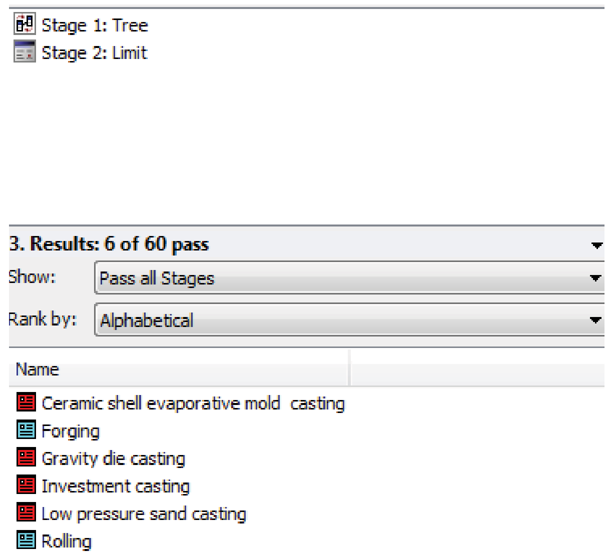
If the Xebra hydraulic electric hybrid were to be created for mass production we predict that 1,000 vehicles could be produced. The ZAP Company, founded in 1994, produced the electric Xebra truck that was modified into our project's hydraulic electric hybrid proof-of-concept*. They have sold over 100,000 advanced alternative fuel-efficient vehicles, most of which were electric vehicles*.Based on these numbers, if a hydraulic electric hybrid vehicle were to be mass produced 500 to 1,000 vehicles should be able to supply the demand for such a product.

During our material selection process, 1020 steel was chosen for the mounting beams that support the weight of the slow fill pump, manifold, filter and flow meter. 1020 steel was chosen because the ecological impact was smaller than the ecological impact of 6009 aluminum and because the yield strength and Young's modulus of low-carbon steel is higher than age-hardening wrought aluminum alloys. Both steel and aluminum are metals that have good formability, castability, machinability and weldability. Both materials have adequate strength to be used for the mounting rails. When using the CES software in our process selection, 33 of 60 processes were able to be used to form mounting rails made of age-hardening wrought Al-alloys or low-carbon steel.



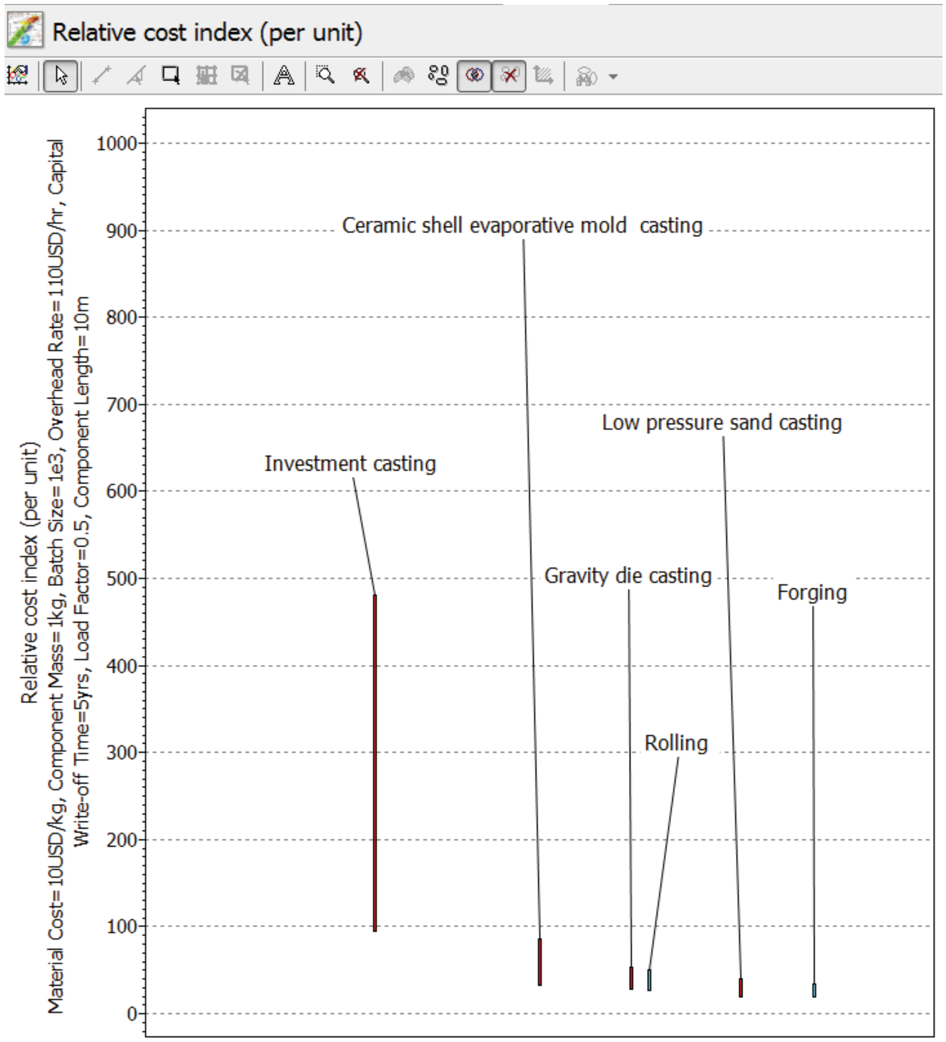
Tree Selection: Steel and Aluminum Alloys

The next stage in our process selection filtered out process that would be able to form non-circular prismatic shapes. The mounting mechanism should be flat and must be at least 1 meter long in order to be securely fixed to the frame of the vehicle. In order to meet a safety factor of three for supporting the 100 Newtons of force the beams will be subjected to, a beam (with the dimensions of the actual beam used) made of 1020 steel would have to be at least 3.5 mm thick. With a length of 1 m and a minimum area of The tolerance of the beam does not need to be very high so we set a maximum tolerance to be 0.5 mm. As discussed in the beginning of the process selection section, we chose an economic batch size of 500 to 1,000 units. After setting these limits, 6 shaping processes remained.



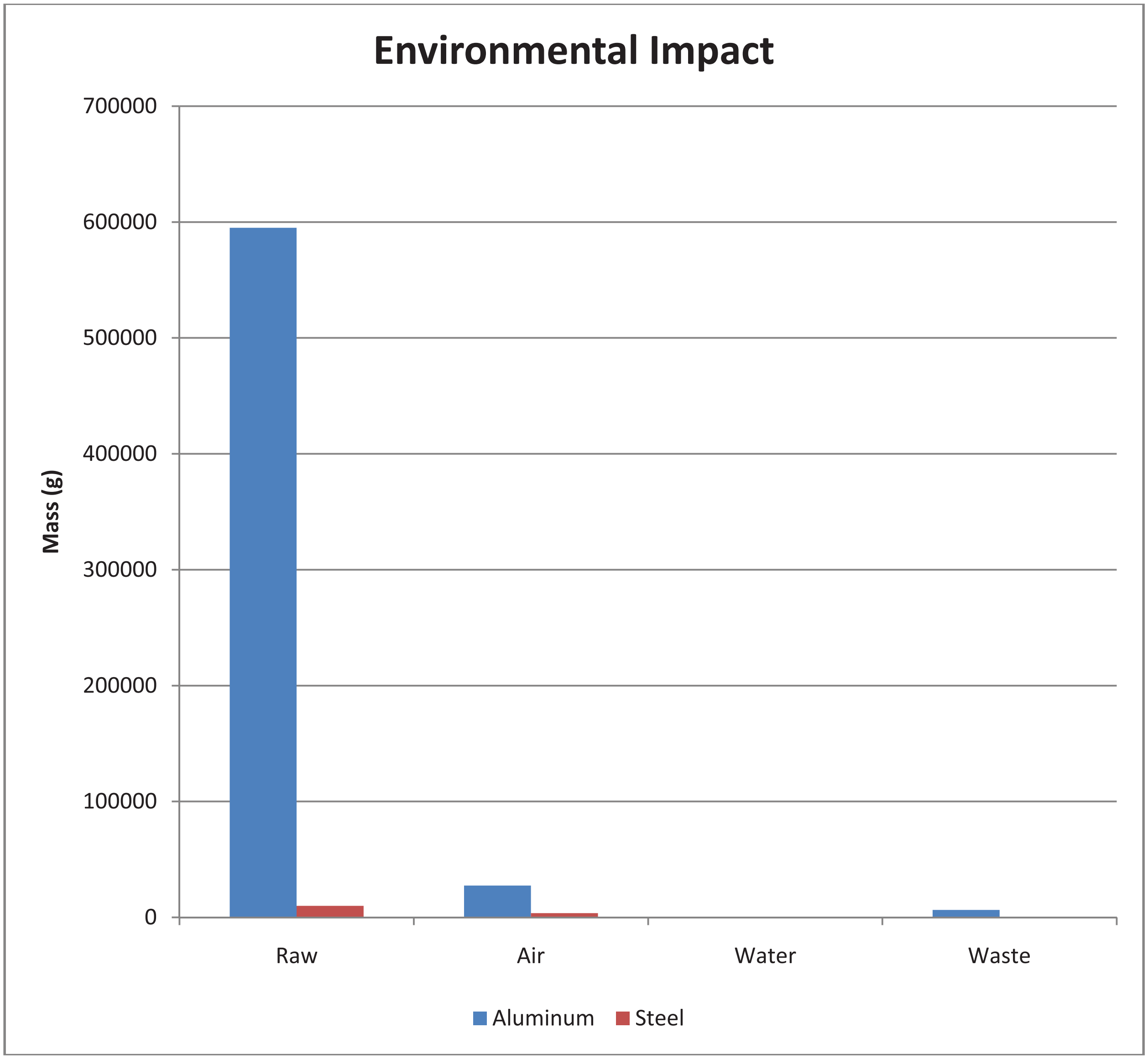
Limit Selection: Shape = Non-circular prismatic, Thickness > 3 mm, Tolerance < 0.5 mm, Economic Batch Size = 500 to 1,000

To further screen through the different processes we compared the relative cost indexes. Investment casting is the most expensive process. The other processes are comparable in cost. We decided to choose forging as our metal shaping process because it is a cheap and popular form of shaping steel products. Almost 90% of all steel products are forged or rolled according to the CES Software. Closed die forging can create precise and complex shapes for components limited to 20 kg. Since the mounting rails weigh less than 20 kg, closed die forging should be used on the rails so they can be shaped to fit underneath the accumulators while raising the manifold above the contactor to increase safety.

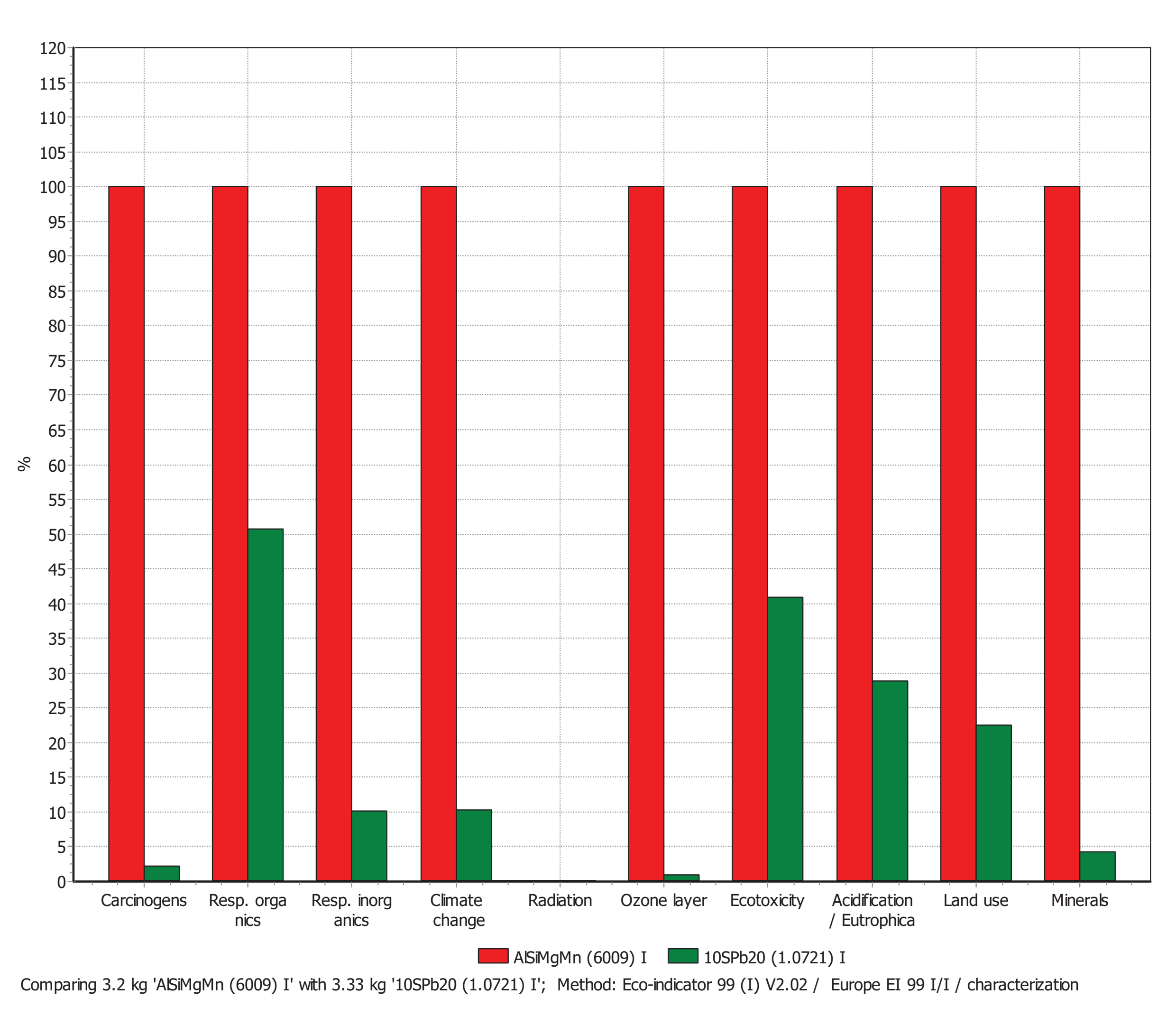


Graph Selection: Relative Cost Index

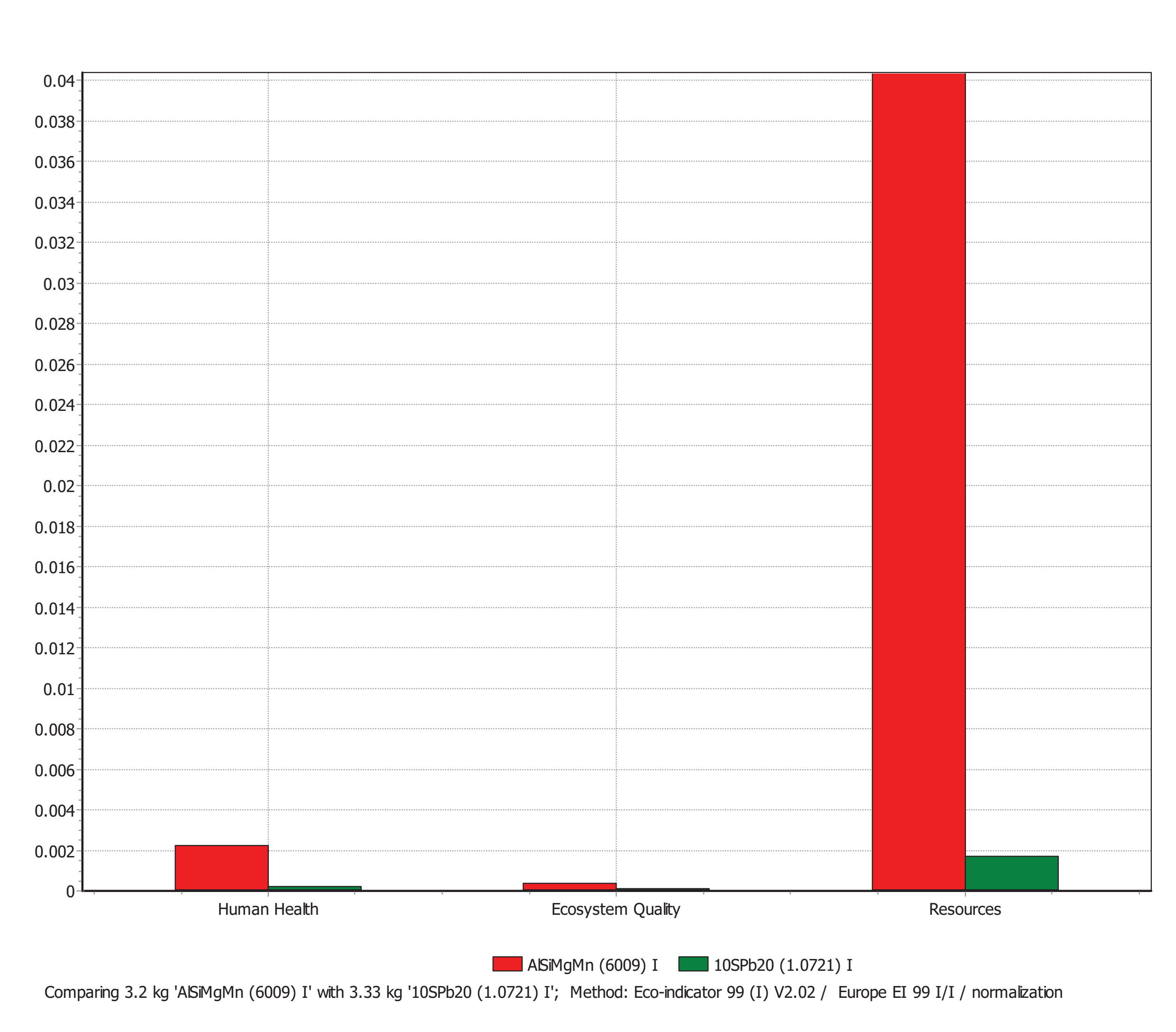
Environmental Impact Analysis



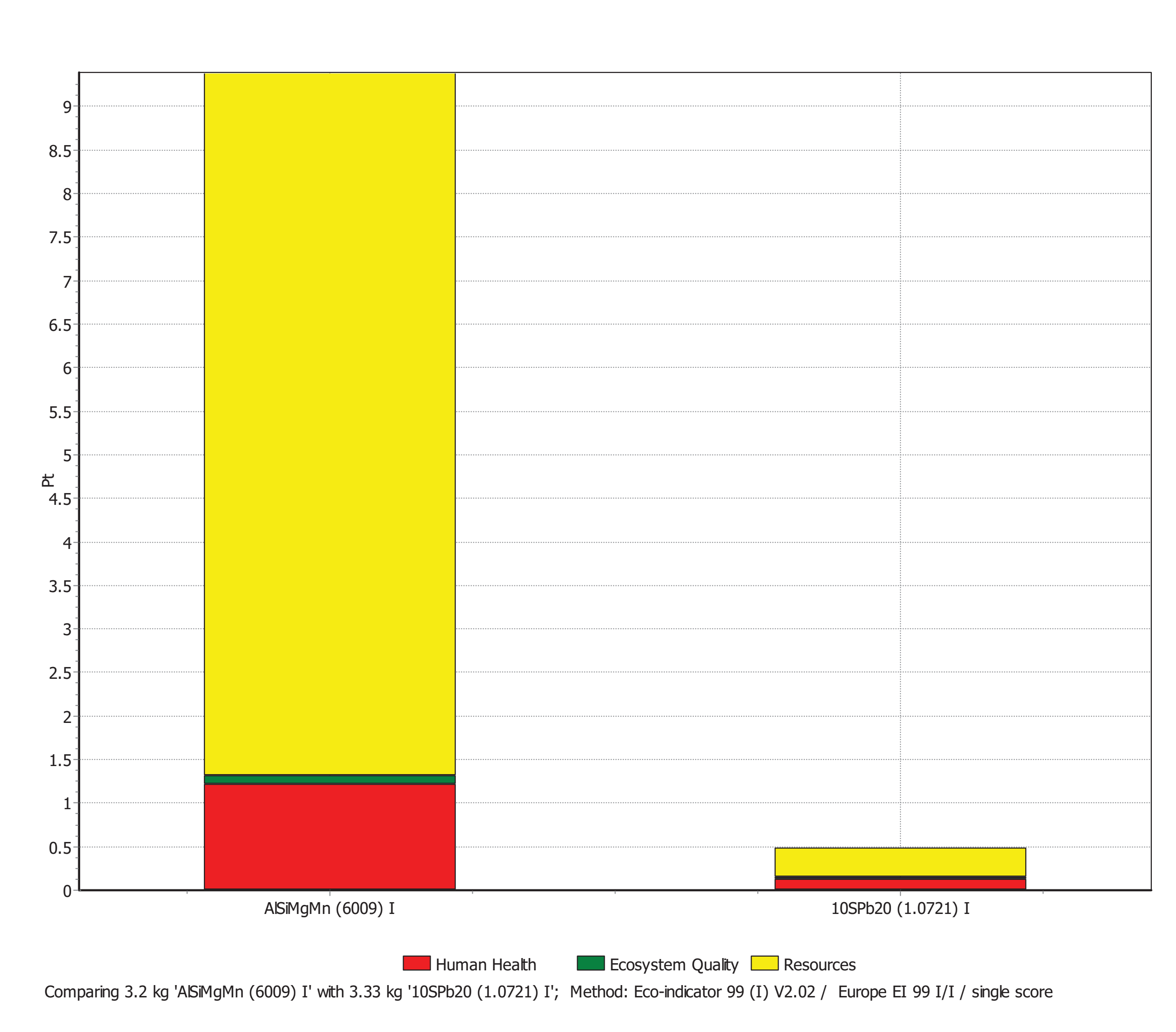
Raw Emissions, Air Emissions, Water Emissions and Solid Waste for Aluminum AlSiMgMn 6009 I and Steel 10SPb20 I



Impact Assessment by Characterization of Harm for Aluminum AlSiMgMn 6009 I and Steel 10SPb20 I



Impact Assessment with Normalization for Aluminum AlSiMgMn 6009 I and Steel 10SPb20 I

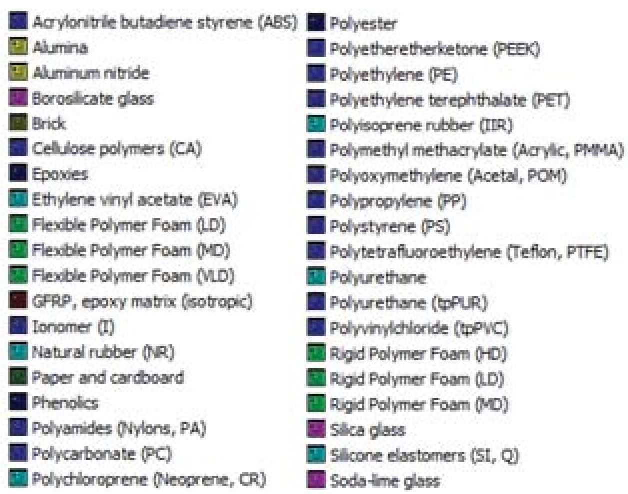


Single Score Impact Assessment for Aluminum AlSiMgMn 6009 I and Steel 10SPb20 I

Insulating Box

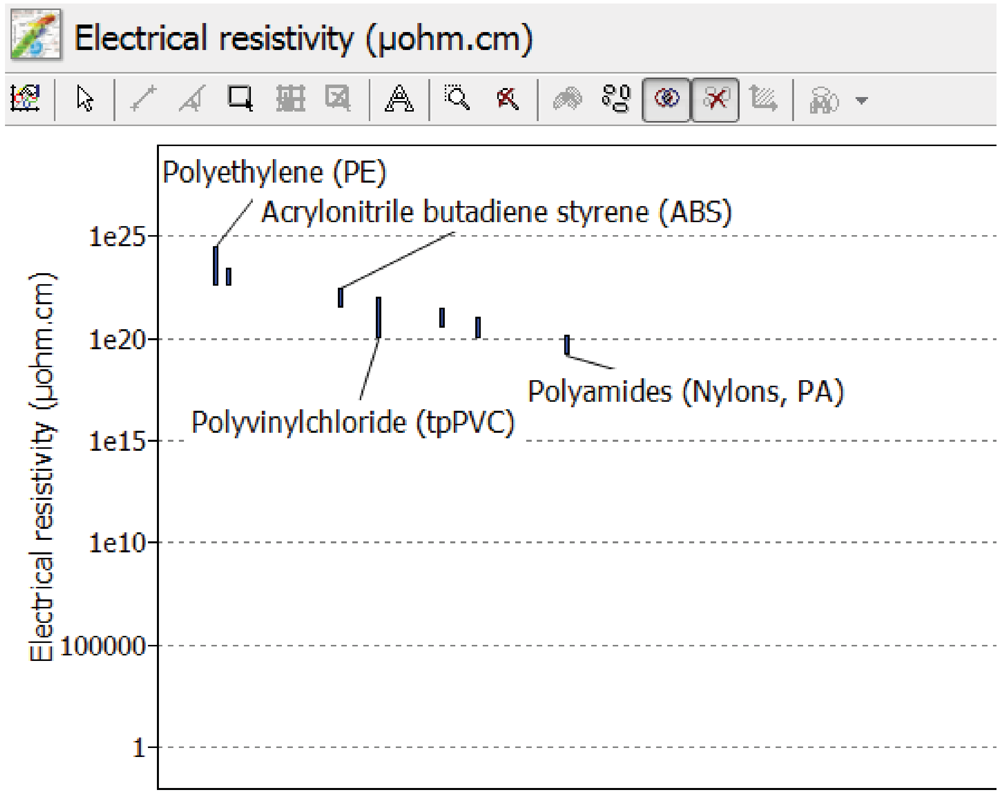
Material Selection

Using the CES Software we decided that an insulating box that would be produced for a fleet of 500 to 1,000 vehicles should be made of Polyvinylchloride (tpPVC) . A component we were not able to manufacture due to time constraints and a lack of information but should be added in the future is an insulating box to cover the contactor between the electric motor and the batteries. We discovered that 72 Volt connections were left exposed to the environment. A student can easily short the circuit if a wrench or another conductive material were to come into contact with the exposed connections and the vehicle frame. We added rubber insulators and electrical tape to the contactor connections to increase the safety of the vehicle; however we recommend the addition of a box that would cover the contactor. We performed a material selection analysis of such an insulating box. Using the CES Software we created a list of good insulators shown below.



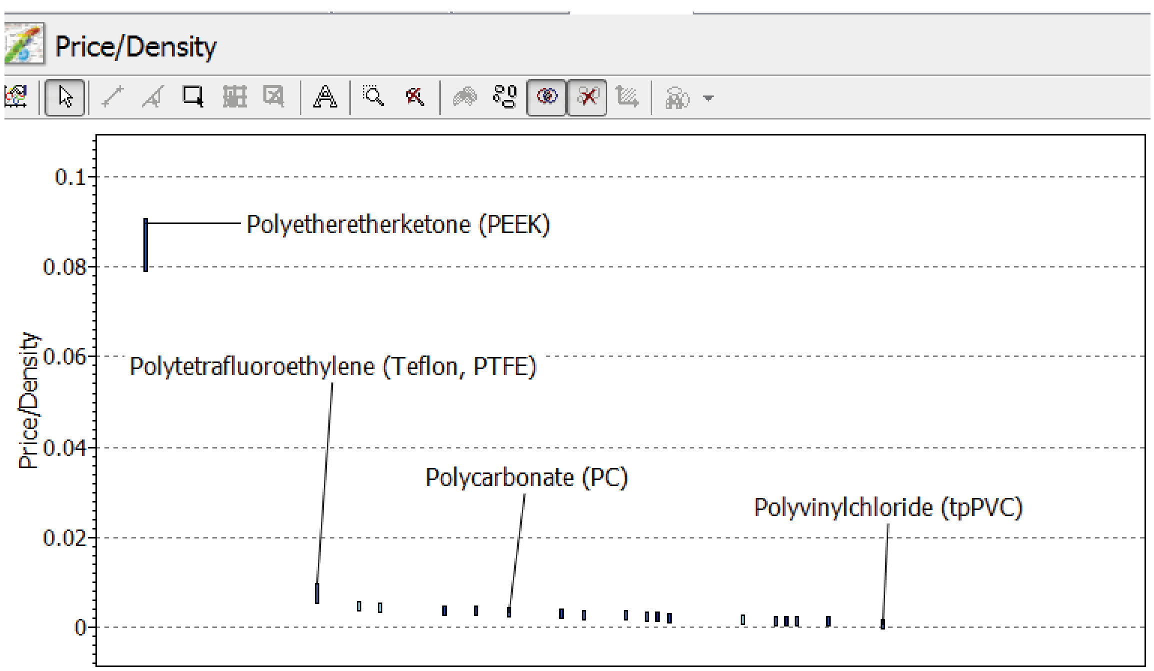
Good Insulators

We then chose to limit the materials to polymers and elastomers because glass and other ceramics are too brittle. Also in the case of an electrical short circuit, many plastics are self extinguishing unlike paper and card board. A plastic insulating box would make the most sense because plastic is easily machinable and relatively durable. We then graphed the electrical resistivity of the remaining plastics. The electrical resistivity is comparable for the remaining plastics as seen in the graph below. The next stage in our selection process was to compare the cost of the material.

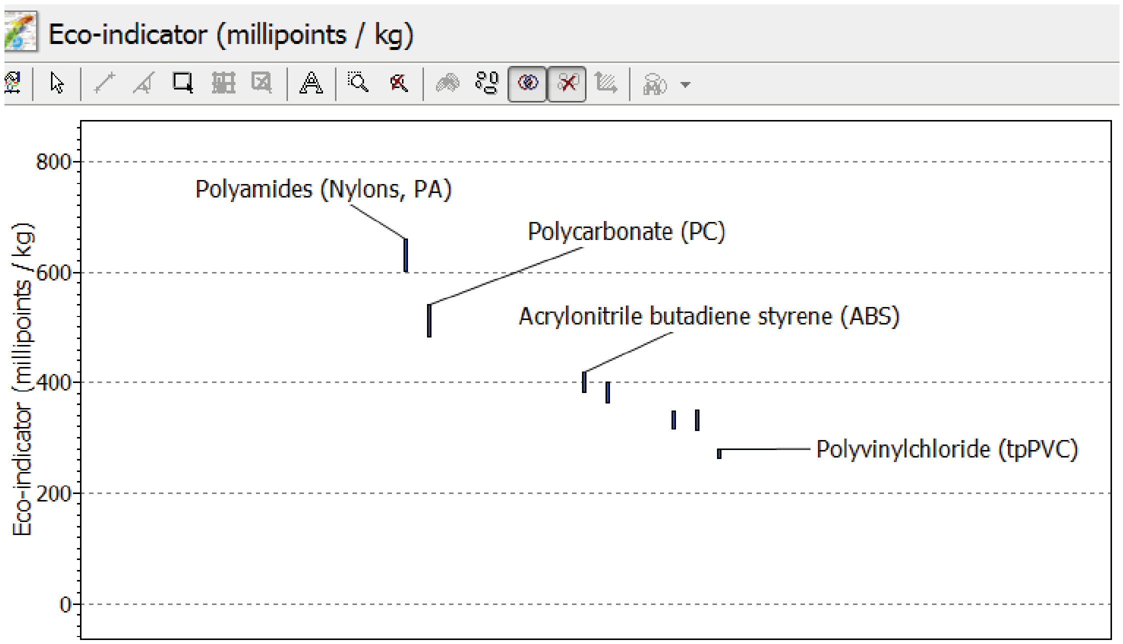


Electrical Resistivity

The price of plastic is very cheap and most of the plastics that have reached this stage are similar in price. The only outlier is Polyetheretherketone (PEEK). Because PEEK is nearly 10 times more expensive than other plastics it does not pass into the next stage. The last stage our material selection process is to compare the eco-indicator values of the remaining plastics.

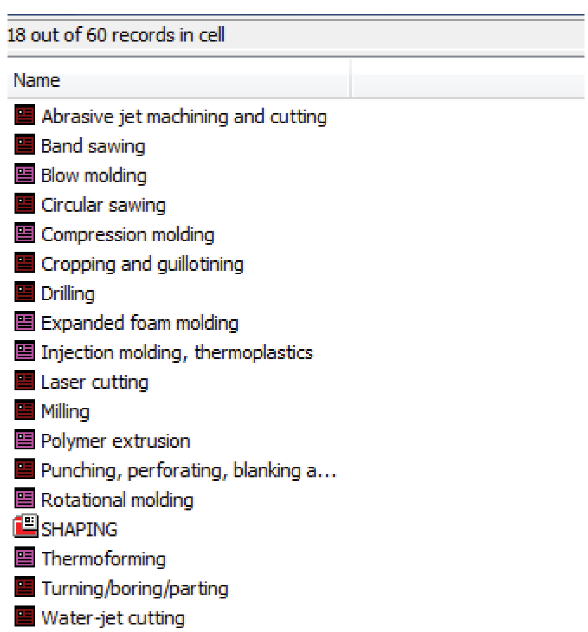


Out of the remaining plastics, Polyvinylchloride (tpPVC) has the lowest eco-indicator. It is easily machinable and durable against a number of materials such as lubricating oil, water and a number of acids. It lacks resistance to some solvents however.



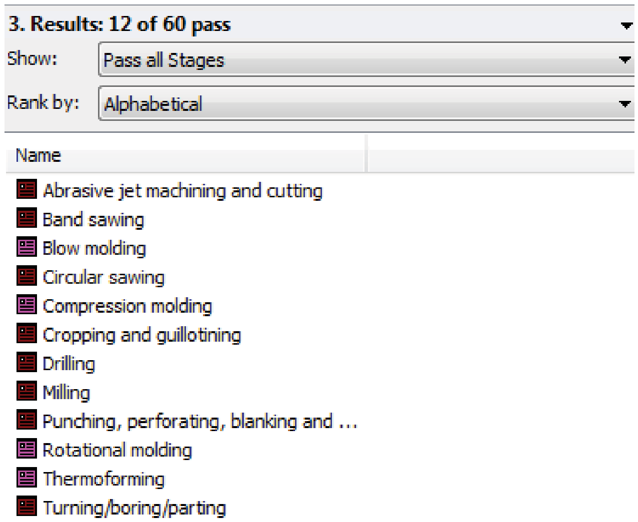
Manufacturing Process Selection

Using the CES Software, we decided that the PVC insulating box should be shaped using compression molding. The first stage in our process selection for the insulating box is to limit the processes that are applicable to PVC plastics. This results in the following list of 18 processes.

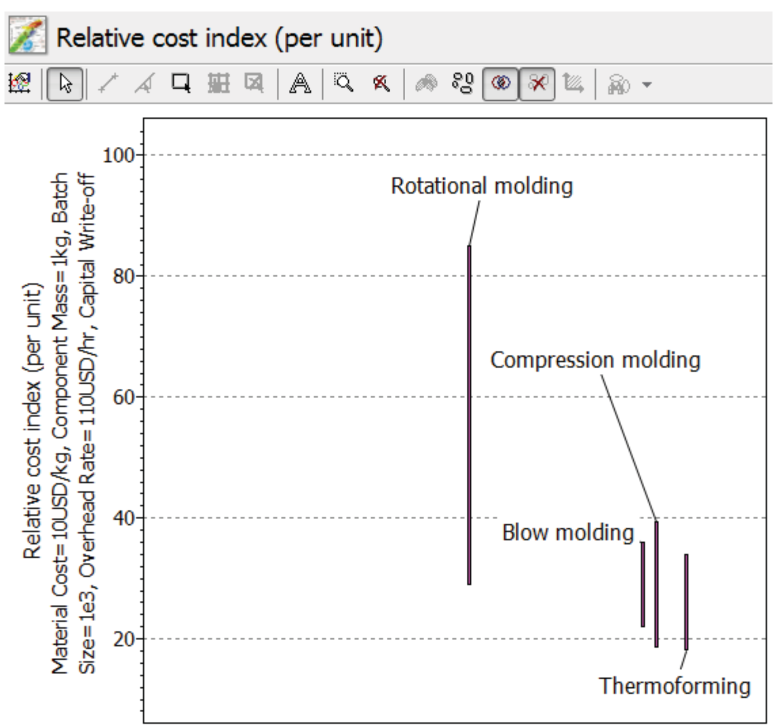


Tree

The next stage in the process selection was to set the economic batch size to be 500 to 1,000 units. This limit results in 12 processes. We then chose compared the relative cost index in a graph.

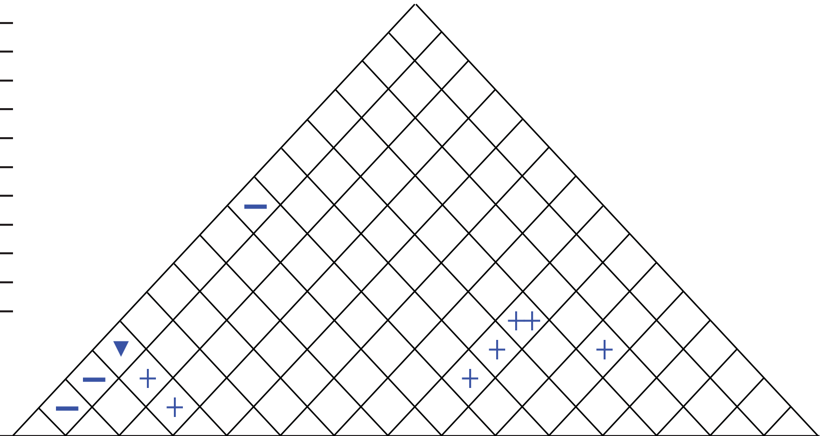


Of the remaining plastics, the process with the lowest relative cost index is thermoforming. However, thermoforming can only create dished sheet shapes. Since there are wire going into the insulating box from the batteries and the motor, a dished sheet would have to be further machined to cut an entrance for the wires. Therefore we chose compression molding to be the process to create the insulating box because it can be used to create a solid 3 dimensional shape.



Appendix IV

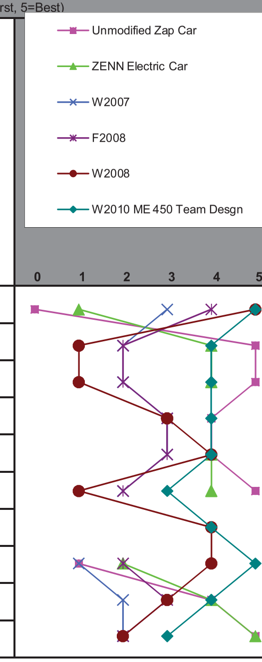
Title: Hydraulic Electric Hybrid Redesign for Accesability
Author: Andres Diaz, Eric Kim, Kevin Lyons, Yutao Chen
Date: 1.21.2010
Notes:



Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
—	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

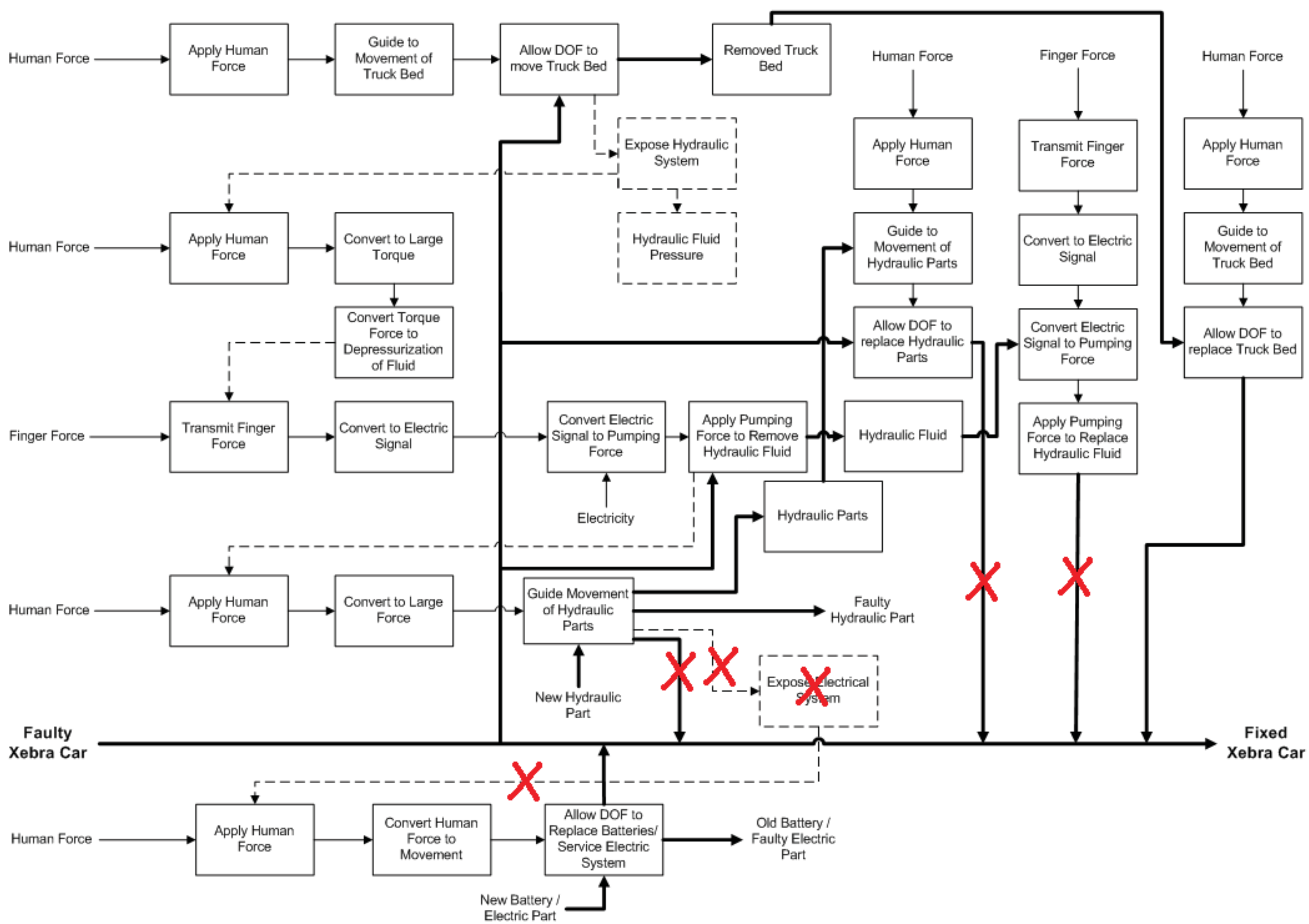
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	1 Mass of Vehicle [kg]	2 Volume of Accumulator [m3]	3 Max Accumulator Pressure [MPa]	4 Time to Reach Top Speed [s]	5 Initial Tank Pressure [MPa]	6 Flow Rate of Accumulators [L/min]	7 Temperature of Electronic System [C]	8 Time to Change Battery [hr]	9 Location of Center of Gravity [m]	10 Electrical System Trouble Shoot Time [hr]	11 Number of Hydraulic Conections	12 Number of Steps for Changing Batteries	13 Total Length of Electrical Wires [m]	14	15	Unmodified Zap Car	ZENN Electric Car	W2007	F2008	W2008	W2010 ME 450 Team Desgn
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)																					
1	9	9.9	9.0	Maintain Previous Performance	Θ	O	O	Θ	Θ	Θ	▲		O							0	1	3	4	5	5
2	9	9.9	9.0	Accessibility (Hydaulics)		▲						Θ	▲	O	Θ	Θ	▲			5	4	2	2	1	4
3	9	12.1	11.0	Accessibility (Batteries)								Θ		O	Θ	Θ	▲			5	4	2	2	1	4
4	9	11.0	10.0	Accessibility (Electronics)								▲		Θ	O	O	Θ			4		3	3	3	4
5	3	9.9	9.0	Transferability								O		O	O	O	O			4	4	3	3	4	4
6	9	11.0	10.0	Maintenance/Serviceability								Θ		Θ	Θ	Θ	Θ			5	4	2	2	1	3
7	9	13.2	12.0	Safety	Θ	O	Θ		O		O		Θ			O								4	4
8	9	7.7	7.0	Simplicity								O	O	O	Θ	Θ	Θ			1	2	1	2	4	5
9	9	11.0	10.0	Reliability		O	Θ	O			O				O		O			4	4	2	3	3	4
10	9	4.4	4.0	Aesthetics		O						O		O	Θ	O	Θ			5	5	2	2	2	3
				Target or Limit Value	<1100 kg	<0.04 m3	< 25MPa	<140 s	24.8 Mpa	21.7 L/min	<135 C	~1 hr	0.8 m	~11hr	15 to 20	5 to 10	10m								
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	1	5	4	7	3	4	3	8	5	5	6	8	9								
				Max Relationship Value in Column	9	3	9	9	9	9	3	9	9	9	9	9	9								
				Weight / Importance	207.7	125.3	247.3	122.0	128.6	89.0	82.4	373.6	181.3	329.7	501.1	481.3	391.2								
				Relative Weight	6.4	3.8	7.6	3.7	3.9	2.7	2.5	11.5	5.6	10.1	15.4	14.8	12.0								

Competitive Analysis (0=Worst, 5=Best)

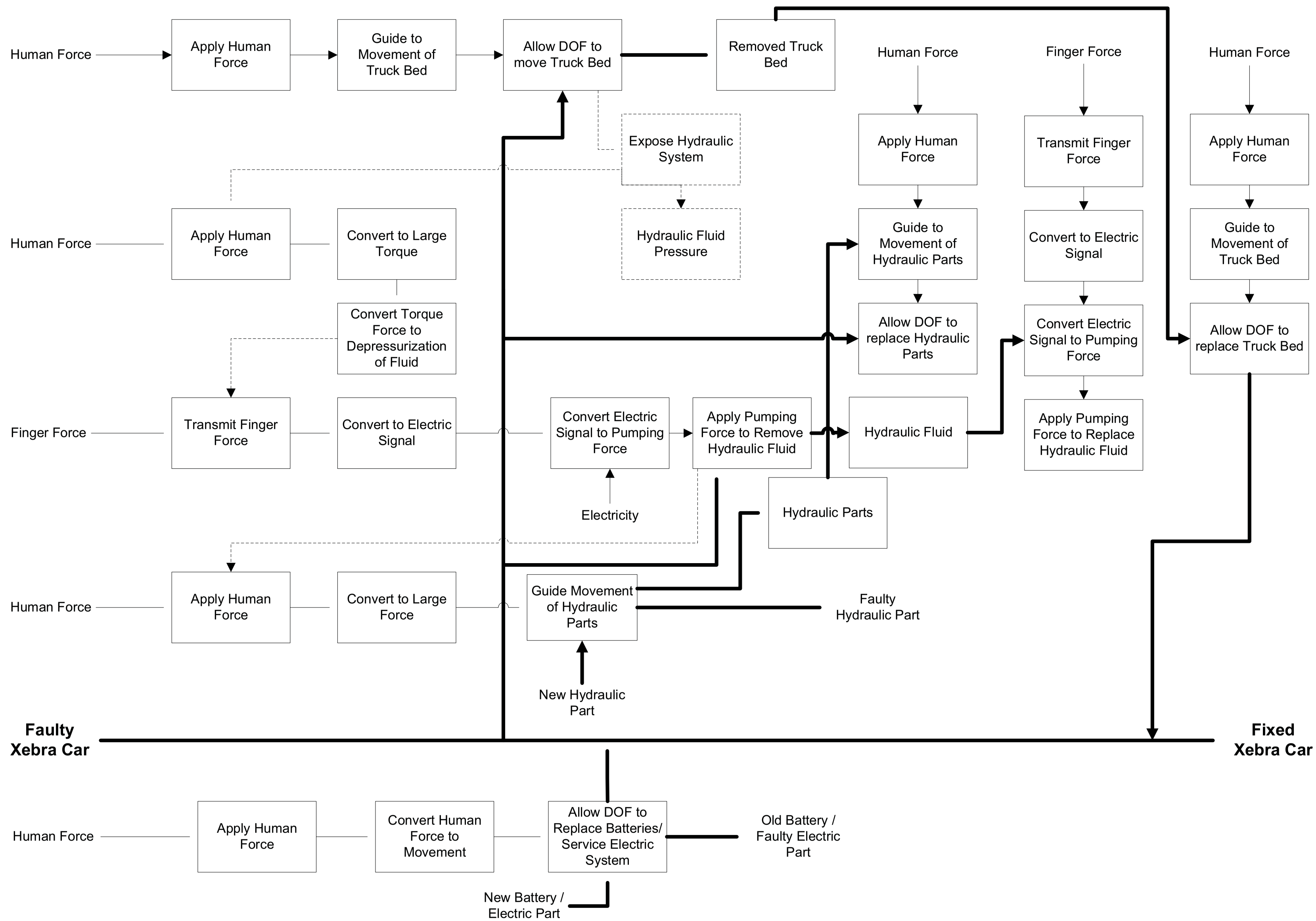


Appendix V

Functional Decomposition Chart



Functional decomposition of the current system



Functional decomposition of the optimized system for battery access

Appendix VI

Concept description

Battery Access
Move Batteries to the Side: One important reason why the batteries are difficult to access is that they are located in the center of the vehicle with the electric and hydraulic components surrounding them. The concept is to move the batteries to the side of car, under the accumulators. The batteries would be easily accessed from the sides of the vehicle.

Move Batteries to the Passenger Seat: This concept is similar to the previous concept. The difference is that instead of putting the batteries under the accumulators, we remove the passenger seat and put the batteries there. According to our sponsors, the Xebra car is currently allowed to transport only one passenger. The concept would not affect the functionality of the car but it would provide better protection for the batteries.

The Drawer Mechanism: Instead of moving the batteries, we think that we can keep the batteries in the original position but allow them to be accessed from the sides through a drawer mechanism. By constructing this mechanism, we can simply pull out all the batteries from the side without disassembling other parts.

Access from the Bottom: This concept consists of putting the batteries into a package and creating a mechanism so that we can access the batteries from the bottom of the car. The general idea is similar to the previous design only that the batteries would be removed in a different direction.

Make the Entire Hydraulic System Movable: In this concept, we think about putting the entire hydraulic system to a module so that we can remove it easily when we need to access the electric system components under it.

Quick release for Critical Connections: This is another idea that focuses on removing the hydraulic system quickly when needed. We would replace some of the critical connections with quick release parts so that we can disassemble these parts easily. The rest of the system would be pulled out piece by piece.

Redesign for Overhead: There are several hydraulic components that are currently located directly over the batteries. This concept would redesign the current hydraulic system layout such that the area over the batteries would be clear for access. The improvements associated with this change would involve improving battery access and condensing the hydraulic circuitry simultaneously.

Partially Modular System: Allowing for a portion of the hydraulics to be removable would also achieve improved battery access. Two variations of this concept would be a full or partial modular system. The full system would encompass the entire hydraulic system including the high pressure accumulators and would require 3-4 people to remove. The partial system would include only the critical components directly above the batteries and would require only 1-2 people to successfully remove.

Hydraulic Access
Create Valve Manifold: To improve the maintainability of the hydraulic system, a central manifold system that would include all relevant valves would be installed. This would greatly simplify the hydraulic circuitry

by making all valves available in an easily accessible location. The concept does not directly address the battery access issue but would decrease the complexity of troubleshooting and maintaining the hydraulic system.

Effective Pipe Spacing: As the system is arranged now, certain places do not have enough space for efficient disassembly. Redesigning the hydraulic circuitry in such a way that would guarantee enough space to gain access to critical fittings would improve the time needed to disassemble the hydraulics.

Move Valves to Surface: The idea behind this concept is that it is difficult to reach some of the valves because they are obstructed by other hydraulic valves and tubing. This concept is to have a design such that all the critical valves are on the outer surface of the car so that we can easily access them, thus improving the hydraulic systems serviceability.

Replace Hard Pipes with Soft Ones: The current hydraulic circuitry is very hard to modify because there are many hard connections in it. If we could replace some of the hard pipes with soft pipes, it would greatly increase the flexibility of our design and make some of our other concepts easier to implement.

Electrical Access

Color-code and Bundle Wires: There is a lot of uncertainty regarding the current status of the electric components of the Xebra. Determining the correct electrical circuitry and color-coding/bundling wires according to the system would clarify the way in which the controls operate. Having a clearer electrical circuitry would simplify the overall complexity of the vehicle and enable future students to understand the system faster and more efficiently.

Electric Circuit Diagram: After organizing the electrical system, a detailed circuit diagram would be placed somewhere in the vehicle for reference. This concept would be implemented in conjunction with color-coding/bundling.

Quick release for Batteries: There are six batteries and if we need to change them, we would have to disconnect them one by one. To save time when changing the batteries, one of the main engineering specifications, we think it would be beneficial to create a quick release mechanism for the battery connections so that we can either unplug the batteries easily or disconnect six of them through one procedure.

Simplicity

Update Current Flow meter: Eliminating unnecessary tubing in the system would improve the overall simplicity of the Xebra car. One area in which this could be improved is the flow meter. Currently, a large and bulky flow meter is used with a lot of excess hydraulic tubing. Purchasing a more advanced (and smaller) flow meter would allow for the possibility of shortening some of the hydraulic tubing behind the driver.

Redesign Controller Box: Another aspect of the electrical system that is complicated is the actual controller box. It is believed that there are a number of unnecessary wires and relays that should be removed or condensed for simplicity. Again, this would greatly simplify the electrical system.

Find New Batteries: The Xebra car currently has six batteries and each weighs more than 20 kg. Due to the fact that the output voltage of the battery pack is related to the number of batteries, the only idea for simplifying the battery pack that we came up with is to choose new batteries that are smaller and lighter. In doing so, we hope to create more space to mount other devices and make battery removal and easier task.

Separate the Duty of Auxiliary Battery: The car has five main batteries and an auxiliary battery. Even though they are identical batteries, the original design is that the main batteries power the car and the auxiliary battery powers all the other devices on board. Previous ME450 teams have connected them all together as one battery pack. Our concept is to separate them again in order to ensure the lifetime of the main batteries.

Drive the Slow Fill Pump Directly from Main motor: The slow fill pump is now powered by a separate motor attached to it. Because we have a main electric motor that powers the vehicle, we are considering the possibility of connecting the pump to the main motor so that we can remove the auxiliary motor.

Combine the Hydraulic Motor and the Hydraulic Pump: The hydraulic motor uses high pressure fluid to drive the vehicle. The hydraulic pump is driven by the main shaft to pressurize the accumulators. Their working principles are similar but just in a reversed order. We want to design a mechanism so that we only have one device which can act as pump or motor accordingly.

Combine Accumulators: There are four accumulators on the vehicle now and this requires a lot of hydraulic connections between these accumulators. If we can combine the accumulators into a large one, then we could remove a lot of hydraulic connections and greatly simplify the circuitry.

Safety

Change the diameter of Critical Connections: Currently, there are locations in the hydraulic circuitry that will potentially see high volumes of high pressure fluid and do not have the most suitable piping. Ideally a larger and more ductile alternative should be installed in these locations to handle the high volumes/pressures. This would eliminate a number of potential safety issues that exist in the Xebra.

Color-Code High Pressure Lines: Along the same lines, color-coding the high pressure fittings and lines of the hydraulic circuitry would eliminate potential issues with maintenance on the hydraulics. Clearly labeling the locations where dangerous high pressure hydraulic fluid exists will improve the overall safety of the car. Considerations associated with people who are color-blind need to be taken into account (e.g. – tactile indicator).

Protect the Driver from Hydraulic Parts and Provide Helmet: These concepts all focus on giving either a shield or a helmet to the driver. We try to ensure that even when the hydraulic components fail and fly out from the bed, the driver would not be hurt.

Cover Exposed Electric Connections: There are several electric connections in the car that are exposed to the air. To ensure the safety of maintenance personnel and to protect the electric system from short circuiting the system, we would cover these connections with reliable methods.

Separate the Hydraulic System with a Layer: Presently the hydraulic system is placed close to the electric system. If there is any leakage from the hydraulic connections, the hydraulic fluid will flow on to the electric system components and cause a short circuit. We want to add a separation layer between the hydraulic system and the electrical system so that the fluid will not destroy the electric parts.

Change the Base of the Electronic Controller Board: The material of the electronic controller is wood. It is not very strong or aesthetically pleasing. We want to change the material to plastic to ensure electric insulation and better strength.

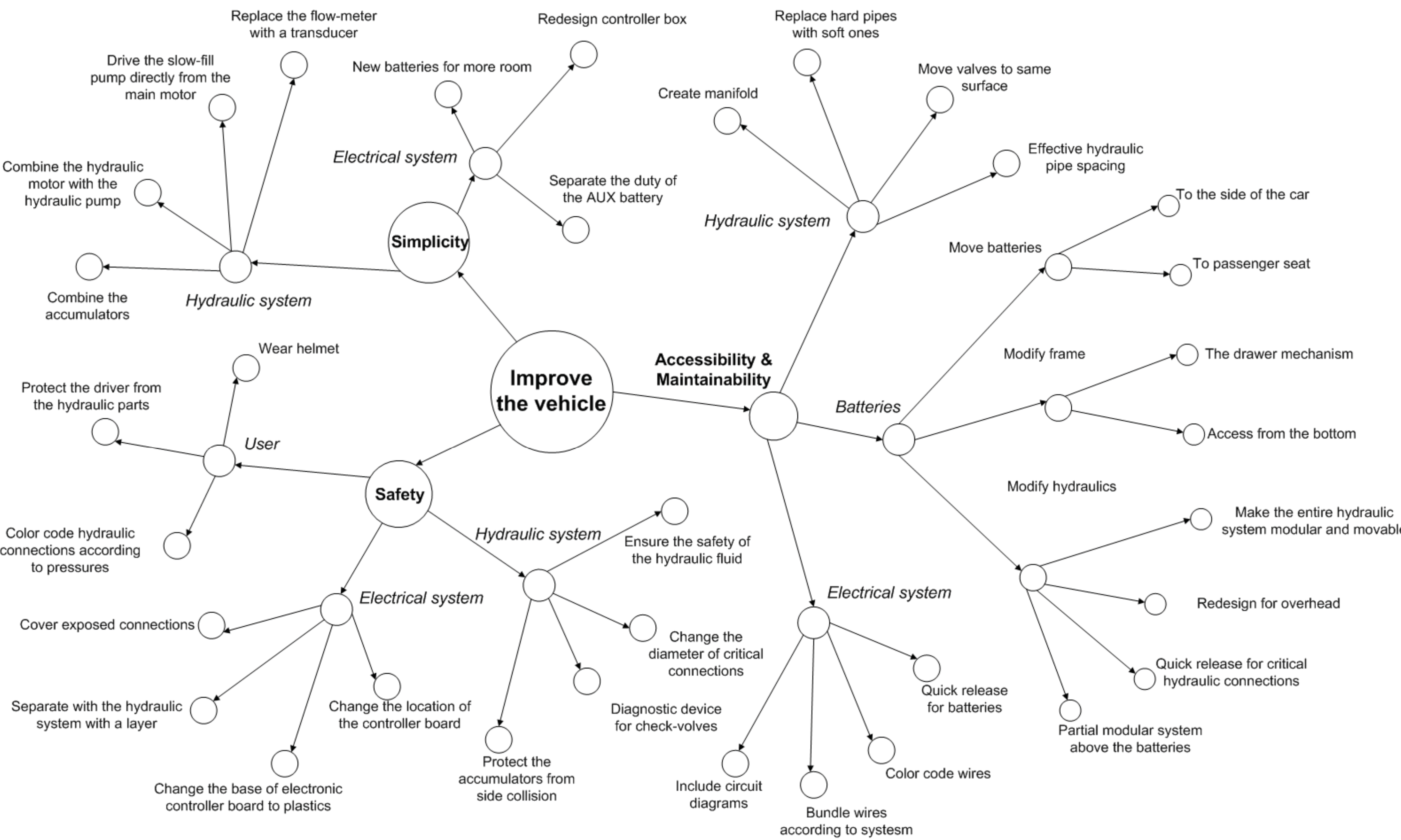
Change the Location of the Controller Board: The board is placed on the top of the high voltage zone of the electric system. We propose to move it to another location to protect the potential danger of contacting the high voltage zone.

Protect the Accumulator from Side Collision: The accumulators are on the side of the vehicle now. Even though the prototype will not be tested on road, we still worry about the safety of the accumulators from side collisions for possible future mass production. The method we have in mind is to wrap some collision absorption material on the accumulators to protect them.

Diagnostic System for Check-Valves: The check valves play an important role in ensuring the safety of the hydraulic system by guiding over-pressurized fluid back to the reservoir. Because of their critical role, we want to install a diagnostic system that can constantly monitor the status of the valves to ensure that they are working normally.

Ensure the Safety of the Hydraulic Fluid: We were told that the hydraulic fluid currently in use is corrosive. We want to either change it to a less dangerous fluid or place additional warning signs so that people are not be accidently harmed.

Appendix VII



Appendix VIII

	Batteries								Hydraulics				Electrical				Simplicity						
Readiness Parameter	Redesign for Overhead	Relocation of Batteries (passenger seat)	Relocation of Batteries (side)	Quick Release	Drawer Mechanism	Bottom Battery Access	Full Modular System	Partial Modular System	Manifold for valves	Lay valves in surface	Effective Hydraulic Pipe Spacing	Replace hard pipes with soft ones	Circuit Diagram	Color-Code	Quick Release for Batteries	Bundle Wires	Redesign Electric Controller Box	Replace Current Flow Meter	Hydraulic Motor/Pump Combine	Clearly Define Objectives of AUX battery	Slow-fill Pump Power Source	Combine Accumulators	New (smaller) batteries
	Assessment																						
Mature	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Manufacturable	Y	N	N	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	N
Knowledge of Technology	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N
Response in Operating Environment	Y	N	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y
Failure Modes Identified	Y	N	N	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y
FINAL	**Y**	**N**	**N**	**Y**	**N**	**N**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**N**	**Y**	**N**	**N**	**N**

	Safety										
	Color Code Hydraulic Connections According to Pressures	Require Helmet for Driver	Ensure the Safety of the Hydraulic Fluid	Change Diameter of Critical Connections	Change the Base of Electronic Controller Board to Plastic	Protect the Driver from the Hydraulic Parts	Move the Electronic Controller Board	Separation Layer between Hydraulics and Electronics	Cover Exposed Electric Connections	Diagnostic Device for Valve Operation	Protect the Accumulators from Side Collision
Readiness Parameter	**Assessment**										
Mature	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Manufacturable	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Knowledge of Technology	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Response in Operating Environment	Y	Y	Y	Y	Y	N	Y	N	Y	N	N
Failure Modes Identified	Y	Y	Y	Y	Y	N	Y	N	Y	N	N
FINAL	**Y**	**Y**	**Y**	**Y**	**Y**	**N**	**Y**	**N**	**Y**	**N**	**N**

Appendix IX

SIMPLICITY

Selection Criteria	Weight	Concepts					
		Replace Current Flow Meter		Redesign Electric Controller Box		Clearly Define Duty of Auxilary Battery	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Maintain Previous Performance	0.09	3.00	0.27	3.00	0.27	3.00	0.27
Accessibility (hydraulics)	0.09	3.50	0.32	3.00	0.27	3.00	0.27
Accessibility (batteries)	0.11	3.50	0.39	3.00	0.33	3.00	0.33
Accessibility (electronics)	0.10	3.00	0.30	4.50	0.45	3.50	0.35
Transferable	0.09	3.20	0.29	4.00	0.36	3.50	0.32
Maintainence/Serviceability	0.10	3.50	0.35	3.50	0.35	3.50	0.35
Safety	0.12	3.00	0.36	4.00	0.48	3.50	0.42
Simplicity of Layout	0.07	3.50	0.25	4.00	0.28	3.50	0.25
Reliability	0.10	3.00	0.30	3.50	0.35	3.00	0.30
Aesthetics	0.04	3.50	0.14	4.00	0.16	3.00	0.12
Implementation	0.09	4.50	0.41	2.00	0.18	3.00	0.27
	Total Score	3.36		3.48		3.24	
	Rank	2		1		3	

SEVICEABILITY & ACCESSABILITY FOR BATTERIES

Selection Criteria	Weight	Concepts							
		Full Modular System		Redesign for Overhead		Quick Release for hydraulic connetions		Partial Modular System	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Maintain Previous Performance	0.09	3.00	0.27	3.00	0.27	3.00	0.27	3.00	0.27
Accessibility (hydraulics)	0.09	3.00	0.27	4.50	0.41	3.00	0.27	3.00	0.27
Accessibility (batteries)	0.11	4.00	0.44	3.50	0.39	3.25	0.36	3.50	0.39
Accessibility (electronics)	0.10	3.00	0.30	3.00	0.30	3.00	0.30	3.00	0.30
Transferable	0.09	3.50	0.32	4.00	0.36	3.00	0.27	3.00	0.27
Maintainence/Serviceability	0.10	3.50	0.35	4.50	0.45	3.20	0.32	3.50	0.35
Safety	0.12	2.00	0.24	3.00	0.36	3.00	0.36	2.50	0.30
Simplicity of Layout	0.07	3.00	0.21	4.00	0.28	3.00	0.21	2.80	0.20
Reliability	0.10	3.00	0.30	3.00	0.30	2.80	0.28	3.00	0.30
Aesthetics	0.04	3.50	0.14	4.00	0.16	3.00	0.12	3.00	0.12
Implementation	0.09	2.80	0.25	4.00	0.36	4.50	0.41	3.00	0.27
	Total Score	3.09		3.63		3.16		3.03	
	Rank	3		1		2		4	

SEVICEABILITY & ACCESSABILITY FOR ELECTRICAL SYSTEM

Selection Criteria	Weight	Concepts							
		Circuit Diagram		Color-Code		Bundle Wires		Quick Release for Batteries	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Maintain Previous Performance	0.09	3.00	0.27	3.00	0.27	3.00	0.27	3.00	0.27
Accessibility (hydraulics)	0.09	3.20	0.29	3.00	0.27	3.20	0.29	3.00	0.27
Accessibility (batteries)	0.11	3.20	0.35	3.00	0.33	3.00	0.33	3.50	0.39
Accessibility (electronics)	0.10	3.50	0.35	3.50	0.35	3.00	0.30	3.20	0.32
Transferable	0.09	4.00	0.36	4.00	0.36	3.50	0.32	3.00	0.27
Maintainence/Serviceability	0.10	3.50	0.35	3.50	0.35	3.50	0.35	3.50	0.35
Safety	0.12	3.50	0.42	3.20	0.38	3.00	0.36	3.50	0.42
Simplicity of Layout	0.07	4.00	0.28	3.20	0.22	3.50	0.25	3.20	0.22
Reliability	0.10	3.00	0.30	3.00	0.30	3.00	0.30	3.50	0.35
Aesthetics	0.04	4.00	0.16	4.00	0.16	4.00	0.16	3.00	0.12
Implementation	0.09	3.00	0.27	3.00	0.27	3.00	0.27	3.00	0.27
	Total Score	3.40		3.27		3.19		3.25	
	Rank	1		2		4		3	

SEVICEABILITY & ACCESSABILITY FOR HYDRAULIC SYSTEM

Selection Criteria	Weight	Concepts							
		Manifold for valves		Lay valves in surface		Effective Hydraulic Pipe Spacing		Replace hard pipes with soft ones	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Maintain Previous Performance	0.09	3.00	0.27	3.00	0.27	3.00	0.27	3.00	0.27
Accessibility (hydraulics)	0.09	4.00	0.36	4.00	0.36	4.00	0.36	3.00	0.27
Accessibility (batteries)	0.11	4.00	0.44	3.00	0.33	3.00	0.33	4.00	0.44
Accessibility (electronics)	0.1	3.20	0.32	3.00	0.30	3.00	0.30	3.00	0.30
Transferable	0.09	4.00	0.36	4.00	0.36	3.00	0.27	3.00	0.27
Maintainence/Serviceability	0.1	4.00	0.40	4.00	0.40	4.00	0.40	4.00	0.40
Safety	0.12	4.00	0.48	3.00	0.36	3.00	0.36	2.00	0.24
Simplicity of Layout	0.07	4.00	0.28	4.00	0.28	3.00	0.21	3.00	0.21
Reliability	0.1	4.00	0.40	4.00	0.40	3.00	0.30	2.00	0.20
Aesthetics	0.04	4.00	0.16	3.00	0.12	4.00	0.16	4.00	0.16
Implementation	0.09	2.00	0.18	3.00	0.27	2.00	0.18	4.00	0.36
	Total Score	3.65		3.45		3.14		3.12	
	Rank	1		2		3		4	

SAFETY

Selection Criteria	Weight	Concepts							
		Cover Exposed Electric Connections		Change the Base of Electronic Controller Board to Plastic		Ensure the Safety of the Hydraulic Fluid		Color Code Hydraulic Connections According to Pressures	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Maintain Previous Performance	0.09	3.00	0.27	3.00	0.27	3.00	0.27	5.00	0.45
Accessibility (hydraulics)	0.09	3.00	0.27	3.00	0.27	3.00	0.27	3.00	0.27
Accessibility (batteries)	0.11	2.80	0.31	3.00	0.33	3.00	0.33	3.00	0.33
Accessibility (electrical)	0.10	2.50	0.25	3.00	0.30	3.00	0.30	3.00	0.30
Transferable	0.09	3.00	0.27	3.00	0.27	3.30	0.30	5.00	0.45
Maintainence/Serviceability	0.10	2.80	0.28	3.00	0.30	3.30	0.33	4.00	0.40
Safety	0.12	3.50	0.42	4.00	0.48	3.30	0.40	3.80	0.46
Simplicity of Layout	0.07	2.80	0.20	3.00	0.21	3.00	0.21	5.00	0.35
Reliability	0.10	3.00	0.30	3.00	0.30	3.00	0.30	3.00	0.30
Aesthetics	0.04	3.00	0.12	4.50	0.18	3.00	0.12	3.00	0.12
Implementation	0.09	4.00	0.36	3.50	0.32	5.00	0.45	5.00	0.45
	Total Score	3.04		3.23		3.27		3.88	
	Rank	7		5		3		1	

Selection Criteria	Weight	Concepts					
		Change Diameter of Critical Connections		Move the Electronic Controller Board		Require Helmet for Driver	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Maintain Previous Performance	0.09	5.00	0.45	3.00	0.27	3.00	0.27
Accessibility (hydraulics)	0.09	3.00	0.27	3.00	0.27	3.00	0.27
Accessibility (batteries)	0.11	3.00	0.33	3.00	0.33	3.00	0.33
Accessibility (electrical)	0.10	3.00	0.30	3.00	0.30	3.00	0.30
Transferable	0.09	3.00	0.27	3.50	0.32	3.00	0.27
Maintainence/Serviceability	0.10	3.30	0.33	3.00	0.30	3.00	0.30
Safety	0.12	4.00	0.48	3.50	0.42	5.00	0.60
Simplicity of Layout	0.07	3.00	0.21	3.50	0.25	3.00	0.21
Reliability	0.10	3.00	0.30	3.00	0.30	3.00	0.30
Aesthetics	0.04	2.50	0.10	3.30	0.13	2.50	0.10
Implementation	0.09	2.50	0.23	2.80	0.25	5.00	0.45
	Total Score	3.27		3.13		3.40	
	Rank	4		6		2	

Appendix X

MATLAB code for concept selection

```
clear
clc

%Define the matrix we wish to analyze
data = [3.63   3.65   3.4    3.48   3.876
3.1625 3.45   3.268  3.358  3.4
3.087  3.14   3.249  3.24   3.273
3.031  3.12   3.188  0      3.265
0      0      0      0      3.225
0      0      0      0      3.134
0      0      0      0      3.044
];

[row column] = size(data);
row;
%Cycling through matrix and saving sums
Tdata = zeros();

alim = length(data(:,1));
blim = length(data(:,2));
clim = length(data(:,3));
dlim = length(data(:,4));
elim = length(data(:,5));

a = 1;
i = 1;
j = 1;
while a <= alim

    b = 1;
    while b <= blim

        c = 1;
        while c <= clim

            d = 1;
            while d <= dlim

                e = 1;
                while e <= elim
                    total = data(a,1)+data(b,2)+data(c,3)+data(d,4)+data(e,5);
                    index = [a b c d e];

                    Tdata(i,j) = total;
                    Tdata(i,j+1:j+5) = index;
                    Tdata;

                    e = e+1;
                    i = i+1;
                    clc
                end
```

```
                d = d+1;
                i = i+1;
            end
            c = c+1;
            i = i+1;
        end
        b = b+1;
        i = i+1;
    end
    a = a+1;
    i = i+1;
end

maximums = sort(Tdata(:,1),'descend');
```

MATLAB Code for Measuring Implementation Easiness

```
clc

%DIRECTIONS: load updated Implementation Matrix (Imp) and Indexing Matrix (Indx)
from
%Excel File

DATA = zeros();
for a = 1:50

    vector = Indx(a,1:5);

    TImp = 0;
    for b = 1:5
        ref = vector(b);

        TImp = TImp + Imp(ref,b);
    end
    DATA(a) = TImp;

end

DATA = DATA';
```

Appendix XI

Boothroyd Dewhurst Chart

MANUAL HANDLING — ESTIMATED TIMES (seconds)

Key:

ONE HAND

		parts are easy to grasp and manipululate					parts present handling difficulties (1)				
		thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
		size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm	size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm
		0	1	2	3	4	5	6	7	8	9
parts can be grasped and manipulated by one hand without the aid of grasping tools	0 — $(\alpha+\beta) < 360°$	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
	1 — $360° \le (\alpha+\beta) < 540°$	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
	2 — $540° \le (\alpha+\beta) < 720°$	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
	3 — $(\alpha+\beta) = 720°$	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

ONE HAND with GRASPING AIDS

		parts need tweezers for grasping and manipulation								parts need standard tools other than tweezers	parts need special tools for grasping and manipulation
		parts can be manipulated without optical magnification				parts require optical magnification for manipulation					
		parts are easy to grasp and manipulate		parts present handling difficulties (1)		parts are easy to grasp and manipulate		parts present handling difficulties (1)			
		thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm		
		0	1	2	3	4	5	6	7	8	9
parts can be grasped and manipulated by one hand but only with the use of grasping tools	4 — $\alpha \le 180°$, $0 \le \beta \le 180°$	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
	5 — $\alpha \le 180°$, $\beta = 360°$	4	7.25	4.75	8	6	8.75	6.75	9	8	8
	6 — $\alpha = 360°$, $0 \le \beta \le 180°$	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
	7 — $\alpha = 360°$, $\beta = 360°$	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

TWO HANDS for MANIPULATION

		parts present no additional handling difficulties					parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)				
		$\alpha \le 180°$			$\alpha = 360°$		$\alpha \le 180°$			$\alpha = 360°$	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary) (2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

TWO HANDS required for LARGE SIZE

		parts can be handled by one person without mechanical assistance									two persons or mechanical assistance required for parts manipulation
		parts do not severely nest or tangle and are not flexible								parts severely nest or tangle or are flexible (2)	
		part weight < 10 lb				parts are heavy (> 10 lb)					
		parts are easy to grasp and manipulate		parts present other handling difficulties (1)		parts are easy to grasp and manipulate		parts present other handling difficulties (1)			
		$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$		
		0	1	2	3	4	5	6	7	8	9
two hands, two persons or mechanical assistance required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

MANUAL INSERTION – ESTIMATED TIMES (seconds)

Key: PART ADDED but NOT SECURED

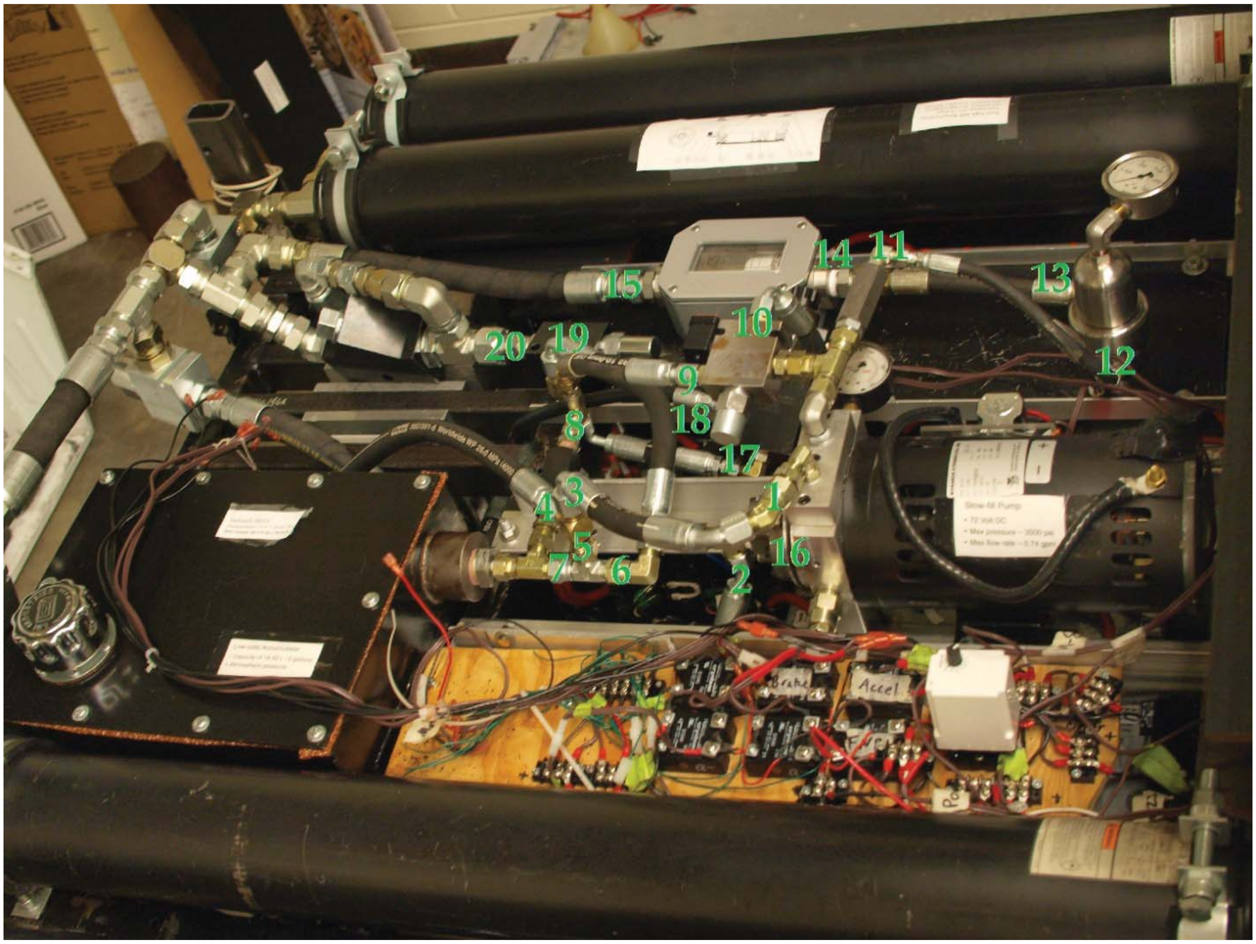
			after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
			easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
			no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
			0	1	2	3	6	7	8	9
addition of any part (1) where neither the part itself nor any other part is finally secured immediately	part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
	part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
	part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

PART SECURED IMMEDIATELY

			no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
					plastic bending or torsion			riveting or similar operation				
						not easy to align or position during assembly			not easy to align or position during assembly			
			easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
			0	1	2	3	4	5	6	7	8	9
addition of any part (1) where the part itself and/or other parts are being finally secured immediately	part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
	part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
	part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

SEPARATE OPERATION

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	riveting or similar processes	screw tightening (6) or other processes	bulk plastic deformation (large proportion of part is plastically deformed during fastening)	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	9
assembly processes where all solid parts are in place	9	4	7	5	3.5	7	8	12	12	9	12



Parts mapping for the BD chart analysis table

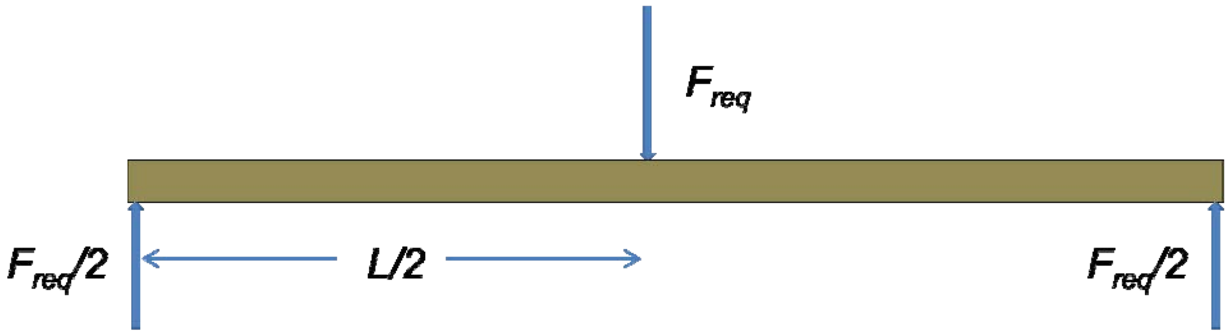
Part Name	Handling Code	Justification	Insertion Code	Justification
Hydraulic Fittings	3,0	The hydraulic fittings can be handled and moved with one hand and have a minimum dimension greater than 15 mm. Lacks symmetry because it has to be oriented in a specific direction.	5,7	The hydraulic fittings are obstructed due to access and restricted vision because some of the fittings are below others and obstructed by other components. They require a torque wrench to connect to the hydraulic lines and there is resistance to insertion.
Slow Fill Pump(SFP) Cable	1,0	The SFP cables can be handled and moved with one hand and have a minimum dimension greater than 15 mm. Has symmetry because it is cylindrical.	3,9	The SFP cables are not obstructed by other components. They require a screw to be inserted.

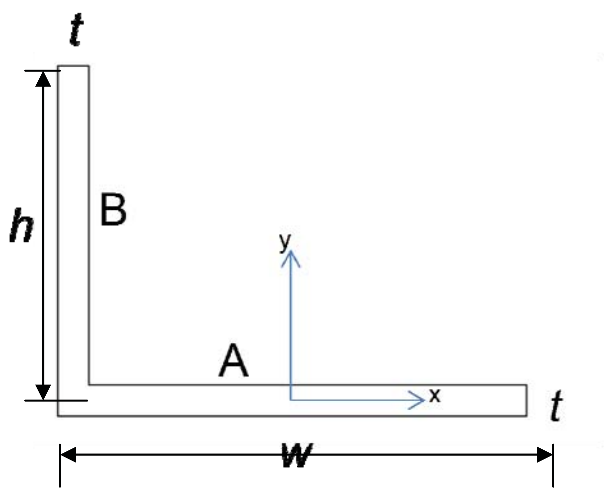
Slow Fill Pump (SFP)	9,7	The slow fill pump requires two hands to hold because it is a large and weighs 33 lbs. There are some difficulties with handling the SFP because there are no handles. Lacks symmetry because it has to be oriented in a specific direction.	5,9	The SFP requires screws to mount the SFP to the mounting beams and access to these screws is obstructed by vision and access.
Mounting for Slow Fill Pump	9,1	The mounting for the SFP requires two hands for its large size but weighs less than 10 lbs. Has symmetry because it can be oriented in different directions as long as the bolt holes can be aligned.	3,7	The mounting for the slow fill pump are not obstructed by other components (after the SFP has been removed). They require a wrench to be secured to the frame.
Filter	3,0	The filter can be handled and moved with one hand and has a minimum dimension greater than 15 mm. Lacks symmetry because it has to be oriented in a specific direction.	3,7	The filter is not obstructed by other components. It requires a torque wrench to be connected to a hydraulic fitting.
Flow meter	3,0	The flow meter can be handled and moved with one hand and has a minimum dimension greater than 15 mm. Lacks symmetry because it has to be oriented in a specific direction.	3,7	The flow meter is not obstructed by other components. It requires a torque wrench to be connected to a hydraulic fitting.
Hydraulic Valves	3,0	The hydraulic valves can be handled and moved with one hand and have a minimum dimension greater than 15 mm. Lacks symmetry because it has to be oriented in a specific direction.	5,7	Access and vision of the hydraulic valves are obstructed by other components. It requires a torque wrench to be connected to a hydraulic fitting.
Electronic Controller Board	3,0	The electronic controller board can be handled and moved with one hand and has a minimum dimension greater than 15 mm. Lacks symmetry because it has to be oriented in a specific direction.	3,8	The electronic controller board is not obstructed by any components and requires screws to fasten it to the frame of the vehicle.

Electrical Connections	1,0	The electrical connections can be handled and moved with one hand and have a minimum dimension greater than 15 mm. Has symmetry because it is a cylindrical tube.	0,0	The electrical connections are easily inserted to hydraulic valves and there is very little resistance to insertion. We assumed that most of the wires would not have to be disconnected from the electronic controller board in order to access the batteries.
Support Beams	9,1	The support beams under the accumulators require two hands for its large size but weighs less than 10 lbs. Has symmetry because it can be oriented in different directions as long as the bolt holes can be aligned.	5,7	The support beams are obstructed by the accumulators and the batteries underneath them. We will require a wrench to secure these parts.
Flow meter and Filter Mountings	9,1	The mounting beams for the flow meter and the filter require two hands for its large size but weighs less than 10 lbs. Has symmetry because it can be oriented in different directions as long as the bolt holes can be aligned.	3,6	The flow meter and filter mountings are not obstructed by other components (after the hydraulic lines above have been disassembled). It requires a torque wrench to be connected to the vehicle frame.
Batteries	9,9	The batteries require two hands for its large size and because it weighs more than 10 lbs. The batteries require two people or mechanical assistance to lift and move.	3,8	The batteries will not be obstructed after the assembly of the above components is removed. The batteries need to be connected to various connections upon insertion
Truck Bed	9,9	The batteries require two hands for its large size and because it weighs more than 10 lbs. The batteries require two people or mechanical assistance to lift and move.	3,0	The truck bed is not obstructed by other components (assuming the truck bed is empty). The truck bed is easily inserted with a pin and a clip.

Appendix XII

Static load analysis for mounting mechanisms





$$I = I_{x,A} + I_{x,B}$$

$$I_{x,A} = \frac{1}{12} * w * t^3$$

$$I_{x,B} = \frac{1}{12} * t * h^3 + t * h * \left(\frac{t}{2} + \frac{h}{2}\right)^2$$

$w = 0.04\,m$

$h = 0.02m$

$L = 0.975\,m$

$F_{req} = 9.81 * (15.0 + 2.2 + 2.52)/2 = 96.73\,N$

$M_{max} = F_{req} * L/2 = 47.2\,N * m$

$\sigma_{Y,S}/SF = 250MPa/3 = 83MPa = \sigma_{max}$

$$\sigma_{max} = \frac{M_{max} * \frac{t+h}{2}}{I_x}$$

$$I_x = \frac{1}{12} * w * t^3 + \frac{1}{12} * t * h^3 + t * h * \left(\frac{t}{2} + \frac{h}{2}\right)^2$$

Using Excel Solver, we determined that with a safety factor of 3, the minimum thickness for the mounting beams to be 3.5 mm.

Appendix XIII: ME 450 Safety Reporting: Winter 2010

Project #: 10 **Date:** 3.29.2010

Report Version #: 0.4

Project Title: Xebra Electric-Hydraulic Hybrid Car Redesign for Serviceability

Team Member Names: Andres Diaz, Eric Kim, Kevin Lyons, Yuntao Chen

Team Member Uniquenames: andiaz (Andres), ericjkim (Eric), kmlyons (Kevin), yuntaoc (Chen)

Attach your Safety Report to this cover page and instructions found on Pages 2 and 3.
The Safety Report is to be completed by your team and must be approved by your section instructor (or approved substitute) prior to any hands-on experimentation, manufacturing or testing of your prototype.
The safety hazards inherent in your experimental plans, component selection, manufacturing methods, assembly techniques, and testing must be expressed and evaluated before any hands-on work with safety consequences will be allowed to proceed.
The purpose of this safety report is to assure that you have thought through your hands-on work before it begins, and that you have shared your plans with your Section Instructor. You may submit more than one version. This will likely be necessary as your project evolves.

APPROVAL:

Name: ____________________________

Signature: ____________________________

Date: ____________________________

Contents

Executive Summary

This safety report introduces the preliminary tests that we have conducted to determine the current status the vehicle. Given enough knowledge of the vehicle, we will also talk about the new components and parts that will be either purchased or designed to meet the established customer requirements and engineering specifications. All new components will be validated through the Design-Safe process. Finally, a validation test plan is provided for effective evaluation of the system.

We are going to perform four tests, which address the malfunctioning parts, in advance of all other modifications. These processes deal with the hydraulic fluids and potential high voltage circuits. Great safety caution is to be taken and a detailed step-by-step plan is given for each individual test. We went through the electronic and hydraulic diagrams to ensure that the system was in a low energy state before we started the tests.

After inspecting and fixing/replacing all the faulty parts, we will focus on the new components that we are going to add to the system to achieve our engineering specifications. The main parts that we are going to add are the manifold for the valves and creating new mounting mechanisms for the relocated filter, slow fill pump, and the manifold. A failure mode effects analysis was performed for all the newly designed parts to ensure safety. A design-safe analysis was also performed to eliminate the potential danger that is brought by the newly purchased components.

As the proposed Dynamometer test at the EPA is not very likely to happen, we prepared an alternative test procedure for testing the functionality of the vehicle in a parking lot. Instead of testing the top performance of the vehicle, the parking lot test will put emphasis on the ability of all the subsystems in the vehicle to function as designed.

Experimentation Plan

Valve Signal Mapping

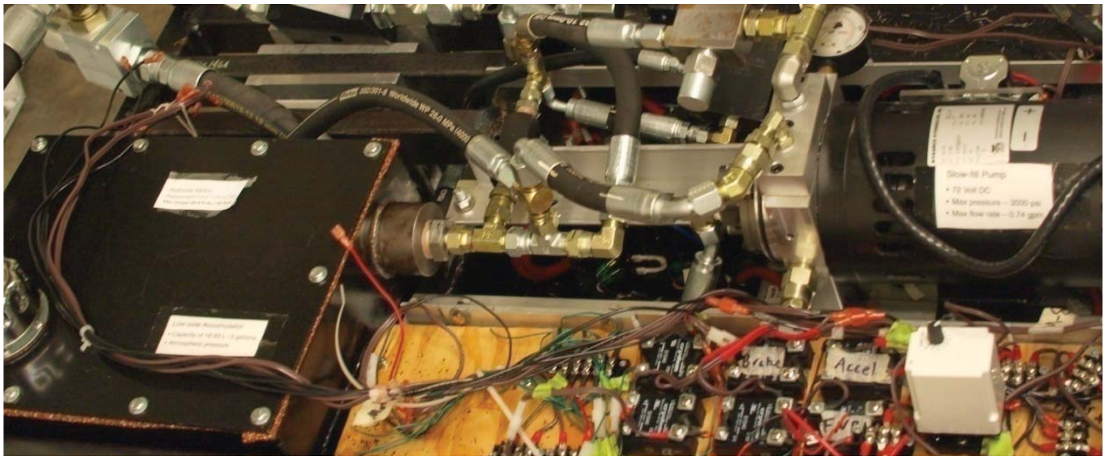


Figure 1. Disconnected electronic connections in the current vehicle

Overview
We are planning and testing the signal sent to the various electrical leads through pressing the sensors on the brake and gas pedals. We will not be testing the response of the vehicle, simply the voltage signal sent to the ends of the numerous electrical leads of the system. This will enable us to map out the response of the valves in relation to the braking/accelerating input they receive. We will not use the power from the car to perform the test, but rather use a DC source in the X50 lab. We have got the permission of using the DC source and the multimeter in the X50 lab from Dr. John Baker.

Procedure

1. Disconnect all electrical leads from the controller box to any and all valves to ensure separation from sensor input and valve operation.
2. Put two blocks of metal in front and back side of the front wheel.
3. Jack the Xebra car up with the jack stand in the X50 lab.
4. Remove the acceleration sensor and the braking sensor from the pedals.
5. Disconnect the electric controller box from the auxiliary battery and connect it to the 12V DC source.
6. While pressing the brake sensor, measure the voltage reading across each and every electrical lead in the system and record the response using a multimeter.
7. Record response and label leads accordingly.
8. Repeat steps 5 and 6 several times for both the braking circuit and the acceleration sensor

Safety Concerns
To ensure the safety, we decide to test the control circuit with a DC source so that we don’t need to start the car to perform the test. However we still decide to jack up the car with the hydraulic stand so that in case the car started unexpectedly, it will not cause danger to the team member and other students in the X50 lab. Even though this test will only involve low DC voltage, we will disconnect the wall outlet with the car and wear insulation gloves. All members are also required to wear safety glasses in the lab.

Reinstallation of the Recirculation Valve

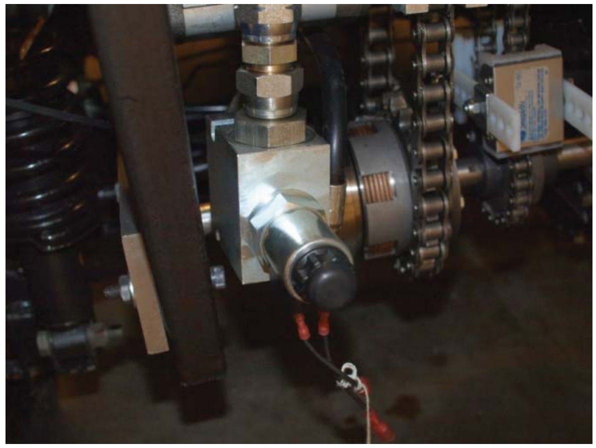


Figure 2. Faulty recirculation valve currently installed on the vehicle

Overview
The hydraulic recirculation valve, as shown in Figure 2, has been determined to be one of the main malfunctioning parts by the previous team. It is believed that the valve was installed in a wrong direction. We are planning on reinstalling the recirculation valve in the correct orientation. According to information provided by Hydac online, the valve allows flow from the inlet marked 1 to the outlet marked 2 and prevents flow in the opposite direction. We will need to verify that our valve is operating in the same function before reinstalling the valve.

Preparation
Because this part of the test involves the dissembling of some hydraulic parts, we carefully studied the hydraulic circuitries. A schematic of the circuitry is shown below in Figure 3.

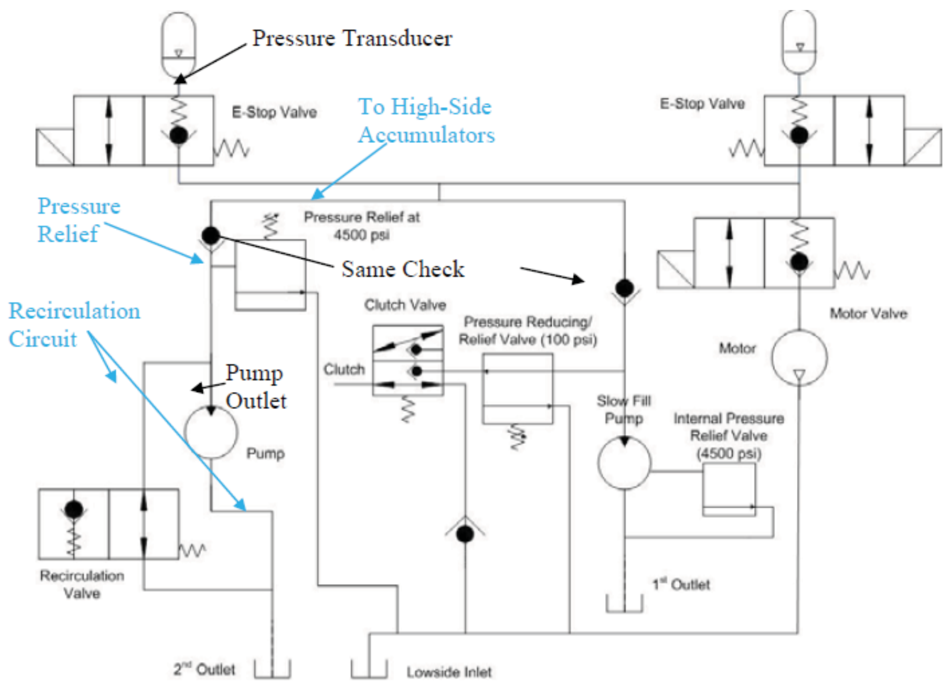


Figure 3. Schematic of the hydraulic circuitry

The most important valve that connects the low pressure part and the high pressure part is the E-stop valve. No information about the operation of the valve was given in the previous report. After we looked up the serial number of the valve (Hydac, WS 16ZR-01-M-SS 16-N-12-DS), we concluded that it is normally open. If the valve is open, then it means that the pressure inside the accumulators is the same with the branch with the pressure gauge. The reading of the gauge is zero now, so that will lead to the conclusion that the pressure inside the accumulators is zero. As a conclusion, we figured out that we will not be threatened by the high pressure fluid in our test.

Procedure

1. Make sure that the vehicle is powered off and has no electric connections with wall outlet.
2. Place safety mats above the electrical system but underneath the hydraulic system.
3. Extricate the hydraulic fluid from the reservoir using the pump available in the X50 lab.
4. Place absorption mat under the recirculation valve that is to be dissembled.
5. Dissemble the two hydraulic pipes that are connected to the valve.
6. Remove the recirculation valve.
7. Perform a simple experiment to test the functionality of the recirculation valve.
    a. Place a bucket over an absorbent safety mat.
    b. Perform experiment over the bucket to contain the hydraulic fluid.
    c. Place some hydraulic oil in to valve.
    d. Observe if flow is allowed in both directions when the valve is not activated.
    e. Activate the valve using the DC source.
    f. Place hydraulic fluid into outlet marked 2.
    g. Observe if flow is not allowed out of the inlet marked 1 when the valve is activated.
    h. Place hydraulic fluid into inlet marked 1.
    i. Observe if flow is allowed out of outlet marked 2 when the valve is activated.
8. Reinstall the recirculation valve in the correct direction if the valve is functioning well.

Safety Concerns

We are told that the hydraulic fluid is harmful, so we all need to wear gloves when performing these procedures. The safety mats are to be used to ensure that any leaked hydraulic fluid will not contact the electric system and cause short circuit. The car will be kept power off and the electric connection with the wall outlet will be unplugged to further safety. Furthermore, the car has been jacked up by hydraulic stands during the previous test. The valve is connected to the low pressure reservoir so that most of low pressure fluid would have been already extricated when we drain the reservoir. However, we will wear safety glasses to protect us from the residue of the fluid inside the connections. If the valve is not functioning, we will need to report to our sponsor and prepare to purchase a new replacement.

Dissemble hydraulic connections

Overview

The current electronic controller on the car is not capable of delivering enough power to the electric motor, so as part of our improvement goals, we need to replace it with a new controller. The controller is under many hydraulic connections now. In order to access the controller, we decide to dissemble part of the hydraulic connections and clear up the space for the operation of replacing the controller. We have finished draining the hydraulic fluid from the low pressure reservoir in a previous test, so we are expecting to work with very few fluid residues in this test. Also, the vehicle has been jacked up by a hydraulic stand.

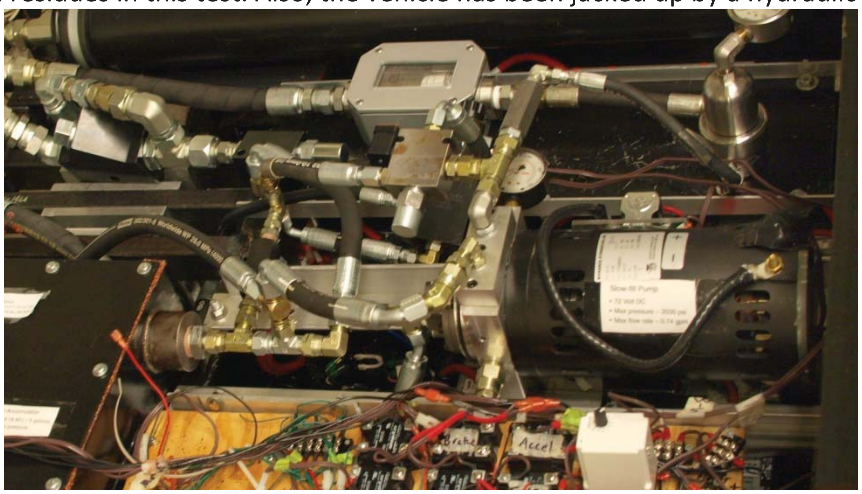


Figure 4. Current system layout showing the main working zone for this test

Procedure

1. Wear safety glasses and insulation gloves.
2. Disconnect all electric connections between the wall outlet.
3. Disconnect the electric connections between the batteries and the slow fill pump and electronic controller.
4. Put a piece of absorption cloth between the batteries and the hydraulic connections.
5. Loose the connections between the two sides of the flow meter with two wrenches and take the flow meter out from the car.
6. Dissemble the connections for the filter and take it out.
7. Take out more segments of the pipe if the space is not enough.
9. Use screw drivers to unfasten the screws in the metal plate under the flow meter.

Safety Concerns

A lot of safety preparations have been done in the previous procedures. In this test, we don't need to worry about high pressure fluid because the fluid has been drained. The remaining safety concerns mainly lie in the electric side. We will double check that no high voltage wall outlet is connected and insulation gloves should be worn at all time. We will also try to limit our operation zone to only the overhead of the controller so that we will not reach the high voltage zone of the vehicle and the number of hydraulic connections that we need to be removed is minimized. A mat is placed between the hydraulic connections and the batteries to prevent the residues of the fluid cause any short circuit in the system. As usual, all team members are required to wear safety glasses and the door of the X50 lab will be closed to prevent any distraction.

Electronic Controller Replacement

Overview

As we have mentioned before, the electric controller on board is outdated. Currently, this controller only provides 300 amperes of output current. We will install an electronic controller that provides a maximum current output of 450 amperes. This controller, manufactured by Alltrax Inc (model AXE- 7245P, shown in Figure2), will allow the Xebra vehicle to reach and maintain a speed of 45 mph.

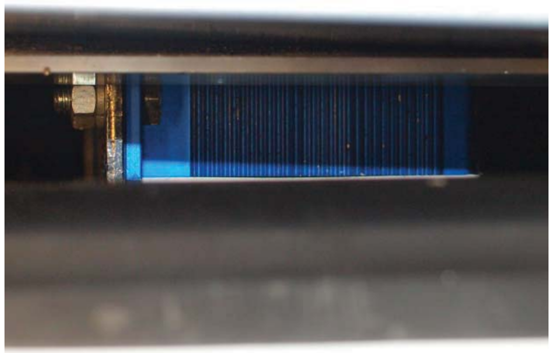


Figure 5.Electric controller currently installed

Http://www.alltrax.com

Figure 6. New Alltrax AXE-7245P controller

Procedure

1. Disconnect cables and remove outdated controller.
2. When disconnecting the batteries we will disconnect the negative terminal first.
3. Pull out the old controller and replace it with the new controller.
4. Choose appropriate wiring according to amperage. Refer to AXE Operators Manual.
5. Install fuse in the battery circuit rated for 450 Amperes.
6. Install a battery contactor rated for the correct amperage and voltage of system. (Not supplied with controller)
7. Install safety interlocks to prevent enabling the controller when charging.
8. Install diode (1A, 100V) across the solenoid/contactor coil (and any other relays that may be installed to control lights or accessories). Refer to wiring diagrams supplied by manufacturer.
9. Install pre charged resistor
10. Place the drive axle on jack stands allowing the wheels to have no contact with the floor.
11. Place a block in front of the front wheel to prevent forward acceleration.
12. When connecting the batteries we will connect the negative terminal last.
13. Power the controller using two 9 volt batteries connected in series.
14. Determine configured throttle type for controller
15. Reprogram the controller if necessary following manufacturers guidelines.
16. Disconnect the new controller from the main motor.
17. When connecting the batteries we will connect the negative terminal last.
18. Reconnect the batteries to the car, double check the entire system connections
19. Slightly touch the acceleration pedal, test the output of the controller with a multimeter.
20. Resolve any problem occurred
21. Leave the vehicle as it is, wait for further operations.

Safety Concerns

Most of the dangerous procedures that we need to conduct to access the controller have been finished by previous tests. Nevertheless, all team members working on this replacement must remove all metal personal effects (e.g. rings, watches). We will also disconnect the negative terminal of the battery first and connect the negative terminal last to prevent short circuiting. Eye protection and insulated tools must be used. The team members must also make sure that the batteries are disconnected and the system is not powered. A laptop should never be connected to the controller if the vehicle is charging as recommended by the electronic controller manufacturer. Installing a battery contactor, a fuse in the battery circuit and a diode across the solenoid are crucial elements for safety. Safety precautions are to be taken when placing the vehicle on jack stands. We will also place a block in front of the front wheel to prevent motion of the vehicle.

Purchased Component and Material Inventory

The main components that we are going to purchase for this project are listed below.

Item	Serial #	Amount	Manufacturer
Steel beams	N/A	2	Alro Metal Plus
Steel plate	N/A	1	Alro Metal Plus
Manifold	Customized	1	RHF Fluid Power Inc.
Electronic controller	AXE- 7245P	1	Alltrex
Filter	DFBN/HC30TB5B1	1	Morrel Inc.

The steel beams and plate will be used for the mounting mechanism of the filter and the slow fill pump. We have performed extensive engineering analysis on the components to ensure the strength of the material, which are provided in our DR3 report. The engineering drawings for the beam and the plate can be found in Appendix XIV of the report.

The new electronic controller has already been purchased and delivered on March 18th. The manifold provided by our sponsor at the RHF hydraulics has also been picked up on March 22th. Before we can install these components into our car, we carried out Failure Mode and Effects Analysis (FMEA) for all of the components that we plan to install. The Potential failures modes have been identified for all of the components as well as the potential effect of failure, severity, probability of occurrence, controls for detection/prevention, recommended action, and the person/s responsible, as shown below.

Custom manifold FMEA

<table>
<tr><td colspan="3">Failure Mode and Effects Analysis Worksheet (Adapted from Cincinnati Machine PFMEA)</td></tr>
<tr><td rowspan="3">Custom Manifold:
The manifold was custom made by Hasan Shahid of RHM Fluid Power, Inc. The manifold has two logic valves that control the slow fill pump's pressurizing of the high pressure accumulator.</td><td>Key Contact / Phone:
Andres Diaz 734-389-5712</td><td>Date of Initial FMEA:
March 14 2010</td></tr>
<tr><td>Core Team:
Team 10</td><td>Date of Initial System Demonstration:</td></tr>
<tr><td>Location:
Univ. of Michigan, Ann Arbor</td><td>Review Board Approval / Date:</td></tr>
<tr><td colspan="3">Potential Failure Modes and Hazard Identification Discussion:

Identify all potential failures and safety hazards for this system in the applicable mode of operation. Complete a FMEA rating form for each significant item. 1. Pressures and flow rates are too high for the valves and connections. 2. The manifold is too large to fit under the truck bed. 3. The hydraulic lines cannot be connected to the manifold without being tangled. 4. The valves can get clogged by debris.</td></tr>
</table>

FMEA rating form for a pressure and flow rates are too high for valves and connections															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			5		2		4	40							

1. Discuss root cause of the failure mode (based on the 5 whys) This failure mode occurs if the valves and connections in the manifold have insufficiently rated components.

2. Discuss/justify the severity rating (SEV) Moderate. The valves and connections in the manifold do not pose a safety risk because the valves are rated to handle the flow rates and pressures coming out of the slow-fill pump. If the valves and connections were not rated high enough there would be damage to the custom manifold.

3. Discuss/justify the rating for probability of occurrence (OCC) Remote. If the correct precautions are not taken or if insufficient components are used than this failure may occur. The custom manifold was designed to support the flow rate and pressures from the slow fill pump and the hydraulic line coming from the clutch.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) If the slow fill pump does not pressurize the accumulators we can detect if the manifold has failed. The slow fill pump should be pressurizing the high pressure accumulators and this can be detected by visually checking the low pressure reservoir as well as the pressure of the accumulators.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. The manifold was designed to ensure that the valves and connections would be able to withstand the pressures and flow rates that will go into the manifold. The manifold will use the same valves that are currently used in the Xebra vehicle so they should operate the same.

6. Notes on Actions taken: Kevin and Hasan corresponded regularly to ensure that the manifold will be rated to withstand the pressure and flow rates of the hydraulic system.

FMEA rating form for manifold does not fit under truck bed															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			2		1		1	2							

1. Discuss root cause of the failure mode (based on the 5 whys) The manifold has to fit under the truck bed and must allow the proper clearance to avoid any interference.

2. Discuss/justify the severity rating (SEV) Slight. This failure mode is easily avoided by designing the manifold to fit underneath the truck bed.

3. Discuss/justify the rating for probability of occurrence (OCC) Remote. The manifold is not large enough to interfere with the truck bed.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) Detection of this failure would be easy because manifold should fit underneath the truck bed. If the manifold does not appear to fit underneath the truck bed we will have to reposition the manifold.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. The manifold was designed to fit underneath the truck bed. The manifold will not be much larger than the current hydraulic valves in the present system.

6. Notes on Actions taken: Kevin and Hasan corresponded regularly to ensure that the manifold would fit underneath the truck bed.

FMEA rating form for hydraulic lines cannot be connected to manifold without being tangled															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode and 5 Whys [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			1		3		2	6							

1. Discuss root cause of the failure mode (based on the 5 whys) If the connections to the manifold are not in the best positions, the hydraulic lines connected to mounted components will create higher head losses.

2. Discuss/justify the severity rating (SEV) Slight. Head losses will decrease the efficiency of the system and loss of energy but it would not create a dangerous situation.

3. Discuss/justify the rating for probability of occurrence (OCC) Remote. Kevin and Hasan ensured that this failure mode would be avoided by placing the inlets and outlets of the manifold to match the layout we have planned.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) We were able to avoid this failure mode by reviewing the manifold design before construction of the manifold began.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. If the manifold were to arrive with the inlets and outlets in incorrect positions we would have to considering adjusting the mounting of hydraulic components to avoid head losses. The manifold should arrive as specified and head losses will be avoided.

6. Notes on Actions taken: Kevin asked Hasan to reposition the inlets to simplify the connections and to avoid tangling and inefficient hydraulic lines.

FMEA rating form for the valves and connections being clogged from debris																
											Action Results					
Categorize: Identify subsystems and mode of operation	Potential Failure Mode and 5 Whys [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			2		5		4	40							

1. Discuss root cause of the failure mode (based on the 5 whys) The filter in the present hydraulic system is connected after the logic valves. Unfiltered hydraulic oil from the low pressure reservoir has metal and other debris that can clog the logic valves.

2. Discuss/justify the severity rating (SEV) Slight. The valves in the present system have worked well and should continue to work because we will be using valves with the same properties.

3. Discuss/justify the rating for probability of occurrence (OCC) Moderate. The present filter has not caused any clogs in the present valves that are the same as the valves in the custom manifold.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) We will have to trouble shoot the hydraulic system if the regenerative braking or the slow fill pump are not operating correctly.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. We plan to move the filter from its current location to be positioned after the slow fill pump and before the manifolds connection. This will ensure that debris will be filtered from the hydraulic oil before it goes into the manifold.

6. Notes on Actions taken: We changed the planned layout of the hydraulic system to have the hydraulic oil filtered before it flows into the manifold.

Mounting rails FMEA

<table>
<tr><td colspan="3">Failure Mode and Effects Analysis Worksheet (Adapted from Cincinnati Machine PFMEA)</td></tr>
<tr><td rowspan="3">Mounting beams:
Steel mounting rails will be used to mount the slow fill pump, filter, custom manifold and flow meter. A pair of mounting rails will support the slow fill pump , the filter and the manifold. Another mounting rail will be used to support the flow meter.</td><td>Key Contact / Phone:
Andres Diaz 734-389-5712</td><td>Date of Initial FMEA:
March 14 2010</td></tr>
<tr><td>Core Team:
Team 10</td><td>Date of Initial System Demonstration:</td></tr>
<tr><td>Location:
Univ. of Michigan, Ann Arbor</td><td>Review Board Approval / Date:</td></tr>
<tr><td colspan="3">Potential Failure Modes and Hazard Identification Discussion:

Identify all potential failures and safety hazards for this system in the applicable mode of operation. Complete a FMEA rating form for each significant item. 1. Weight of components supported will cause the rails to yield. 2. Holes for screwing the mounting rails to the car frame are in incorrect locations and will not allow the frames to be mounted.</td></tr>
</table>

FMEA rating form for mounting rails yielding															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			7		1		2	14							

1. Discuss root cause of the failure mode (based on the 5 whys) This failure mode occurs if the mounting rails are not strong enough to support the weight of the slow fill pump, the filter and the manifold / the flow meter.

2. Discuss/justify the severity rating (SEV) Slight. The mounting rails will be used to support the weight of the larger hydraulic components that would cause stress in the hydraulic lines. The mounting rails will be fabricated from 1020 Steel which is stronger than the aluminum rails presently being used to mount the slow fill pump.

3. Discuss/justify the rating for probability of occurrence (OCC) Remote. We have done static analysis of the mounting rails. The mounting rails will be able to support the slow fill pump, the filter and the manifold. The slow fill pump is the heaviest component and only has a mass of 15 kg. The steel mounting rails have a yield strength of 295 MPa. With a thickness of 10 mm the safety factor is 4.93.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) Any displacement by the aluminum will be visible which will indicate that the mounting rail is elastically deforming. The beam will not be supporting enough weight to yield.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. We considered using steel because it has a smaller negative effect on the environment but we chose to reuse material that is already present in the present vehicle as this will prevent wasted material.

6. Notes on Actions taken: We have done static analysis on the mounting rails to ensure that they will not yield.

FMEA rating form for misalignment of the screw holes																
											Action Results					
Categorize: Identify subsystems and mode of operation	Potential Failure Mode and 5 Whys [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			1		2		2	4							

1. Discuss root cause of the failure mode (based on the 5 whys) If the holes of the mounting rail and the vehicle frame are misaligned, the screws will not be able to fasten the mounting rails to the frame.

2. Discuss/justify the severity rating (SEV) Slight. This failure mode would cause lost time but will not cause a dangerous situation.

3. Discuss/justify the rating for probability of occurrence (OCC) Remote. The mounting rails are two separate rails that will be connected to the vehicles frame. Therefore it should be easier to align the holes correctly than if we used one mounting rail instead.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) It will be clearly visible if the holes are misaligned when we fasten the mounting rails to the vehicle's frame.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. We considered using one mounting rail but decided to reuse the aluminum mounting rails in the present design which will avoid this failure mode.

6. Notes on Actions taken:

Electronic controller FMEA

<table>
<tr><td colspan="3">Failure Mode and Effects Analysis Worksheet (Adapted from Cincinnati Machine PFMEA)</td></tr>
<tr><td rowspan="3">Electronic Controller:
Employs MOSFETs to provide low "on" resistance, synchronous freewheel rectification permits extended high power operation, microprocessor based controller system monitors functions of electric motor, windows interface allows changing operating parameters and monitoring performance</td><td>Key Contact / Phone:
Andres Diaz 734-389-5712</td><td>Date of Initial FMEA:
March 3, 2010</td></tr>
<tr><td>Core Team:
Team 10</td><td>Date of Initial System Demonstration:</td></tr>
<tr><td>Location:
Univ. of Michigan, Ann Arbor</td><td>Review Board Approval / Date:</td></tr>
<tr><td colspan="3">Potential Failure Modes and Hazard Identification Discussion:

Identify all potential failures and safety hazards for this system in the applicable mode of operation. Complete a FMEA rating form for each significant item. 1. Runaway (stuck throttle) conditions that can lead to damage to controller and serious injury or death to users or bystanders. 2. Catastrophic battery failure or fire in the event of an electrical system failure. 3. Erroneous signals produced from the speed sensor. 4. When the contactor closes to apply power to the controller, the capacitors can arc the contactor. 5. Incorrect software calibration.</td></tr>
</table>

FMEA rating form for a single Failure / Hazard Runaway (stuck throttle) conditions															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode and 5 Whys [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			10		2		5	100							

1. Discuss root cause of the failure mode (based on the 5 whys) This failure mode occurs when there are improper connections or there are insufficiently rated components.

2. Discuss/justify the severity rating (SEV) A hazard runaway (stuck throttle) conditions would be very severe. This could cause damage to the lab, the surrounding area and the vehicle and serious injury to a driver or a bystander. This failure can also cause damage to the electronic controller and the electric system. The wheels spinning can cause instability and any contact with the drive train, axle, and transmission chain could cause serious injury.

3. Discuss/justify the rating for probability of occurrence (OCC) Remote. If the correct precautions are not taken or if insufficient components are used than this failure may occur. With the vehicle raised on jack stands, the wheels will not be in contact with the floor and will not be able to accelerate. The probability of this failure occurring is remote because we will follow the operators manual which has detailed steps for installing the electronic controller correctly.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) If the rear wheels are rotating and are in a hazard runaway (stuck throttle) conditions than we will disconnect the power source immediately. The vehicle will be on two jack stands and the wheels will be clearly visible when testing in the X50 lab so detection of a failure imminent will be easy to see. Prevention will be more important than failure imminent conditions.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. Safety interlocks must be used to prevent enabling the controller while the vehicle is not being used or is charging. Use a contactor in the battery circuit, rated for amperage and voltage of the system (not provided with controller). Use a fuse rated for the voltage and available fault current of the battery (provided with controller). Must follow the Recommended Controller Wiring System document in the manual to prevent damage to controller and serious injury or death to users or bystanders. We will also place the car on a jack stand so that the rear wheels will not be in contact with the ground. We will also place a block in front of the front wheel. This will prevent the car from accelerating foward.

6. Notes on Actions taken:

FMEA rating form for a single Failure / Hazard Catastrophic battery or Electrical system failure															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode and 5 Whys [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			10		2		6	120							

1. Discuss root cause of the failure mode (based on the 5 whys) Improper connections, insufficiently rated components

2. Discuss/justify the severity rating (SEV) Severe. This failure would cause a great amount of damage to the vehicle and could harm team members operating on the vehicle. This failure could damage the electronic controller and other electrical parts. Since the hydraulic fluid is flammable an electrical fire would be extremely dangerous.

3. Discuss/justify the rating for probability of occurrence (OCC) Remote. If improper connections are made and insufficient components are used this failure may occur. We will follow the operators manual closely to avoid this from happening. The main fuse should prevent the wiring in the drive system and prevent this failure mode from occurring. Also, the vehicle will not be running for prolonged times during testing which will avoid electrical components from heating up.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) Detection of this failure would be more difficult because the voltage and currents are not visible. Electrical system failure would be visible if the system began to release sparks however this would be a very dangerous failure so prevention will be very important. Any detection of overheating will also be a way to detect an imminent failure.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. A fuse would be added to prevent battery or electrical system failure. Some of the same precautions to prevent hazard runaway conditions would be used. We will use a contactor in the battery circuit, rated for amperage and voltage of the system (not provided with controller). We will use a fuse rated for the voltage and available fault current of the battery (provided with controller). We must follow the Recommended Controller Wiring System document in the manual to prevent damage to controller and serious injury or death to users or bystanders.

6. Notes on Actions taken:

FMEA rating form for a single Failure / Hazard Erroneous signals produced from the speed sensor															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode and 5 Whys [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			1		3		4	12							

1. Discuss root cause of the failure mode (based on the 5 whys) Without a diode the speed sensor can produce incorrect signals.

2. Discuss/justify the severity rating (SEV) Slight. This mode of failure does not create any safety hazards while testing and can be easily avoided through the use of a proper diode. Incorrect readings do not pose safety risks during testing but can cause a hazard while driving.

3. Discuss/justify the rating for probability of occurrence (OCC) Unlikely as the use of a diode will prevent this mode of failure.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) Detecting this failure would depend on how incorrect the signal was. For example if the reading is off by 5 mph or less it will be harder to detect than if the reading is incorrect by 20 mph or more.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. A contactor coil diode (1A, 100V) must be used across the solenoid/contactor coil. According to the operators manual use of this diode should prevent this failure mode. We will install the diode according to the operators manual, with the banded end facing the positive terminal.

6. Notes on Actions taken:

FMEA rating form for a single Failure / Hazard Capacitors can arc the contactor															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode and 5 Whys [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			1		3		3	9							

1. Discuss root cause of the failure mode (based on the 5 whys) When the contactor closes to apply power to the controller the capacitors can arc the contactor because there is no current being supplied to the capacitors.

2. Discuss/justify the severity rating (SEV) Slight. This would cause the electronic controller not to work but it would not cause stuck throttle conditions.

3. Discuss/justify the rating for probability of occurrence (OCC) Slight. The use of a pre-charge resistor should prevent the capacitors from arcing the contactor. The proper values for the properties of the pre-charge resistor are provided in the schematics in the operators manual.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) Use of a multimeter should be able to detect this failures occurrence.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. A pre-charge resistor will be used to prevent the capacitors from arcing the contactor. A pre-charge resistor applies a low current to the capacitors to prevent arcing and it also dissipates the arc when the contactor disengages. The schematics in the operators manual provides the proper values for the properties of the pre-charge resistor.

6. Notes on Actions taken:

FMEA rating form for a single Failure / Hazard Incorrect software calibration															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode and 5 Whys [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			5		2		3	30							

1. Discuss root cause of the failure mode (based on the 5 whys) Using incorrect values for the software calibration can cause the vehicle to run improperly. We will avoid this mode of failure by receiving help from Zap Cars, which manufactures the Xebra vehicle. We will follow the operators manual for software calibration.

2. Discuss/justify the severity rating (SEV) Moderate. Installing the controller with incorrectly calibrated software may cause the vehicle to run improperly which could cause damage to the vehicle.

3. Discuss/justify the rating for probability of occurrence (OCC) Slight. This mode of failure can be avoided by using the correct values for the software calibration.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) It will be difficult to detect this failure before it occurs because the software is not a visible component. We will have to ensure that we use the correct values before we install the electronic controller.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. We will refer to the Controller Pro Operators manual to ensure that we use and calibrate the controller using the provided software. We will have to refer to the Xebra's operator manual as well to determine the correct calibration values.

6. Notes on Actions taken:

Filter FMEA

<table>
<tr><td colspan="3">Failure Mode and Effects Analysis Worksheet (Adapted from Cincinnati Machine PFMEA)</td></tr>
<tr><td rowspan="3">Filter:
The filter will be purchased from Morrell Inc. and produced by Hydac</td><td>Key Contact / Phone:
Andres Diaz 734-389-5712</td><td>Date of Initial FMEA:
March 14 2010</td></tr>
<tr><td>Core Team:
Team 10</td><td>Date of Initial System Demonstration:</td></tr>
<tr><td>Location:
Univ. of Michigan, Ann Arbor</td><td>Review Board Approval / Date:</td></tr>
<tr><td colspan="3">Potential Failure Modes and Hazard Identification Discussion:
Identify all potential failures and safety hazards for this system in the applicable mode of operation. Complete a FMEA rating form for each significant item. 1. Pressures and flow rates are too high for the filter. 2. The filter can cause cavitation in hydraulic oil flowing out of the filter. 3. The filter can become clogged by debris over time.</td></tr>
</table>

FMEA rating form for pressure and flow rates are too high for the filter															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			5		2		4	40							

1. Discuss root cause of the failure mode (based on the 5 whys) This failure mode occurs if the filter is insufficiently rated to withstand the pressure and flow rate of the slow fill pump.

2. Discuss/justify the severity rating (SEV) Moderate. The filter does not pose a safety risk because the valves are rated to handle the flow rates and pressures coming out of the slow-fill pump. If filter was not rated high enough there would be damage to the filter and hydraulic connections.

3. Discuss/justify the rating for probability of occurrence (OCC) Remote. If the correct precautions are not taken or if insufficient components are used than this failure may occur. The filter was chosen to support the flow rate and pressures from the slow fill pump and the hydraulic line coming from the clutch. The filter is rated for 6000 psi and the maximum pressure coming out of the slow fill pump is 2700 psi.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) If the slow fill pump does not pressurize the accumulators we can detect if the filter has failed. The slow fill pump should be pressurizing the high pressure accumulators and this can be detected by visually checking the low pressure reservoir as well as the pressure of the accumulators.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. The filter was chosen to ensure that the valves and connections would be able to withstand the pressures and flow rates that will go into the manifold. The filter is rated for 6000 psi and the maximum pressure coming out of the slow fill pump is 2700 psi. The flow rate coming out of the slow fill pump is 0.07 lps the filter is rated for 5 lps.

6. Notes on Actions taken: Kevin and a representative from Morrell corresponded regularly to ensure that the manifold will be rated to withstand the pressure and flow rates of the hydraulic system.

FMEA rating form for the filter can cause cavitation in the hydraulic oil															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			7		0		4	0							

1. Discuss root cause of the failure mode (based on the 5 whys) This failure mode occurs because fluid passing through the filter can form vapor bubbles due to the pressure drop across the filter.

2. Discuss/justify the severity rating (SEV) Moderate. If cavitation occurs and the vapor bubbles enter the slow fill pump, the slow fill pump will be damaged.

3. Discuss/justify the rating for probability of occurrence (OCC) None. We specifically chose to use a filter rated for 6000 psi so we can place the filter after the slow fill pump. The reason we chose to place the filter after the slow fill pump is because of packaging issues. There is little room in our design to allow a filter to be places before the slow fill pump because of all the hydraulic components that are connected after the slow fill pump.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) It is difficult to observe cavitation before it is too late.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. We will place the filter after the slow fill pump to ensure that there will be no cavitation of the hydraulic oil which would damage the slow fill pump.

6. Notes on Actions taken: We chose to use a filter that would withstand the flow rate and pressure coming out of the slow fill pump to ensure that cavitation would not damage the slow fill pump.

FMEA rating form for the filter can become clogged with debris over time															
											Action Results				
Categorize: Identify subsystems and mode of operation	Potential Failure Mode [1]	Potential Effect of Failure [2]	SEV	Probability of Occurrence of Failure [3]	OCC	Current Controls for Detection / Prevention [4]	DET	RPN	Recommended Action [5]	Person Responsible & Completion Date	Action Taken [6]	SEV	OCC	DET	RPN
			3		5		3	45							

1. Discuss root cause of the failure mode (based on the 5 whys) This failure mode occurs because use of the filter will eventually lead to particles being stuck in the filter to the point that the filter element would need replacement.

2. Discuss/justify the severity rating (SEV) Moderate. If the filter element becomes clogged, future teams may lose time trying to troubleshoot the vehicle, decreasing the maintainability and transferability of the project.

3. Discuss/justify the rating for probability of occurrence (OCC) Moderate. Eventually this mode of failure will occur if enough particles clog the filter element. It is not known when this will occur however.

4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET) It is difficult to predict when the filter element will become clogged because the hydraulic oil accumulates debris with use but the rate of debris accumulation is unknown.

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. We mentioned to the sponsors that the filter has an optional filter element indicator that costs $50. Our sponsors felt that the benefit to the maintainability to the hydraulic system justified the cost. Therefore, we chose to add the filter element indicator.

6. Notes on Actions taken: We chose to use a filter with a filter element indicator that would indicate when the filter element needs replacement.

Design-Safe Summary for Designed Parts

Following the finalization of our proposed design, the safety of it was investigated using the Design-Safe software. The first step in this process is to identify the main users that will be interacting with the product or process. In our case, our product is the modified Xebra car and the main users were determined to be the driver and maintenance personnel. Next, the various tasks that each operator performs on the vehicle were also identified. For the user this was 'normal operation' of the vehicle and for the maintenance personnel 'periodic maintenance' was chosen. These tasks were chosen to encompass the main objectives of the given user. The final step in the setup process is to then list all possible hazards that the operator may encounter during their task. A summary table of the setup conclusions for the low pressure reservoir can be found below.

	Operator (driver)	**Maintenance Technician**
Task	*Normal Operation*	*Periodic Maintenance*
Hazards	fatigue	flammable liquid
	improper wiring	hazardous waste
	flammable liquid	lack of fresh air
	hazardous waste	reaction to/with chemicals
	lack of fresh air	irritant chemicals
	reaction to/with chemicals	hydraulics rupture
	irritant chemicals	fluid leakage/ejection
	hydraulics rupture	high pressure ATF
	fluid leakage	

The first step in assessing and reducing the risk associated with a given product or process is to identify in more detail the specific hazard that may occur with the product being analyzed. These descriptions can be found in the actual Design-Safe table and can be found in the following pages. After fully identifying the hazard, appropriate ratings for Severity, Exposure, and Probability are assigned. These ratings are used to identify how serious a hazard is taking into account the above three criteria. Severity and Probability are self-explanatory in the context of a analyzing a hazard however, Exposure requires a bit more explanation. The Exposure criterion is a measure of 1) how often the hazard is 'tested' 2) the duration of the hazard and 3) how many people are exposed to the hazard.

After a rating for each criterion has been decided, the highest rated hazards (most dangerous) are further evaluated by implementing engineering or process controls to reduce one or more of the three criterion. The result is an improvement in overall safety of the product or process through the above analysis.

Item	User	Task	Hazard category	Hazard	Cause/ Failure mode	Severity	Exposure	Probability	Risk level	Reduce risk	Severity	Exposure	Probability	Risk level	Person responsible	Status
1-1-1	operator	normal operation	mechanical	fatigue	failure of LP welds/connections	Serious	Remote	Negligible	Low	defined by material properties and quality of weld						
1-1-2	operator	normal operation	electrical / electronic	improper wiring	malfunctioning valve logic	Serious	Frequent	Negligible	Moderate	electrical wiring overhaul is part of secondary objectives. However, regardless of time constraints a brief overview of proper electrical connections will be performed	Serious	Remote	Negligible	Low	Team Xebra	In-process
1-1-3	operator	normal operation	fire and explosions	flammable liquid / vapor	leaked automatic transmission fluid (ATF) catching fire. Requires external ignitant.	Serious	Remote	Negligible	Low							
1-1-4	operator	normal operation	environmental / industrial hygiene	hazardous waste	leaking ATF during operation => improper disposal	Slight	Remote	Unlikely	Low							
1-1-5	operator	normal operation	ventilation	lack of fresh air	ventaliation issues with strong smelling ATF could lead to decrease in awareness on road	Serious	None	Unlikely	Low							
1-1-6	operator	normal operation	chemical	reaction to / with chemicals	ATF is corrosive to a number of materials (latex, skin, etc.)	Slight	Remote	Unlikely	Low							
1-1-7	operator	normal operation	chemical	irritant chemicals	ATF is skin irritant. prolonged exposure to fluid will cause discomfort to operator (assuming leakage).	Slight	Remote	Unlikely	Low							
1-1-8	operator	normal operation	fluid / pressure	hydraulics rupture	hydraulic piping mis-spec'd and piping ruptures during operation.	Serious	None	Negligible	Low							
1-1-9	operator	normal operation	fluid / pressure	fluid leakage / ejection	ATF leaks during operation	Slight	Remote	Unlikely	Low							
2-1-1	maintenance technician	periodic maintenance	fire and explosions	flammable liquid / vapor	ATF is ignited during maintenance.	Serious	Remote	Unlikely	Moderate	implement strict maintenance procedures for when working on vehicle (e.g. - no smoking)	Serious	Remote	Negligible	Low	Team Xebra	In-process
2-1-2	maintenance technician	periodic maintenance	environmental / industrial hygiene	hazardous waste	old ATF is not properly disposed of by the technician	Serious	Remote	Unlikely	Moderate	implement strict maintenance procedures for when working on vehicle (e.g. - no smoking)	Serious	Remote	Negligible	Low	Team Xebra	In-process
2-1-3	maintenance technician	periodic maintenance	ventilation	lack of fresh air	productivity and/or health could decrease due to lack of ventilation	Slight	Occasional	Possible	Moderate	ensure quantity and quality of ventilation (engineering control) is properly implemented	Serious	Remote	Negligible	Low	Team Xebra	In-process
2-1-4	maintenance technician	periodic maintenance	chemical	reaction to / with chemicals	prolonged skin exposure to ATF can lead to health issues.	Slight	Occasional	Possible	Moderate	implement strict maintenance procedures for when working on vehicle (e.g. - wear gloves at all times)	Serious	Remote	Negligible	Low	Team Xebra	In-process
2-1-5	maintenance technician	periodic maintenance	chemical	irritant chemicals	ATF is a skin irritant	Slight	Occasional	Possible	Moderate	implement strict maintenance procedures for when working on vehicle (e.g. - wear gloves at all times)	Serious	Remote	Negligible	Low	Team Xebra	In-process
2-1-6	maintenance technician	periodic maintenance	fluid / pressure	hydraulics rupture	unintended release of high pressure fluid could potential cause series injury or death	Serious	Remote	Unlikely	Moderate	extensive training sessions and maintenance procedures must be strictly required	Serious	Remote	Negligible	Low	Team Xebra	In-process
2-1-7	maintenance technician	periodic maintenance	fluid / pressure	fluid leakage / ejection	skin irritant and disposal issues exist with fluid leakage	Slight	Occasional	Possible	Moderate	implement strict maintenance procedures for when working on vehicle (e.g. - handeling and disposal procedures)	Serious	Remote	Negligible	Low	Team Xebra	In-process
2-1-8	maintenance technician	periodic maintenance	fluid / pressure	high pressure ATF	releasing high pressures (<4000 psi) while car is intendend to be stationary could cause car to move.	Serious	Remote	Unlikely	Moderate	extensive training sessions and maintenance procedures must be strictly required	Serious	Remote	Negligible	Low	Team Xebra	In-process

Item	User	Task	Hazard category	Hazard	Cause/ Failure mode	Severity	Exposure	Probability	Risk level	Reduce risk	Severity	Exposure	Probability	Risk level	Person responsible	Status
1-1-1	operator	normal operation	mechanical	fatigue	Excess weight on rails cause fracture	Serious	Remote	Negligible	Low		Serious	Remote	Negligible	Low	Team Xebra	In-process
1-1-2	maintenance technician	periodic maintenance	ergonomics / human factors	duration	Assuming rails need to be modified: the location of fastener would require long durations of bending (posture issues)	Slight	Remote	Probable	Moderate	In depth engineering analysis on the structural validity of the rails to ensure no maintenance/replacement will be required	Slight	None	Probable	Low	Team Xebra	In-process
1-1-3	maintenance technician	periodic maintenance	confined spaces	confined spaces	location of fasteners is located in a very small space	Slight	Remote	Probable	Moderate	In depth engineering analysis on the structural validity of the rails to ensure no maintenance/replacement will be required	Slight	None	Probable	Low	Team Xebra	In-process

Design Testing and Validation

After successfully manufacturing the parts and assembling the vehicle, we performed several tests to gauge how the improvements that we have made satisfy the customer requirements and the engineering specifications. The main tests were the functionality test and the accessibility test.

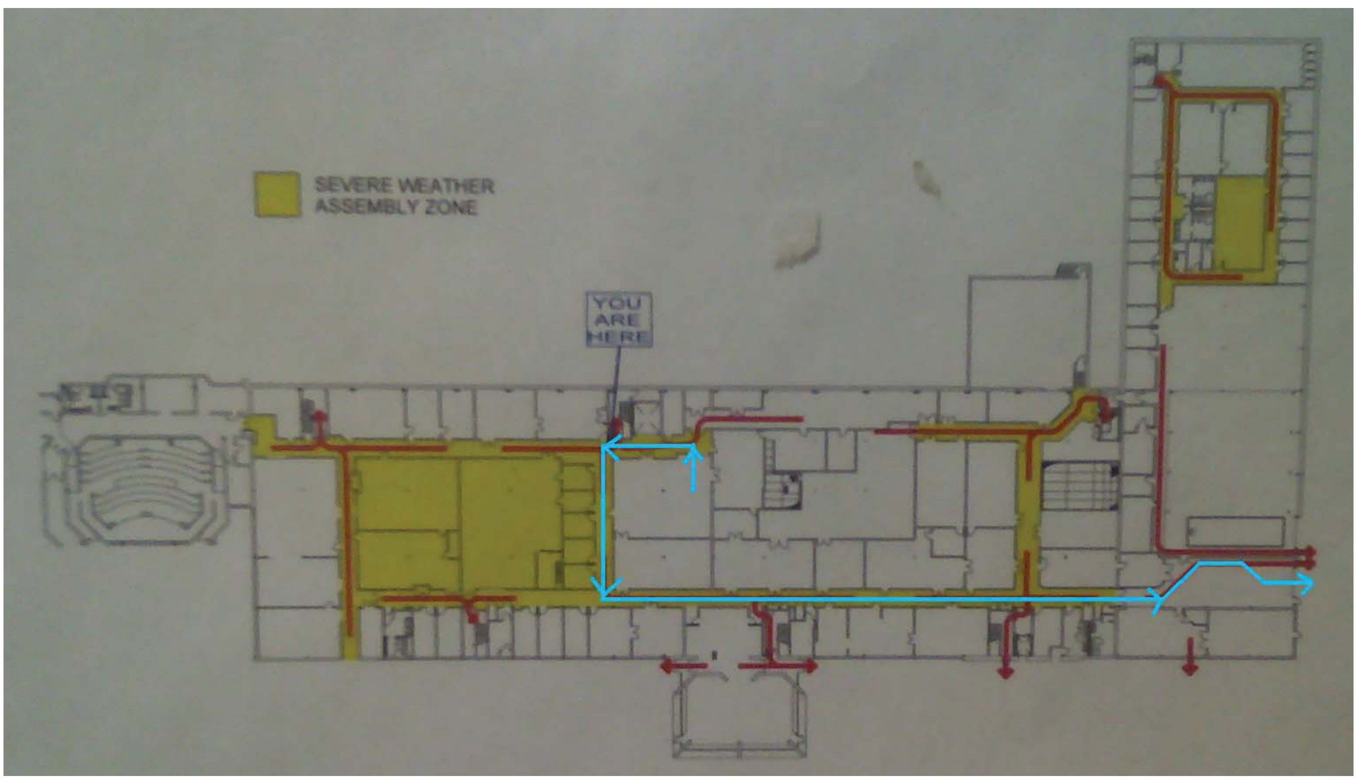
Functionality Test

The functionality test mainly focused on testing the initial performance of the electric system. Test procedures consisted of the following stages.

Moving the vehicle to the test location

Inside the G.G. Brown Laboratory

The vehicle is disconnected in the X50 lab now for safety. We will connect the batteries back and ensure that all the connections are secure. Then we will lower the hydraulic jack and let the wheels of the vehicle touch the ground and release the hand brake. We are able to pull the chain and open the door of the assembly room and push the car along the hall way (shown in the figure below, highlighted in light blue) all the way to the loading dock in the 1st floor of G. G. Brown Laboratory. The door of the loading dock is controlled by an electric switch and we have tried and successfully opened it. So the vehicle will be pushed out of the door and be at outside of the building.



Outside the G.G. Brown Laboratory

After we successfully move the vehicle out of the loading dock of the first floor of G.G. Brown Laboratory, we will start the vehicle and drive to the NC53 parking lot that we have reserved. Kevin Lyons will be the driver and no passenger is allowed on boards. All other team members will be surrounding the vehicle while it is moving, to warn any pedestrians and watch out for passing cars. The vehicle will be kept below 5 mph and run by the right side of the road. If any fast car wants to pass, we will yield the vehicle and let it go first. Our team members will also bring a white plastic board (there is one in X50 now) with “please pass from the left” sign and show it to the drivers if they don’t understand and wait for us. The route is shown below in the Google maps screen shot. The road condition is ideal and the distance measured by Google is 0.3 miles.

On location test

After we arrive at the test location, the test will be performed according the following procedures.

1. Position the car in perpendicular to the parking space line
2. A team member take the position ten parking spaces away from the car, mark as finish line
3. Start the car with a continuous acceleration
4. Record the travelling time from the start line to the finish line
5. After the car passing the finish line, decelerate the car and relocate the car to the finish line
6. The team member with the stop watch take the position on the start line
7. Accelerate the car and take the time again
8. Repeat the procedure 1 to 7 for three times

One point need to be mentioned here is that the parking lot ground has a natural slope. So our test result will be affected by the gravitational acceleration. In order to avoid this interference, we decide to test the vehicle on the same route with two directions. So the average of the back and forth test results will be able to cancel the gravity effect and give us fairly accurate acceleration values.

Accessibility Test

After validating the functionality of our vehicle, we will step further by testing whether our improvements on the serviceability of the vehicle meets our engineering specifications. The accessibility test will focus on testing the time and the number of procedures that are required to change the batteries of the vehicle.

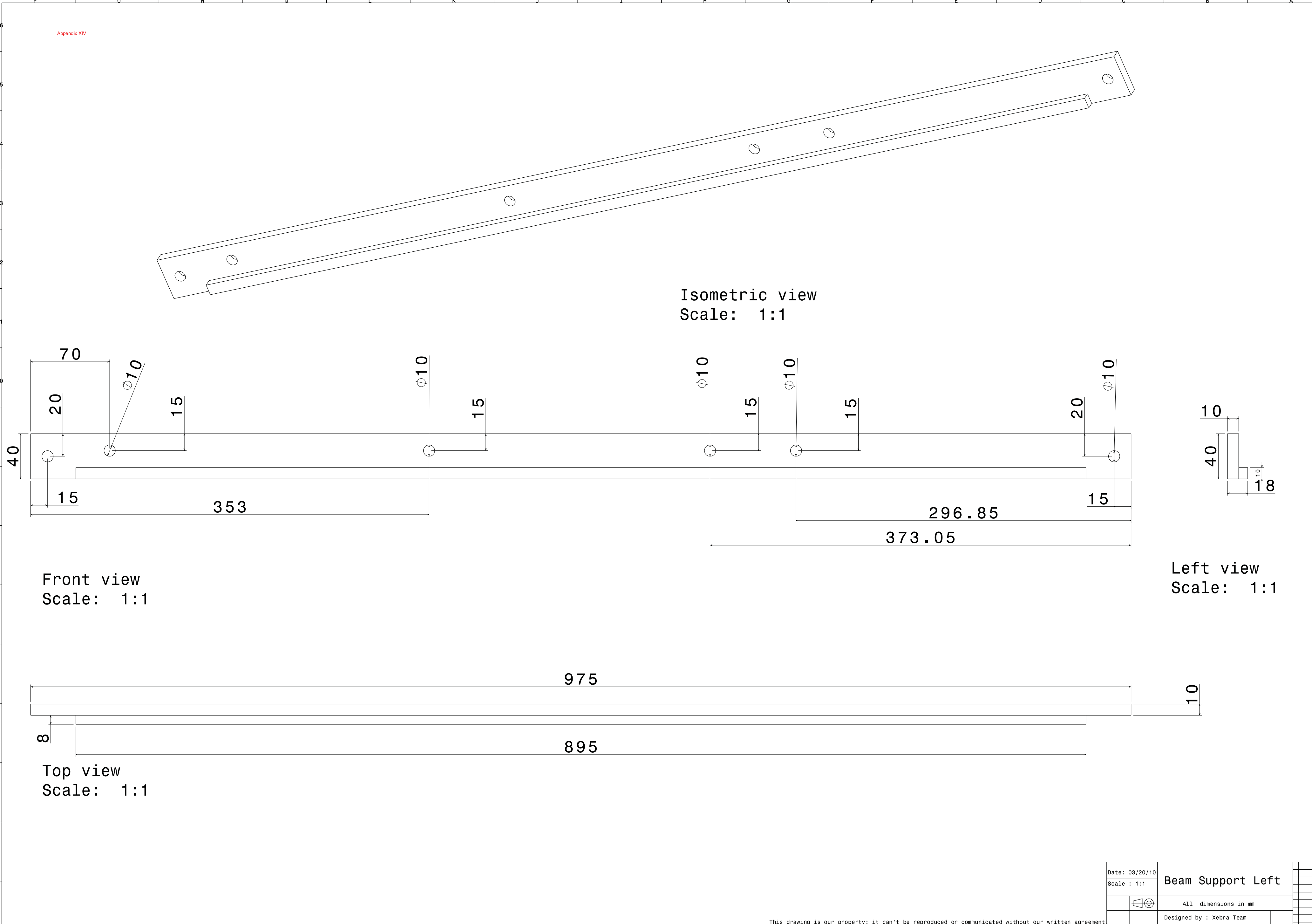
This test will be performed after we finish the functionality test and before the design Expo. To ensure safety and the reliability of the vehicle, we will not actually pull out all the batteries. The batteries will be counted as “removed” when we are able to touch the batteries without any constraints or obstacles. The detailed test procedures are provided below.

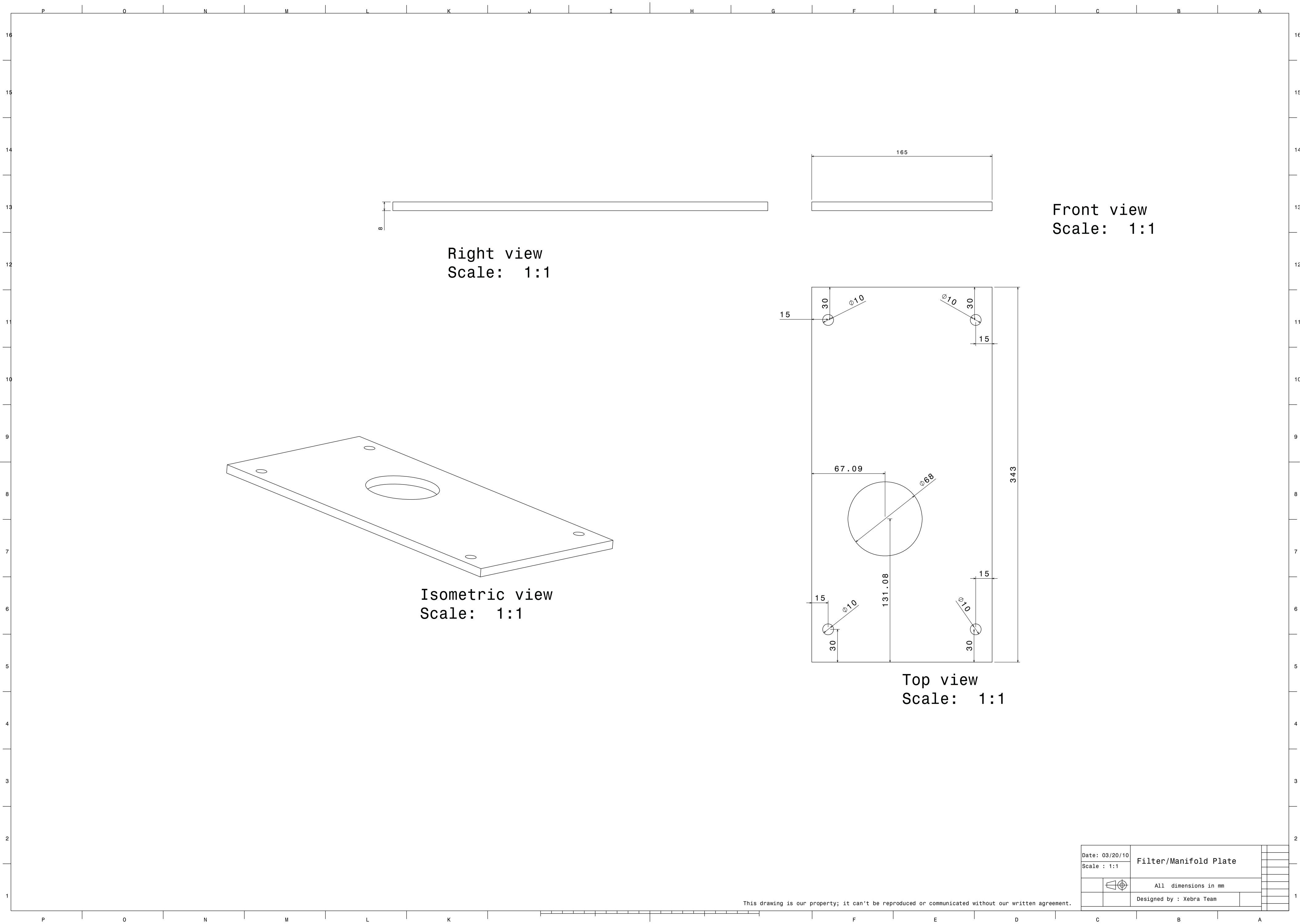
1. Disconnect any external power source from the car, make sure that the car is powered off
2. Remove the truck bed and the connections
3. Jack the car up and hold it with the hydraulic stand in the X50 lab.
4. When disconnecting the batteries we will disconnect the negative terminal first
5. Disconnect the wires between the electric controller and the batteries
6. When connecting the batteries we will connect the negative terminal last.
7. Connect the wires back to the operating condition
8. Record the time of the disconnecting and re-connecting process
9. Repeat step 4 to step 6 for 3 times and take the average time.

Because our design is to clear up the overhead space of the batteries, in the process of accessing the batteries, we will not need to have any contact with the hydraulic parts. As safety concerns, we will wear the insulation gloves and safety glasses through the entire test process.

The outcome of this test will be the average time for our team member to change the batteries of the vehicle batteries. The value will be compared with our engineering specifications and will be reported during the design Expo.

Appendix XIV




165
8
Front view
Scale: 1:1
Right view
Scale: 1:1
15
30
⌀10
⌀10
30
15
67.09
⌀68
343
131.08
15
15
⌀10
⌀10
30
30
Isometric view
Scale: 1:1
Top view
Scale: 1:1
Date: 03/20/10
Scale : 1:1
Filter/Manifold Plate
All dimensions in mm
Designed by : Xebra Team

Appendix XV

Design B002-259-A05

Created by: Hasan Shahid, Feb 25 2010 9:12AM
Distributor: A053, RHM Fluid Power, Inc.
Rev: 3, Mar 1 2010 1:10PM
Current Date/Time: Mar 1 2010 1:21PM

Bill of Materials

Type	Item	Qty	Stamp(s)
Cartridge	DWDAMAN512 (T-11A)	1	DWDA
Cartridge	PPDBLBN (T-11A)	1	PPDB
Ports: SAE O-ring sealing - ISO 11926-1	SAE 4	1	G
Ports: SAE O-ring sealing - ISO 11926-1	SAE 6	2	SFP CLUTCH
Ports: SAE O-ring sealing - ISO 11926-1	SAE 8	1	LP
Manifold	Aluminum	1	

Connections

Ports

CLUTCH	G	LP	SFP
C	B	D	A

Cavities

DWDA

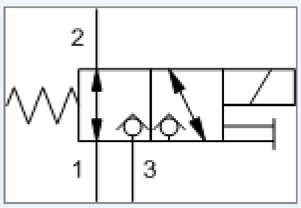
3	B
2	C
1	D

PPDB

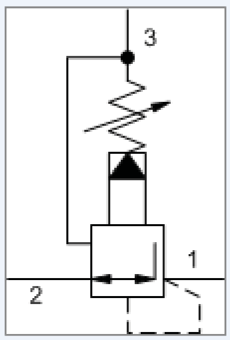
3	D
2	A
1	B

Symbols

DWDA



PPDB



Net Summary and Port Types

Net	Item	Stamp	Port	G,P,D,V	Isolate
A	T-11A	PPDB	2		
	SAE 6	SFP	1		
B	T-11A	DWDA	3		
	SAE 4	G	1		
	T-11A	PPDB	1		
C	SAE 6	CLUTCH	1		
	T-11A	DWDA	2		
D	T-11A	DWDA	1		
	SAE 8	LP	1		
	T-11A	PPDB	3		

G,P,D,V: Gage, Pilot, Drain or Vent. If checked, the passageway will be .188 inch and isolated from any other passageways in the net.
Isolate: If selected on its own (G,P,D,V remains unselected) the passageway will be >= the diameter through fitting and isolated from all other passageway size determinations in the net.

Constraints

Face Constraints

The **Bottom** face is the mounting face.

Cartridges are NOT allowed on:	**Bottom .**
Working ports are NOT allowed on:	**Bottom .**

Component Constraints

Cartridges		Faces	Options
DWDA	DWDAMAN512	**Top .**	
PPDB	PPDBLBN	**Top .**	

Ports		Faces	Options
CLUTCH	SAE 6	**Back .**	
G	SAE 4	**Back .**	
LP	SAE 8	**Left .**	
SFP	SAE 6	**Front .**	

Construction Port:

(●) STD SAE

Mounting Holes

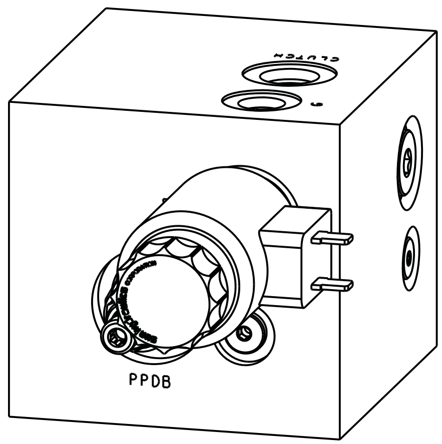
(●) Threaded (inch)

No. Holes	2
Item	.250-20UNC STD THD HOLE
Calc. Weight	4.310

Output to: inch

Appendix XVI

VERSION	PROJECT I.D.
3	B002-259-A05



1. SAE PORTS ARE O-RING SEALING PER ISO 11926-1
2. MOUNTING THREADS .250-20 UNC-2B x .50 DP.

ITEM	PART NO.	SETTING	MATERIAL	PART NAME	QTY
5	A330-006-006			SAE-6 PLUG	2
4	A330-006-002			SAE-2 PLUG	2
3	PPDB-LBN			PRESSURE REDUCING/RELIEVING VALVE	1
2	DWDA-MAN512			SOLENOID-OPERATED DIRECTIONAL VALVE	1
1	B002-259-A05-Q		6061-T6 ALUMINUM	BODY	1

DESIGNED BY:	DATE			
HASAN SHAHID	01MAR2010	ALL DIMENSIONS IN INCH VIEWS ARE THIRD ANGLE		FIRST ANGLE / THIRD ANGLE
REFERENCE	SCALE 1.000	TITLE: CUSTOM MANIFOLD FOR UNIVERSITY OF MICHIGAN BY RHM FLUID POWER, INC.	VERSION 3	PROJECT I.D. B002-259-A05

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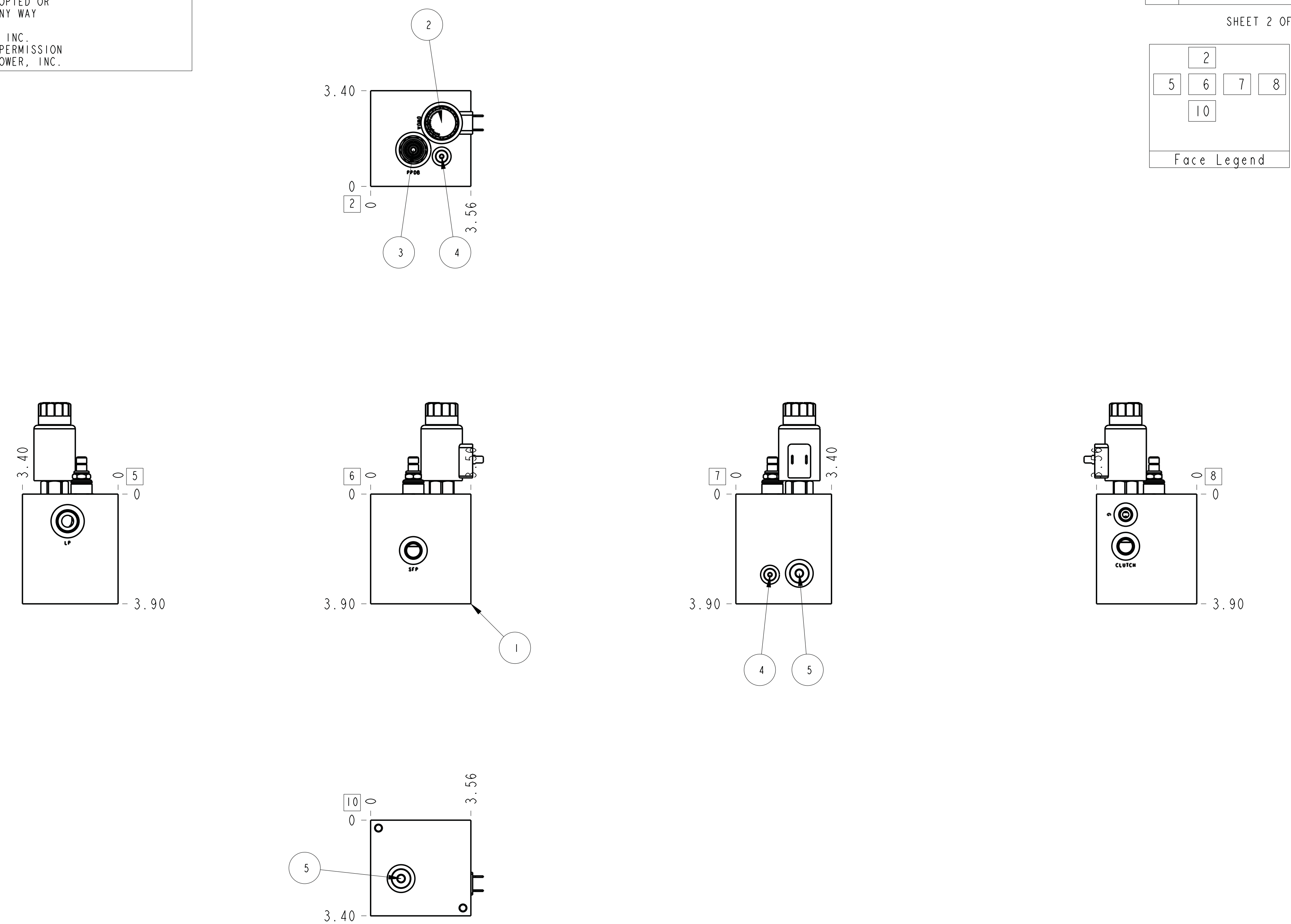
VERSION	PROJECT I.D.
3	B002-259-A05

SHEET 2 OF 8



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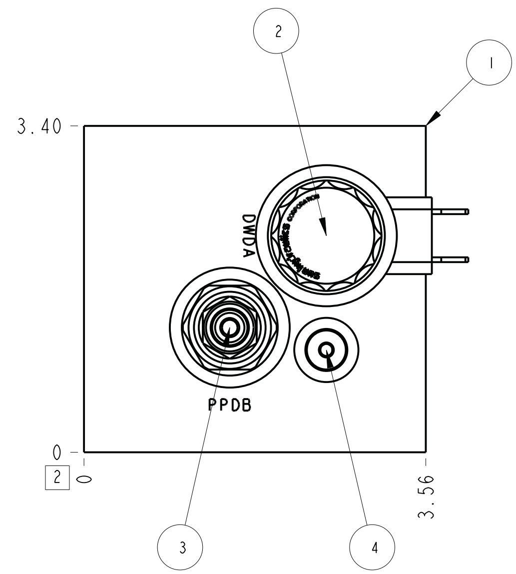
DESIGNED BY: HASAN SHAHID	DATE 01MAR2010	ALL DIMENSIONS IN INCH VIEWS ARE THIRD ANGLE		FIRST ANGLE / THIRD ANGLE
REFERENCE	SCALE 0.422	TITLE CUSTOM MANIFOLD FOR UNIVERSITY OF MICHIGAN BY RHM FLUID POWER, INC.	VERSION 3	PROJECT I.D. B002-259-A05

VERSION	PROJECT I.D.
3	B002-259-A05

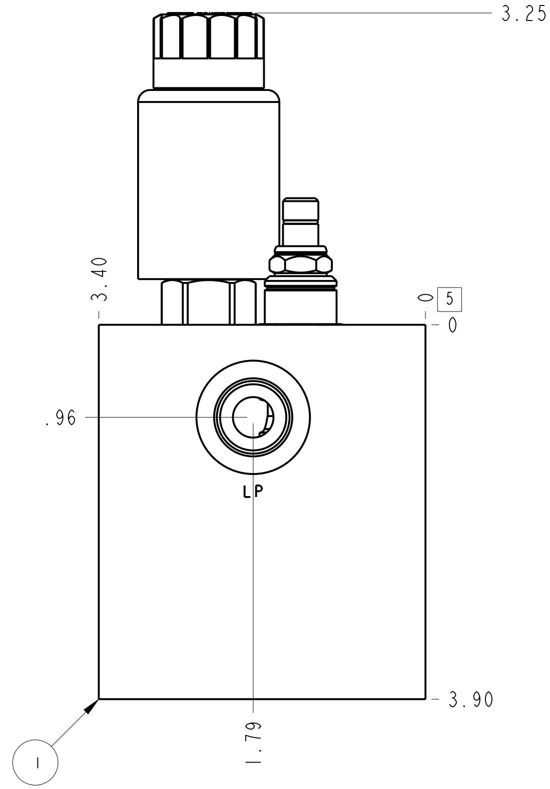
Face Legend: 2; 5 6 7 8; 10



DESIGNED BY:	DATE		
HASAN SHAHID	01MAR2010	ALL DIMENSIONS IN INCH VIEWS ARE THIRD ANGLE	FIRST ANGLE / THIRD ANGLE
REFERENCE	SCALE 1.000	TITLE CUSTOM MANIFOLD FOR UNIVERSITY OF MICHIGAN BY RHM FLUID POWER, INC.	VERSION 3 PROJECT I.D. B002-259-A05

	2		
5	6	7	8
	10		

Face Legend



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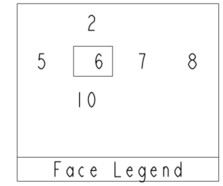
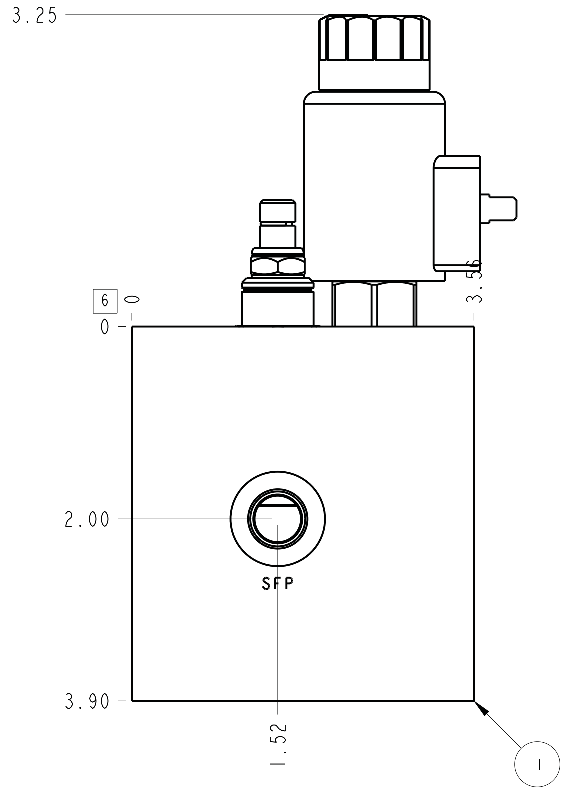
DESIGNED BY:	DATE			
HASAN SHAHID	01MAR2010	ALL DIMENSIONS IN INCH VIEWS ARE THIRD ANGLE		FIRST ANGLE / THIRD ANGLE
REFERENCE	SCALE 1.000	TITLE CUSTOM MANIFOLD FOR UNIVERSITY OF MICHIGAN BY RHM FLUID POWER, INC.	VERSION 3	PROJECT I.D. B002-259-A05

VERSION	PROJECT I.D.
3	B002-259-A05





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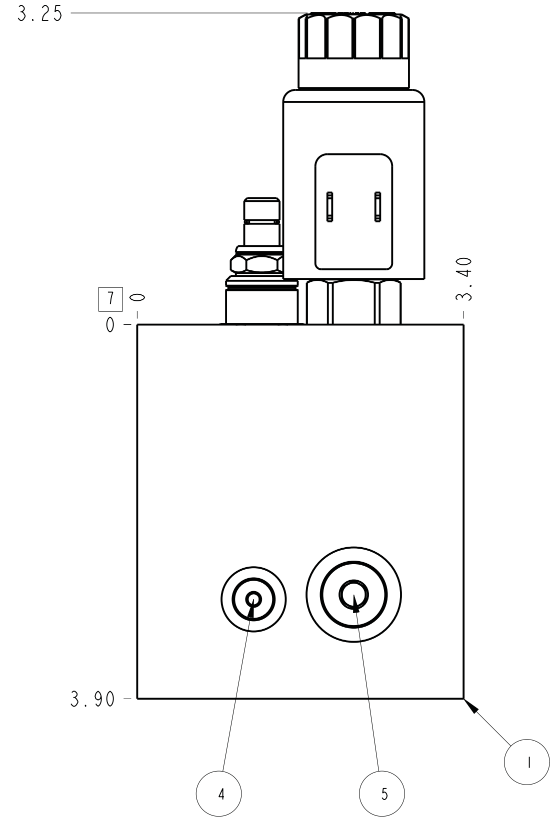
VERSION	PROJECT I.D.
3	B002-259-A05

SHEET 6 OF 8

	2		
5	6	7	8
	10		

Face Legend



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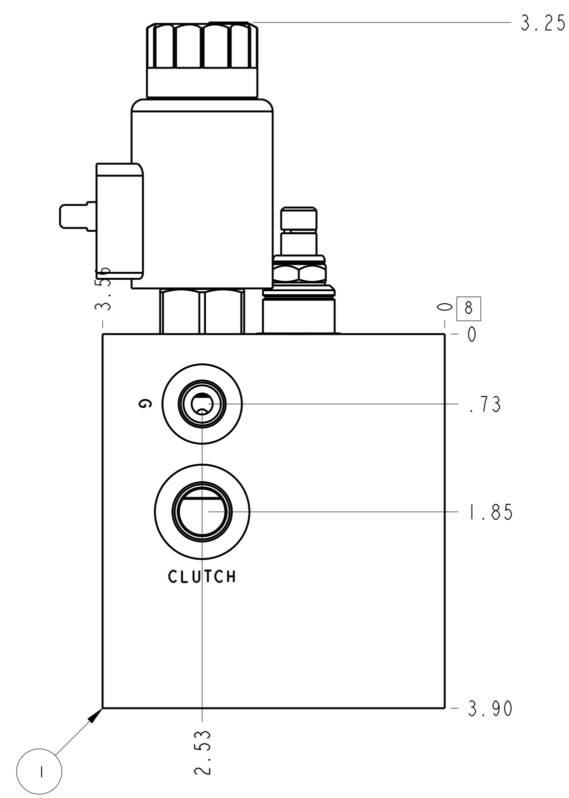
HASAN SHAHID	01MAR2010	ALL DIMENSIONS IN INCH VIEWS ARE THIRD ANGLE	FIRST ANGLE / THIRD ANGLE
REFERENCE	SCALE 1.000	TITLE CUSTOM MANIFOLD FOR UNIVERSITY OF MICHIGAN BY RHM FLUID POWER, INC.	VERSION 3 / PROJECT I.D. B002-259-A05

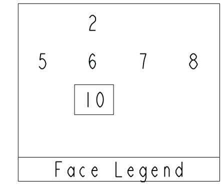
	2		
5	6	7	8
	10		

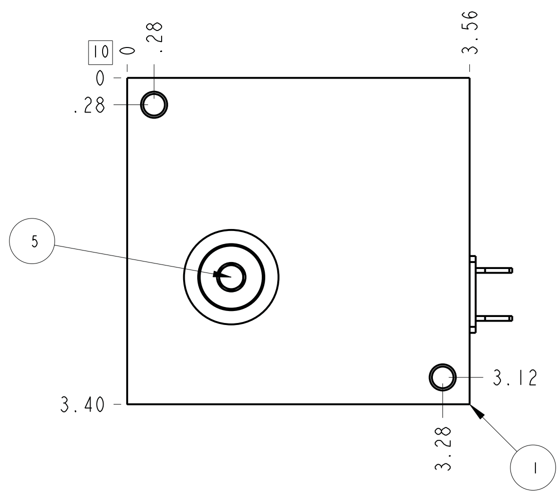
Face Legend



DESIGNED BY:	DATE		
HASAN SHAHID	01MAR2010	ALL DIMENSIONS IN INCH VIEWS ARE THIRD ANGLE	FIRST ANGLE / THIRD ANGLE
REFERENCE	SCALE 1.000	TITLE CUSTOM MANIFOLD FOR UNIVERSITY OF MICHIGAN BY RHM FLUID POWER, INC.	VERSION 3 PROJECT I.D. B002-259-A05

VERSION	PROJECT I.D.
3	B002-259-A05





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DESIGNED BY: HASAN SHAHID	DATE 01MAR2010	ALL DIMENSIONS IN INCH VIEWS ARE THIRD ANGLE	FIRST ANGLE / THIRD ANGLE
REFERENCE	SCALE 1.000	TITLE CUSTOM MANIFOLD FOR UNIVERSITY OF MICHIGAN BY RHM FLUID POWER, INC.	VERSION 3 / PROJECT I.D. B002-259-A05

PG		517											B	1	B	1
Gear design	Type		Unit	Dis-placement	Rotation	Shaft	Flange	Shaft seal	Inlet side ports option		Outlet		No rear ports (rear ports on request)			

Code	Type
P	Pump

Code	Unit Pump
A	Single unit
M	Single distributor unit
B	Multiple unit

Displacement	
Code	ccm
0140	14.0
0160	16.0
0190	19.0
0230	23.0
0250	25.0
0280	28.0
0330	33.0
0380	38.0
0440	44.0
0520	52.0
0700	70.0

Code	Rotation
C	Clockwise
A	Counter- clock-wise

Code	Shaft
D1 2)	13T, 16/32DP, 41.2L, SAE "B" spline
M1 2)	Ø22.2, 6.3key, no thread, 41.2L, SAE "B", parallel
M2 2)	Ø25.4, 6.3key, no thread, 46L, SAE "B-B", parallel
T1 3)	Ø21.59, 11.2L, 4.0key, M14x1.5, taper 1:8

2) Only used with flange H3.
3) Only used with flange D7.

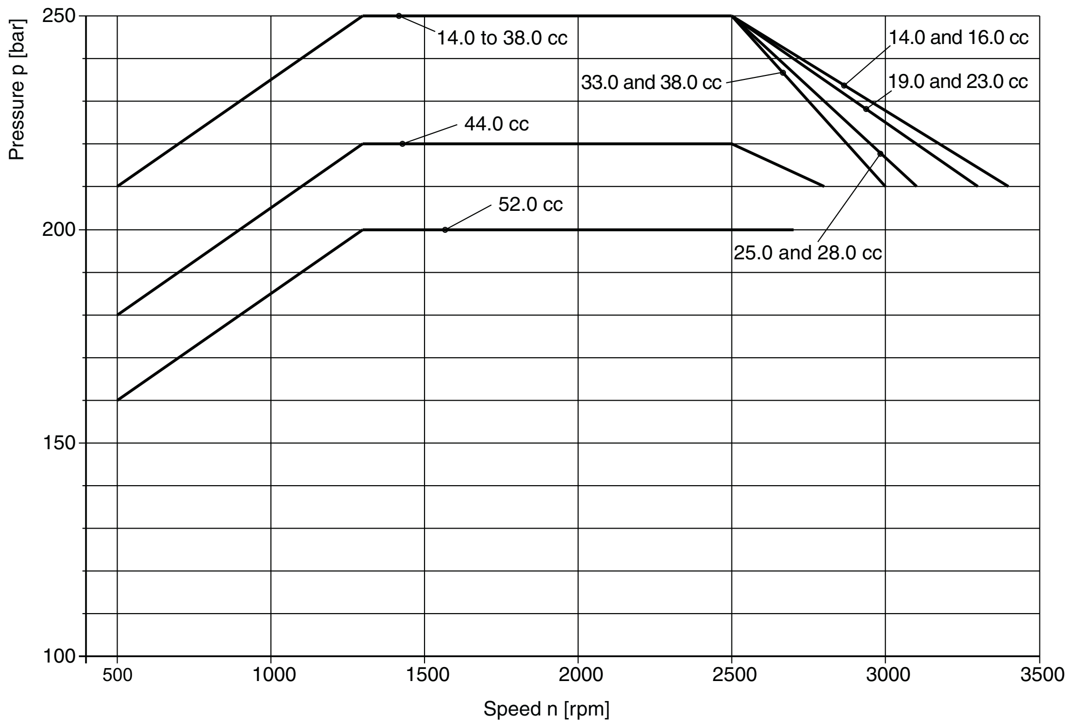
Code	Port options
E6E5	1"-11 BSP thread/ 3/4"-14 BSP thread rec. from 14 ccm to 19 ccm
E7E6	1 1/4"-11 BSP thread/ 1"-11 BSP thread rec. from 23 ccm to 38 ccm
E8E6	1 1/2"-11 BSP thread/ 1"-11 BSP thread rec. from 44 ccm to 70 ccm
J9J8	Ø26 mm-Ø55 mm-M8 square flange Ø18 mm-Ø55 mm-M8 square flange rec. from 14 ccm to 52 ccm
L3L2	Ø27 mm-Ø51 mm-M10 diamond flange Ø19 mm-Ø40 mm-M8 diamond flange rec. from 14 ccm to 52 ccm
P3P2	1"-M10 SAE metric flange 3/4"-M10 SAE metric flange rec. from 16 ccm to 23 ccm
P4P3	1 1/4"-M10 SAE metric flange 1"-M10 SAE metric flange rec. from 25 ccm to 44 ccm
P5P3	1 1/2"-M12 SAE metric flange 1"-M10 SAE metric flange rec. from 44 ccm to 70 ccm

Example: P4 = inlet port
P3 = outlet port

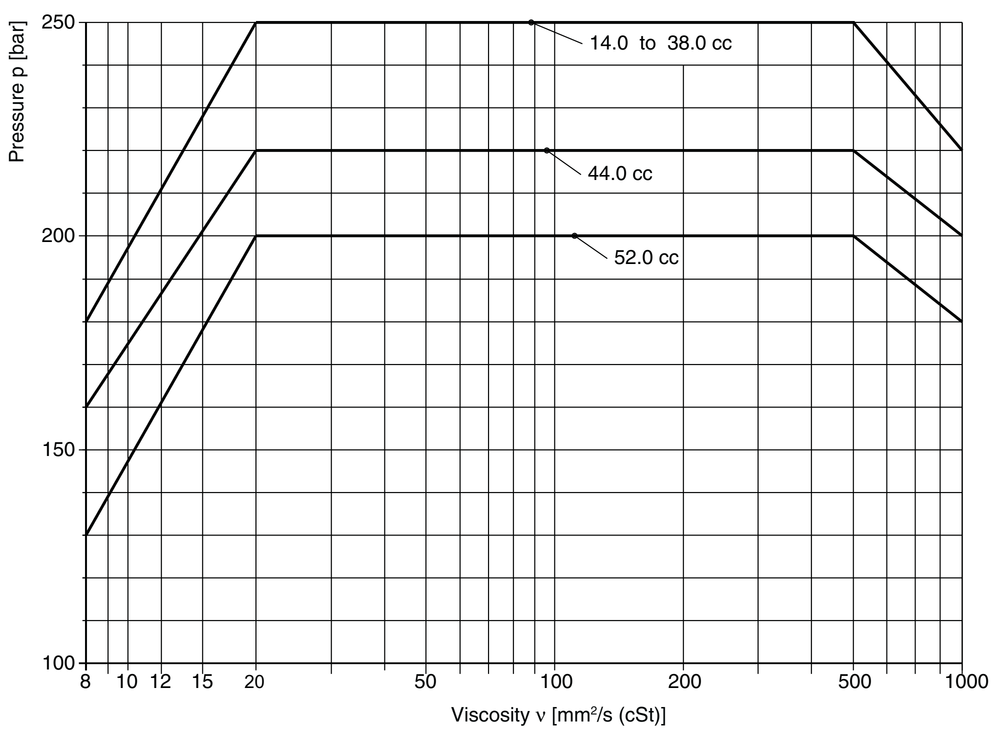
Code	Shaft seal
X	No seal
N	NBR
V	FPM

Code	Flange
D7	98.4x128.2 - Ø50.77 rectangular
H3	146.1 - Ø101.06 SAE "B" 2 bolt flange

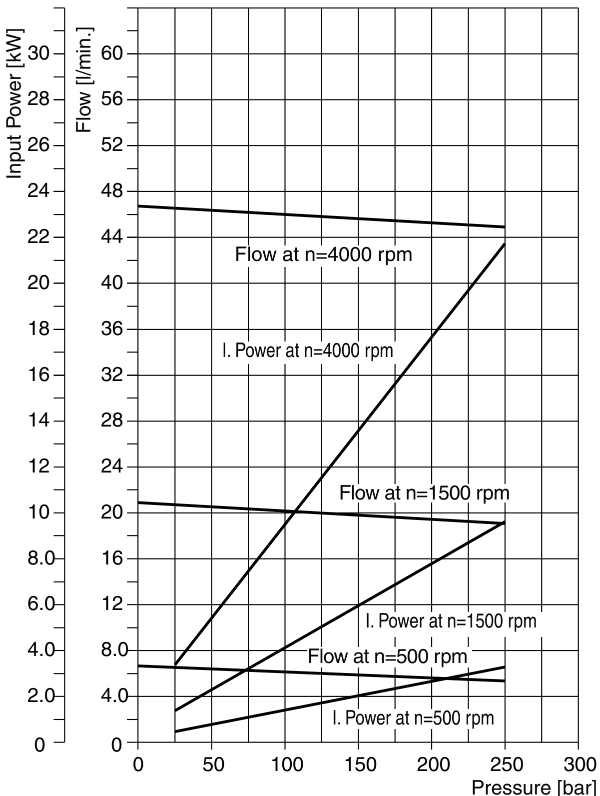
Pressure depending on speed



Pressure depending on viscosity



PGP517 - 14.0 CC



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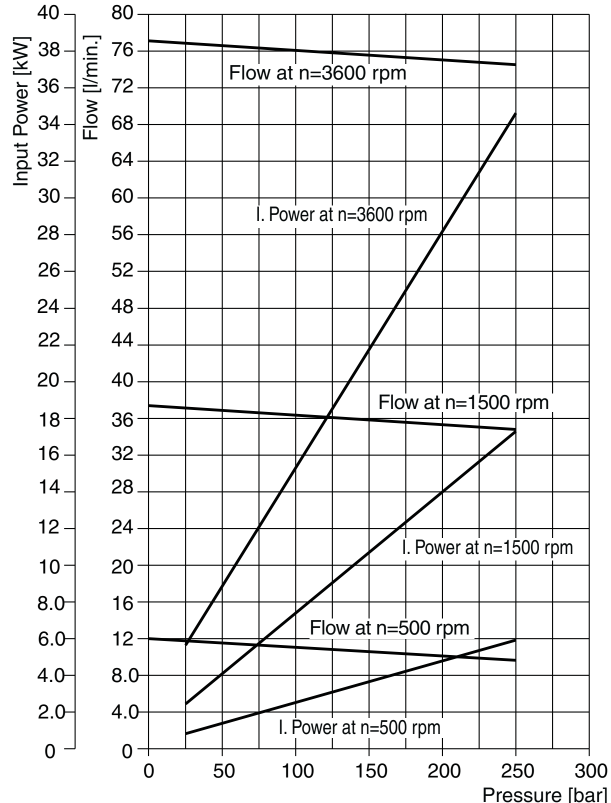

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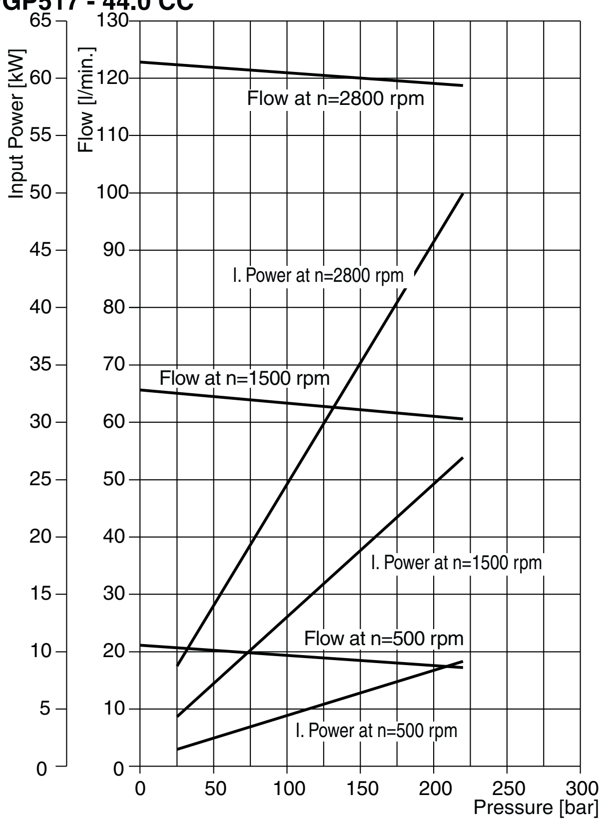
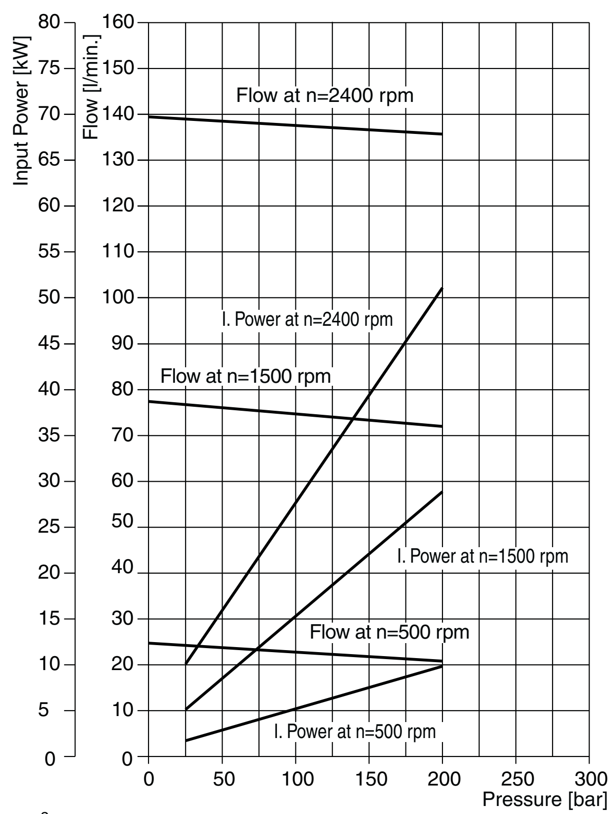


PGP517 - 52.0 CC

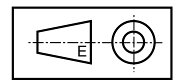


Fluid temperature: 45 °C ± 2K ; Viscosity: 36mm^2/s ; Inlet pressure: 0.9 + 0.1 bar absolute

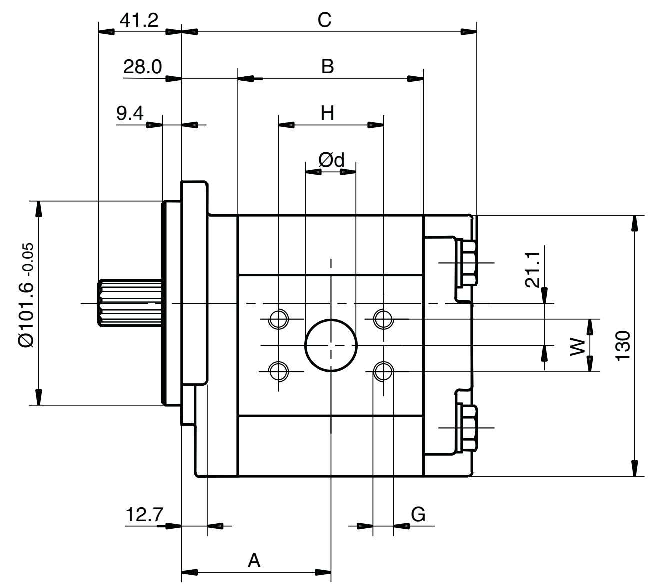
PGP517 A XXXX Y D1 H3 N SS PP B1 B1

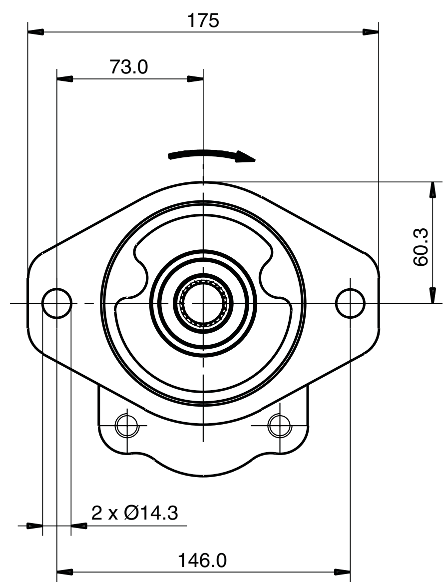
"Y" = C (clockwise rotation)
= A (counter-clockwise rotation)

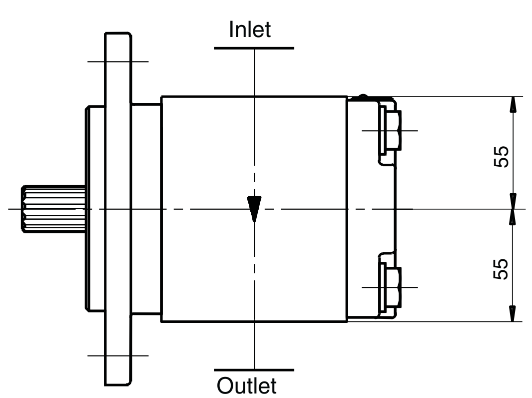
Displacement		Dimension			Inlet port					Outlet port					Speed of rotation		Working pressure	Order number direction of rotation	
XXXX	cm³/rev	A	B	C	SS	d	G	H	W	PP	d	G	H	W	min. rpm	max. rpm	max. bar	clockwise	counter-clockwise
0140	14.0	62.1	68.3	122.8	P2	3/4"	M10	47.63	22.23	P2	3/4"	M10	47.63	22.23	500	3000	250		
0160	16.0	63.2	70.3	124.8	P3	1"	M10	52.37	26.19	P2	3/4"	M10	47.63	22.23	500	3400	250		
0190	19.0	64.7	73.3	127.8	P3	1"	M10	52.37	26.19	P2	3/4"	M10	47.63	22.23	500	3300	250		333 9112 180
0230	23.0	66.7	77.4	131.9	P3	1"	M10	52.37	26.19	P2	3/4"	M10	47.63	22.23	500	3300	250	333 9111 193	333 9112 177
0250	25.0	67.7	79.4	133.9	P4	1 1/4"	M10	58.72	30.17	P3	1"	M10	52.37	26.19	500	3100	250		333 9112 388
0280	28.0	69.2	82.4	136.9	P4	1 1/4"	M10	58.72	30.17	P3	1"	M10	52.37	26.19	500	3100	250	333 9111 669	333 9112 274
0330	33.0	71.7	87.5	142.0	P4	1 1/4"	M10	58.72	30.17	P3	1"	M10	52.37	26.19	500	3000	250		333 9112 374
0380	38.0	74.3	92.5	147.0	P4	1 1/4"	M10	58.72	30.17	P3	1"	M10	52.37	26.19	500	3000	250	333 9111 290	333 9112 412
0440	44.0	77.3	98.6	153.1	P4	1 1/4"	M10	58.72	30.17	P3	1"	M10	52.37	26.19	500	2800	225	333 9111 150	333 9112 346
0520	52.0	81.3	106.7	161.2	P5	1 1/2"	M12	69.82	35.71	P3	1"	M10	52.37	26.19	500	2700	190	333 9111 360	333 9112 357
0700	70.0	90.4	124.9	179.4	P5	1 1/2"	M12	69.82	35.71	P3	1"	M10	52.37	26.19	500	2300	165	333 9111 563	

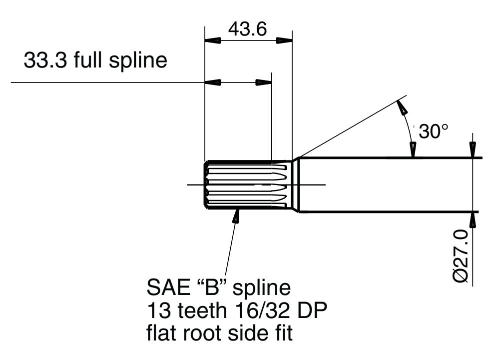


Dimensions (clockwise rotation shown)







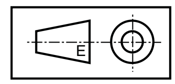


PI PGP-PGM UK.PMD RH

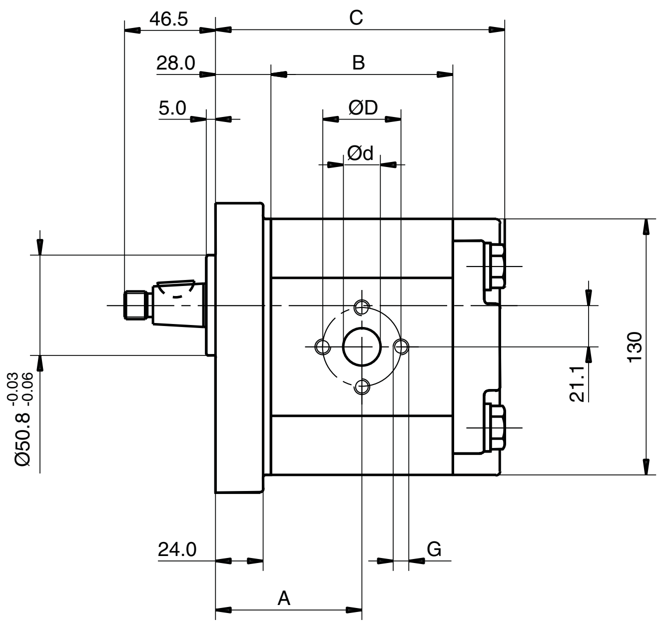
PGP517 A XXXX Y T1 D7 N SS PP B1 B1

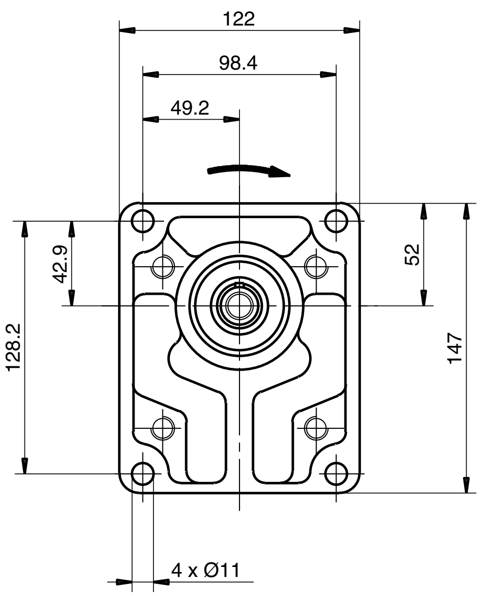
"Y" = C (clockwise rotation)
= A (counter-clockwise rotation)

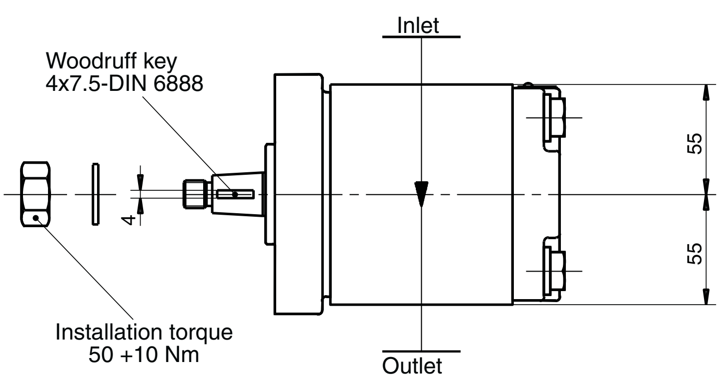
Displacement		Dimension			Inlet port				Outlet port				Speed of rotation		Working pressure	Order number direction of rotation	
XXXX	cm³/rev	A	B	C	SS	d	D	G	PP	d	D	G	min. rpm	max. rpm	max. bar	clockwise	counter-clockwise
0140	14.0	62.1	68.3	122.8	L3	27	51	M10	L2	19	40	M8	500	3400	250	333 9111 503	
0160	16.0	63.2	70.3	124.8	L3	27	51	M10	L2	19	40	M8	500	3400	250	333 9111 505	333 9112 430
0190	19.0	64.7	73.3	127.8	L3	27	51	M10	L2	19	40	M8	500	3300	250	333 9111 285	333 9112 212
0230	23.0	66.7	77.4	131.9	L3	27	51	M10	L2	19	40	M8	500	3300	250	333 9111 119	333 9112 213
0250	25.0	67.7	79.4	133.9	L3	27	51	M10	L2	19	40	M8	500	3100	250	333 9111 047	333 9112 068
0280	28.0	69.2	82.4	136.9	L3	27	51	M10	L2	19	40	M8	500	3100	250	333 9111 287	333 9112 214
0330	33.0	71.7	87.5	142.0	L3	27	51	M10	L2	19	40	M8	500	2600	250	333 9111 014	333 9112 035
0380	38.0	74.3	92.5	147.0	L3	27	51	M10	L2	19	40	M8	500	2300	250	333 9111 015	333 9112 036
0440	44.0	77.3	98.6	153.1	L3	27	51	M10	L2	19	40	M8	500	2000	220	333 9111 046	333 9112 040
0520	52.0	81.3	106.7	161.2	L3	27	51	M10	L2	19	40	M8	500	1700	200	333 9111 242	333 9112 215

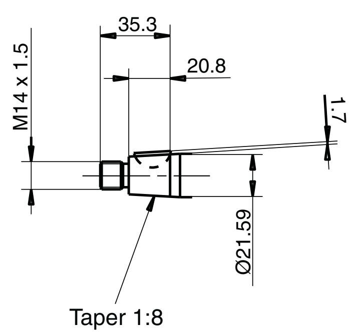


Dimensions (clockwise rotation shown)

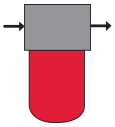




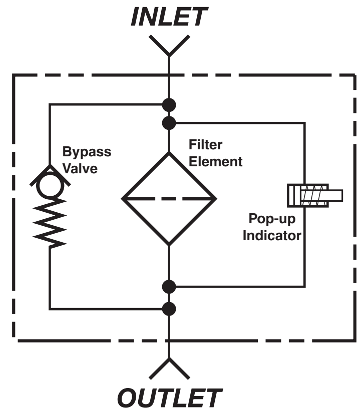




DF Series
Inline Filters
6000 PSI • up to 180 GPM



Hydraulic Symbol



Features

- Non-welded housing design reduces stress concentrations and prevents fatigue failure.
- Choice of NPT, SAE straight thread O-ring boss, and SAE 4-bolt flange porting (sizes 60 - 1320) to allow easy installation without costly adapters.
- O-ring seals are used to provide positive, reliable sealing. Choice of O-ring materials (Nitrile, Fluoroelastomer, EPDM) provides compatibility with petroleum oils, synthetic fluids, water-glycols, oil/water emulsions, and high water base fluids.
- Screw-in bowl mounted below the filter head requires minimal clearance to remove the element for replacement, and contaminated fluid cannot be washed downstream when element is serviced.
- Differential Pressure Indicators. HYDAC indicators have no external dynamic seal. This results in a high system reliability due to magnetic actuation, thus eliminating a potential leak point.
- A poppet-type bypass valve (optional) provides positive sealing during normal operation and fast opening during cold starts and flow surges.
- For special finishes and coatings – consult HYDAC for minimum quantities, availability and pricing.
- Fatigue pressure ratings equals maximum allowable working pressure rating.

Applications

Technical Details

Mounting Method	4 mounting holes	
Port Connection		
30	SAE-8, 1/2" NPT, 1/2" BSPP	
60/110	SAE-12, 3/4" NPT, 3/4" BSPP	
160/240/280	SAE-20, 1 1/4" NPT, 1 1/4" BSPP	
330/660/1320	SAE-24, 1 1/2" NPT, 1 1/2" BSPP 2" SAE Flange Code 62	
Flow Direction	Inlet: Side	Outlet: Side
Construction Materials		
Head	Ductile iron	
Bowl	Steel	
Housing (1320)	Steel	
Cap (660 & 1320 ver. 2)	Ductile iron	
Flow Capacity		
30	8 gpm (30 lpm)	
60	16 gpm (60 lpm)	
110	29 gpm (110 lpm)	
160	42 gpm (160 lpm)	
240	63 gpm (240 lpm)	
280	74 gpm (280 lpm)	
330	87 gpm (330 lpm)	
660	174 gpm (660 lpm)	
1320	190 gpm (720 lpm)	
Housing Pressure Rating		
Max. Operating Pressure	6000 psi (420 bar)	
Proof Pressure	9000 psi (610 bar)	
Fatigue Pressure	6000 psi (420 bar) @ 1 million cycles	
Burst Pressure	30	15950 psi (1100 bar)
	60/110	17400 psi (1200 bar)
	160/240/280	17110 psi (1180 bar)
	330/660/1320	15080 psi (1040 bar
Element Collapse Pressure Rating		
BH/HC, V	3000 psid (207 bar)	
BN/HC, W/HC	250 psid (17 bar)	
Fluid Temp. Range	-22° to 250°F (-30° to 121°C)	
Fluid Compatability		
Compatible with all petroleum oils and synthetic fluids rated for use with Fluoroelastomer or Ethylene Propylene seals. Contact HYDAC for information on special housing and element constructions available for use with water glycols, oil/water emulsions, and HWBF.		
Indicator Trip Pressure		
ΔP = 29 psid (2 bar) -10% *(optional)*		
ΔP = 72 psid (5 bar) -10% *(standard)*		
ΔP = 116 psid (8 bar) -10% *(optional non bypass)*		
Bypass Valve Cracking Pressure		
ΔP = 43 psid (3 bar) +10% *(optional)*		
ΔP = 87 psid (6 bar) +10% *(standard)*		
Non Bypass Available		

Model Code

DF BN/HC 30 T B 3 A 1 . X 12 - V B6 __

Filter Type
DF = Inline filter

Element Media
BH/HC = Betamicron® *(High Collapse)* BN/HC = Betamicron® *(Low Collapse)*
V = Metal Fiber W/HC = Wire Screen

Size
30, 60, 110, 160, 240, 280, 330, 660, 1320

Pressure Range
T = 420 bar

Size and Nominal Connection
B = 1/2 Threaded (size 30 only)
C = 3/4 Threaded (sizes 60-140 only)
E = 1 1/4 Threaded (sizes 160-280 only)
F = 1 1/2 Threaded (sizes 330-1320 only)
I = SAE 3/4" Code 62 Flange (sizes 60-140 only)
J = SAE 1 1/4" Code 62 Flange (sizes 160-280 only)
L = SAE 2" Code 62 Flange (sizes 330-1320 only)

Filtration Rating *(microns)*
3, 5, 10, 20 = BH/HC, BN/HC 3, 5, 10, 20 = V 25, 74, 149 = W/HC

Type of ∆P Clogging Indicator

			Indicator Model
A	=	metal blanking plug - port machined	
B	=	visual *(pop-up) (Automatic reset)*	VD...B
C	=	electrical *(electric switch)*	VD...C
D	=	electrical/visual *(lamp) (electric switch & light)*	VD...D

(*For details and additional indicator options, see pages 201 - 230*)

Type Number
1 = One piece bowl *(sizes 30-660 only)*
2 = Two piece bowl *(sizes 660-1320 only)*

Modification Number *(latest version always supplied)*

Port Configuration
(omit) = BSPP
3 = NPT ports – NPT ported filters will be SAE with adaptors in each port
12 = SAE straight thread o-ring boss ports
16 = SAE flange ports *(sizes 60-1320 only)*

Seals
(omit) = Nitrile (NBR) standard
V = Fluoroelastomer (FPM)
EPR = Ethylene Propylene (EPDM) Seals *(subject to minimum quantities)*

Bypass Valve
(omit) = Non-bypass
B3 = Bypass *(3 bar)*
B6 = Bypass *(6 bar)*

Supplementary Details
SO103H= Modification of BN4HC *(Low Collapse)* Element For Phosphate Esters
SO155H= Modification of BH4HC *(High Collapse)* Element For Phosphate Esters
SO184 = G-1/2 Drain in Bowl Option For Sizes 60 - 280 *(comes standard for sizes 330, 660, & 1320)*
W = Indicator with brass piston *(for use with water based fluids)*
L24 = Lamp for 24 Volts
L48 = Lamp for 48 Volts
L115 = Lamp for 115 Volts
L230 = Lamp for 230 Volts
(L24–L230: D-type clogging indicator only)
T100 = Indicator Thermal Lockout, 100°F *(Consult factory on B & BM Indicators for thermal lockout)*

Replacement Element Model Code

0030 D 010 BN4HC / V

Size
0030, 0060, 0110, 0160, 0240, 0280, 0330, 0660, 1320

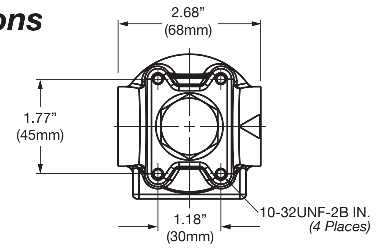
Filtration Rating *(micron)*
3, 5, 10, 20 = BH4HC, BN4HC 3, 5, 10, 20 = V 25, 74, 149 = W/HC

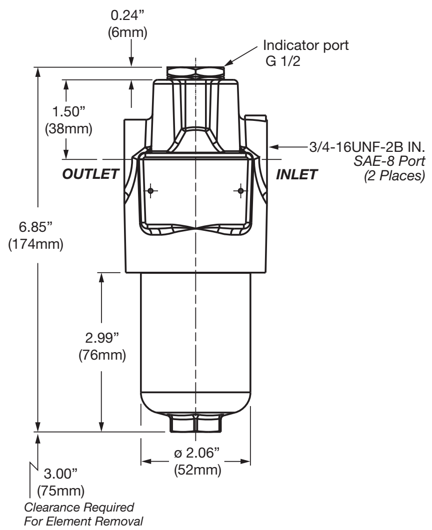
Element Media
BH4HC, BN4HC, V, W/HC

Supplementary Details
(omit) = standard
V = Fluoroelastomer (FPM) seals

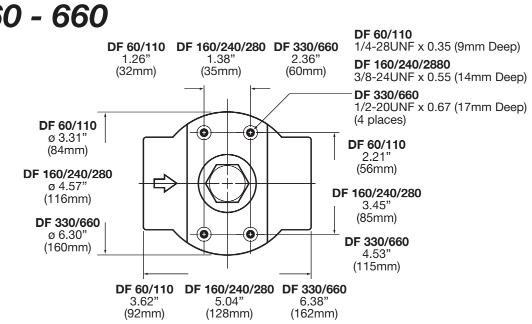
Model Codes Containing RED are non-stock items — Minimum quantities may apply – Contact HYDAC for information and availability

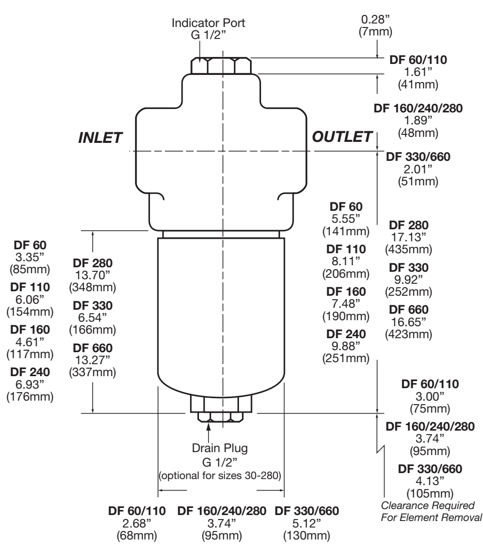
Dimensions
DF 30



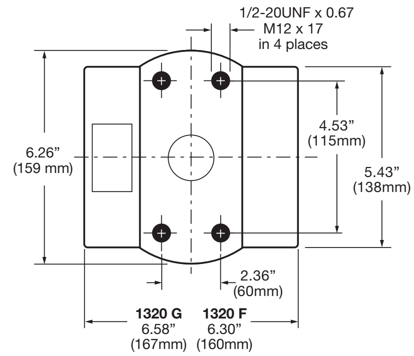


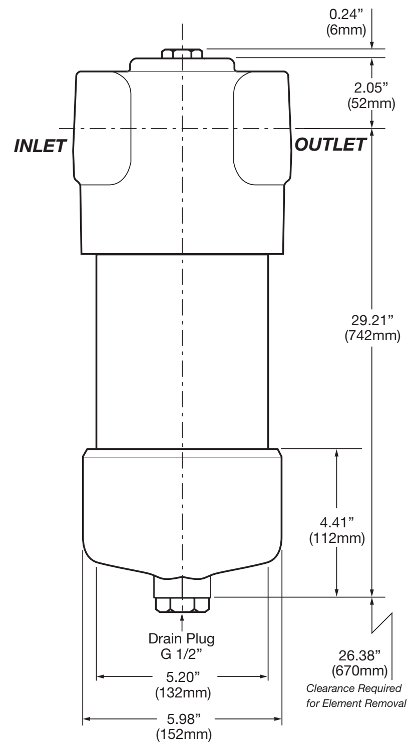
DF 60 - 660



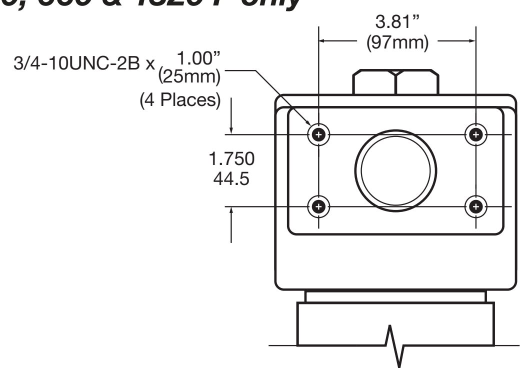


DF 1320





SAE - 32 Flange Code 62
DF 330, 660 & 1320 F only



Size	30	60	110	160	240	280	330	660	1320
Weight (lbs.)	4.0	8.6	10.5	20.0	23.4	32.0	47.2	62.4	105.8

Dimensions shown are for general information and overall envelope size only. Weights listed are without element.
For complete dimensions please contact HYDAC to request a certified print.

Sizing Information

Total pressure loss through the filter is as follows:

Assembly ΔP = Housing ΔP + Element ΔP

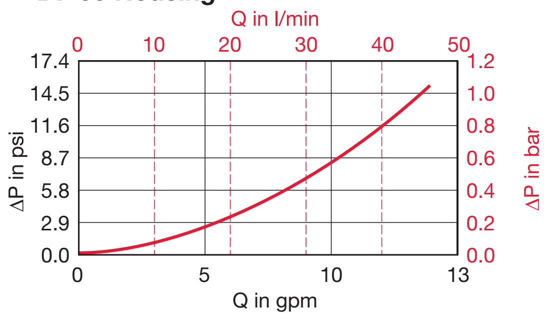
Housing Curve:

Pressure loss through housing is as follows:

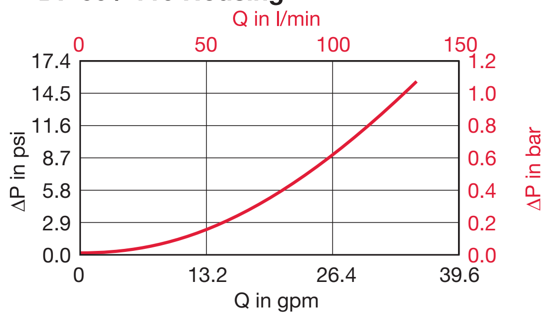
$$\text{Housing } \Delta P = \text{Housing Curve } \Delta P \times \frac{\text{Actual Specific Gravity}}{0.86}$$

Adjustments must be made for viscosity & specific gravity of the fluid to be used! *(see sizing section on page 21)*

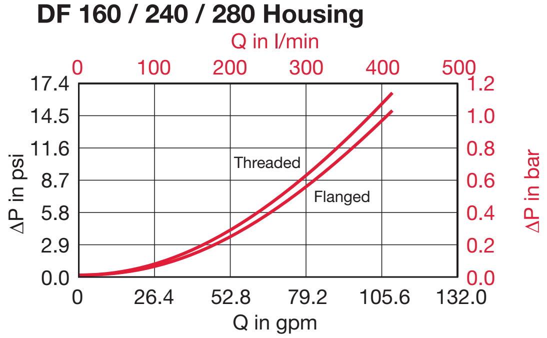
DF 30 Housing



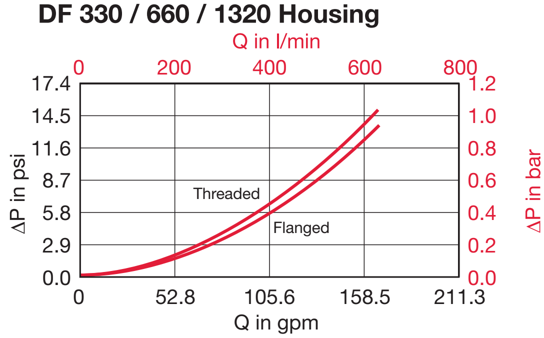
DF 60 / 110 Housing



DF 160 / 240 / 280 Housing



DF 330 / 660 / 1320 Housing



Element K Factors

$$\Delta P \text{ Elements} = \text{Elements (K) Flow Factor} \times \text{Flow Rate (gpm)} \times \frac{\text{Actual Viscosity (SUS)}}{141 \text{ SUS}} \times \frac{\text{Actual Specific Gravity}}{0.86}$$

(From Tables Below)

Size	...D...BN4HC (Betamicron® Low Collapse)			
	3 µm	5 µm	10 µm	20 µm
0030	3.504	2.374	1.251	0.618
0060	1.582	1.116	0.723	0.433
0110	0.819	0.585	0.361	0.205
0160	0.718	0.480	0.252	0.193
0240	0.450	0.333	0.196	0.128
0280	0.220	0.171	0.092	0.071
0330	0.294	0.215	0.163	0.095
0660	0.136	0.099	0.061	0.044
1320	0.068	0.048	0.030	0.021

Size	...D...BH4HC (Betamicron® High Collapse)			
	3 µm	5 µm	10 µm	20 µm
0030	5.000	2.780	1.989	1.042
0060	3.210	1.785	0.993	0.669
0110	1.394	0.819	0.488	0.307
0160	0.919	0.569	0.322	0.240
0240	0.578	0.374	0.214	0.158
0280	0.313	0.184	0.097	0.090
0330	0.422	0.244	0.154	0.108
0660	0.179	0.106	0.055	0.049
1320	0.089	0.054	0.031	0.024

Size	...D...V Elements			
	3 µm	5 µm	10 µm	20 µm
0030	1.011	0.740	0.411	0.200
0060	0.877	0.511	0.296	0.183
0110	0.452	0.304	0.182	0.118
0160	0.251	0.177	0.123	0.079
0240	0.169	0.137	0.093	0.062
0280	0.126	0.093	0.064	0.041
0330	0.121	0.097	0.065	0.043
0660	0.063	0.050	0.034	0.021
1320	0.032	0.026	0.018	0.012

Size	...D...W/HC Elements
	25, 50, 74, 100, 149, 200 µm
0030	0.166
0060	0.042
0110	0.023
0160	0.016
0240	0.010
0280	0.009
0330	0.008
0660	0.004
1320	0.002

All Element K Factors in psi / gpm.

Appendix XIX

EATON | Vickers

Target Cleanliness Worksheet

Systemic Contamination Control

Target Cleanliness Worksheet

1. SET A TARGET

Eaton Recommended Cleanliness Code Chart

PUMPS PRESSURE	<140 BAR <20000 PSI	140 - 210 BAR 2000 - 3000 PSI	210+BAR 3000+PSI
Fixed Gear	20/18/15	19/17/15	18/16/13
Fixed Vane	20/18/15	19/17/14	18/16/13
Fixed Piston	19/17/15	18/16/14	17/15/13
Variable Vane	19/17/15	18/16/14	17/15/13
Variable Piston	18/16/14	17/15/13	16/14/12

VALVES PRESSURE	<210 BAR <3000 PSI	210+BAR 3000+PSI
Directional (solenoid)	20/18/15	19/17/14
Pressure Control (modulating)	19/17/14	19/17/14
Flow Controls (standard)	19/17/14	19/17/14
Check Valves	20/18/15	20/18/15
Cartridge Valves	20/18/14	19/17/14
Screw-In Valves	18/16/13	17/15/12
Prefill	18/16/13	17/15/12
Load-Sensing Directional Valves	18/16/13	17/15/12
Hydraulic Remote Controls	18/16/13	17/15/12
Proportional Directional (throttle valves)	18/16/13	17/15/12*
Proportional Pressure Controls	18/16/13	17/15/12*
Proportional Cartridge Valves	18/16/13	17/15/12*
Proportional Screw-In Valves	18/16/13	17/15/12
Servo Valves	16-14-11*	15/13/10*

ACTUATORS PRESSURE	<140 BAR <2000 PSI	140 - 210 BAR 2000 - 3000 PSI	210+BAR 3000+PSI
Cylinders	20/18/15	20/18/15	20/18/15
Vane Motors	20/18/15	19/17/14	18/16/13
Axial Piston Motors	19/17/14	18/16/13	17/15/13
Gear Motors	20/19/17	20/18/15	19/17/14
Radial Piston Motors	20/18/14	19/17/13	18/16/13
Swash Plate Design Motors	18/16/14	17/15/13	16/14/12*

HYDROSTATIC TRANSMISSIONS PRESSURE	<210 BAR <3000 PSI	140 - 210 BAR 2000 - 3000 PSI	210+BAR 3000+PSI
Hydrostatic Transmissions (in-loop fluid)	17/15/13	16/14/12*	16/14/11*
BEARINGS			
Fixed Gear	20/18/15	19/17/15	18/16/13
Fixed Vane	20/18/15	19/17/14	18/16/13
Fixed Piston	19/17/15	18/16/14	17/15/13
Variable Vane	19/17/15	18/16/14	17/15/13
Variable Piston	18/16/14	17/15/13	16/14/12

* Requires precise sampling practices to verify cleanliness levels.

How to Set a Target Cleanliness Level

Using the Eaton Recommended Cleanliness Code Chart, determine the cleanest fluid (lowest code) required by any component in the system. All components that draw fluid from a common reservoir should be considered to be part of the same system even if their operations are independent or sequential (i.e. a central power unit running several different machines). The pressure rating for the system is the maximum system pressure achieved by the machine during a complete cycle of operation.

STEP TWO:

For any system where the fluid is not 100% petroleum oil, set the target one Range Code cleaner for each particle size.

Example: If the cleanest code required was 17/15/13 and water glycol is the system fluid, the target becomes 16/14/12.

STEP THREE:

If any of the following condition are experienced by the machine or system, set the target cleanliness one level lower for each particle size.

- Frequent cold starts at less than 0°F (-18C°)
- Intermittent operation with fluid temperatures over 160°F (70°C)
- High vibration or high shock operation

Again, looking at the example above, if this system was expected to intermittently operate about 70°C, the target cleanliness would become 15/13/11.

Using this three step procedure, the system target cleanliness code for the system is now set.

TEST STANDS

Target cleanliness level for test stands should be one range code cleaner, for each particle size, than the code for the most sensitive condition and component to be tested. Example: Variable piston pump tested at 170 bar (2500 psi) cleanliness level should be 17/15/13 so the TEST STAND cleanliness level should be at least 16/14/12.

FLUID CONDITIONING

Proper fluid condition is essential for long and satisfactory life of hydraulic components and systems. Hydraulic fluid must have the correct balance of cleanliness, materials and additives for protection against wear of components, elevated viscosity and inclusion of air. Eaton supports and recommends the hydraulic Systems Standards For Stationary Industrial Machinery advanced by the American National Standards Institute; ANSI(NFPA/JIC) T2.24, 1-1991. Key elements of the Standard, as well as other vital information on the "Guide To Systemic Contamination Control," available from your local Eaton distributor.

Target Cleanliness Worksheet

SYSTEMIC CONTAMINATION CONTROL WORKSHEET

Company Name ______________________________ Date ______________

Company Address ______________________________

Contact Person ______________________________ Title______________

Type of Machine (System) ______________________________

SETTING A TARGET CLEANLINESS LEVEL

STEP ONE:

Maximum Operating Pressure ______________________________ Pump Flow ____________

Total System Volume (including lines and actuators) ______________________

Most Sensitive Component

Pump Type ______________________________ Target Cleanliness __/__/__

STEP TWO:

Fluid Type and Brand ______________________________

Fluid Adjustment? _______ Yes ______ No

STEP THREE:

Operating Temperatures _______ F° (min) _____ F°(max)

Intermittent Fluid Temperatures Above 70°C (160°F)? _______Yes ______ No

Frequent Cold Starts at Less Than -18°C (0°F)? _______Yes ______ No

High Vibration or Shock? _______Yes ______ No

System Stress Adjustment? _______Yes ______ No

FINAL SYSTEMIC CONTAMINATION CONTROL TARGET CLEANLINESS _________/________ / ______

CONTAMINATION CONTROL DEVICE PLACEMENT

Return Line Flow ________ Max L/min (GPM) _______ Min L/min (GPM) Pressure _______Max bar (psi)

Pressure Line Flow ________ Max L/min (GPM) _______ Min L/min (GPM) Pressure _______Max bar (psi)

Recirculation Line Flow ________ Max L/min (GPM) _______ Min L/min (GPM) Pressure _______Max bar (psi)

Pressure Filter Model # ______________________________ C ______________

Return Filter Model # ______________________________ C ______________

Recirculating Filter Model # ______________________________ C

Replacement Element Model Numbers

Return Line ______________________________

Pressure Line ______________________________ Analysis Done By ____________

Recirculating Loop ______________________________ Title ______________

Reservoir Vent Breather Filter # ______________________________

2. BUILD TO ACHIEVE TARGET

Filter Placements

This chart helps select the grade of Eaton medium, and the filter placement(s) that will achieve the required target cleanliness. It assumes the system will experience "average" ingression and that maintenance of the system will be consistent with current technology. If in operation the system is running dirtier than expected, corrective actions should be initiated. Suggested corrective actions are:

1. Check the indicator to see if the filters are on by-pass.
2. Check the sources of ingression and correct problems.
3. Check that the filters are positioned properly to see maximum fluid flow.
4. Consider using a finer grade of Vickers filter.
5. Add a filter to the system.

Target Cleanliness	Full flow pressure line or return line	Full flow pressure line and return line	Pressure line (or return line) and recirculating loop at 20% of system fluid volume per minute	Pressure line plus return line plus recirculating loop	Recirculating loop at 20% of system volume per minute	Recirculating loop at 10% of system volume per minute
14/12/10		03	03	03		
15/13/11		03	03	05		
16/14/12	03	05	05	05	03	
17/15/13	03	05	05	05 or 10	03	03
18/16/14	05	10	05 or 10	10	05	03
19/17/15	05 or 10	10	10	10	05 or 10	05
	Recommended filter placements for fixed volume pumps	Recommended filter placements for high ingression systems with fixed volume pumps	Recommended filter placements for systems with variable volume pumps	Recommended filter placements for high ingression systems with variable volume pumps	Recommended filter placements for systems with fixed or variable volume pumps	Recommended filter placements for low ingression systems with fixed or variable volume pumps

Note: All systems need a reservoir with 3 micron air breather filtration.

C-Pak System Cleanliness Ratings

CODE	NUMBER OF TIMES PUMP FLOW PASSES THROUGH FILTER(S) (SEE NOTE 1)	TYPICAL ISO 4406 CLEANLINESS LEVEL ACHIEVED (SEE NOTE 2)
03	2.0	14/12/10
	1.5	15/13/11
	1.0	16/14/12
	.5	17/15/13
05	2.0	16/14/12
	1.5	17/15/13
	1.0	18/16/14
	.5	19/17/15
10	2.0	18/16/14
	1.5	19/17/15
	1.0	20/18/15
	.5	21/19/16

Note 1

# OF PASSES THROUGH FILTER OF MAXIMUM PUMP FLOW	TYPICAL FILTER PLACEMENTS
2.0	Full flow pressure and return
1.5	Full flow pressure or return and recirculation loop
1.0	Full flow pressure or return line
0.5	Recirculation loop sized to 15% of system volume per minute

Note 2

Cleanliness level achieved is affected by percentage of system flow that passed through the filters, filter housing integrity, element performance and contamination ingression and generation rates. For more detailed assistance, please contact your local Eaton Distributor.

3. CONFIRM ACHIEVEMENT OF TARGET

Vickers Fluid Analysis Kit
Part Number 894276
(Standard Report)

Vickers Fluid Analysis Kit
Part Number 894277
(Standard Report plus Spectographic)

Vickers Sampling Pump
Part Number 894279
(Not Shown in Picture)

Fluid Analysis Report Includes the Following:

- Photomicrograph
- Particle count information
- Cleanliness code and comparison to target
- Viscosity and comparison to target
- Water content and comparison to target
- Trend information of previous two samples
- Comments and recommendation

Recommended System Sampling Frequency Chart

SYSTEMS WITH TARGET CLEANLINESS 17/15/12 OR LOWER

SYSTEM PRESSURE	<140 BAR (2000 PSI)	140 - 210 BAR (2000 - 3000 PSI)	>210 BAR 3000 PSI
8 hours or less operation per day	4 months	3 months	3 months
Over 8 hours of operation per day	3 months	2 months	2 months

SYSTEMS WITH TARGET CLEANLINESS 18/16/13 OR HIGHER

SYSTEM PRESSURE	<140 BAR (2000 PSI)	140 - 210 BAR (2000 - 3000 PSI)	>210 BAR 3000 PSI
8 hours or less operation per day	6 months	4 months	4 months
Over 8 hours of operation per day	4 months	3 months	3 months

INITIAL COMMISSIONING OR MAJOR REBUILD

Large system (2000 liters (530 USgal) or more) and systems with servo valves:

- Sample fluid before start-up
- Sample fluid during first day running
- Sample fluid after one week
- Sample fluid after one month

Other systems:

- Sample fluid during first day running
- Sample fluid after one month

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14615 Lone Oak Road
Eden Prairie, MN 55344
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Tel: 952 937-9800
Fax: 952 974-7722
www.hydraulics.eaton.com

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Fax: (49) 7221 682-788

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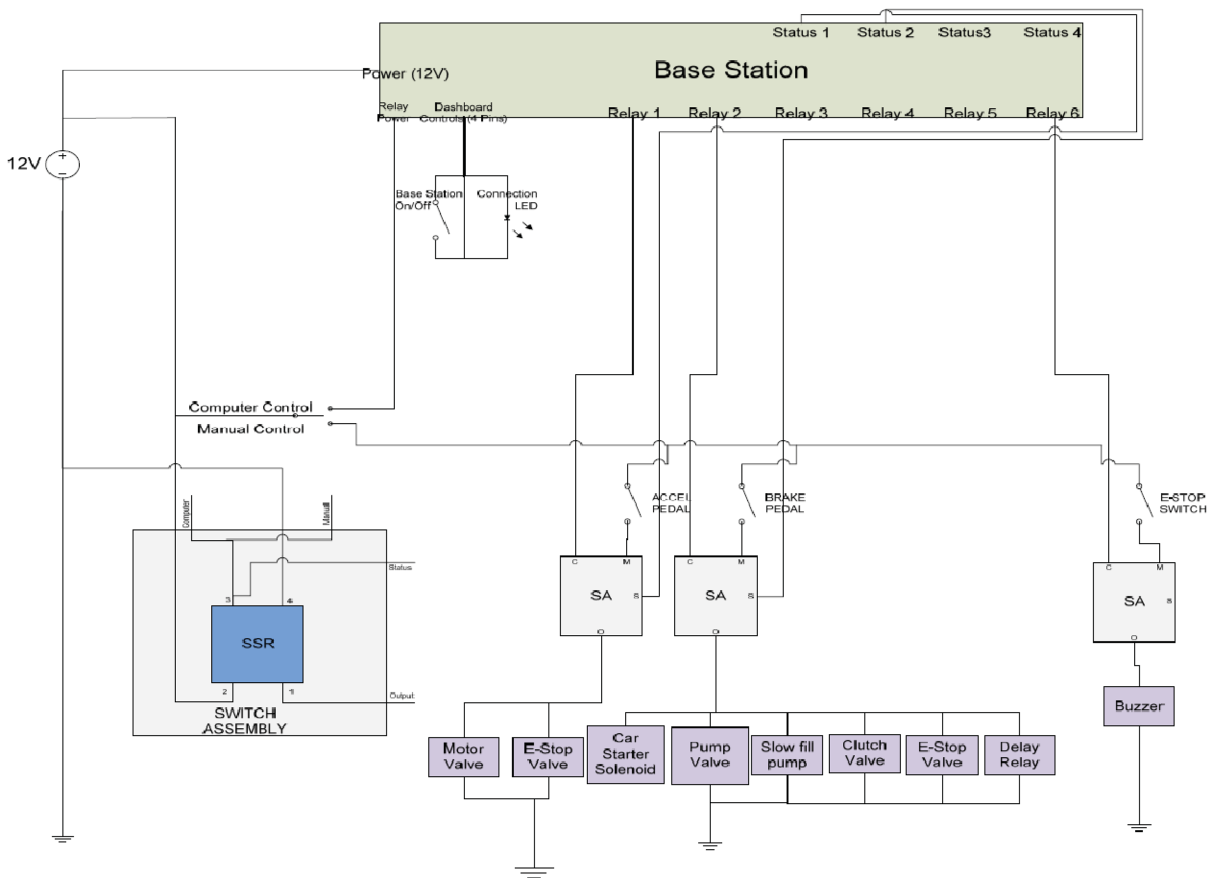
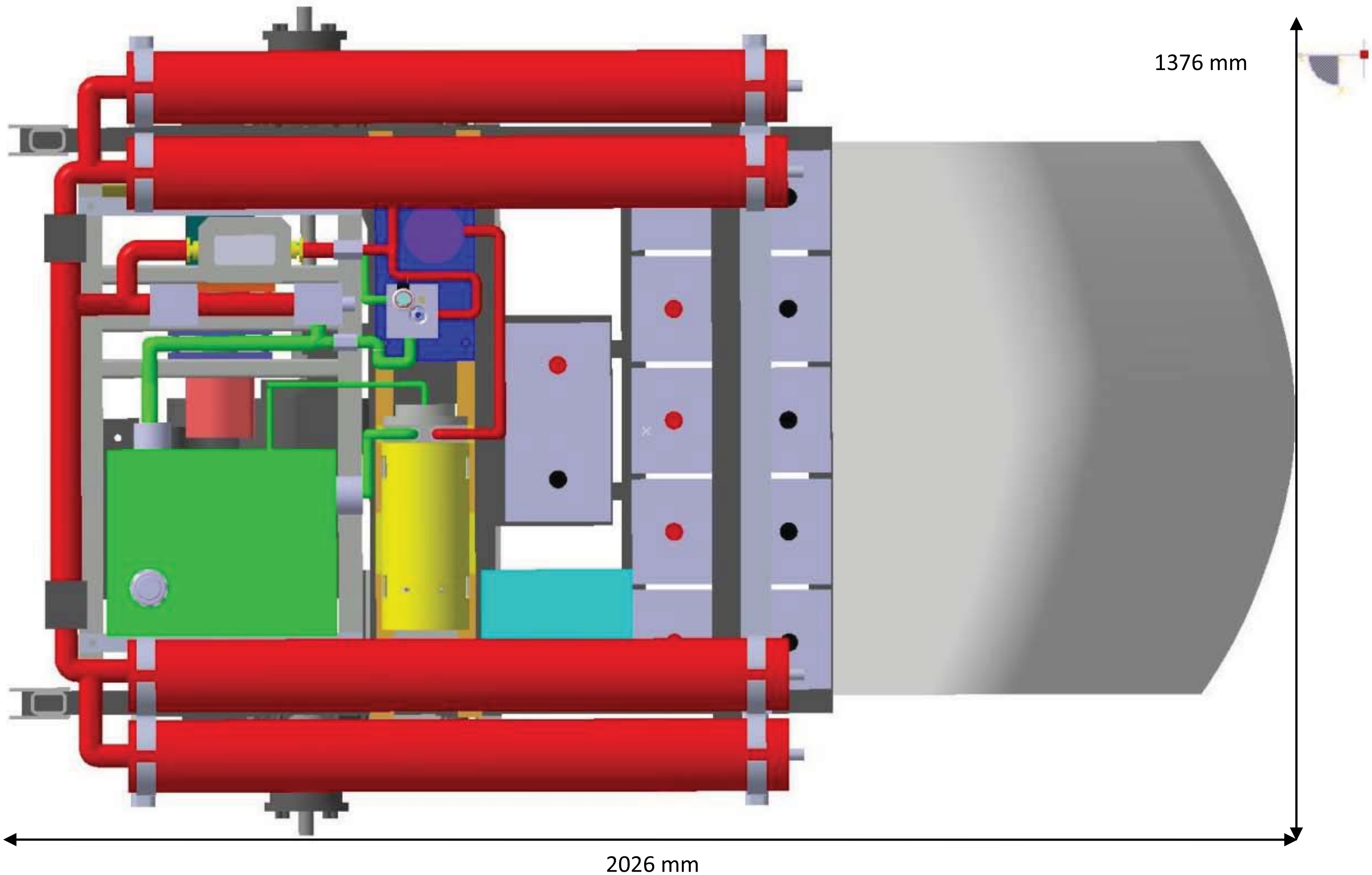
Appendix XX

Circuit diagram of the original controller board



Appendix XXI

Drawing of the current system



ELECTRICAL SPECIFICATIONS:

AXE CONTROLLERS FOR DC *SERIES MOTORS*

AXE MODEL #	2434	2444	4834	4844	4845	4855	4865	7234	7245
Battery Voltage	12-24V	12-24V	24-48V	24-48V	24-48V	24-48V	24-48V	24-72V	24-72V
Current Limit	300A	400A	300A	400A	400A	500A	650A	300A	450A
2 Minute Rating	300A	400A	300A	400A	400A	500A	650A	300A	450A
5 Minute Rating	200A	350A	200A	300A	300A	350A	400A	200A	350A
60 Minute Rating	135A	200A	135A	150A	175A	250A	250A	125A	200A
Voltage Drop @100Amp	<0.30V	<0.10V	<0.30V	<0.13V	<0.18V	<0.09V	<0.08V	<0.16V	<0.11V

Type: Series wound DC motor controller
Operating Frequency: 18Khz
Throttle Input: 0-5K ohm (2-3Wire) / 5K-0 ohm / 0-1K ohm / 0-5V / 6-10VDC / ITS
Throttle Curves: Linear, Progressive, Inductive, and S-Curve
Key Switch Input voltage: 18V – nominal battery voltage
Max Voltage: 24VDC Nominal = 30VDC Max
48VDC Nominal = 60VDC Max
72VDC Nominal = 90VDC Max
Quiescent current (Powered up): less than 75mA
Thermal cutback: begins at 75°C, 95°C shutdown
Programming interface: RS-232 serial to host PC with freeware Windows interface
Programmable Functions:
Throttle ramp profile, throttle response rate, plug brake on/off, plug brake current, High Pedal Disable (on/off), battery under voltage, battery over voltage cutback, and Half speed reverse

Alltrax 300 & 400 Amp Controllers Fit Under The E-ZGO Cover With Solenoid Attached!

AXE

Doc100-055-B_SPEC-AXE-Product-Family.pub
Released: 03-20-2007

ALLTRAX INC.

1111 Cheney Creek Road
Grants Pass, Oregon 97527

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Appendix XXIII

Operators Manual

Model: AXE Series

Series Wound DC Electric Motor Controller

AllTrax inc
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www.alltraxinc.com

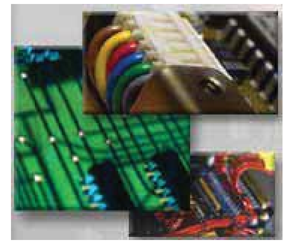
PN: Doc100- 003-A_OP-AXE-Operators-Manaul.doc (Rev A)

Table of Contents

Keep this manual

1. AXE Motor Control Product Overview

Thank You for purchasing the Alltrax motor controller. We design and manufacture products for a variety of electric vehicles and markets. This motor controller employs modern power MOSFETs to provide extremely low “on” resistance, in both the main switch function and freewheel diode.



Synchronous freewheel rectification permits extended high power operation over similar sized controllers due to increased efficiency. A microprocessor based control system monitors numerous functions, and a windows interface allows the user to change numerous operating parameters and perform status monitoring.

Replaces Curtis
1204 (6.5” long)

Replaces Curtis
1205 (8.5” long)

2. Required Accessories

These components **<u>are not supplied</u>** with the controller, ***except the main fuse***. For your safety and that of others, some basic precautionary measures must be employed when designing, working on, and driving electric vehicles.

- ***<u>Use a contactor in the battery circuit, rated for the amperage and voltage of the system.</u>***
- ***<u>Use a fuse rated for the voltage and available fault current of the battery, such as the one provided.</u>***
- ***<u>Safety interlocks must be employed to prevent enabling the controller while the vehicle is unoccupied or charging.</u>***

Controllers have failure modes which can result in runaway (stuck throttle) conditions. This controller has been designed to prevent and preclude as many of those from ever occurring as possible. Please follow the Recommended Controller Wiring System document in this manual. Failure to do so could result in damage to the controller, and serious injury or death to vehicle occupants or bystanders

2.1 Battery Contactor (Solenoid or Relay)

The main battery contactor needs to be rated correctly in terms of amps and volts, in order to safely carry the intended continuous battery current, and to interrupt the pack DC voltage. It's coil voltage should also be rated for the pack voltage.


2.2 Main Fuse (Provided with Controller)

- The main fuse needs to be sized to protect the wiring in the drive system.
- Fuse DC voltage rating must be greater than the peak battery voltage.
- Fuse current rating equal to or less than amperage rating of controller.

Most high current fuses have very long tolerance (2 minutes or more) up to 50 - 100% overloads. Thus a 300A fuse likely won't open in a 500A vehicle application. Most Golf OEM vehicles may not have a fuse and must be added with these performance controller upgrades. When carts are equipped with large controllers, the wire gauge must be made larger. This in turn permits higher fault currents, due to the reduced wiring resistance. Under these conditions, we strongly recommend the addition of a fuse to prevent catastrophic battery failure or fire in the event of an electrical system failure.

2.3 Safety Disconnect

The safety disconnect provides a way to disconnect the battery pack from the controller and contactor. It may be a circuit breaker, a mechanical switch, or a large removable connector. Make sure it is rated for the current capacity and DC Voltage of your system. Some installations disconnect both the positive and negative leg of the battery pack. Most Golf type vehicles do not have a battery disconnect.

2.4 Drive Motors

The motor controller is designed to operate with series wound brush commutated and permanent magnet motors rated for operation from 12-72 VDC. Operation with compound motors is possible. Contact Alltrax, Inc. for information on using compound motors.

3. Controller Installation

Choose a location outside the driver's compartment to mount the controller. Any mounting position is acceptable. It is recommended that you protect the controller from direct contact with water, as the electrical connections can corrode. In high moisture environments, seal the electrical connections with silicone or grease.

Mount the controller as close to the motor as is reasonably possible. Ideally, your motor leads should be less than 4 feet long. Making a twisted pair out of the motor leads will reduce RF emissions.

- Most car employ small (6AWG) battery interconnect wiring.
- For 400A controllers, a minimum of 4AWG wire should be used in light weight carts.
- 2AWG to 1/0 is appropriate for higher amperage controllers and heavier vehicles.

High current wiring to the motor controller should use 5/16" mounting hole ring terminals of tinned copper. Bolt them to the controller using 5/16" hardware.

3.1 Contactor Coil Diode:

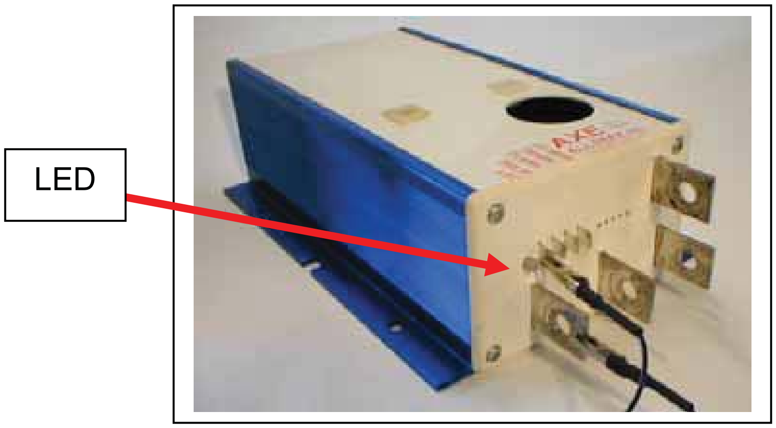
CAUTION: A Diode (1A, 100V) MUST BE USED across the solenoid/contactor coil (and any other relays that may be installed to control lights or accessories). The Cathode or banded end faces the positive terminal. These diodes are required to prevent the speed sensor from producing erroneous signals.

3.2 Pre-charge Resistor:

The controller has a fair amount of DC filter capacitance. When the contactor closes to apply power to the controller, the capacitors can arc the contactor. The pre-charge resistor wil apply a low current to the capacitors to prevent any arcing and keep the capacitors at bus voltages. It also acts as a discharge snubber that helps dissipate the arc when the contactor disengages. (see schematics for proper value).

4. LED Status Indicator

The AXE controller has a bicolor front panel LED. This LED displays a variety of information each time the controller is powered up, by series of blinks. Count the number of green blinks to identify the type of throttle the controller is configured for. *After* the blink code indicating throttle type, the LED will stay green if there are no errors.



LED Blink Codes:

At power up the number of green blinks indicates the configured throttle type:

1 Green = 0-5k
2 Green = 5k-0
3 Green = 0-5V
4 Green = EZ-GO inductive (ITS)
5 Green = Yamaha 0-1K
6 Green = Taylor-Dunn 6-10.5V
7 Green = CLUBCAR 5K-0, 3-wire

Normal display status:

Solid Green: Controller ready to run
Solid Red: Controller in programming mode
Solid Yellow: Controller throttle is wide open, controller is supplying max output, and is not in current limit.

Error code display:

Number of RED blinks indicates any error conditions that might exist.

1 Red = Throttle Position Sensor Over Range. Check for open wires.
2 Red = Under Temperature. Controller below -25C.
3 Red = HPD. Throttle hasn't gone to zero during this power on cycle.
4 Red = Over Temperature. Controller over 95C.
5 Red = unused for series controllers.
6 Red = Battery Under Voltage detected. Battery V < undervoltage slider.
7 Red = Battery Over Voltage detected. Battery V > overvoltage slider.

Errors are self clearing when the fault is corrected.

5. Software Use and Calibration

The Alltrax Motor controllers utilize a computer program to provide the motor drive functions, motor field current mapping, and a myriad of other customizable features such as speed, current, throttles, etc.

A majority of the Alltrax motor controllers also have the ability to be re-programmed with upgraded software. In most cases, it is not necessary to upgrade the unit's software for stock or aftermarket replacements unless a specific revision is needed for a particular application.

See Controller Pro Operators manual for more detailed operation.

Software:

- Controller Pro Software (see www.alltraxinc.com and download http://www.alltraxinc.com/old/Software/WEBControllerPRO.zip

Through may customer service calls we have found 90% of the problems with communicating between the computer and the motor controller was the inability of the windows software to assign communications ports. We found using a USB to Serial Adapter eliminated any communications port issues with success to connect properly the first time.

Recommended serial to USB adapter:

- Cables to Go, Port Authority™ 2 USB to Serial Adapter. www.cablestogo.com (shown above)
- Radio Shack, 6 Ft. (1.8m) USB-to-Serial Port Cable, Model: 26-183, Catalog #: 26-183 (Shown below)

WARNING: Disconnect all battery charging sources while programming your Axe Controller.
The controllers RS-232 serial port is referenced to the B- battery connection.

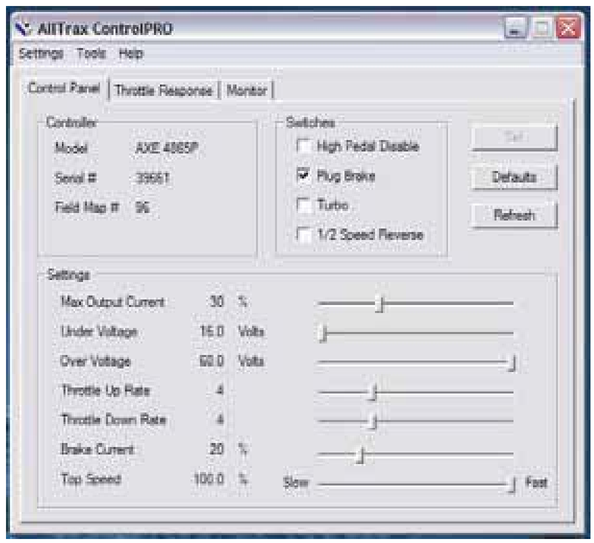
Beware any possible ground loop faults between your computer and the controller which could damage both the Axe Controller and PC, plus the person doing the work!

6. Programming the Controller:

The AXE controller must be powered up before the Controller Pro program will have any effect. Any programming changes done in the vehicle should be performed with the vehicle safely disabled. Either put the drive wheels on jack stands, or position the vehicle where it is safe to drive while altering the controller. For bench programming prior to installation, two 9V batteries in series may used to power up the controller. Connect battery negative to the B- bus bar, battery positive to pin 1, (spade tab closest to the LED).

When the AXE is connected to the PC, and both units are energized, launch ControllerPro.EXE. If you see an error "Motor Controller Not Responding", it means the Controller and PC are not communicating. Hit "OK", and the Controller Pro will display a window. Recheck the cable connections then close and re-open Controller Pro. Controller Pro automatically determines which com port the controller is connected to. If, after going through this the controller will still not establish communications with the PC, try turning the AXE controller off, then back on. Observe the LED on the AXE went out, then came back on, indicating you cycled the power. Restart the Controller Pro program.

When communications is established with the controller, a Model number (like AXE4844) should be displayed in the Control Panel pane, along with the current configuration of the AXE motor controller.



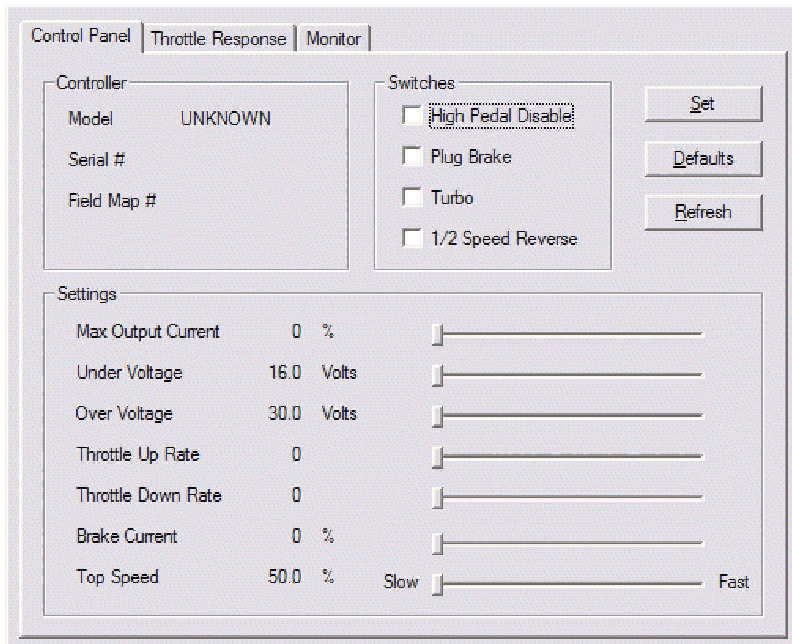
The top row of functions is Settings, Tools and Help. The normal parameters of the "settings, program…" portion of this program will enable the software to work on most PCs. However, in some very electrically noisy systems, it may be necessary to increase the write delay above 20mS or increase the number of retries, such that communications errors are eliminated.

Tools: This function of the program allows you to modify the main executable program that operates the controller (to modify the behavior of a standard controller by adding special features like increased throttle response speeds for go-karts) or extract an error log from the controller for diagnostics.

Upgrade: This function loads a new executable program into the controller.
Reset: Restarts the controller without cycling the power.
Write error log: This function downloads the last 32 (if any) errors that the controller has logged into it's EEPROM memory. These are things like HPD, hi/low battery voltage, and over/under temperature.

6.1 Control Panel Tab

This tab allows you to alter the operating characteristics of the AXE. Changes made on this pane only take effect after the "SET' button is pressed. "Refresh" will read the current settings from the controller. After any changes have been "SET", always click "REFRESH" to confirm the changes were accepted by the controller. Note: HPD and Plug Brake switches only take effect at power up, the power to the controller will have to be cycled before these two controls have any effect on the machines operation. The "DEFAULTS" button will restore the factory default values of the sliders, note that "SET" must still be pressed for these parameters to be stored in the AXE controller.



6.1.1 SWITCHES:

High Pedal Disable

Checking this box enables HPD, which will prevent the controller from providing output power in the event the throttle is applied when the controller is powered on. When this box is clear, the controller will start up and provide output power, when KSI energized, regardless of initial throttle position.

Plug Brake

Checking this box enable plug braking on those controllers equipped with an A2 bus bar terminal. Plug braking on AXE controllers is proportional to throttle position, reaching full braking force at about 25% of throttle travel. Deselecting this box disable plug braking, the unit will apply normal power to motor if direction is reversed. (vehicle may jerk or spin tires if motor direction is reversed while in motion)

Turbo

A feature that allows **DCX** controllers (not AXE controllers) to go faster if under light load and 100% throttle.

½ Speed Reverse

Limits speed of golf car to 50% of throttle setting when pack + is applied to this pin.

6.1.2 SETTINGS:

Maximum Output Current

This slider adjusts the maximum output current that the controller can provide to the motor. Output current is adjusted as a percent of the maximum rating of the controller. For example, an AXE4844 will provide a maximum of 400A to the motor when this slider is set to 100%. A 75% setting on Maximum Output Current will limit the controller to 300A, 50% will limit the max output current to 200A and so forth.

Under Voltage

This slider sets the under voltage shutdown of the controller, in units of 1/10ths Volt. Generally speaking, it is undesirable to pull the terminal voltage of a 6V lead-acid battery below 4.0V, for example 24V on a 36V system.

Over Voltage

This slider sets the maximum operating voltage of the controller. If the voltage present across the B- to B+ bus bars exceeds this setting, the controller will not produce output, given that DC voltage is below the absolute ratings of the controller.

Throttle Up Rate

This slider adjusts the rate at which the controller increases it's output current in response to an increase in throttle position. 1 is the slowest, 15 the fastest.

Throttle Down Rate

This slider adjusts the rate at which the controller reduces it's output current in response to a decrease in throttle position. 0 is the slowest, 15 the fastest. It is recommended that this parameter typically be set to twice the value of the throttle up rate, when throttle up rate is less than 7. Lower values of Throttle Down Rate can result in the vehicle feeling as if their were a large flywheel connected to the motor.

Brake Current

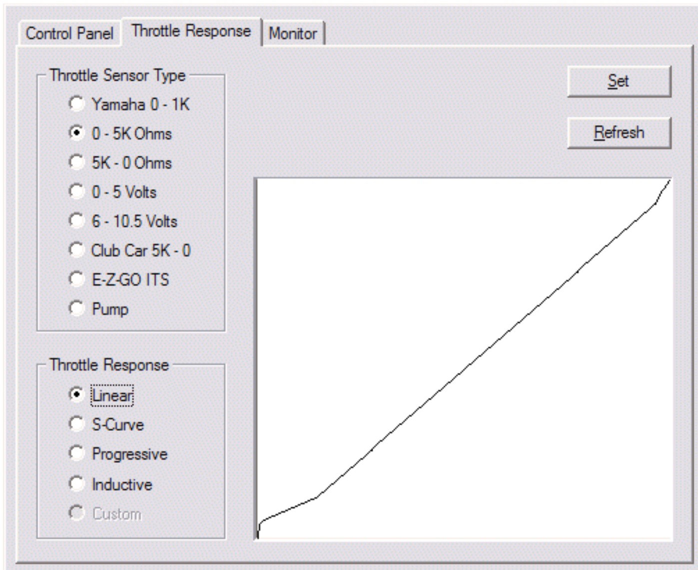
On those models equipped with a plug brake (suffix "P" in the model number), this slider adjusts the amount of brake current as a percent of maximum available brake current. Refer to AXE specifications for maximum available brake current depending on the model of controller.

Top Speed

Top speed of the controller can be limited from 100% down to 50%. This is a helpful tool for elderly or handicapped drivers.

6.2 Throttle Response Tab

This pane allows you to select which type of throttle position sensor the controller is working with and what type of throttle response profile to use with the sensor. Changes to throttle sensor type check boxes must be SET to take effect, and then only after the power to the Axe has been cycled do they actually change the sensor type.



6.2.1 Throttle Sensor Type

0-1K Ohm (Yamaha type):
When selected, the controller interprets 0-80 ohms = throttle off, 1K ohms = full on.

0-5K Ohm:
When selected, the controller interprets 0 ohms = full off throttle, 5K ohms equals full on. Specifically, Zero ohms to 180 ohms = full off, 4.7K to 5K = full on.

5K-0 Ohm:
When selected, the controller interprets 5K ohms = full off throttle, 0 ohms equals full on. Specifically, Zero ohms to 250 ohms = full on, 4.3K to 5K = full off.

0-5V:
This selects a voltage controlled type of throttle input. 0V = full off output from controller, 5V = full on. Actual operating range is 0.15 – 4.90V.

6-10.5V (Taylor-Dunn type):
This throttle sensor is voltage controlled. 0-6V = throttle off, 10.5V = full on.

5K-0, 3 wire (Club Car type):
This throttle sensor employs a 3 wire potentiometer, or the V-Glide throttle position unit. 5K = throttle off, <200 ohms = full throttle.

EZ-GO ITS:
This throttle sensor type is compatible with the EZ-Go type of inductive throttle position sensor (ITS).

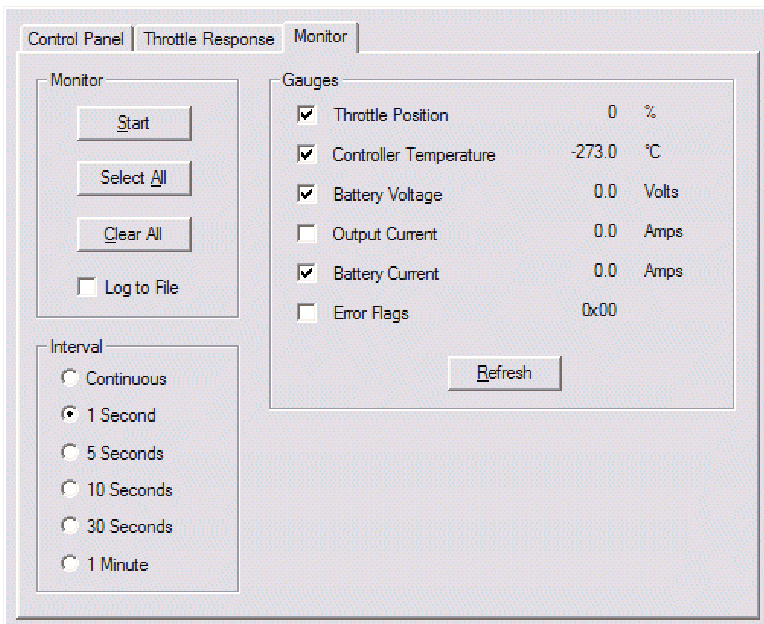
Throttle Sensor Type Continued:

Pump:

This throttle setting allows the AXE controller to power pumps used on fork lifts and other hydraulic applications where pumps are used. The controller turns on 100% output when the Pin 1 spade lug sees pack voltage. The ramp-up and ramp-down rate is still controlled by the two sliders on the Control Panel.

6.3 Monitor Tab

This screen is the status monitor of the Axe controller, it gives you the ability to measure and record numerous operating parameters of the Axe motor controller and the vehicle in which it is installed. When used with a Notebook computer, both real-time data display and data logging may be performed while the vehicle is in use. This gives the vehicle designer significant insight to the interaction of the motor controller with other system components. Log files may be used for problem analysis and diagnostics. You can email the log file to Alltraxinc.com for a detailed analysis by our applications engineers.



6.3.1 Monitor Section:

Start/Stop: This starts and stops the data measurement process

Select All: Checks all the gauges

Clear All: Deselects all the gauges

Log to File:

This checkbox will log all of the selected gauge values to a file when selected. The file is in a comma delimited format (CSV) which can be imported into a spreadsheet program like Excel and viewed. The resulting file will be placed into a subdirectory called "Logs" in the same directory as the program Motorcontrol.exe

6.3.2 Interval Section:

This checkbox selects the update rate, or frequency of data collection. For real time display, select continuous. When used in conjunction with "Log to File", a slower update rate may be more desirable to reduce the amount of raw data being gathered.

6.3.3 Gauges Section:

These are the motor controller parameters which are to be monitored. Checking an adjacent box enables that measurement. Clicking "Refresh" will perform a one-time update to the gauges which are selected. It is generally recommended that you select all the gauges, as this will provide the most insight into the operation of the controller.

Throttle Position:

This gauge displays the % modulation of the controllers PWM output. For example 50% would be ½ throttle. The displayed parameter is the actual throttle position, limited by the fact that the controller could be in current limit. If the controllers output current reaches the maximum rating, the throttle position won't advance any further, regardless if the throttle is full on.

Controller Temperature:

This is the internal temperature of the controller, in Celsius. Accuracy: +/- 5%.

Battery Voltage:

This is the voltage present across the B+ and B- bus bars of the controller. Exception: Club Car compatible models. This is the voltage present across the KSI input to B- bus bar of the AXE controller. Accuracy: +/- 5%

Output Current:

This is the measured output or motor current of the controller, accuracy +/-10%

Battery Current:

This is the calculated input or battery current to the controller. It is calculated as: Battery current = motor current x throttle position %. It is accurate, given that motor current is continuous (which it generally is with any series motor), not discontinuous. Accuracy: +/- 10%

Error Flags:

This register should display as 0x00 during normal operation. Any value greater than zero is an error, and the controller will not provide any output power.
At the moment, this data is in hexadecimal format. If the two right-most hex digits (those to the right of 0x) are converted to an 8 bit binary value, the individual bit positions (with bit 0 being the right-most digit) when set represent the following error flags:

Bit 0 set =	Throttle Position Sensor Over Range
Bit 1 set =	Under Temperature. Controller below -25C
Bit 2 set =	HPD. Throttle hasn't gone to zero during this power on cycle.
Bit 3 set =	Over Temperature. Controller over 95C
Bit 4 set =	unused
Bit 5 set =	Battery Under Voltage detected. Battery V < under voltage slider
Bit 6 set =	Battery Over Voltage detected. Battery V > over voltage slider
Bit 7 set =	Controller in boot sequence. Occurs within 25mS of power up.

7. LIMITED WARRANTY

Alltrax, Inc. warrants every product it sells to be free from defects in materials or workmanship for a period of ***2 years*** from the date of manufacture. This warranty does not apply to defects due directly or indirectly to misuse, abuse, negligence, accidents, repairs or alterations. We shall in no event be liable for death, injuries to persons or property or for incidental, contingent or consequential damages arising through the use of our products. Alltrax, Inc. specifically disclaims the implied warranties of merchantability and fitness for a particular purpose; however some areas do not allow limitations on how long an implied warranty lasts, so the preceding exclusion may not apply to you. This is Alltrax, Inc. sole written warranty; no other warranty is expressed or implied.
In the event you should need warranty repair, Please see the Return Procedure below. Alltrax reserves the right to repair or replace merchandise at its option. Alltrax reserves the right to make changes to any of its products or specifications without notice.

Return Procedure:

Call Alltrax, Inc. at (541) 476-3565
Fax us at (541) 476-3566
Or visit us on the Web at **www.alltraxinc.com**

Explain the nature of the problem to our service personnel and we will provide you with return directions You pay shipping to us, we pay the return shipping. Package the device securely in original shipping box if at all possible; we are not responsible for damage in shipping.

ALLTRAX
www.alltraxinc.com

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Controller Pro
Instruction Manual

These instructions cover:

- Installing Controller Pro
- Programming
- Troubleshooting

Doc#	Doc120-017	Revision:	D	ECO:	102208

Note: Document revision history and EC information also located in "Revision History" section on page 3

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Table of Contents

1. Document Scope

The following is the manual for using Alltrax's Controller Pro communications program. Controller Pro allows a computer to communicate with most Alltrax controller models. This revision document reflects using the USB to RS232 port adapter for communications to the controller. When only using the RS232 serial cable, there has been com port problems associated with various computers. A USB adapter simplifies the process and is highly recommended to use.

1.1. Revision History:

At each revision, all the changes made to the document should be discussed, including the principal author of each revision should be included.

- **Rev A** - Initial Release per EC-081106
- **Rev B** – Added new error code, fix formatting issues, Released per EC-010507
- **Rev C** – Changed information on ControllerPro location and DCX throttle off braking.
- **Rev D** – Added changing COM port instructions. Per EC-102209

1.2. References:

The reference documents section should contain a list of all supporting and related documents. The list should include both internal and external document reference either specifically called out in the document, or relevant documents that give more detail or background.

1.3. Glossary:

2. Items Needed:

Hardware:

- A computer with Windows 98/2000/NT/XP/Vista
- A serial cable with a male DB-9 connector and USB adapter listed below.
  - Cables to Go, Port Authority™ 2 USB to Serial Adapter. www.cablestogo.com
  - Radio Shack, 6 Ft. (1.8m) USB-to-Serial Port Cable, Catalog #: 26-949 (Vista Capable)
  - Sewell, USB-to-Serial Adapter. www.sewelldirect.com
  - *Note: At this time, the Belkin USB-Serial Adapter Model #F5U103 does not work with Controller Pro*
- A 18v minimum power source, if bench programming units.

  (Two 9v batteries in series work well for this application)

Software:

- Controller Pro Software (see http://www.alltraxinc.com/Products_ControllerPro.html and select Download Software

3. Warnings:

Disconnect all battery charging sources while programming the Alltrax Controller.

Any programming changes done in the vehicle should be performed with the vehicle safely disabled. Either put the drive wheels on jack stands, or position the vehicle where it is safe to drive while altering the controller.

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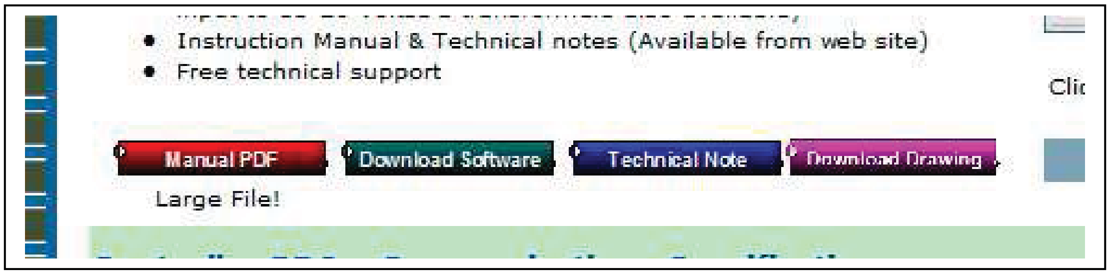
4. Controller Pro Installation:

- Go to http://www.alltraxinc.com/Products_ControllerPro.html
- Scroll about 1/4th of the way down until you see the green "Download Software" button.



- Click on the button.
- Save the file to your desktop.
- Whenever you want to program a controller, you need to double-click on the controller image.

5. Installing the Adapter Cable

- Follow the manufacturer's recommended installation instructions. This installation will require a driver CD supplied WITH the cable. Alltrax does not supply the driver software for the cable, if your cable does not come with the driver CD, contact the cable manufacturer for details.

- Remove the black 2" plug on the top of the controller to expose the DB-9 serial connector.
- Connect the adapter cable from the computer to the connector on the controller and make sure the connections are snug.

6. Powering up the controller:

6.1. Power up outside of a vehicle

6.1.1. AXE:

Connect the negative wire to the B- bus bar. The positive wire is connected to Pin 1. (See Fig 1)

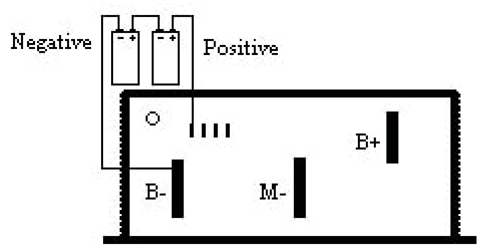


Figure 1

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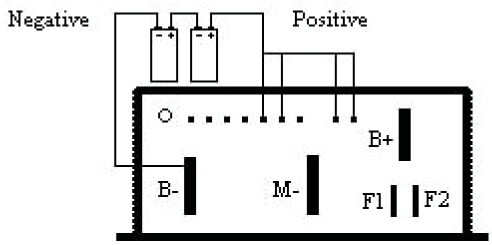
6.1.2. DCX:

Connect the negative wire to the B- bus bar. The positive wire is connected to Pins 5, 6, 9 and 10. (See Fig 2)



Note: Flashing red LED's may appear when the controller is powered up outside of a vehicle, this is normal and will not affect programming the controller.

6.2. Power up in a vehicle:

6.2.1. AXE:

In order for the AXE controller to be powered up, the key switch must be turned on and the throttle foot pedal depressed enough to close the throttle switch. The foot pedal must be depressed the entire time for programming. Once the foot pedal is released, the controller will shut down.

Warning: *Running a series motor unloaded (ie wheels off the ground) can damage the motor. Be sure to take necessary precautions to prevent this by disconnecting the motor or removing the throttle wires for programming.*

6.2.2. DCX:

Turn on the key switch and put the car into Forward or Reverse.

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7. Getting Started

Before you can talk to the Alltrax controller you need to make sure of a couple of things.

- When using the USB to DB-9 adapter cable ensure that the software drivers are installed properly.
- Any battery charging devices need to be disconnected before programming, failure to do so could damage the controller or the computer.
- The controller needs to be powered up BEFORE starting ControllerPro.exe.
- Make sure the vehicle is up on jacks or is in a safe position to be programmed while driven.
- Remove the black plug on the top of the controller to expose the DB-9 programming port on the controller.
- Controller Pro will automatically detect the settings to communicate with the controller, there is no need to set these like with previous versions of Controller Pro know as MotorControl
- Any changes made to the settings of the controller do not take effect in the controller until the Set button has been pushed.

(Note the DCX is shown for reference only – all RS232 ports are in the same location)

8. Quick Programming Guide

Programming the controller is a very simple operation.

- Turn on the computer
- Connect cables from computer to controller
- Power up controller
- Start ControllerPro.exe
- Change the setting(s) to the desired value.
- Press the Set button to program the changes into the controller
- Press the Refresh button to display the updated settings

9. Upgrading Controller Software

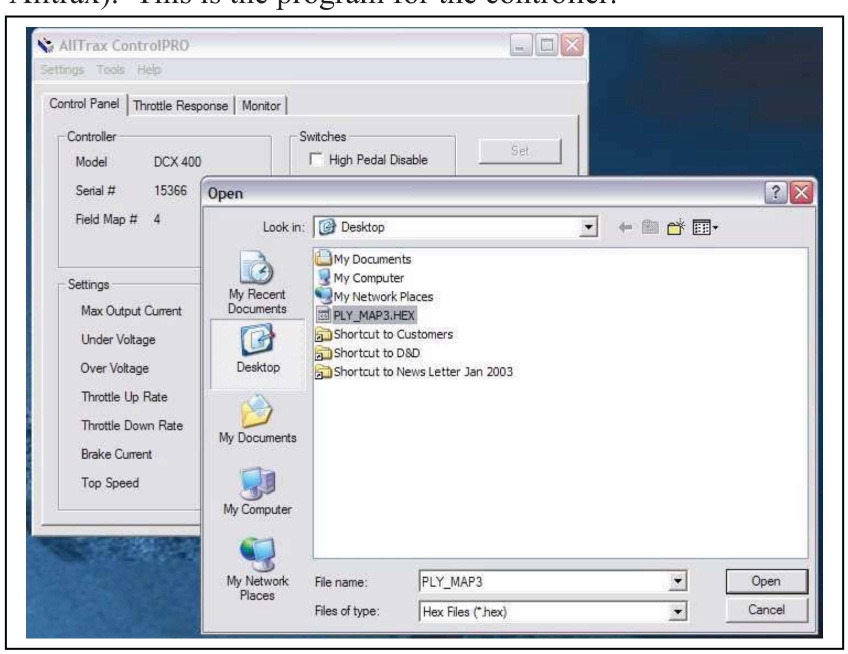
A majority of the Alltrax motor controllers also have the ability to be re-programmed with upgraded software. In most cases, it is not necessary to upgrade the unit's software for stock or aftermarket replacements unless a specific revision is needed for a particular application.

Note: Upgrades are to be only done when directed to do so by Alltrax or one of its Authorized Distributors, Dealers or OEM's.

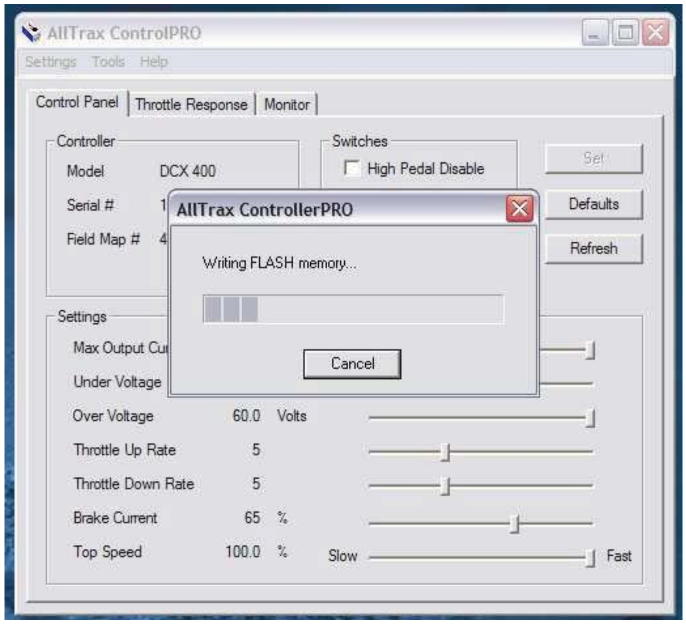
- Power up the controller and start Controller Pro (Sections 5 and 6 details)
- In the Tools menu, select Upgrade (In this example we are upgrading from Field Map 4 to Field Map 9)

- Select the "HEX" file located on your desk top (or other location that you saved the file that was provided by Alltrax). This is the program for the controller.

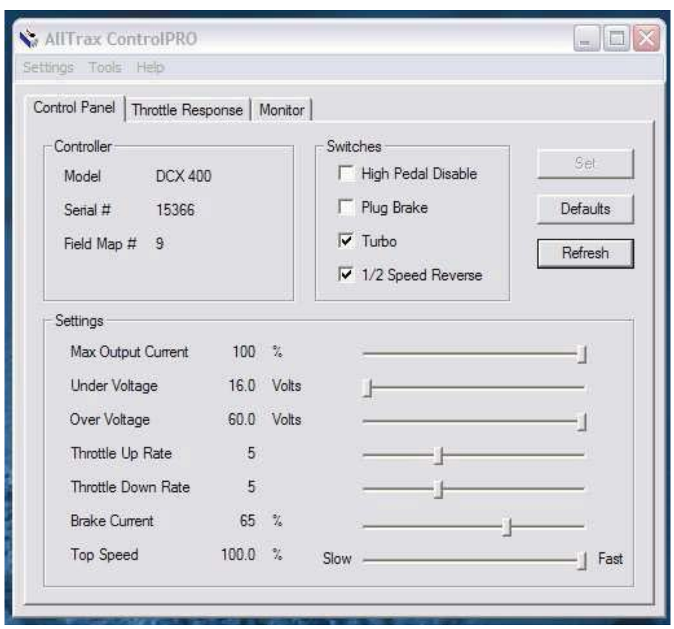
Note: The HEX file name may not match the actual field map – don't confuse the "file name" with "Field Map"



- The Upgrade will program the unit with the new Field Map program and show the controller is writing the program into the controllers flash memory.



- After the program is finished writing the memory locations, hit REFRESH to re-read the program. The field map now shows the new Field Map #



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10. The Interface

10.1. Control Panel

The Control Panel is typically the default screen Controller Pro opens to. (select control panel if not). It is where most of the changes you will make to a controller are made. To change a setting, do the following:

(Sample Image)

There are 3 tabs on the Control Panel screen that are important to programming a controller.

Set - This is button is what uploads any changes made to the controller. Until this button is pressed, no changes are made to the controller.

Defaults – This button changes the settings to the factory default mode. Set still must be pressed to change the settings in the controller

Refresh – This refreshes the connection if power is lost while using Controller Pro, it is also used to verify the settings were changed. If the settings change after pressing Refresh, they were not saved in the controller.

10.1.1. Switches and Settings

High Pedal Disable – AXE and DCX Models

Checking this box enables HPD, which will prevent the controller from providing output power in the event the throttle is applied when the controller is powered on. When this box is clear, the controller will start up and provide output power, when KSI energized, if the throttle is depressed.

Plug Brake – AXE and DCX Models

AXE "P" models

Checking this box enable plug braking on those controllers equipped with an A2 bus bar terminal. Plug braking on AXE controllers is proportional to throttle position, reaching full braking force at about 25% of throttle travel. Deselecting this box disables plug braking. The unit will apply normal power to motor if direction is reversed. (Vehicle may jerk or spin tires if motor direction is reversed while in motion). (Plug brake takes effect after a power cycle when this option is changed)

DCX Models

Checking this box enables "throttle off braking". When the throttle pedal is returned to a zero or off position, the controller will go into a plug brake mode. This will slow the vehicle down but does not provide an regenerative functionality. The amount of braking force is controlled by the Brake Current Slider.

Turbo – DCX models only

This feature enables a turbo boost mode when enabled. It only goes into and stays in turbo mode when two conditions are met. The throttle position is at 100% for at least 1 second and the controller is not in current limit. The controller will adjust the field map to allow for extra speed while those conditions are met.

½ Speed Reverse – AXE and DCX Models

Checking this box enables ½ Speed reverse. When reversing this limits the vehicle speed to half of the throttle position. Top speed is reduced by half by this setting. Disabling ½ Speed Reverse does not reduce the vehicle speed when going in reverse.

Max Output Current – All models

This slider sets the maximum output current the controller can supply to the motor. Output current is adjusted as a percentage of maximum rated current of the controller. For example, an AXE4844 can supply a maximum of 400A with the slider at 100%, 300A at 75% and 200A at 50%.

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Under Voltage – All models

This slider sets the under voltage shut off of the controller. It prevents battery damage by turning off the controller in case the battery voltage drops too low. Generally speaking, it is undesirable to pull the terminal voltage of a 6V lead-acid battery below 4.0V, for example 24V on a 36V system. Adjusting this slider increments the under voltage setting in 1/10ths of a volts.

Over Voltage – All models

This slider sets the over voltage shut off of the controller. It prevents damage to the controller in an over voltage situation. If the batteries get over charged or any other situation that exceeds the voltage rating of the controller, the controller will shut down. Adjusting this slider increments the over voltage setting in 1/10ths of a volts.

Throttle Up Rate – All models

This slider adjusts the rate the controller output current responds to an increase in throttle position. The rate of increase is on a scale of 1 to 15, with 1 being the slowest and 15 being the fastest. Typical settings are between 3-8.

Throttle Down Rate – All models

This slider adjusts the rate the controller output current responds to an decrease in throttle position. The rate of increase is on a scale of 1 to 15, with 1 being the slowest setting It is recommended that this parameter typically be set to twice the value of the throttle up rate, when throttle up rate is less than 7.

Brake Current – AXE "P" and DCX models

On AXE models equipped with a plug brake (suffix "P" in the model number), this slider adjusts the amount of brake current as a percent of 100A of brake current. Refer to AXE specifications for maximum available brake current depending on the model of controller.

On DCX models, this is the Regen feature. The setting is the percentage of possible current available. This all depends on the motor. A hi-torque low-speed motor needs a lower percentage value and a hi-speed low-torque motor needs a higher value. (Note: On 48v systems, the Regen feature may not turn on due to the higher RPM needed to switch this function on.)

Top Speed – All Models

This slider sets the top speed of the vehicle as a percentage of top speed. The controller applies this percentage to the actual throttle position. If the slider is set to 75%, whatever the actual throttle position is, the controller interprets it as 3/4ths that position.

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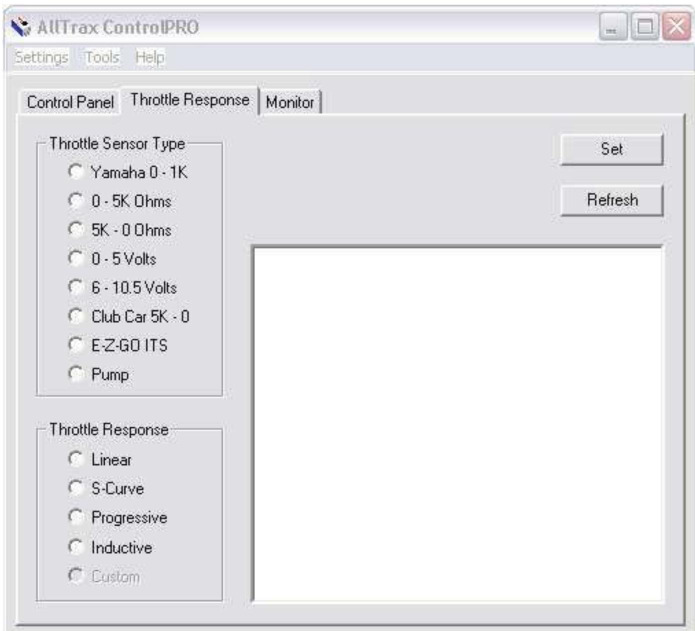
10.2. Throttle Response

This panel is where you can make changes to the throttle type and throttle curve. The curve is the behavior of the controller at various throttle positions. Any change to the throttle setting will take effect immediately.



(Sample Image)

10.2.1. Throttle Sensor Types

The following is a list of all the supported throttle types and the most common vehicle that uses the throttle. By no means is this an exhaustive or complete list.

Yamaha 0-1k – AXE models

Typically used on the Yamaha Mid 92-94, G9, G14 & G16

0-5k – AXE and DCX models

Typically used on 95 and older Club Cars, 94 and older EZ-GO Marathons & Yamaha G8

5k-0 – AXE and DCX models

Typically used on Melex Cars

0-5 Volts – AXE models

6-10.5 Volts – AXE models
Typically used on Taylor Dunn cars

Club Car 5k-0 3 wire – AXE models (Also known as V-Glide or M-Core throttles)
Typically used in 96 and newer Club Cars

EZ-GO ITS – AXE and DCX models
Typically used on all PDS and DCS, 95 and newer Medalist and TXT EZ-GO, Yamaha G19 and Club Car Regen2/PD+

Pump – AXE models
This sensor setting treats any throttle position as 100% throttle. Throttle ramp rates still function.

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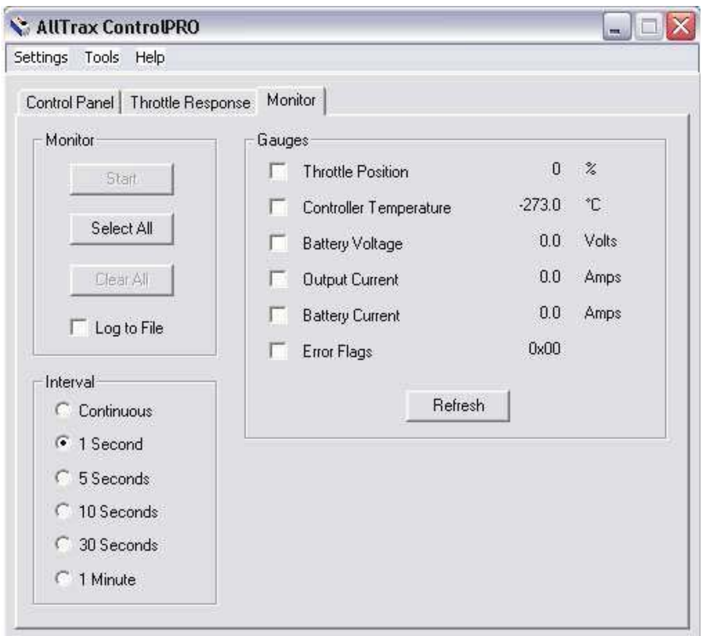
10.3. Monitor

This screen is the status monitor of the controller, it gives you the ability to measure and record numerous operating parameters of the motor controller and the vehicle in which it is installed. When used with a Notebook computer, both real-time data display and data logging may be performed while the vehicle is in use. This gives the vehicle designer significant insight to the interaction of the motor controller with other system components. Log files may be used for problem analysis and diagnostics. You can email the log file to Alltraxinc.com for a detailed analysis by our applications engineers.



(Sample Image)

10.3.1. Monitor

Start/Stop – This starts and stops the data measurement process

Select All – Checks all the gauges

Clear All – Deselects all the gauges

10.3.2. Interval

This checkbox selects the update rate, or frequency of data collection. For real time display, select continuous. When used in conjunction with “Log to File”, a slower update rate may be more desirable to reduce the amount of raw data being gathered.

10.3.3. Gauges

These are the motor controller parameters which are to be monitored. Checking an adjacent box enables that measurement. Clicking "Refresh" will perform a one-time update to the gauges which are selected. It is generally recommended that you select all the gauges, as this will provide the most insight into the operation of the controller.

Throttle Position

This gauge displays the % of total throttle output. For example 50% would be at ½ throttle. The displayed parameter is the actual throttle position, limited by the fact that the controller could be in current limit. If the controller's output current reaches the maximum rating, the throttle position won't advance any further, regardless if the throttle is full on.

Controller Temperature

This is the internal temperature of the controller, in Celsius. Accuracy: +/- 5%.

Battery Voltage

This is the voltage present across the B+ and B- bus bars of the controller. Exception: Club Car compatible models. This is the voltage present across the KSI input to B- bus bar of the DCX controller. Accuracy: +/- 5%

Output Current

This is the measured output or motor current of the controller. Accuracy +/-10%

Battery Current

This is the calculated input or battery current to the controller. It is calculated as: Battery current = motor current times throttle position %. It is accurate, given that motor current is continuous (which it generally is with any series motor), not discontinuous. Accuracy: +/- 10%

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Error Flags

This register should display as 0x00 during normal operation. Any value greater than zero is an error, and the controller will not provide any output power. The following is a list of errors that might appear during monitoring. Each of errors has a code that blinks Red on the LED on the front panel.

0x01 = Throttle Position Sensor Over Range

0x02 = Under Temperature. Controller below -25°C

0x04 = HPD. Throttle hasn't gone to zero during this power on cycle.

0x08 = Over Temperature. Controller over 95°C

0x10 = Open Field (DCX Only)

0x20 = Battery Under Voltage detected. Battery V < undervoltage slider

0x40 = Battery Over Voltage detected. Battery V > overvoltage slider

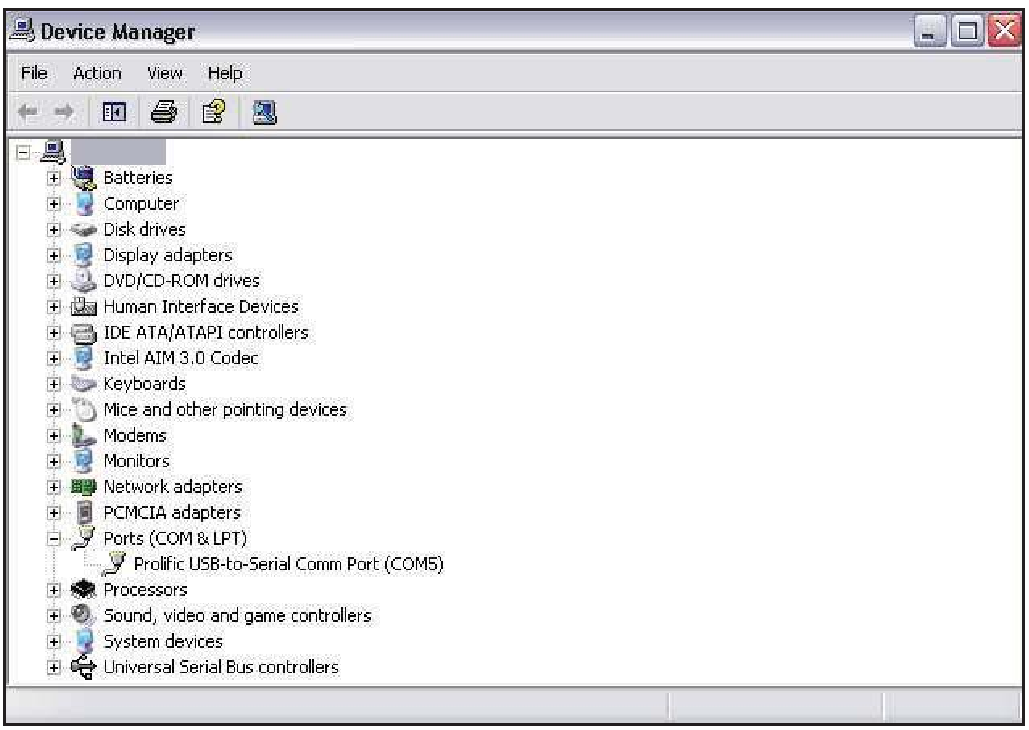
0x80 = Controller in boot sequence. Occurs within 25mS of power up.

If any other number appears as an error code, contact Alltrax Technical Support for more assistance.

11. Troubleshooting

11.1. Controller Not Responding Error message

- Make sure the controller is powered up with at least 18v
- Check all connections
- Check to see if the driver was installed for the USB cable:
    - Go to Start > Settings > Control Panel > System > Hardware > Device Manager



- The screen should look something like the above picture, change the location of the cable and see if the Com port changes with each move. If it doesn't, reinstall the driver software.
- If the COM Port number is above 15, go to the next section to change it. ControllerPro will only talk to the controller on COM1 – COM8.

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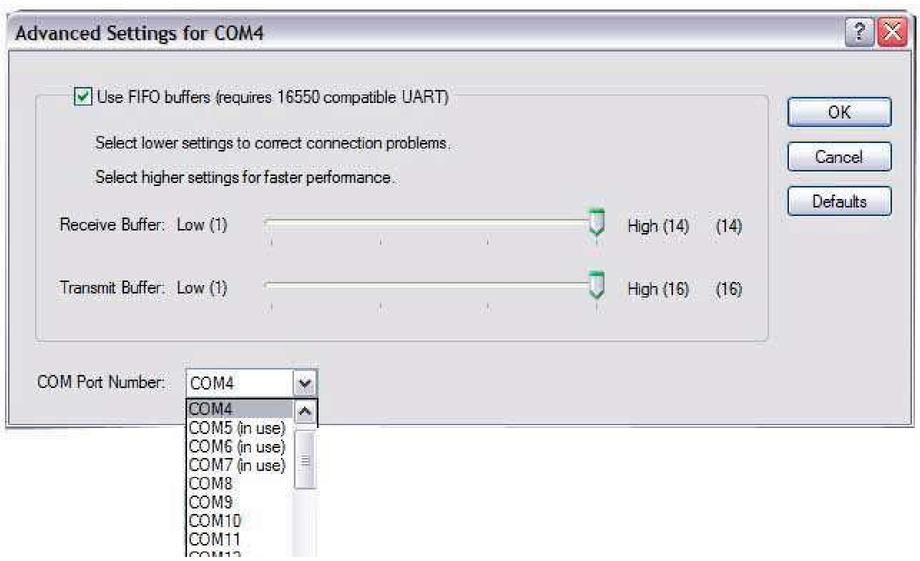
- Verify the com port settings are correct or to change the COM port number:
  - Get to the Device Manager screen the same way as in the previous step.
  - Right click on the cable, and select properties.

  - Make sure the settings match the above picture

If the COM port needs to be changed, press the Advance button on the Port Settings screen. A new screen will appear.



- To change the COM port, pick a COM port that is COM8 or lower that is not marked "(in use)"
- Hit the "OK" button on both the Advanced Settings Window and the Port Settings Window to make the changes take effect.

- Is the cable a Belkin adapter cable?
  - **Alltrax have experienced customer problems when using this adapter cable and it is not recommended for use with Alltrax products.**

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11.2. Changes to settings are not taking effect

- Press the Set button
- Press Refresh to update the screen
- Turn off controller, and then back on. Then restart Controller Pro program.

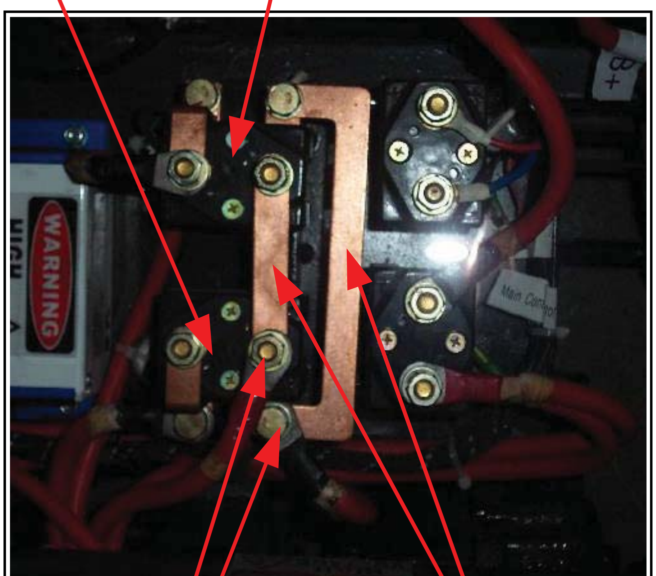
"The company was founded at the track"

Xebra Vehicle Contactor Rewiring

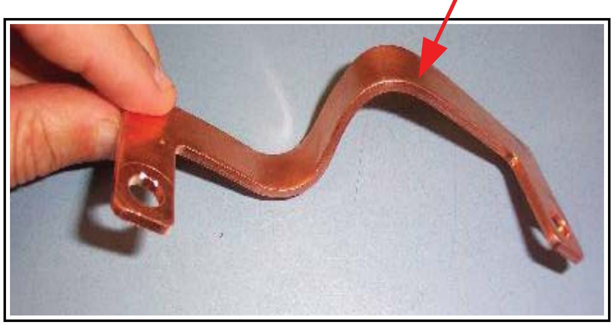
Last updated May 22, 2007

Intended Readers
The purpose of this manual is to provide a qualified electric car mechanic or technician with the information to correct the addressed service issues. Check with ZAP if you are unsure who to have do the work. ZAP is not responsible for damage to your vehicle or personal injury for work done by non-qualified personnel.

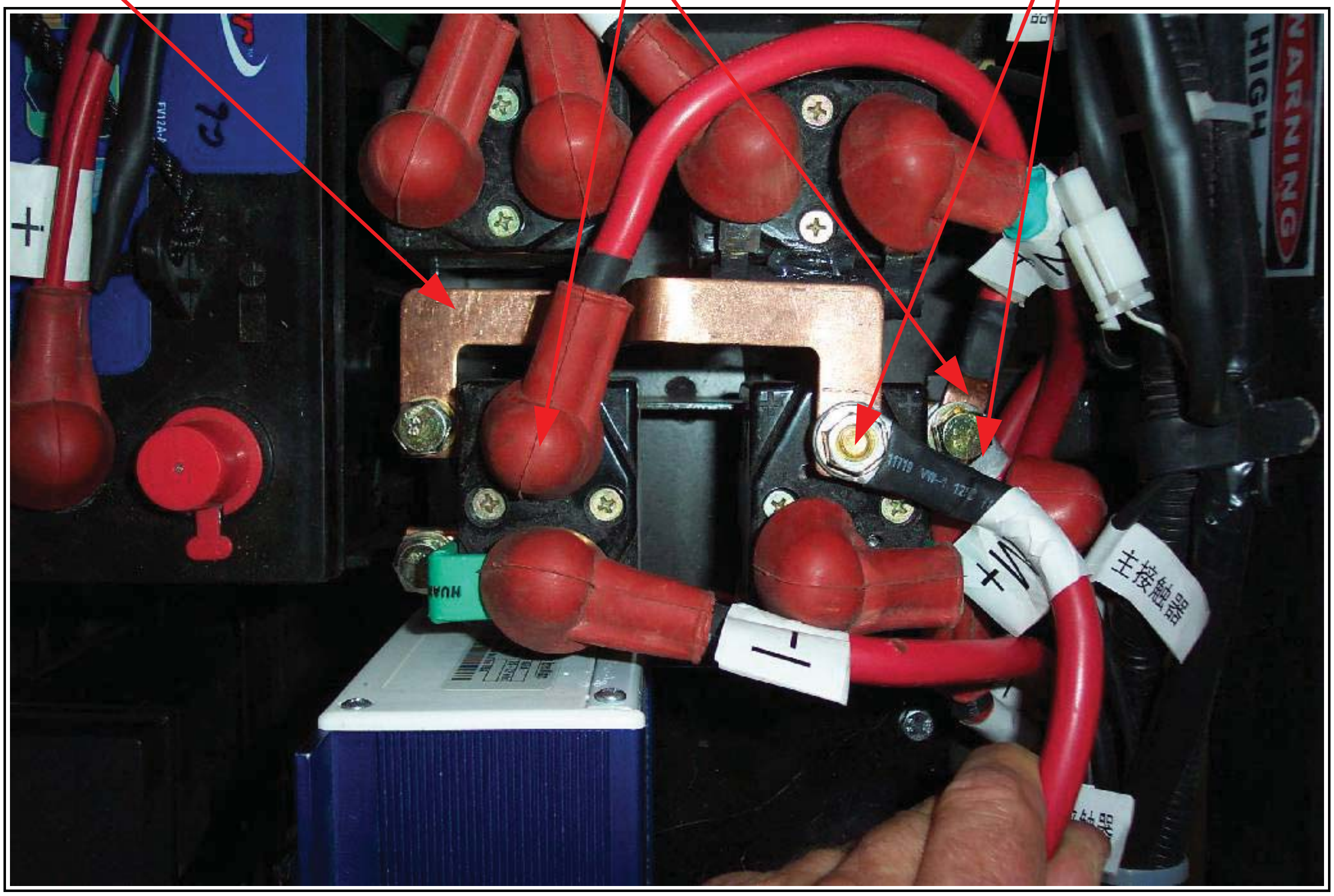
The purpose of this document is to describe how to rewire the forward and reverse contactors so both are energized in the forward direction and neither are energized in the reverse direction. Having all contactors powered during forward driving prevents the reverse contactor from chattering and arcing thus extending the life of the contactor. Your original wiring will look like the following and the reverse (J2) and forward (J3) contactors are here.



Remove the two wires and two copper bus bars. Upon reassembly the two wires will reverse positions. Bend the long copper bar as shown.



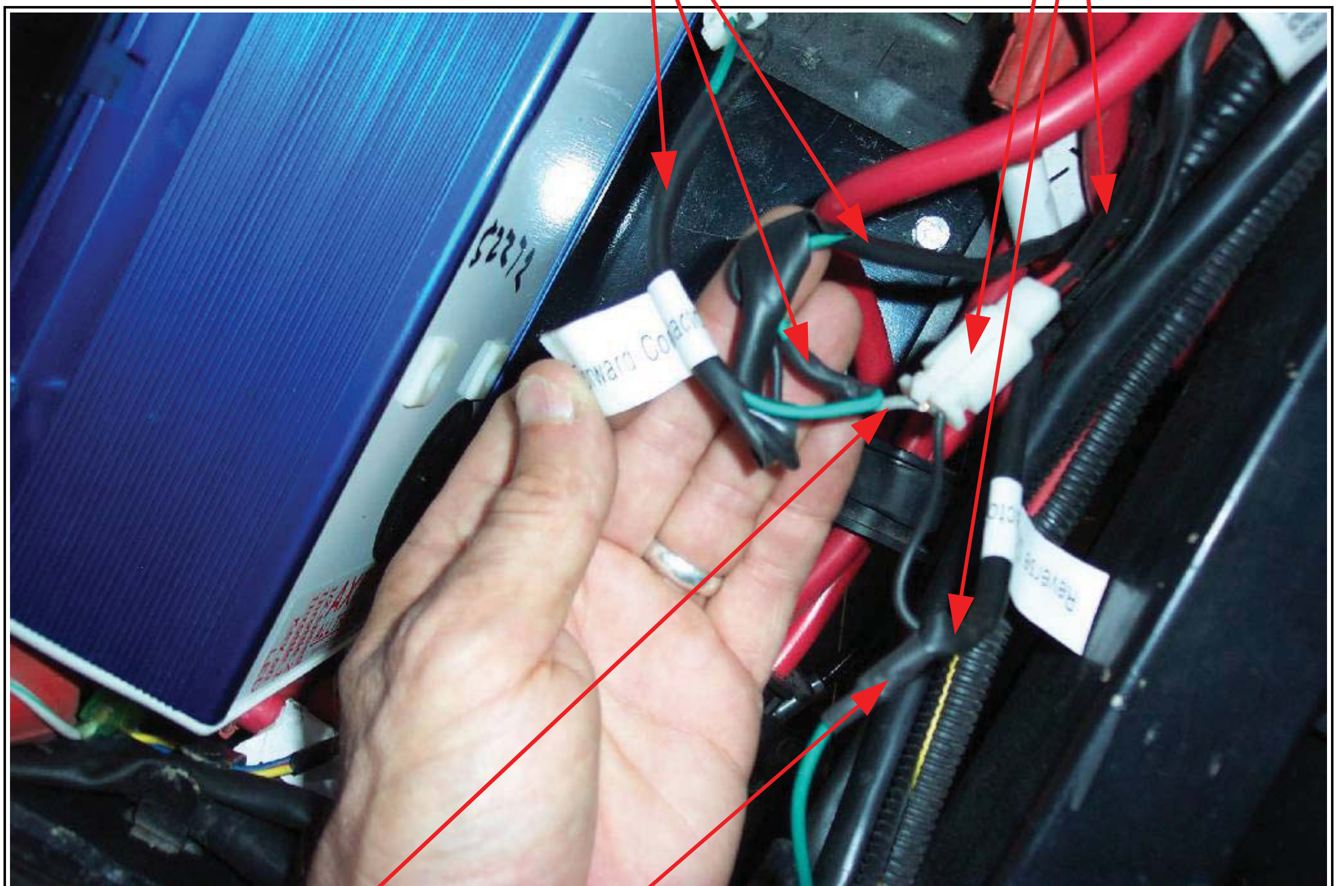
Now reassemble as shown below.
Bent bar here. Can't use old short bar so jumper here. These two connections reversed.



Power to the forward contactor coil J3 must also be connected to the reverse contactor coil J2 because both contactors are powered in the forward direction and neither are powered in the reverse direction.

Below is an example of how a PK has been modified. This is the reverse contactor wire harness.

The forward contactor wires

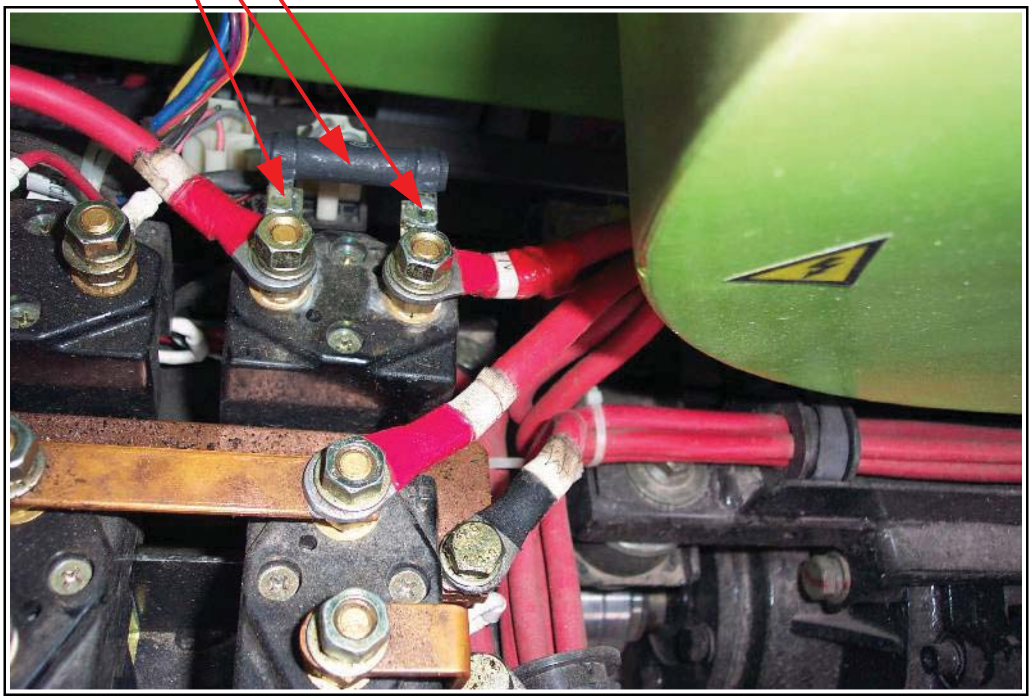


The reverse contactor wire is cut here about one inch from the reverse connector and spliced into the forward contactor wire. The old reverse contactor wire is spliced to a wire that goes to the half speed reverse input of the controller.

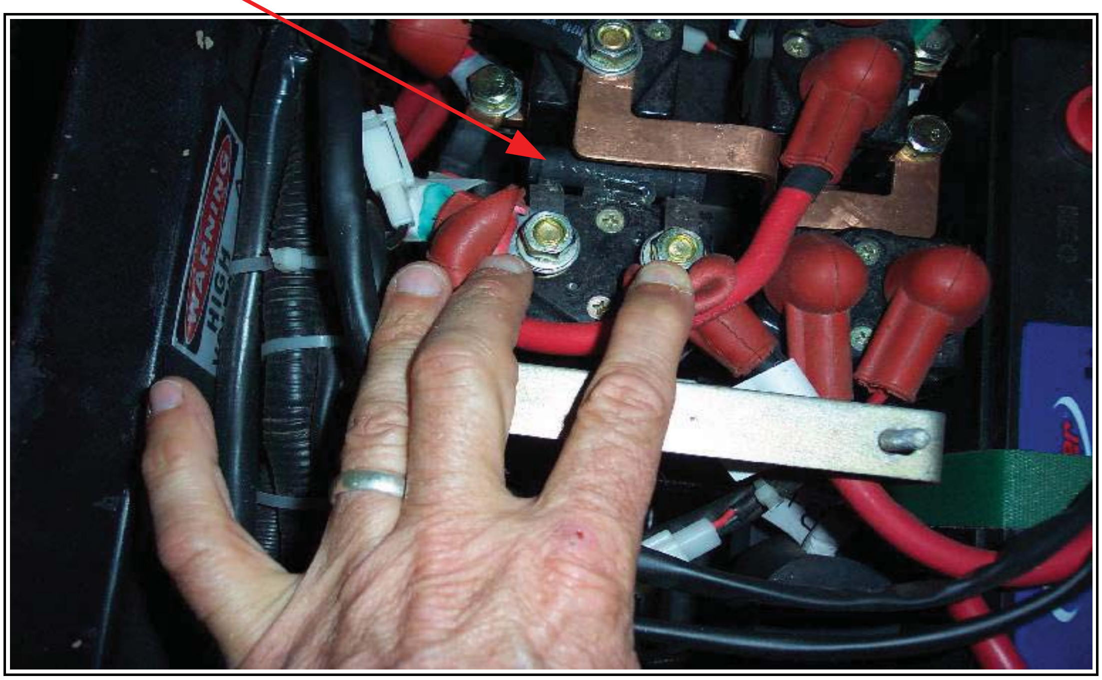
Currently the Alltrax controller does use the reverse wire and the Curtis does not. Be sure and wrap the reverse contactor wire in electrical tape to prevent shorts if not used.

Also, make sure you have a 1K precharge resistor here if you have the Alltrax controller. This resistor extends the life of the capacitors in the Alltrax controller.

For Alltrax controllers a 1K ohm precharge resistor should be placed across the main contactor as shown.

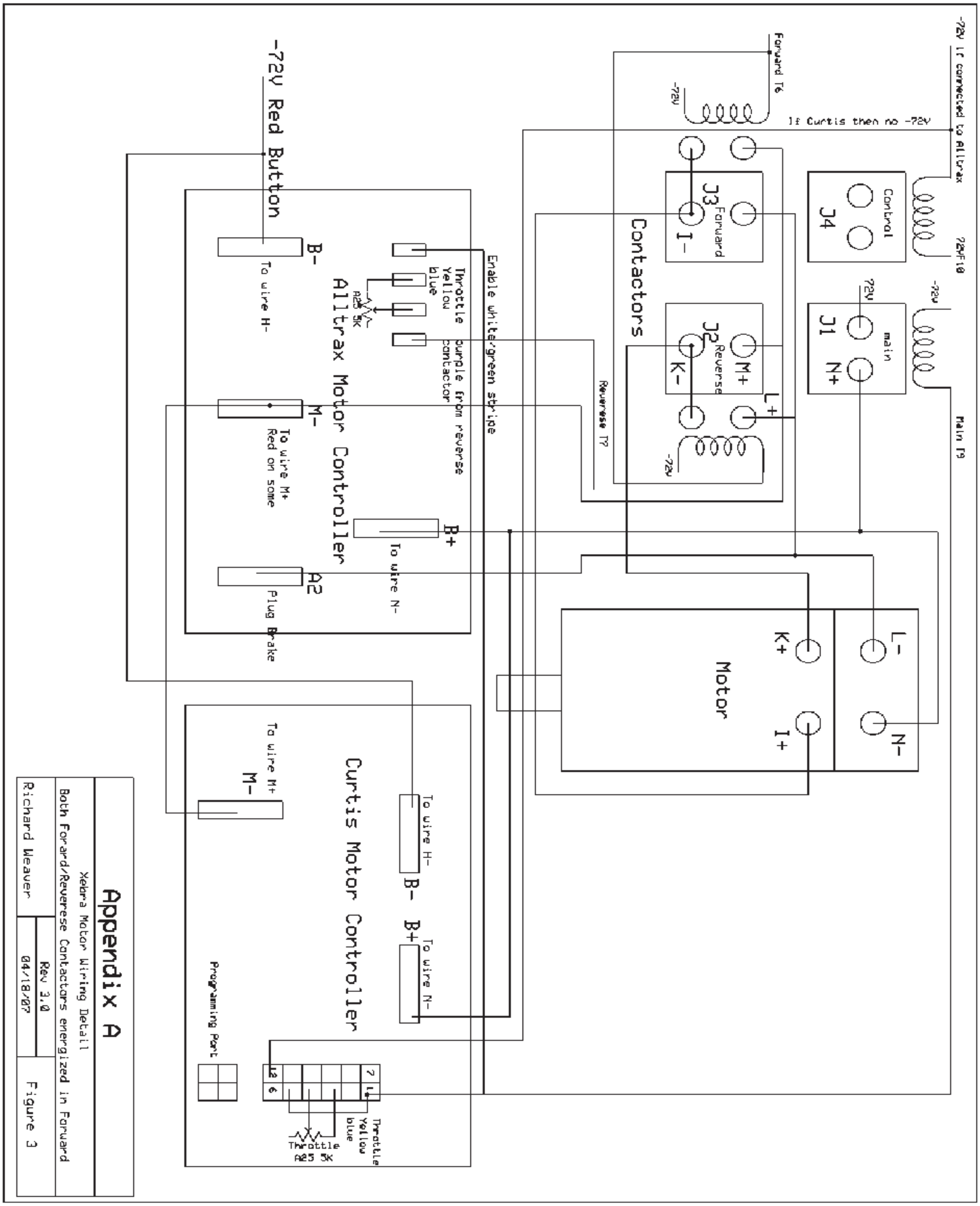


Same for the PK.

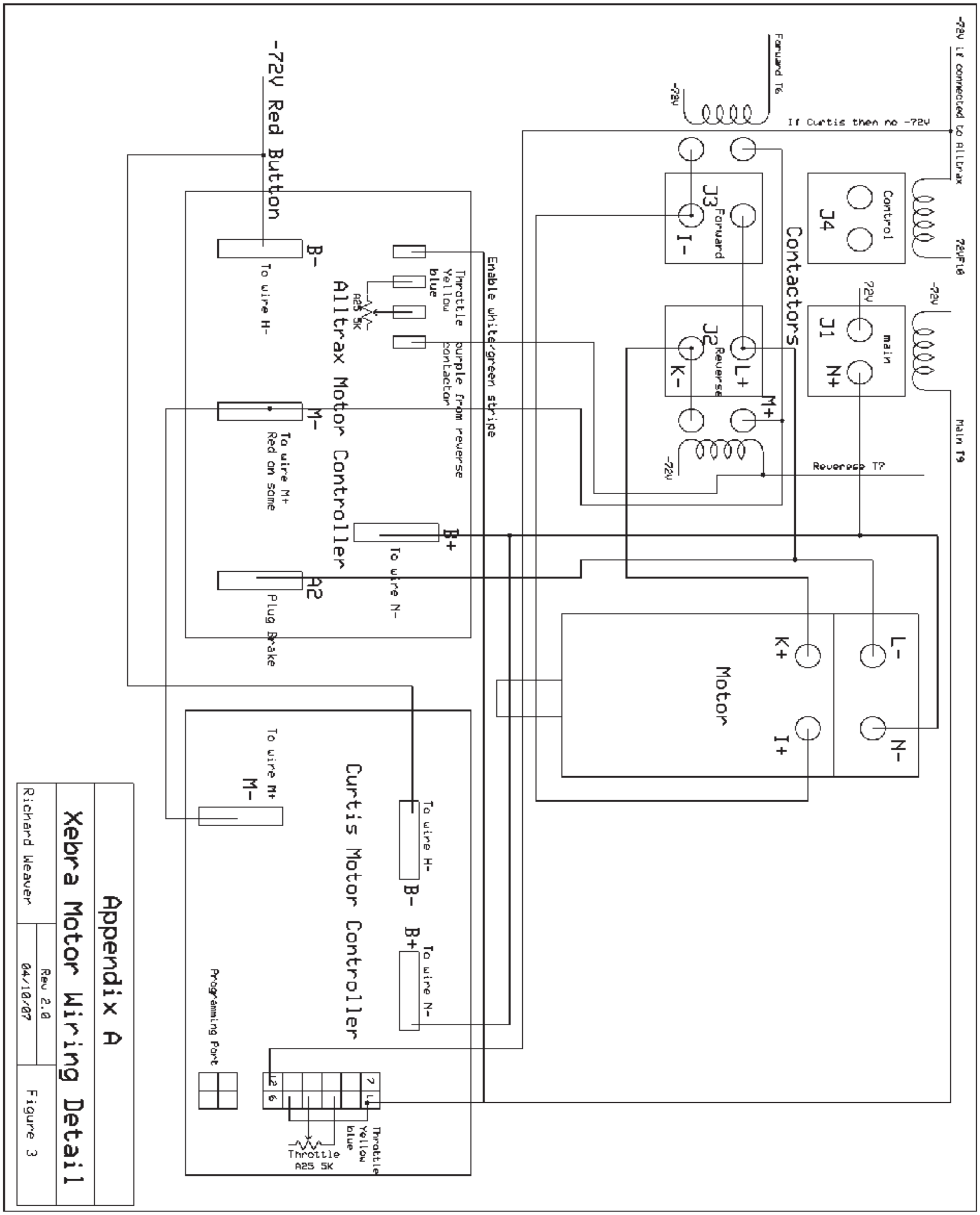


If you have a Curtis controller then you do not need to worry about installing this resistor.

The new contactor wiring diagram.



The old contactor wiring diagram.



Installation Guide: Battery Fuse

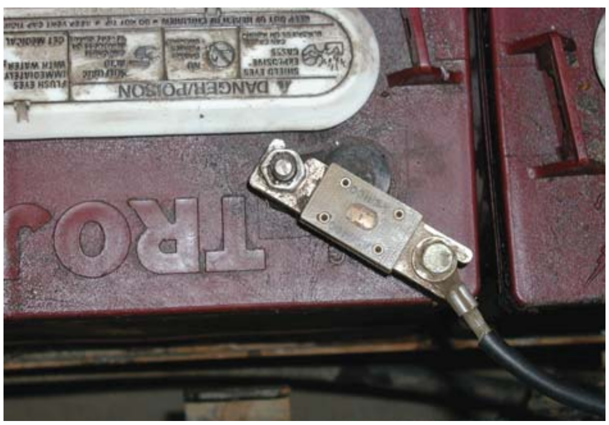
Damon Crockett
Dir Engineering
ALLTRAX Inc.

June 01, 2006

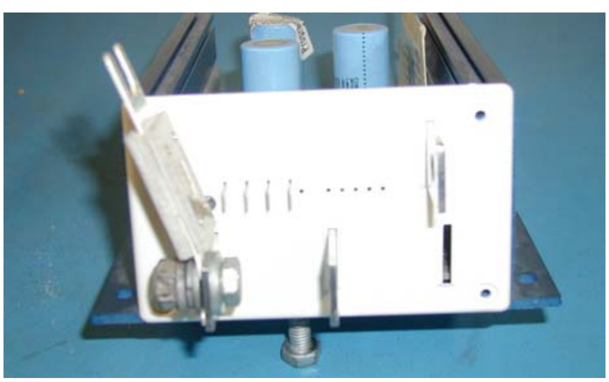
FUSE INSTALLATION GUIDE

Alltrax recommends that all motor controller applications have a fuse in the battery circuit. Many vehicles do not have a fuse. Follow these guidelines to determine a suitable location. The fuse may be installed anywhere in the battery string or at either [+] or [-] end of the battery pack where it connects to the controller or solenoid.

Controller Rated Current:	Recommended Fuse:
400 amps or less	ANN250 Bussman or Littlefuse
450 amps or more	ANN400 Bussman or Littlefuse



Example 1: On Battery



Example 2: On Controller B- bar

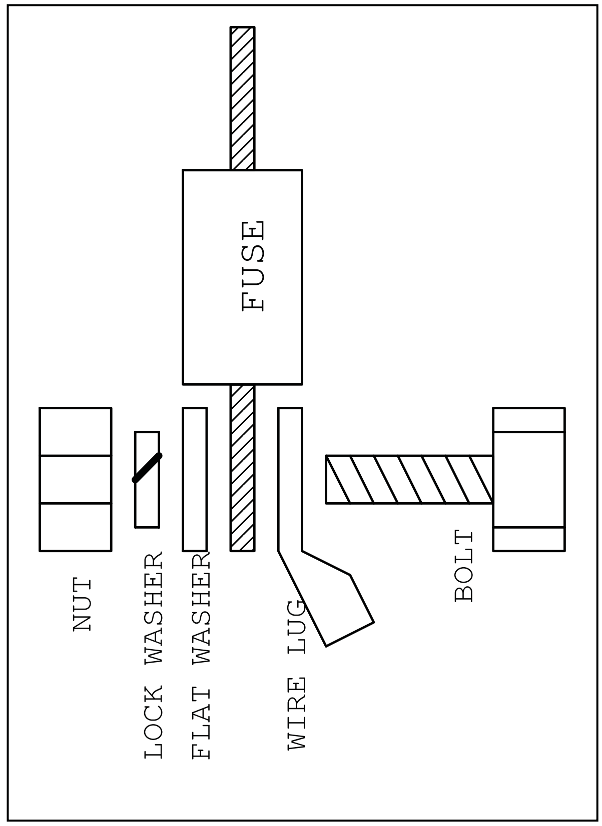


Diagram: Fuse terminal hardware

For Technical Assistance, please call 541-476-3565

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Appendix XXVII

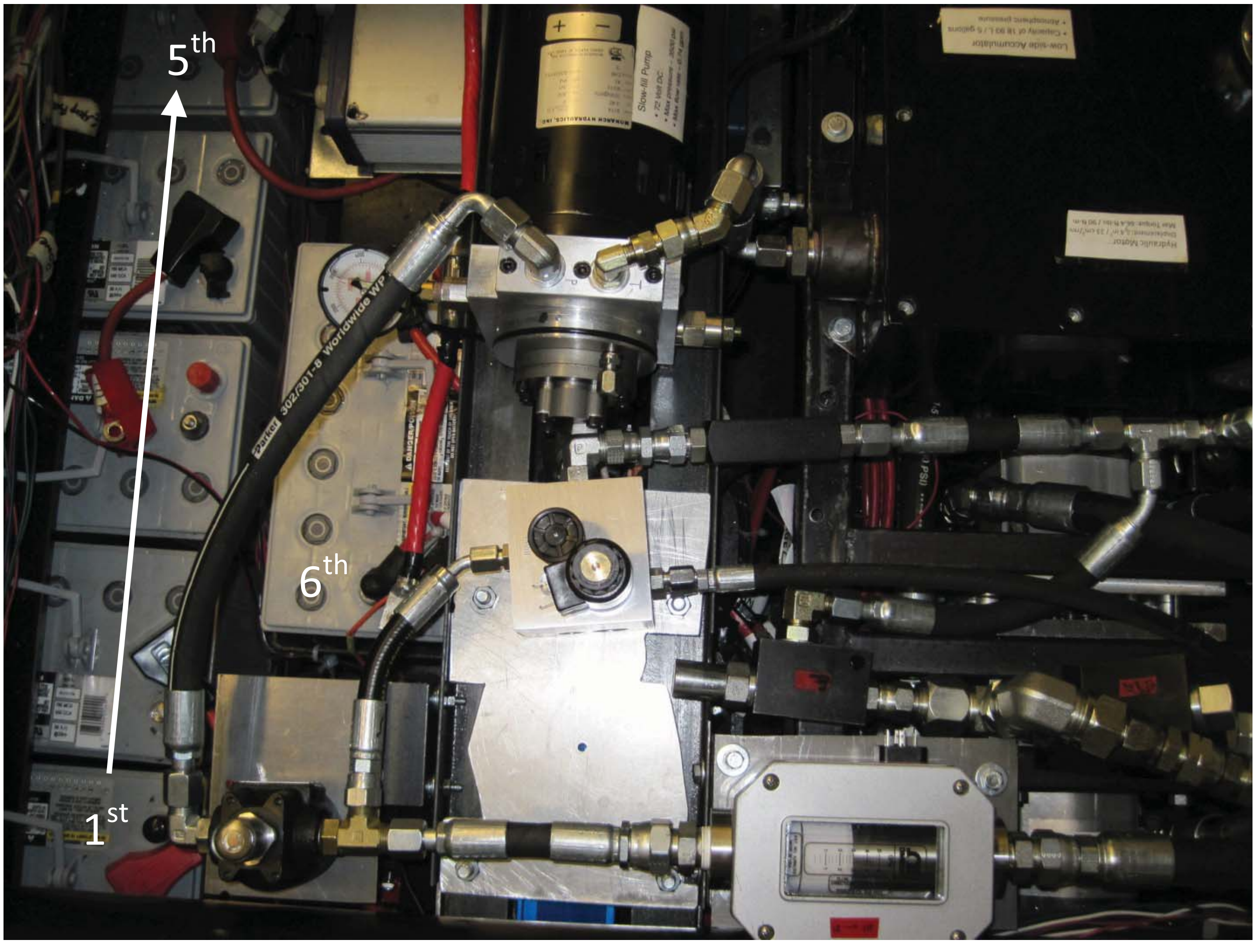
Battery Accessing Manual

The battery pack on the Xebra PK Truck has a total voltage of 72volts. While this voltage may not be enough to cause serious injury to human, the consequences of improper safety precautions in handling the batteries are capable of causing irreversible injuries and even ***death***.

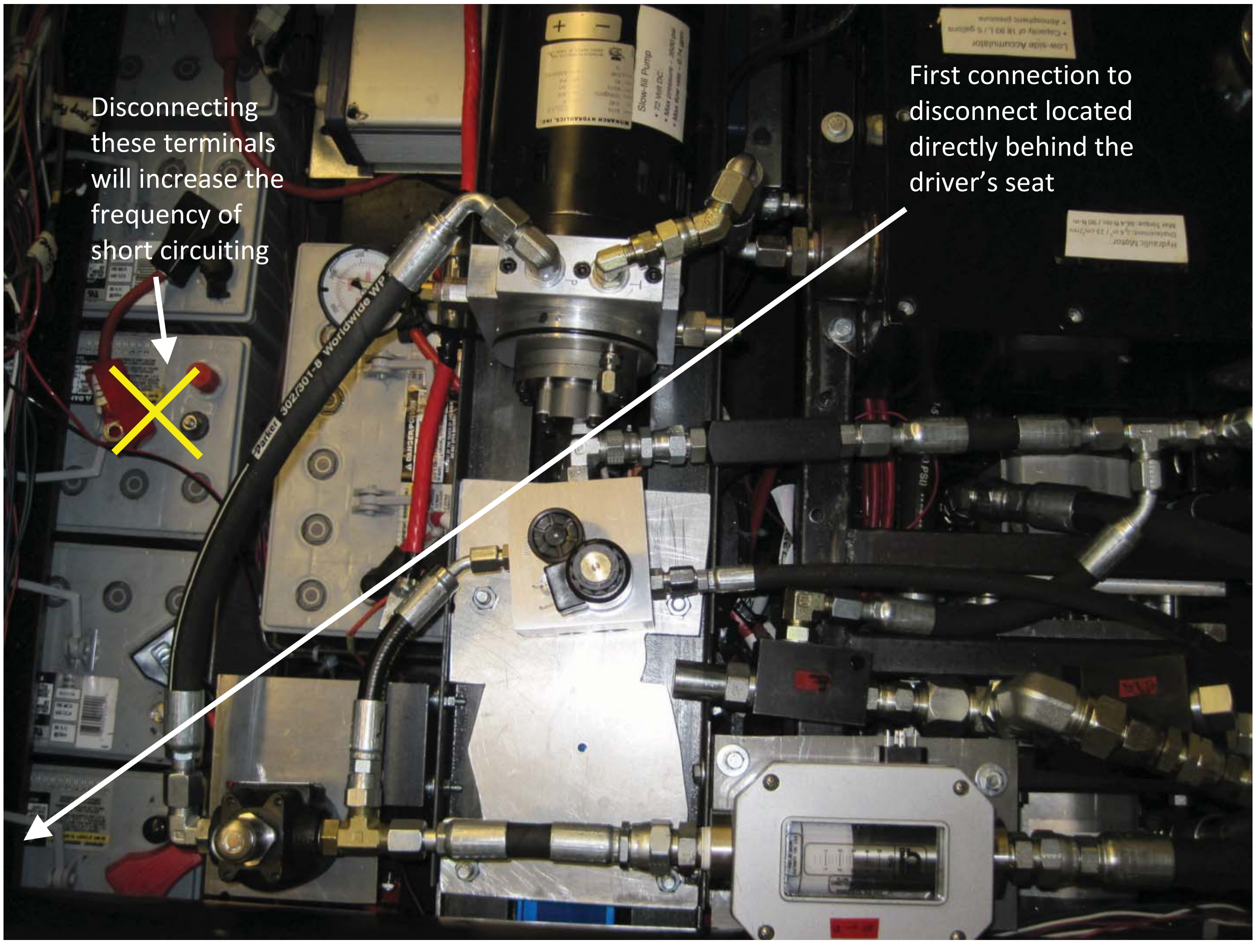
Throughout our time with the Xebra, we observed evidence of misuse in the form of 'spot welds' that resulted from an unexpected short created from a high voltage component and the frame of the vehicle (ground). These happenings can cause sparks in the proximity of the lead acid batteries that are present on the vehicle. These sparks can potentially cause the batteries to ***explode*** by igniting the highly flammable gases that are vented from the battery during operation. A battery explosion can cause permanent blindness, deafness, or even death.

In discovering these safety concerns associated with the vehicle, we are including this detailed procedure specifically for removing the batteries, **but steps 1 through 5 should be followed before doing even routine maintenance on the vehicle.**

1. Understand the layout of the system and the naming convention that will be used in the rest of the report. The batteries will be labeled 1st through 6th according to the following figure. With all terminals connected the positive terminals of batteries 1 through 6 hold voltages of 12 to 72 volts in increments of 12V.



2. Disconnect the negative terminal (black) of the 1st battery. This will eliminate any chance of current to flow through the circuit, however, the voltage still remain.



3. Disconnect the negative terminals of the remaining batteries in series (battery 2 through battery 6 in order) to reduce the level of voltage carried by a single terminal.

    A number of negative terminals are difficult to reach and attempting to loosen the nut/bolt connection may increase the chances of a short circuit. As a result, investigate the voltage state of the surrounding components and be aware of any potential differences. At the end of this step, no single terminal of the battery pack should hold more than 12V.

4. Disconnect and insulate the positive terminal of the 6th battery.

    At the end of the battery pack, the 72 volts are transferred to a number of components throughout the system (solenoid contactor, forward reverse contactor, electric motor, etc.) that will hold 72 volts as well if this connection is not disconnected. An updated Xebra vehicle purchased by the EPA has these terminals properly insulated with thick rubber caps (figure x). The currently available vehicle lacks some of these insulations.

5. Wait 10 minutes before performing any work on the vehicle.

    The internal resistances of the vehicle require this time to sufficiently drop the residual voltage level of subsequent components. Failure to perform step 4 will create a number of connections that hold 12 volts. Failure to perform steps 3 and 4 will create a number of 72 volt connections throughout the vehicle. While 12 volts may seem harmless, it is enough to create sparks if short circuited. These sparks could potentially cause the batteries to explode as discussed above.

6. Remove the 6th battery and the 3rd battery (in that order)

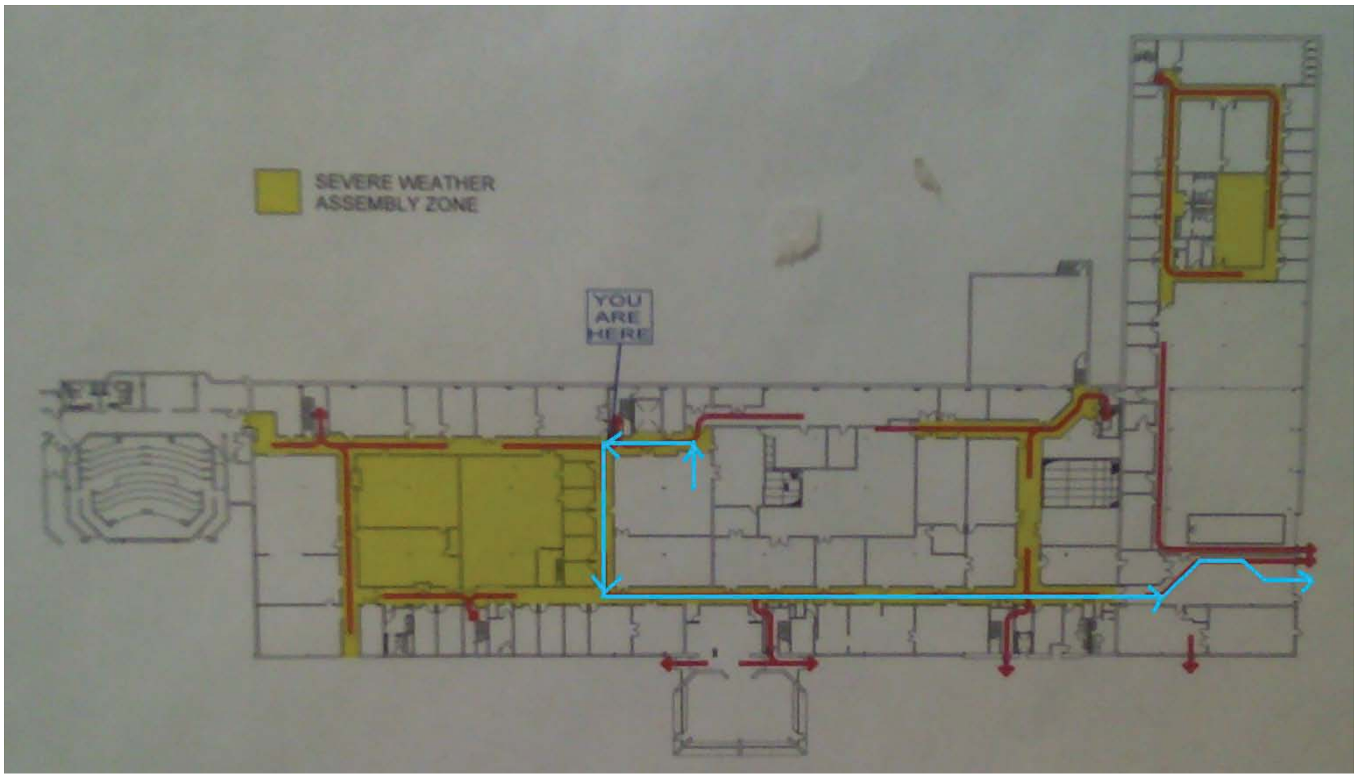
    Removing the 6th battery will create enough space for the 3rd battery to be removed. Removal of the 3rd battery will allow for lateral movement between batteries 1, 2, 4, and 5. This movement is essential for successful removal of the remaining batteries.

7. Remove the remaining batteries.

Appendix XXVIII

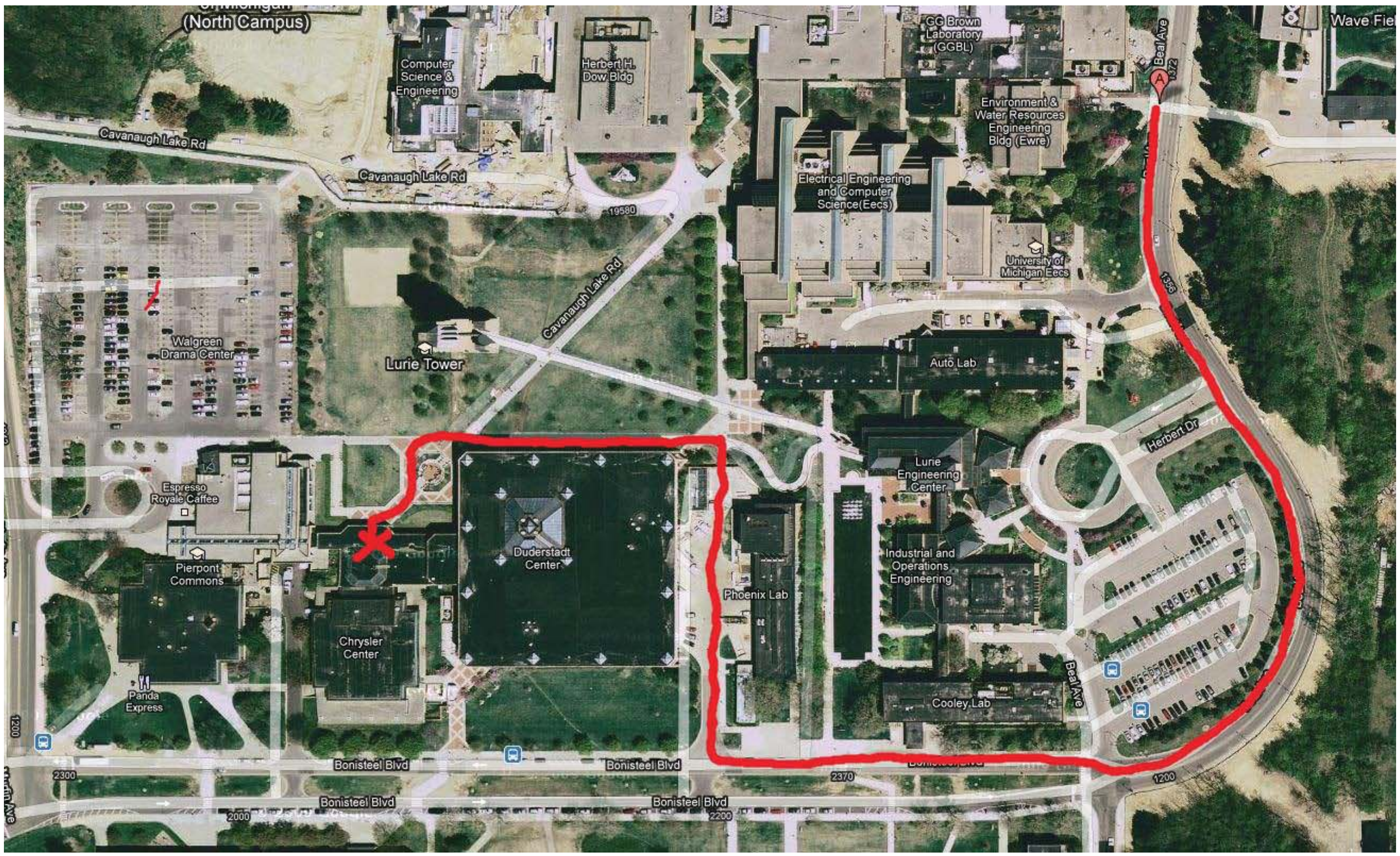
Inside the G.G. Brown Laboratory

The vehicle is disconnected in the X50 lab now for safety. We will connect the batteries back and ensure that all the connections are secure. Then we will lower the hydraulic jack and let the wheels of the vehicle touch the ground and release the hand brake. We are able to pull the chain and open the door of the assembly room and push the car along the hall way (shown in the figure below, highlighted in light blue) all the way to the loading dock in the 1st floor of G. G. Brown Laboratory. The door of the loading dock is controlled by an electric switch and we have tried and successfully opened it. So the vehicle will be pushed out of the door and be at outside of the building.



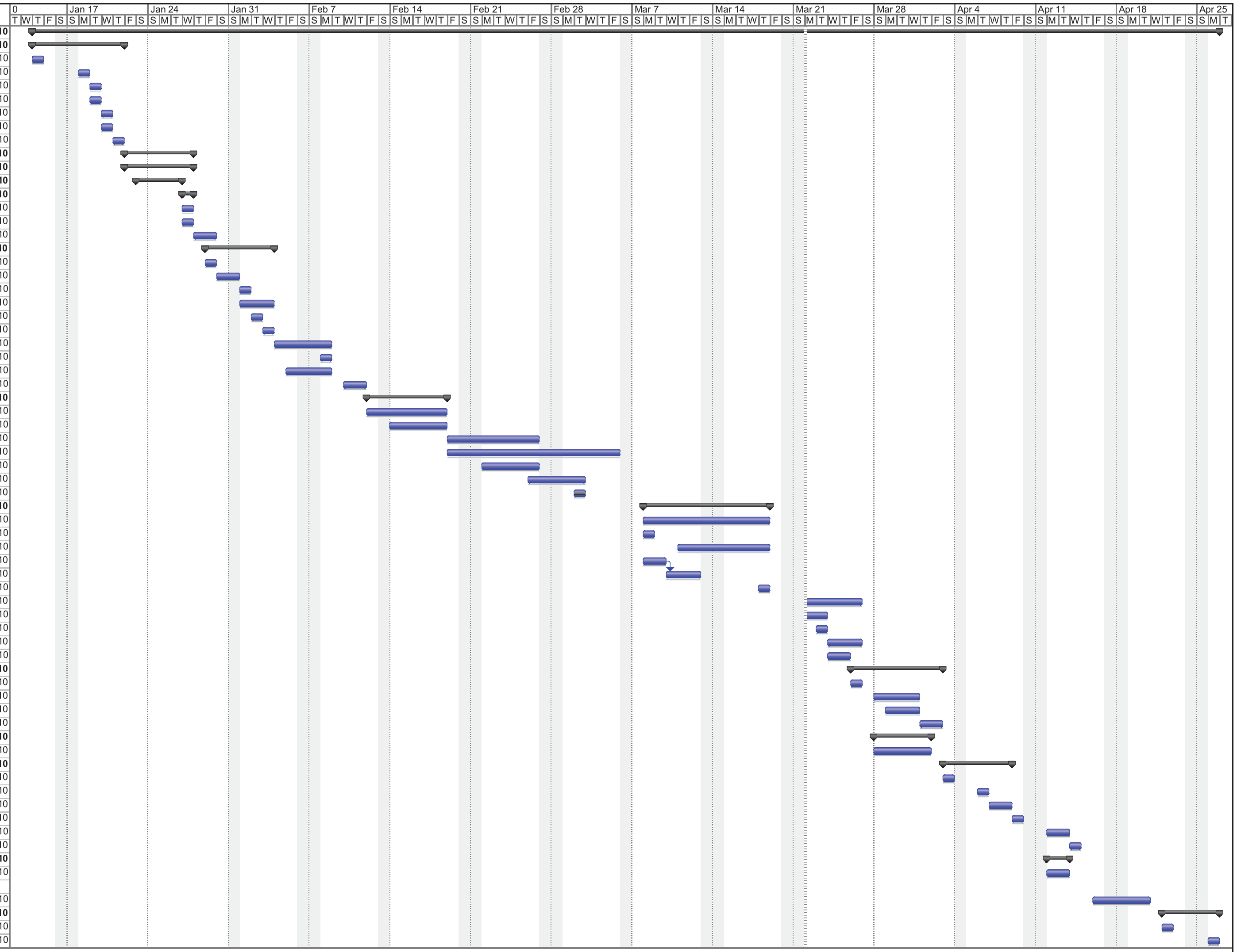
Outside the G.G. Brown Laboratory

After we successfully move the vehicle out of the loading dock of the first floor of G.G. Brown Laboratory, we will start the vehicle and drive to the Duderstadt center. Kevin Lyons will be the driver and no passenger is allowed on board. Eric will drive his car in front of the vehicle and Andres will drive the car following the vehicle. The speed will be kept below 5 mph and we will yield to any passing vehicle. Chen will walk along with the vehicle in case any driver did not understand. The route of the moving process is shown below in the Google maps screen shot. The route is selected in such way that it is the shortest and can avoid most of the pedestrians in the North Diag and Pierpont Commons building.



Appendix XXIX

ID	Task Name	Duration	Start	Finish
1	**ME450**	**81 days?**	**Thu 1/14/10**	**Mon 4/26/10**
2	**Preliminary stage**	**6 days**	**Thu 1/14/10**	**Thu 1/21/10**
3	First Sponsor meeting	1 day	Thu 1/14/10	Thu 1/14/10
4	First Team meeting	1 day	Mon 1/18/10	Mon 1/18/10
5	Gant Chart generation	1 day	Tue 1/19/10	Tue 1/19/10
6	Gather previous term's files	1 day	Tue 1/19/10	Tue 1/19/10
7	Summarizing customer req.	1 day	Wed 1/20/10	Wed 1/20/10
8	Specifying engineering spec.	1 day	Wed 1/20/10	Wed 1/20/10
9	Building QFD diagram	1 day	Thu 1/21/10	Thu 1/21/10
10	**Design Review 1**	**6 days**	**Fri 1/22/10**	**Wed 1/27/10**
11	**Report 1**	**6 days**	**Fri 1/22/10**	**Wed 1/27/10**
18	**Oral Presentation**	**4 days**	**Sat 1/23/10**	**Tue 1/26/10**
24	**Meeting with Jason Moore**	**1 day**	**Wed 1/27/10**	**Wed 1/27/10**
25	Understand hydraulic system of Xebra	1 day	Wed 1/27/10	Wed 1/27/10
26	Discuss hydraulic redesign posibilities	1 day	Wed 1/27/10	Wed 1/27/10
27	Welding training	2 days	Thu 1/28/10	Fri 1/29/10
28	**Concept generation**	**5 days**	**Fri 1/29/10**	**Wed 2/3/10**
29	Further research hydraulic systems	1 day	Fri 1/29/10	Fri 1/29/10
30	Brainstorming, Proposing solutions	1 day	Sat 1/30/10	Sun 1/31/10
31	drawing concepts/ informal presentation	1 day	Mon 2/1/10	Mon 2/1/10
32	Develop 8-10 designs (hydraulic and battery)	3 days	Mon 2/1/10	Wed 2/3/10
33	Informal concept gen. in class presentation	1 day	Tue 2/2/10	Tue 2/2/10
34	Team meeting	1 day	Wed 2/3/10	Wed 2/3/10
35	Pugh chart/ concept classification tree, DR1 edit	3 days	Thu 2/4/10	Mon 2/8/10
36	Russ Pitts skype meeting DR1 feedback	1 day	Mon 2/8/10	Mon 2/8/10
37	Design comparison	2 days	Fri 2/5/10	Mon 2/8/10
38	Initial CAD design	2 days	Wed 2/10/10	Thu 2/11/10
39	**Design Review 2**	**6 days**	**Fri 2/12/10**	**Thu 2/18/10**
40	Report 2	6 days	Fri 2/12/10	Thu 2/18/10
41	Oral presentation	5 days	Sun 2/14/10	Thu 2/18/10
42	Finalizing alpha design	6 days	Fri 2/19/10	Fri 2/26/10
43	Safety Report	11 days	Fri 2/19/10	Fri 3/5/10
44	CAD with dimensions	5 days	Mon 2/22/10	Fri 2/26/10
45	Finalize Manifold Design	3 days	Fri 2/26/10	Tue 3/2/10
46	Order Manifold	1 day	Tue 3/2/10	Tue 3/2/10
47	**Design Review 3**	**9 days**	**Mon 3/8/10**	**Thu 3/18/10**
48	Report 3	9 days	Mon 3/8/10	Thu 3/18/10
49	machine shop opens, start manufacturing	1 day	Mon 3/8/10	Mon 3/8/10
50	Oral presentation	6 days	Thu 3/11/10	Thu 3/18/10
51	Recirculation Valve Testing	2 days?	Mon 3/8/10	Tue 3/9/10
52	Fix recirculation valve	3 days	Wed 3/10/10	Fri 3/12/10
53	Receive Electronic Controller	1 day	Thu 3/18/10	Thu 3/18/10
54	Receive manifold	5 days?	Mon 3/22/10	Fri 3/26/10
55	Disassemble Hydraulic System	2 days	Mon 3/22/10	Tue 3/23/10
56	Install Electronic Controller	1 day	Tue 3/23/10	Tue 3/23/10
57	LP Reservior Redesign-New Inlet	3 days	Wed 3/24/10	Fri 3/26/10
58	Hardware manufacturing	2 days	Wed 3/24/10	Thu 3/25/10
59	**System assembly and testing**	**8 days**	**Fri 3/26/10**	**Fri 4/2/10**
60	Hardware installation	1 day	Fri 3/26/10	Fri 3/26/10
61	Installation of Hydraulic Manifold	4 days	Sun 3/28/10	Wed 3/31/10
62	Rerouting of Hydraulic Lines	3 days	Mon 3/29/10	Wed 3/31/10
63	Rewire Electronic Controller Board	2 days	Thu 4/1/10	Fri 4/2/10
64	**Design Review 4**	**5 days**	**Sun 3/28/10**	**Thu 4/1/10**
65	Oral presentation	5 days	Sun 3/28/10	Thu 4/1/10
66	**Electronic Controller Board Redesign**	**5 days?**	**Sat 4/3/10**	**Thu 4/8/10**
67	Design	1 day?	Sat 4/3/10	Sat 4/3/10
68	Install	1 day?	Tue 4/6/10	Tue 4/6/10
69	Trouble shoot	2 days?	Wed 4/7/10	Thu 4/8/10
70	Functionality test	1 day	Fri 4/9/10	Fri 4/9/10
71	System trouble shoot	2 days	Mon 4/12/10	Tue 4/13/10
72	Accessibility test	1 day?	Wed 4/14/10	Wed 4/14/10
73	**Design Expo**	**2 days**	**Mon 4/12/10**	**Tue 4/13/10**
74	Make Poster	2 days	Mon 4/12/10	Tue 4/13/10
75				
76	Final report	3 days	Fri 4/16/10	Tue 4/20/10
77	**Prototype submission**	**3 days?**	**Thu 4/22/10**	**Mon 4/26/10**
78	Fill out reimbursments	1 day?	Thu 4/22/10	Thu 4/22/10
79	Clean area	1 day?	Mon 4/26/10	Mon 4/26/10



Project: Gant Chart revised
Date: Mon 3/22/10

Task | Progress | Summary | External Tasks | Deadline
Split | Milestone | Project Summary | External Milestone

Appendix XXX: Bios

Yuntao Chen

My home is at a small town called Baishan in the Northeastern part of China. If you want to find it on a world map, it’s right on the border between China and North Korea. I transferred from Shanghai Jiaotong University to the University of Michigan at the end of my sophomore year and this is the last semester before I graduate with a B.S.E. in mechanical engineering. I love cars when I was a small child and became interested in all kind of machines later, so mechanical engineering is a natural choice when I applied to college. Now I am more interested in aircraft and spacecraft engines, so I have applied to several aerospace engineering programs for graduate school. After that I plan to get a job as an engineer and enjoy the rest of my life.

Andres Diaz

I am currently a senior at the University of Michigan, and I will be graduating in May 2010 with a B.S.E in Mechanical Engineering. I am originally from Colombia, but I also lived in Puerto Rico, Michigan, and in France. I am interested in internal combustion engines, vehicle dynamics, and I enjoy modeling parts in 3-D software as well. Hopefully, I will work in the car industry at some point in the near future. In my spare time I follow formula 1 closely, play soccer, and go often salsa dancing.

Eric Kim

I am a senior at the University of Michigan, majoring in Mechanical Engineering. I was born in Queens and raised in Brooklyn, New York. My interest in mechanical engineering comes from my interest in designing and analyzing physical systems. I also have a strong desire to improve the environmental sustainability and the overall efficiency of energy usage. I am unsure of my future plans at the moment. I am deciding whether to continue my education and pursue a Master’s degree or to enter the workforce. Outside of school, I am a member of Pi Lambda Phi fraternity. My interests include listening to music, watching movies and following football, basketball and boxing.

Kevin Lyons

I am a senior engineering student at the University of Michigan. I will graduate in May 2010 with a BSE in Mechanical Engineering with a concentration in energy. I was born and raised in Kalamazoo, MI for all 22 years of my life. In addition to the engineering discipline, I am also interested in volunteering and any athletic sport, soccer and basketball are my favorites. I have played soccer since I was 5 years old and my senior year of high school I achieved All State Honors as a goalie. I first became interested in engineering when I spent an incredible amount of time on a high school physics project without realizing how much time I was spending. It was too much fun. I am interested in design and fabrication of new and exciting mechanical structures and their applications. Most recently, I have been involved in the kinetics and dynamics of carbon nanotube growth and hope to continue with the applications of such materials. This project combines both design and optimization in the field of energy, which all interest me greatly.