FORCE MONITOR:

A SYSTEM FOR

HUMAN STRENGTH MEASUREMENT

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INTRODUCTION

The Force Monitor is a third generation human strength measurement system developed to assess the strength of workers in simulations of material handling tasks. The system was designed to provide an efficient, simple, and flexible method of measuring human strength suitable for use by a plant's medical staff. Components have been selected and developed which allow easy set-up and efficient use of test resources.

The system is comprised of handles and supporting hardware, a load cell, and an electronic force monitor. The handles and supporting hardware can be easily adjusted to accommodate a wide range of postures and tasks in order to measure the strengths of various muscle groups in simulations of job activities. The electronic force monitor provides automatic control of the testing sequence, checks for testing errors, and displays test results. These features result in an ease of operation suitable for clinical use.

The Force Monitor electronic module integrates measurement and control functions in a functional package. Through the use of both analog and digital logic the unit provides:

1) automatic sequencing of testing;
2) tests for proper exercise performance; and
3) measurement and display of instantaneous force, true 3-second average force, and peak force.

The third generation system serves to demonstrate that a measurement system can be engineered which incorporates features of sequential control and logical testing. Arguments of both data validity and human factors considerations require that a system be engineered with these issues fully recognized. The system fully implements features necessary to insure valid measurement utilizing a simple operating procedure. The simplicity of this system for the level of measurement provided insures cost effectiveness for routine use.

COMPONENTS

The force monitor system includes the following components:

1. Handles and Supporting Hardware - The handles and supporting hardware for the force monitor system are illustrated in Figure 1. Typically, the handles are provided with the system while the supporting hardware is built by the user. This is necessary because of the different strength testing requirements of different installations, and the need to adapt and modify the supporting hardware in order that it can be securely mounted in different facilities. Additional details concerning the supporting hardware are given in the Specifications section.
2. Load Cell - The load cell, also pictured in Figure 1, is an electronic strain gauge which measures the forces exerted on the handles. This component is provided with the system.

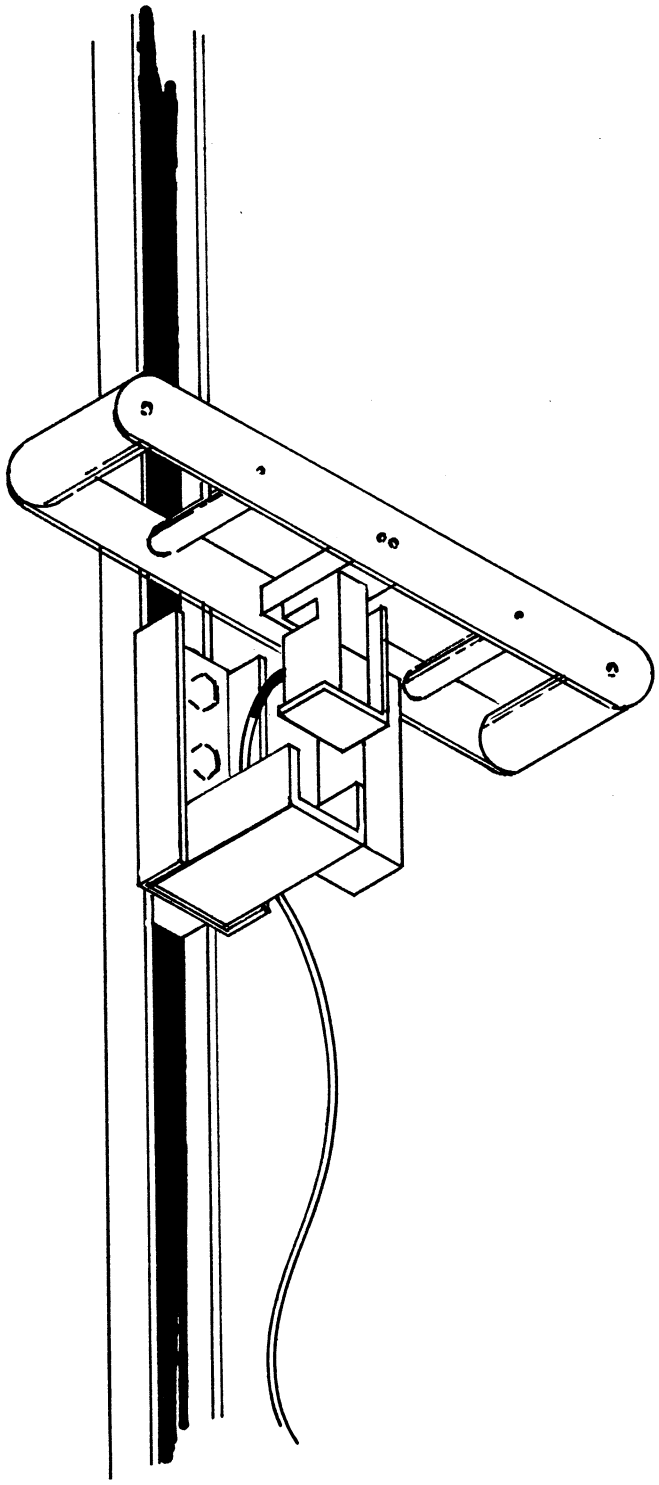


Figure 1: Force monitor system: handles, supporting hardware and load cell

3. Force Monitor Electronic Module - The force monitor electronic module is shown in Figure 2. This component receives an electronic signal from the load cell, processes this information, and displays strength test results. The operation of this unit is explained in the following two sections.

CONTROLS AND DISPLAYS

A detailed illustration of the force monitor control panel is given in Figure 3. Operating instructions for the various controls are given below:

Power Switch ("ON") - The unit is turned on or off by depressing this button.

Load Cell Plug - The input lead from the load cell plugs into this receptacle.

Zero Balance Control ("ZERO") - This knob is used to zero the Digital Force Readout display when no force is applied to the handles. To use this control, the Display Readout Selector should be set in the "RUN" position. The value displayed on the digital readout is increased by turning the knob clockwise and decreased by turning the knob counter-clockwise. Typically, the display should read approximately zero when the unit is turned on, and only

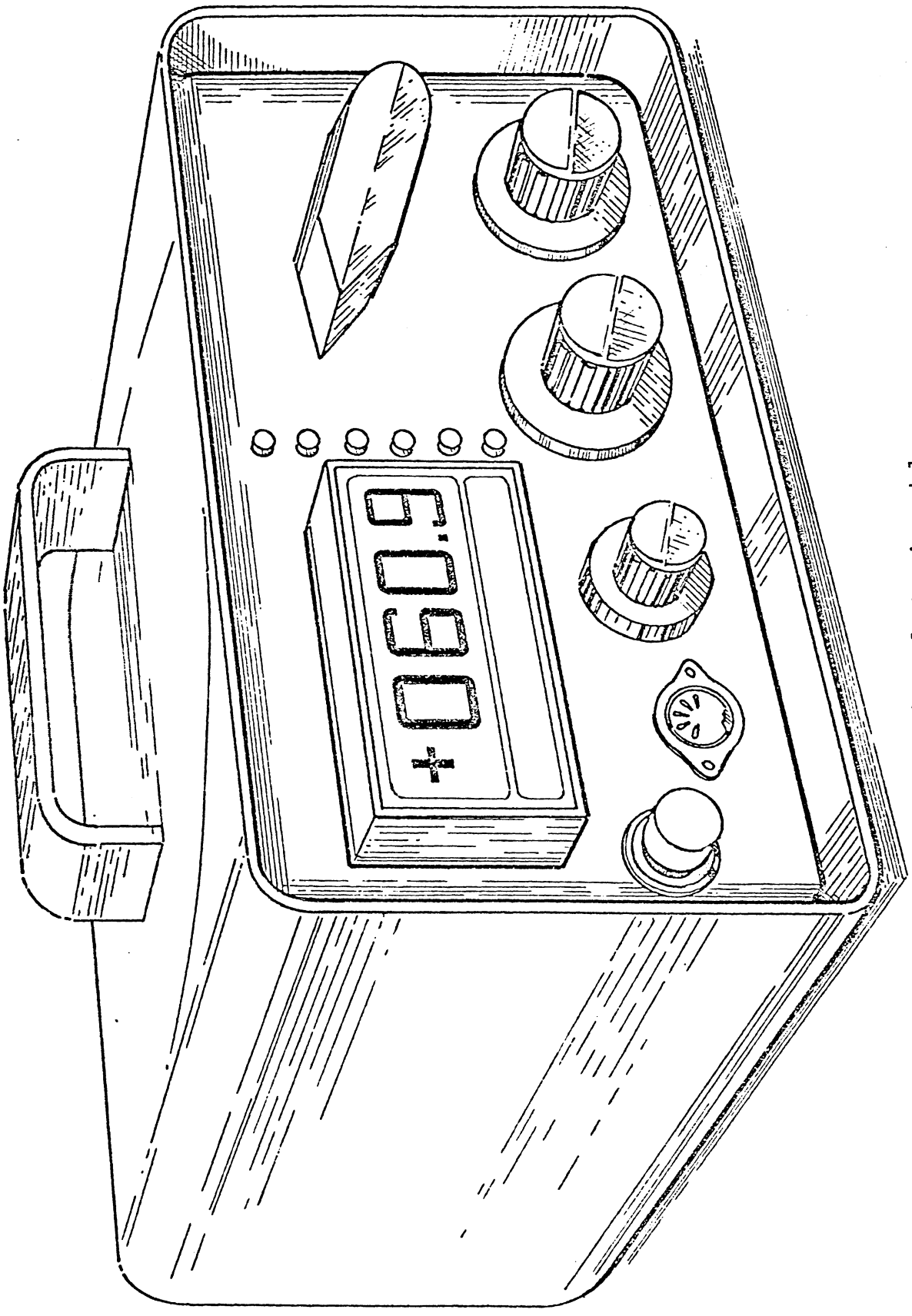


Figure 2: Force monitor electronic module

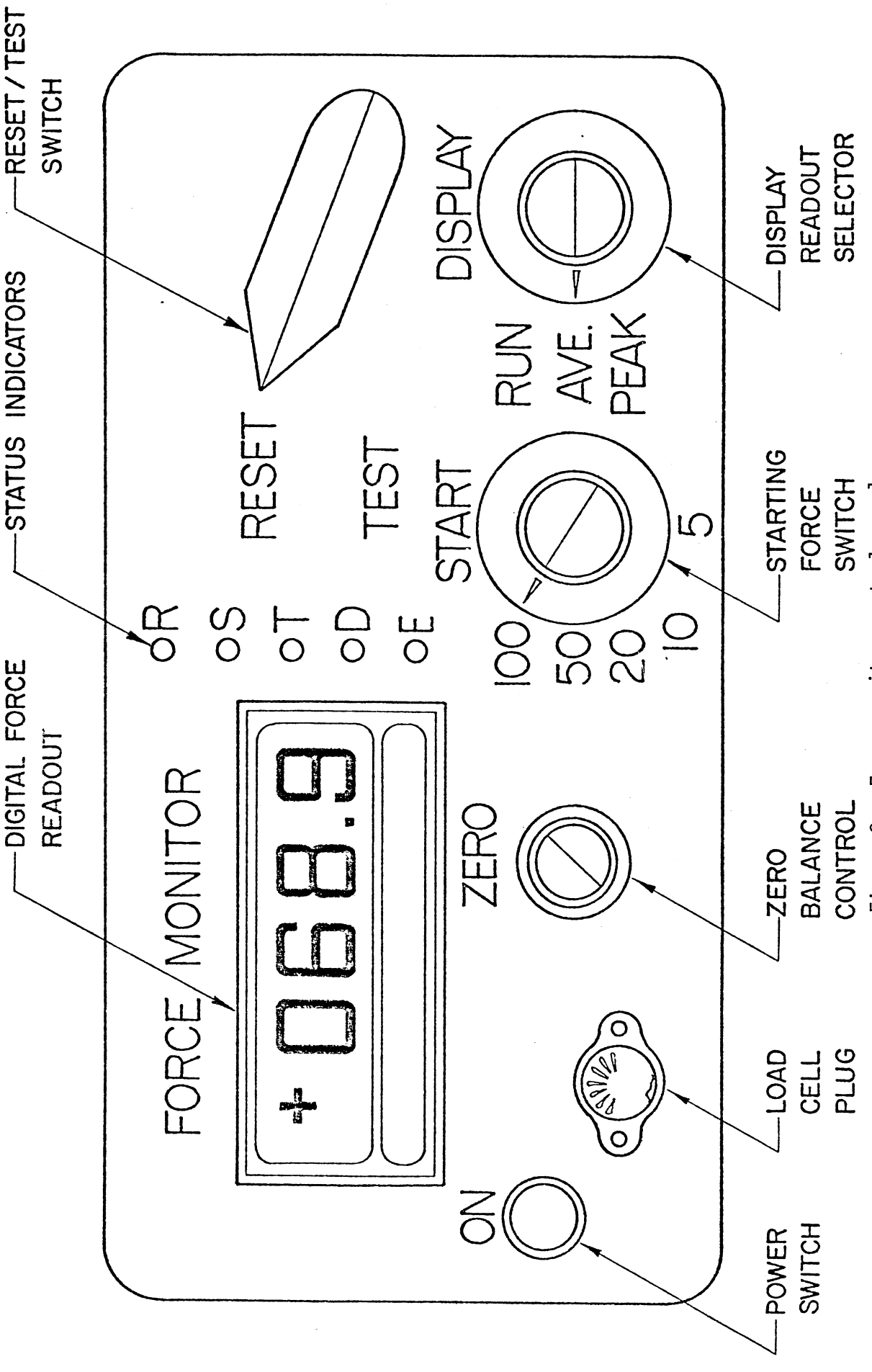


Figure 3: Force monitor control panel

a minor adjustment is required. In the event of a large deviation from zero, the operator should check to see that there is no load on the handles before adjusting the zero balance.

Starting Force Switch ("START") - This switch is used to select the threshold force (lbs.) which must be exceeded in order to start the timing mechanism of the testing sequence. There are no simple rules for selecting a threshold force since this value is highly dependent upon the nature of the strength test.

Display Readout Selector ("DISPLAY") - This switch is used to select the information displayed on the Digital Force Readout. Depending on its position, the following information can be obtained:

"RUN" - In this position, the instantaneous force on the load cell is displayed. This is the normal position for zeroing the unit and running a strength test.

"AVE" - In this position, the instrument displays the three second average force exerted during the testing sequence.

"PEAK" - The position displays the largest force measured during the three second testing sequence.

Reset/Test Switch - This control is used to reset the force monitor following a strength test. This switch should be placed in the "RESET" position for zeroing the unit and "TEST" position for running a strength test. After a test is completed and appropriate results recorded, the switch should be placed in the "RESET" position to prepare for the next test.

Status Indicators - This series of lights are used to indicate the status of the testing sequence according to the following code:

"R" - This light comes on when the unit is reset and indicates that it is ready for a new strength test.

"S" - This light comes on when the instantaneous force exceeds the threshold value selected with the starting force switch. It remains on throughout the test sequence as long as the instantaneous force is greater than the threshold value.

"T" - This light comes on at the beginning of the three second measurement period and remains on while the test is in progress.

"D" - This light comes on at the end of the three second monitoring period to indicate that the testing sequence has been completed. On certain models of the force monitor, this light is accompanied by an audible tone to indicate the end of the test.

"E" - This light indicates that an error condition occurred sometime during the test period. Two types of errors are detected by the system:

1. If the instantaneous force drops below the threshold force selected with the starting force switch, this condition is detected as an error.
2. If the average force drops below 70 percent of the peak force, this condition is detected as an error.

Whenever the error light comes on, the test results are invalid and the trial must be repeated.

Digital Force Readout - This display shows the instantaneous, average, or peak force (lbs.) demonstrated during the strength test, depending on the position of the display readout selector.

Audible Warning (not shown) - An audible warning system is included to protect the system from mechanical damage in the event that it is overstressed. The force level which triggers this alarm is set internally.

Output Jack (not shown) - An electrical output is provided on the back panel for external display and/or recording of the instantaneous force on the load cell. Nominal output is 1 volt/100 lbs.

OPERATION

The force monitor is operated according to the following steps which are explained in detail below:

A. Set up apparatus.

B. Zero instrument and verify calibration.

C. Set handles to test condition.

D. Conduct strength test.

1. Reset force monitor.
2. Perform strength exertion.
3. Record data.

A. Set up apparatus.

1. Install load cell to anchoring bracket and check that the connection is secure.
2. Install handles to load cell and check that the connection is secure.
3. Plug force monitor line cord into AC receptacle, and load cell cord into force monitor.
4. Press the power switch to turn the unit on. This should cause the digital force readout to display a number. Allow the unit to warm up for several minutes before proceeding to the next step.

B. Zero instrument and verify calibration.

1. Use the zero control to obtain a zero reading on the digital force readout for the following conditions:
   - No load applied to the handles
   - Display readout selector in the "RUN" position
   - Reset/Test Switch in the "RESET" position
   - Load cell calibration switch to the "RUN" position (see below).

2. After a zero reading is obtained, the calibration should be checked using the load cell calibration switch which is located on the load cell cord. Calibration is performed for the following conditions:
   - No load applied to the handles
   - Display readout switch in the "RUN" position
   - Reset/Test Switch in the "RESET" position
   - Load cell calibration switch in the "CALIBRATE" position

   The value displayed on the digital force readout should be within the calibration limits of the monitor. These limits are ± 1 percent of the nominal calibration value, ± 3 lbs. (For an instrument with a 100 lb. calibration switch the acceptable range is 96-104 lbs. For an instrument with a 200 lb. calibration switch, the acceptable calibration range is 195-205 lbs.) If the displayed value does not fall within these limits, corrective action must be taken.

Be sure to place the load cell calibration switch in the "RUN" position before proceeding with the test.

C. Set handles to test condition.

Adjust the height and orientation of the handles as specified for the strength test. (Note: Marking the vertical height of the handle for different tests will facilitate making the adjustment.)

D. Conduct the strength test.

1. Place the reset/test switch in the "RESET" position.
2. Select threshold force with the starting force switch.
3. When ready to test, place the reset/test switch in the "TEST" position.
4. Observe the "S", "T", and "D" display lights to note the progress of the test. When the "D" light comes on, the testing sequence is completed. If the "E" light comes on, an error has occurred in the testing procedure, and the test must be repeated.
5. Use the display readout selector to obtain the results of the test ("AVERAGE" and/or "PEAK") strengths. Record these data in the appropriate manner on the strength test reporting forms.

SPECIFICATIONS

A. Operating Specifications

Force Range - 0-500 lb. normal, determined by load cell and display readout range.

3 Sec. Average Force - Average force is obtained by integrating the force for 3 seconds. The integrating period starts 0.5 second following the time when the force exceeds the criteria level if the force at the instant is greater than the criteria level. Once started, the integration period cannot be reset.

Peak Force - A fast peak detection will track the maximum force input when the reset/test control is placed in the "TEST" position.

Instantaneous Force - The instantaneous input force level can be displayed at any time and is available as an electrical output on the back panel in the "TEST" mode.

Automatic Sequencing - In the "TEST" mode automatic sequencing is initiated when the input force exceeds the threshold criterion (start) level. The status of the sequence is indicated by the R, S, T, and D status indicators.

Auditory Over Force - An internal adjustment sets a force level which if exceeded results in an auditory warning. Normally this level will be set to maintain the mechanical integrity of the system, however, the level may be set lower if it is desired to limit voluntary strength exertions.

Procedural Error - Tests to insure reliable force measurement can be made by determining if one of the following conditions occurred. Instantaneous force dropped

1) below a set percentage of the peak force, or
2) below the starting threshold during the 3 second integration.

If so the E display is illuminated.

Calibration - An electrical calibration has been incorporated into a commerical load cell for which the sensitivity has been standardized to provide interchangeability without requiring recalibration. Except for complete mechanical failure, the system may be calibrated or verified with the electrical calibration provided.

Accuracy - Accuracy is typically specified as a percentage of full scale resulting in accuracy specifications of better than 1%. Typical calibrations for nominal test levels of 100 and 200 is equal to $\pm$ 1 lb. Specified accuracy will be stated as the maximum of $\pm$ 2% or 2 lb.

Output - A digital display provides an easily read high resolution readout of the strength measurement. An electrical output is provided for connecting a remote display or chart recorder. Nominal output is 1V/100 lb.

B. Handles and Supporting Hardware

The handles and supporting hardward for the force monitor system were illustrated earlier in Figure 1. Typically, the handles are provided with the unit and the supporting

hardware is built by the user. This is necessary because the supporting hardware must be securely and permanently mounted in the user's facilities.

Sketches giving dimensions and materials for the supporting hardware are presented in Figures 4 through 7.

C. Force Monitor Circuit Description

See Appendix.

Load Cell - A pull force is measured using a strain-gauge bridge load cell. Approximately 30 MV output is produced from a 500# load, (10 volts excitation and 3 MV/V full scale sensitivity). The load cell assembly is provided with a calibration network to normalize the sensitivity of individual units permitting interchangeability of units.

Load Cell Amplifiers - A differential input (A,B) and a non-inverting amplifier form the input gain system. The two amplifiers produce a 5V level for a 500# equivalent input:

$$\text{gain} = \frac{5000 \text{ MV out}}{30 \text{ MB in}} = 167$$

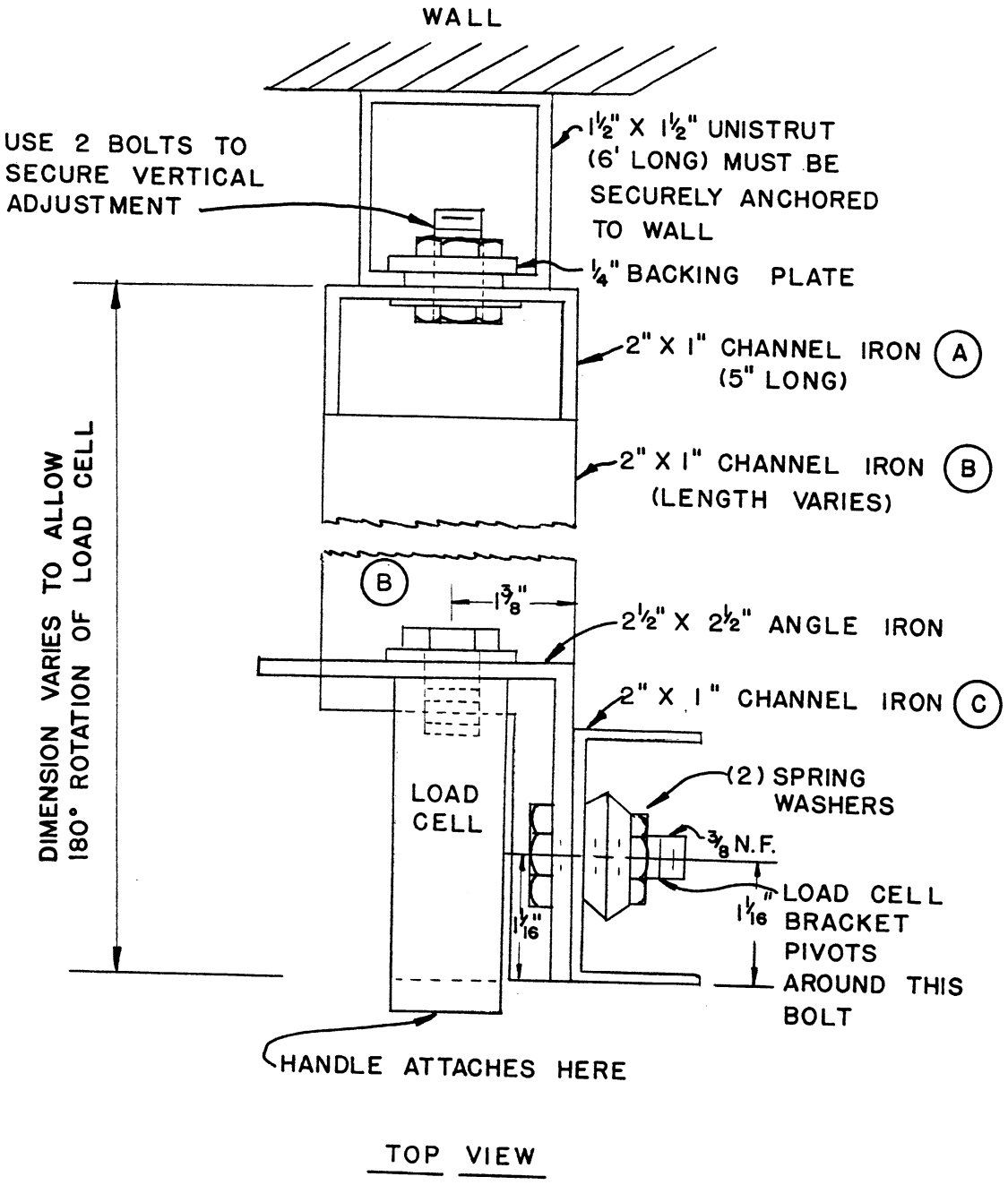


Figure 4: Load Cell Support Bracket (top view)

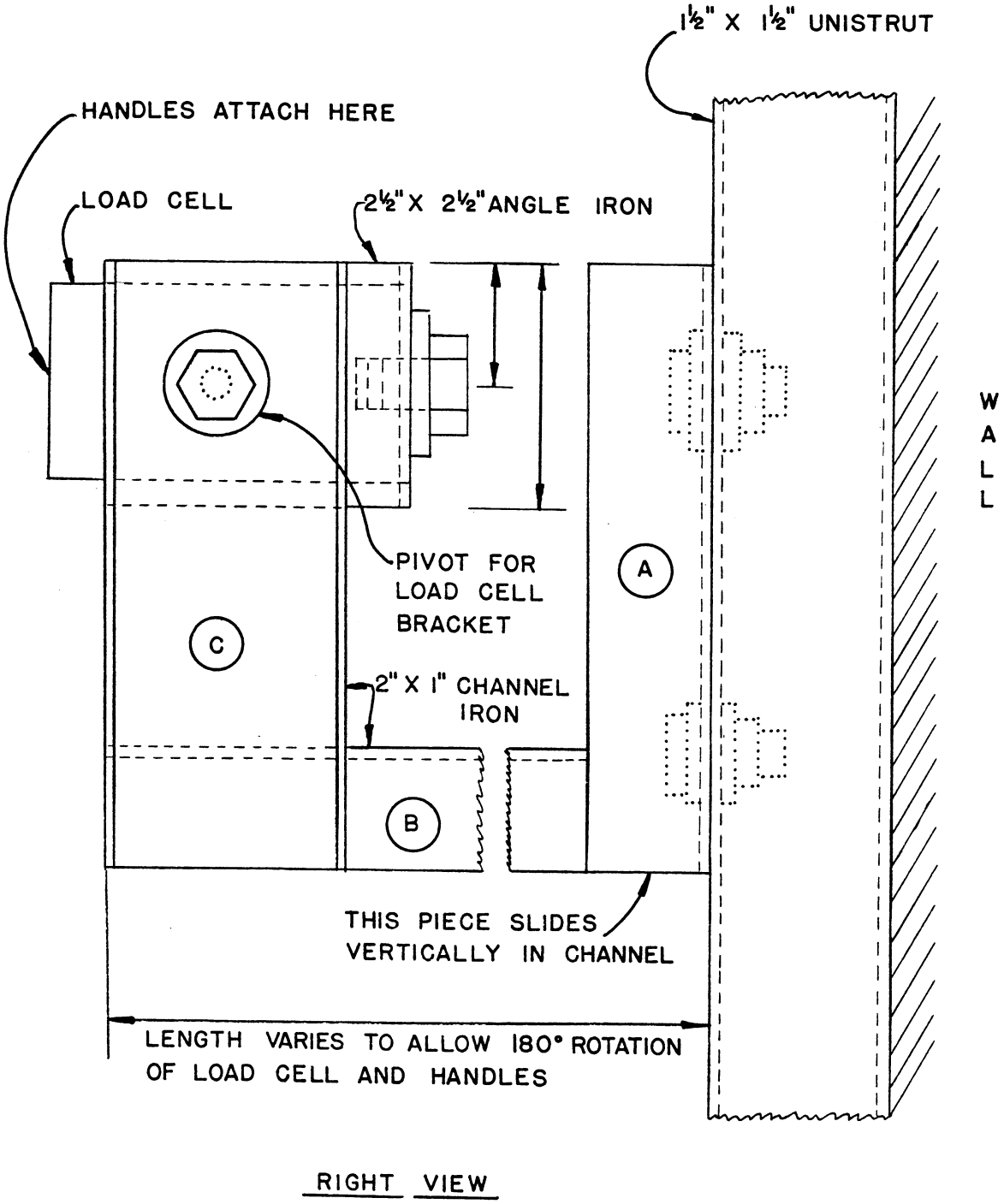


Figure 5: Load Cell Support Bracket (right view)

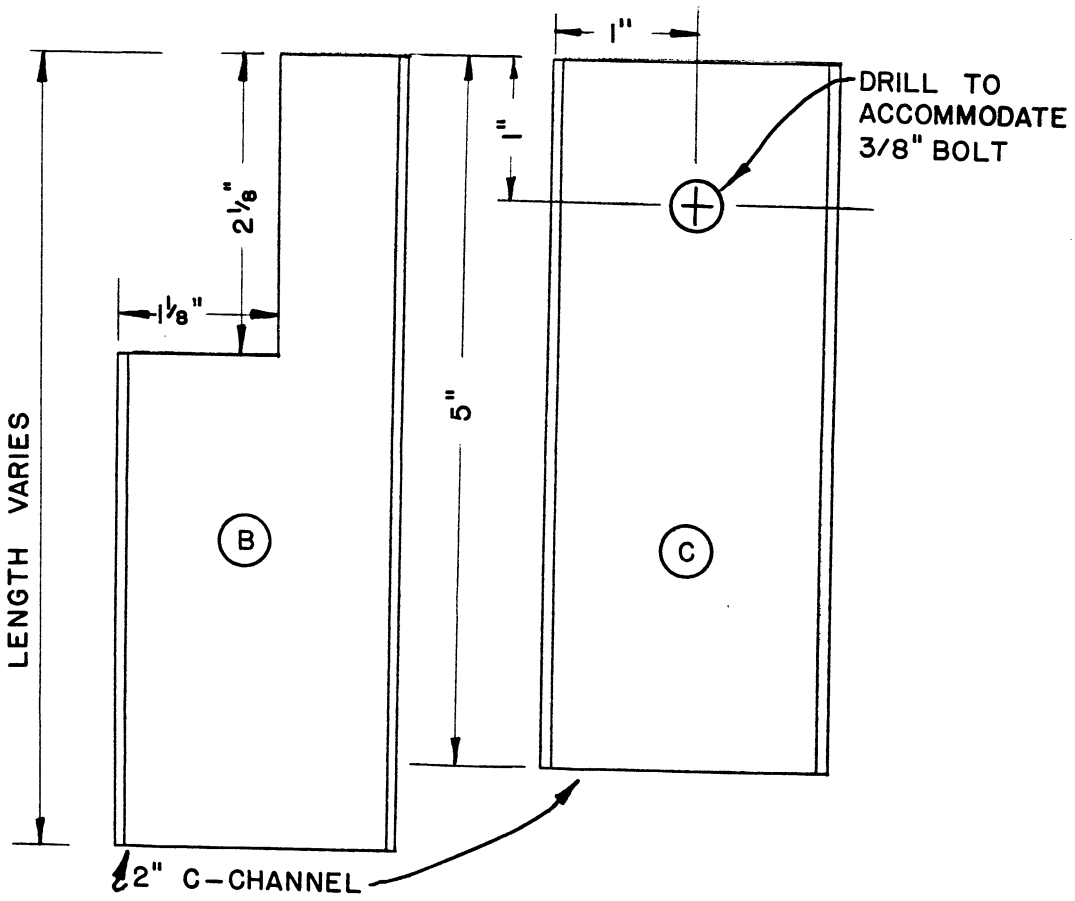


Figure 6: Components of Support Bracket (parts B and C)

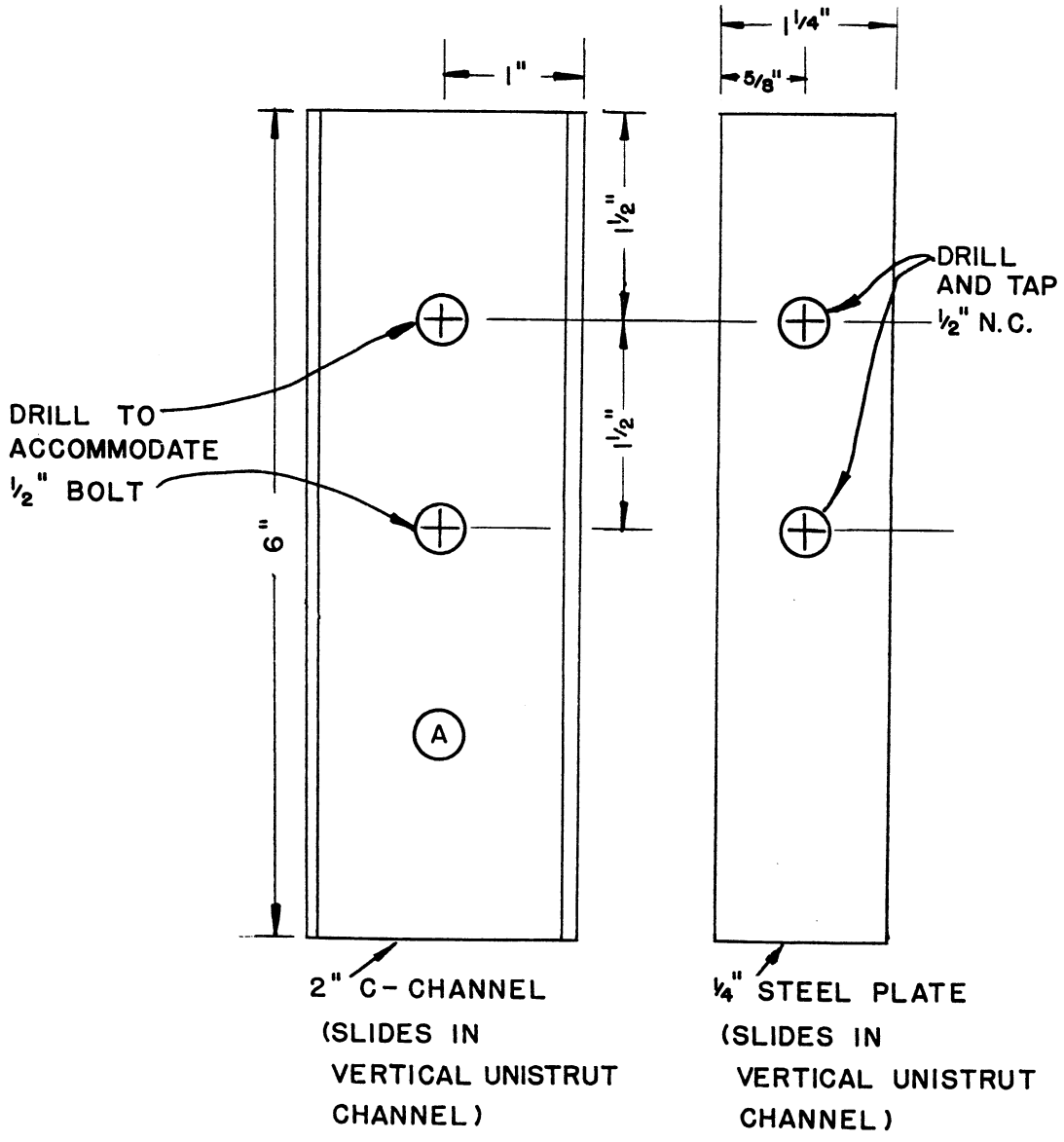


Figure 7: Components of Support Bracket (Part A and Backing Plate)

Guarded Peak Detector (C,D) - An amplifier pair, operating as cascaded unity gain amplifier, charge and monitor a capacitor. The first amplifier drives the storage capacitor through an isolation diode. The capacitor is charged when the input is greater than the voltage on the capacitor. The second amplifier having a very low input current provides the high impedance isolation necessary to monitor the peak force voltage stored in the capacitor. FETs are provided to discharge the stored voltage. The circuit is constructed with passive guarding by holding principle circuit nodes at the capacitor voltage. This eliminates leakage currents by eliminating voltage gradients.

Average Force Integrator (E,F) - Average force is obtained by integrating the input for 3 seconds. A gate signal obtained from the 3 second timer (L) controls the FET switch. The integrator gain is unity after 3 seconds. Amplifier (F) restores the polarity of the integrator average force voltage. A shunt FET switch pair resets the integrator.

Sequence Timing (J,F,L) - Threshold criteria, minimum required force, is tested by a voltage comparetor (J). Where the force exceeds the threshold value, the comparetor output switches high. The high transitions trigger the 2 sec. delay timer (K) starting a delay period during which the subject can reach a sustainable force level. When the subject maintains the force above criteria to the end of the delay period the output of the timer will trigger the 3 second integrating timer (L) through the K-L coupling network.

D. Force Monitor Calibration Sequence

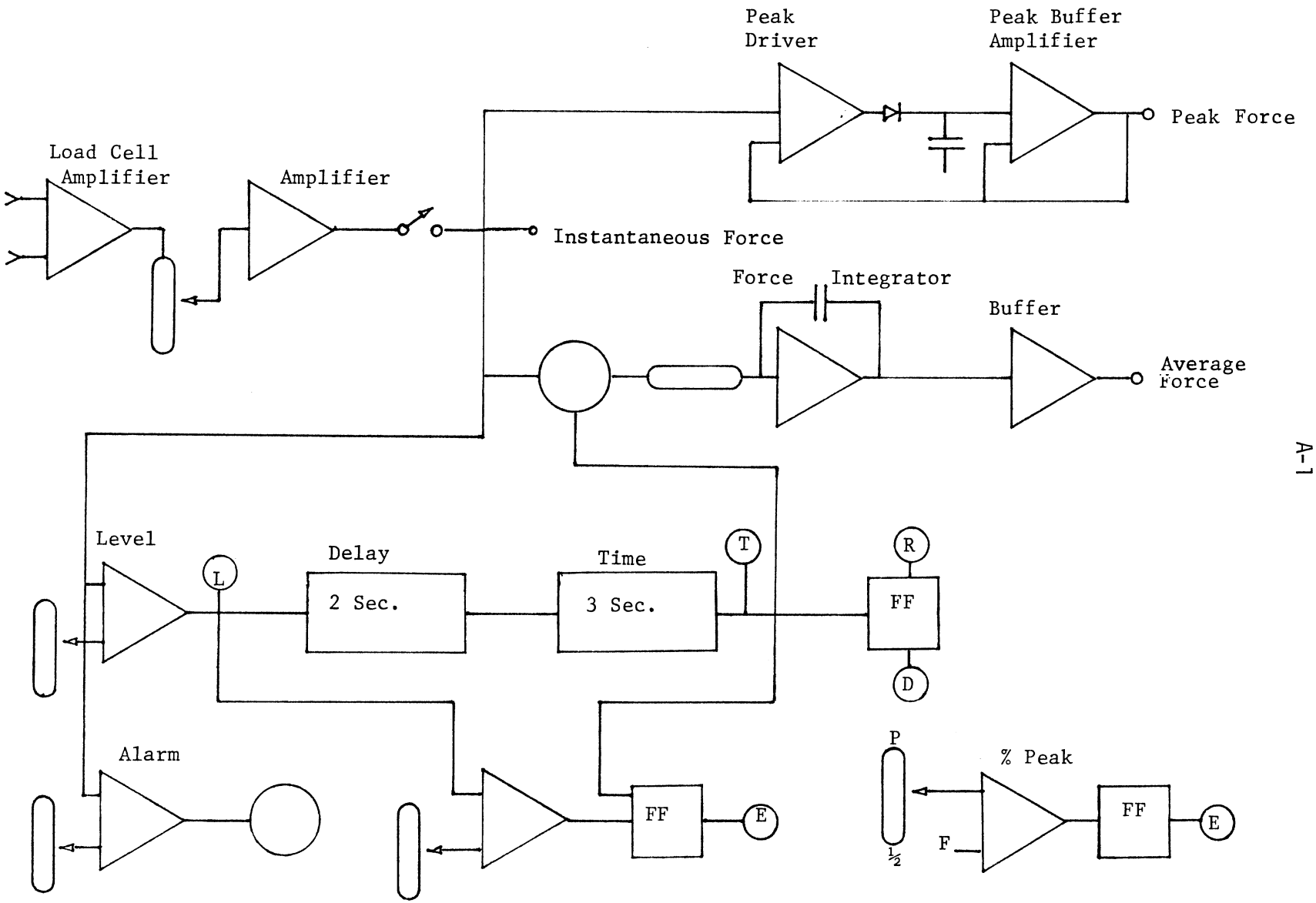
1. Insure correct power supply voltages.
2. Set Balance voltage to zero by adjusting Zero pot till pin 2 = 0.
3. Plug in load cell, short pin 3 to pin 4, using common mode pot A5, adjust until A6 = ϕ. This will balance input amplifier A.
4. Use a strip chart recorder or oscilloscope to set K = 2.0 sec, J = 3.0 sec. Trigger the timing sequence with an external load or signal 30 MV = 500#. Monitor the JC output at the 10K LED Resistor.
5. Force sensitivity is determined by pot B1. Using a simulated load adjust output for a RUN of B6 reading of 1 Volt/100 lb. input. Observe meter in RUN position.
6. The Average circuit E may easily be adjusted by applying a simulated load and adjusting the output from E1 (input E2), based on a trial reading the following relationship may be used:

$$E2^{1} = E2_{trial} \quad \frac{\text{true value}}{\text{actual value}}$$

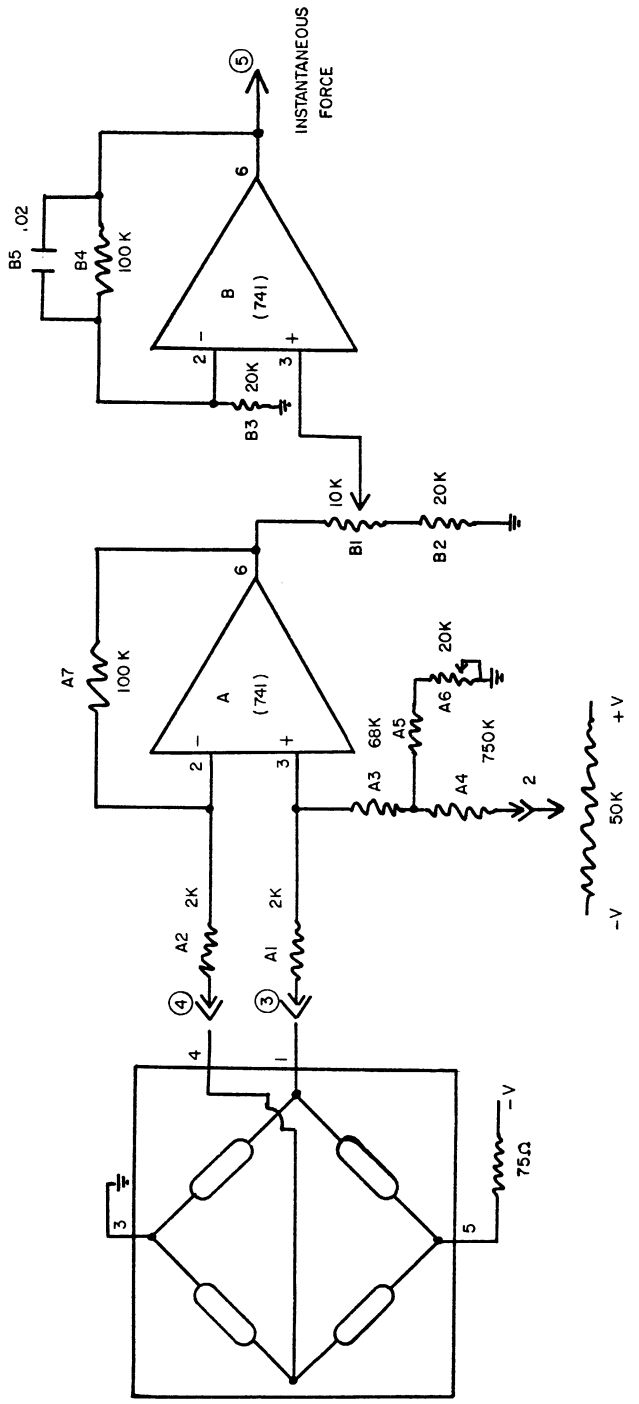
7. The % peak and alarm levels may be adjusted by changing resistor, I4, H3.

APPENDIX

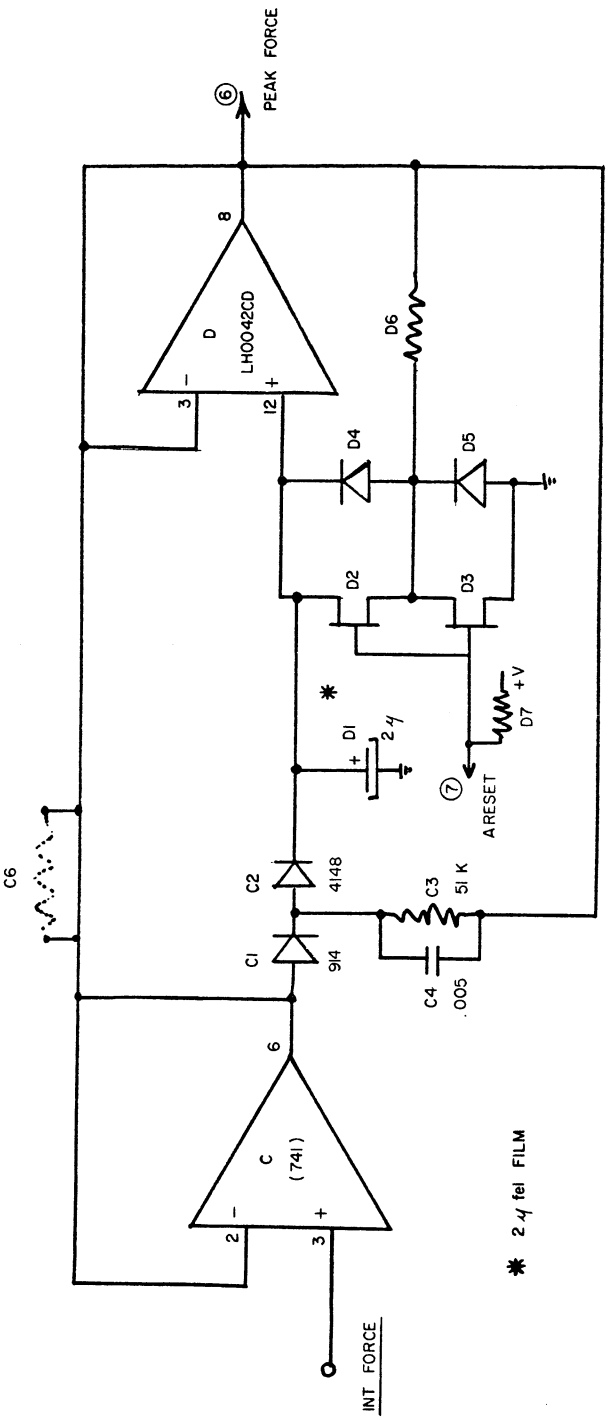
Force Monitor Circuit Description



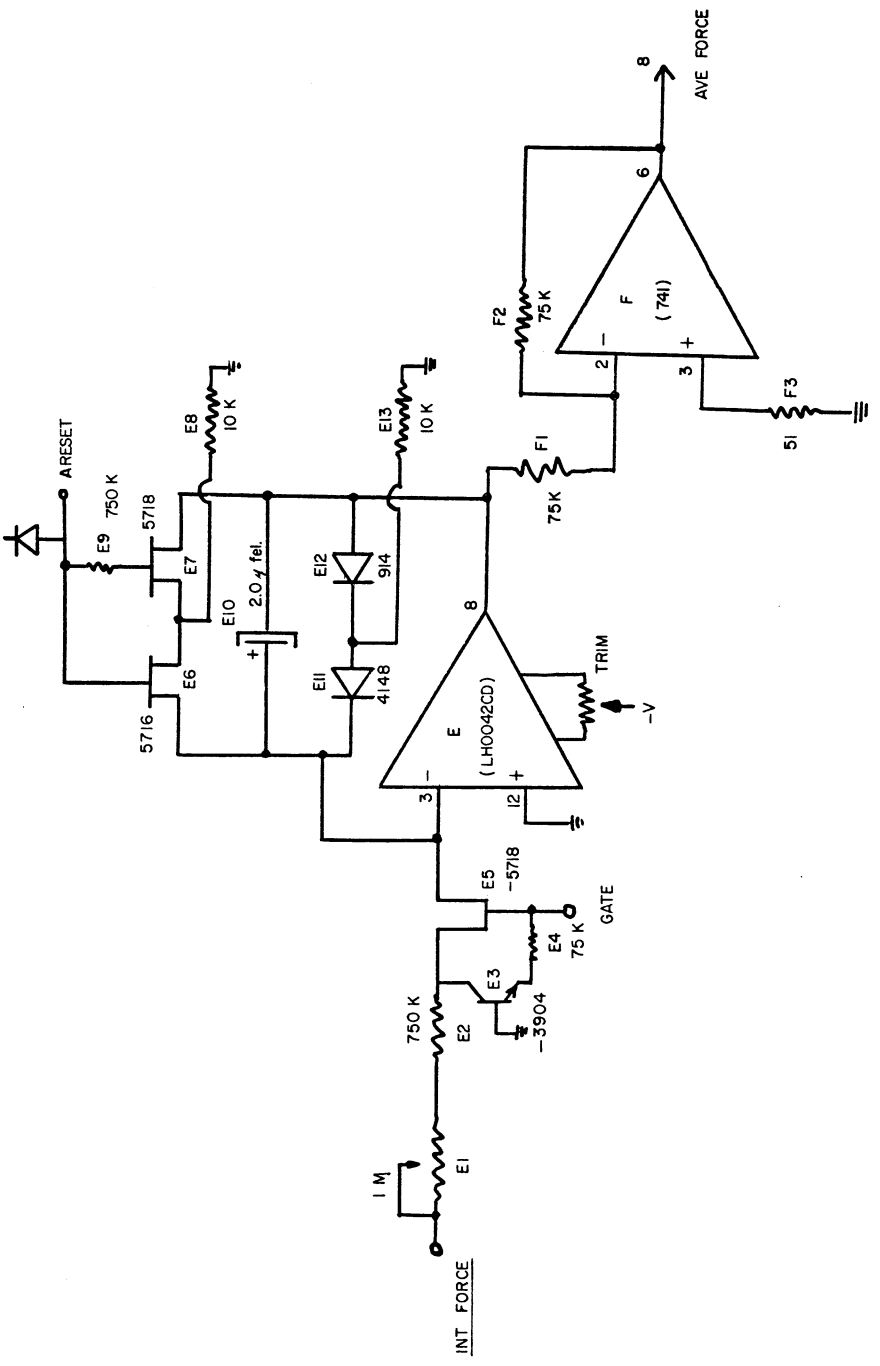
FORCE MONITOR FUNCTION BLOCK DIAGRAM



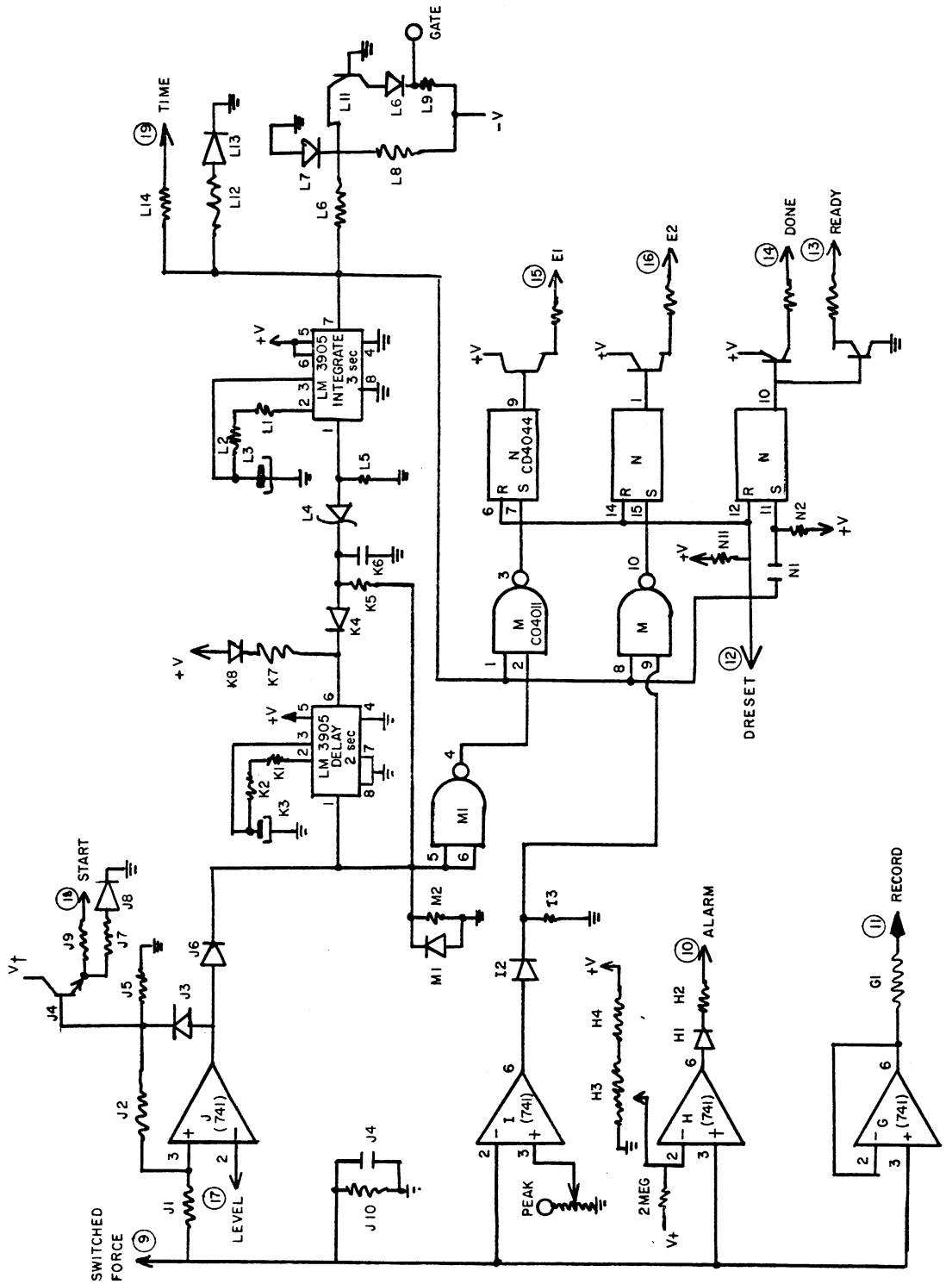
STRAIN GAUGE BRIDGE INPUT



GUARDED PEAK DETECTOR



AVERAGE FORCE INTEGRATER



TIMING AND CONTROL LOGIC

Parts

A-741

1 - 2k
2 - 2k
3 - 68k
4 - 750k
5 - short
6 - 20k pot
7 - 75k

B-741

1 - 10k pot
2 - 20k
3 - 20k
4 - 100k
5 - .02µf

C-741

1 - IN914
2 - IN4148
3 - 51k
4 - .005
5 - 100pf
6 - 1k

D-LH0042CD

1 - 22µf
2 - FET-2N5716
3 - FET-2N5718
4 - IN4148
5 - IN914
6 - 75k
7 - 750k

E-LH0042CD

1 - pot
2 - 500k
3 - 2N3904
4 - 75k
5 - 2N5718
6 - 2N5716
7 - 2N5718
8 - 10k
9 - 750k
10 - 2.0
11 - IN4148
12 - IN914
13 - 10k

F-741

1 - 75k
2 - 75k
3 - 51k

G-741

1 - 2k

H-741

1 - IN914
2 - 2k
3 - 100k pot
4 - 100k

I-741

1 - 10k pot
2 - IN914
3 - 75k

J-741

1 - 5.1k
2 - 75IN
3 - IN914
4 - 2N3904
5 - 75k
6 - IN914
7 - 20k
8 - LED
9 - 1.5k
10 - 100k
11 - .005µf

K-LM3905

1 - 30k
2 - pot 100k
3 - 22µf
4 - IN914
5 - .10k
6 - .01µf
7 - 20k
8 - LED

L - LM3905

1 - 100k
2 - 100k pot
3 - 22µf
4 - 5.1v zener
5 - 75k
6 - 20k
7 - IN914
8 - 75k
9 - 51k
10 - IN914
11 - 2N3904
12 - 20k
13 - LED
14 - 1.5k

M-CD4011

1 - IN914
2 - 75k

N-CD4044

1 - 330pf
2 - 75k
3 - 2N3904
4 - 1.5k
5 - 2N3904
6 - 1.5k
7 - 2N3904
8 - 1.5k
9 - 2N3906
10 - 1.5k
11 - 75k

Front Panel Miscellaneous Hardware

Power Switch
Test/reset 2P/3P
Display 1P/3P
Start 1P/5P
50k pot
5 LED's
Sonalert
Fuse Holder
Power Cord
5 Pin Connector
± 12v power supply
1/4 phone jack
DPM
pointer knob 70-42
knob lock
bar knob
knob 50-

Force Monitor Wire List

P.C. Board Connector

Pin	Color/Stripe	Function	Destination	
1	Black	CKT Ground	P3 P	
2	Red	Zero	Zero pot, Wiper	
3	Gray	+ load	Load cell connector P4	
4	White/Gray	- load	" " " P1	
5	Yellow	force	display, switch run	
6	White/Purple	peak	" " peak	
7	Purple	reset	reset test switch	
8	Brown	average	display, ave.	
9	-	-	n.c.	
10	White	alarm	sonalert, +	
11	Orange	reload	record, BNC	not cable
12	-	-	n.c.	
13	White/Blue	ready	LED, ready, cathode	
14	White/Purple	done	LED, done, anode	
15	White/Orange	error	LED, error, anode	
16	-	-		
17	Blue	level	start switch, wiper	
18	White/Yellow	start	LED, start, anode	
19	White/Green	time	LED, time, anode	
20	White/Brown	-12V	zero, 75R load cell connector P5	-power suppl
21	White/Red	+12V	zero, start, test, ready-LED	+power suppl
22	Black	ground	meter, sonalert, start, LED's chassis	power supply
Meter	White/Yellow	Display Sw.		
	Orange	+5V	Meter	
	Gray	5V Ref	Meter	