A CASE STUDY FOR ROBOTIC ASSEMBLY:

DUALJET CARBURETOR SUBASSEMBLY

by

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PREFACE

This report describes a case study of robotic assembly of a device with substantial complexity. It is a sequel to a previous report of robotic case studies (UM-MEAM-84-28) and is part of the ongoing effort at the University of Michigan to understand the issues involved by generating our own practical experience. The robot used the IBM RS2 and all the programming, fixturing and design modifications were implemented by Napolyon Isikbay, graduate student in the Department of Mechanical Engineering and Applied Mechanics.

I would like to acknowledge the continuing support of IBM Corporation for this project and of William D. Hollenback in particular. Mark Jakiela, Doctoral Candidate, has been of substantial assistance in this work.

Panos Papalambros
Associate Professor

Ann Arbor, August 1985.

ABSTRACT

A Case Study For Automatic Assembly: Dualjet Carburetor Subassembly

This paper discusses the assembly and possible improvements in the design for automated assembly of certain parts of the General Motors Rochester Products E2ME Dualjet Carburetor.

For comparison purposes the method by Boothroyd and Dewhurst developed at the University of Massachusetts was used. For this it was assumed that the product is suitable for automated assembly and it has a rate of assembly of two per minute. The IBM 7565 Manufacturing System with a two-finger gripper was used to perform the assembly. Parts feeders were not used; instead, the robot picked up the parts from simulated feeder points on the fixtures. Rigid fixtures, which kept the parts at required orientation were used.

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1. FOREWORD

Product design is a major requirement for automatic assembly and the transition from manual to automatic assembly is the concern of many design engineers. The first step in designing the parts is to know the limitations and the capabilities of the assembly system.

The E2ME Dualjet Carburetor was taken as a case study and the behavior of the parts during assembly was observed. As a result of this experiment some of the parts which were impossible to handle, locate or insert were modified to allow assembly. Section Two describes the difficulties faced during the process of assembly and includes the modifications done in some parts and suggests further design improvements.

To demonstrate the interest in evaluating assembly efficiency by means of quantitative methods, an assembly evaluation based on the UMASS (Boothroyd) system was performed on the carburetor and it is presented in Section Three.

Limitations of this system and comparison of results between Section Two and Three are discussed briefly in Section Four. Individual component design suggestions are also included in this section.

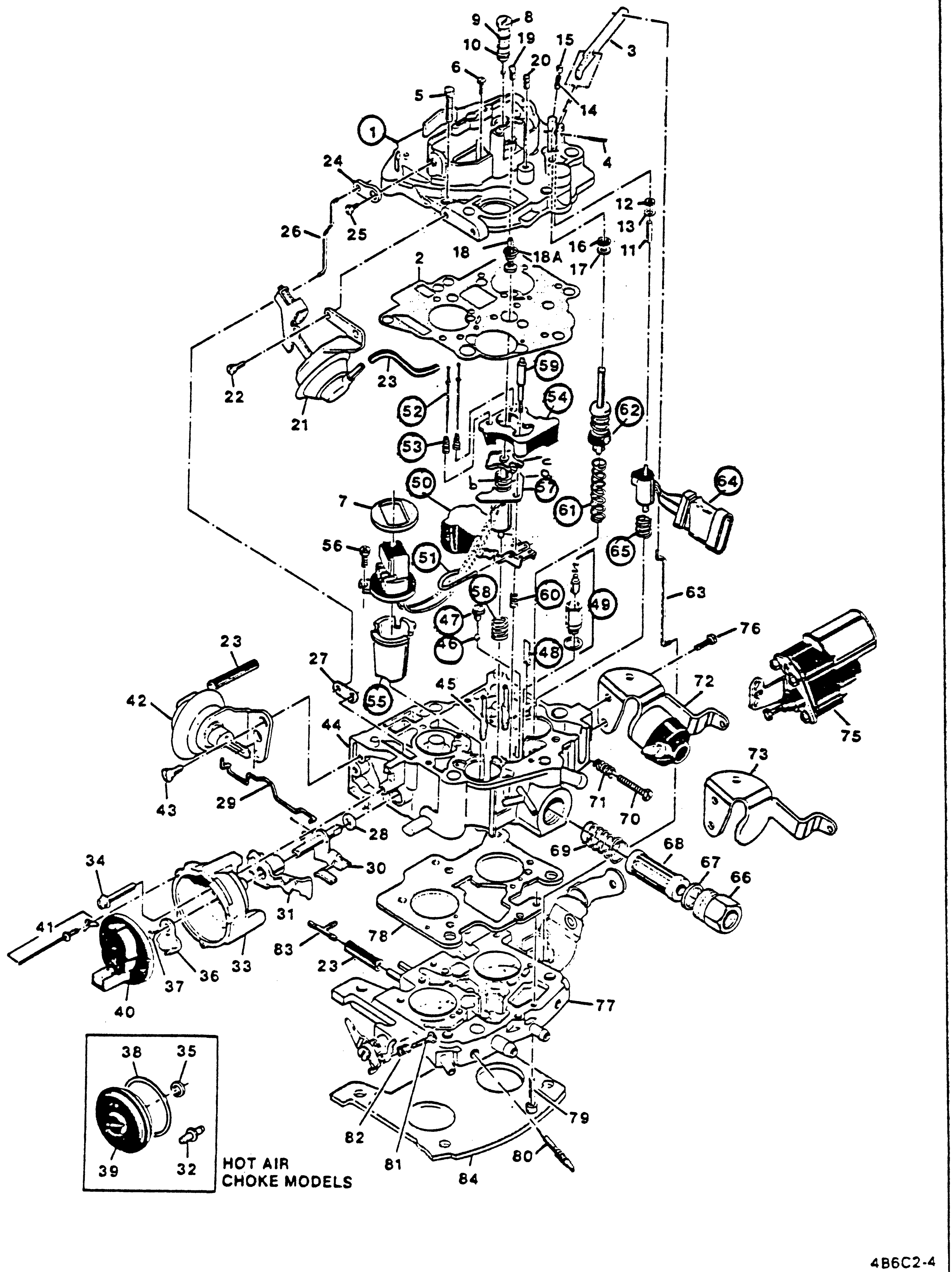

Figure 1.a. Exploded View Of Carburetor Assembly

AIR HORN PARTS

(Not all parts appear on all models.)

No.	Part Name
1.	Air Horn Assembly
2.	Gasket - Air Horn
3.	Lever - Pump Actuating
4.	Roll Pin - Pump Lever Hinge
5.	Screw - Air Horn, Short
6.	Screw - Air Horn, Countersunk (2)
7.	Gasket - Solenoid Connector to Air Horn
8.	Valve - Idle Air Bleed
9.	"O" Ring, Thick - Idle Air Bleed Valve
10.	"O" Ring, Thin - Idle Air Bleed Valve
11.	Plunger - TPS Actuator
12.	Seal - TPS Plunger
13.	Retainer - TPS Seal
14.	Screw - TPS Adjusting
15.	Plug - TPS Screw
16.	Seal - Pump Plunger
17.	Retainer - Pump Seal
18.	Screw - Solenoid Plunger Stop (Rich Mixture Stop)
18a.	Spring - Rich Authority Adjusting
19.	Plug - Plunger Stop Screw (Rich Mixture Stop)
20.	Plug - Solenoid Adjusting Screw (Lean Mixture)

CHOKE PARTS

(Not all parts appear on all models.)

No.	Part Name
21.	Vacuum Break & Bracket - Front
22.	Screw - Vacuum Break Attaching (2)
23.	Hose - Vacuum
24.	Lever - Choke Upper
25.	Screw - Choke Lever
26.	Rod - Choke
27.	Lever - Intermediate Choke - Lower
28.	Seal - Intermediate Choke Shaft
29.	Link - Rear Vacuum Break
30.	Intermediate Choke Shaft & Lever
31.	Cam - Fast Idle
32.	Seal - Choke Housing to Bowl (Hot Air Choke)
33.	Choke Housing
34.	Screw - Choke Housing to Bowl
35.	Seal - Intermediate Choke Shaft (Hot Air Choke)
36.	Lever - Choke Coil
37.	Screw - Choke Coil Lever
38.	Gasket - Stat Cover (Hot Air Choke)
39.	Stat Cover & Coil Assembly (Hot Air Choke)
40.	Stat Cover & Coil Assembly (Electric Choke)
41.	Kit - Stat Cover Attaching
42.	Vacuum Break Assembly - Rear
43.	Screw - Vacuum Break Attaching

FLOAT BOWL PARTS

(Not all parts appear on all models.)

No.	Part Name
44.	Float Bowl Assembly
45.	Jet - Primary Metering (2)
46.	Ball - Pump Discharge
47.	Retainer - Pump Discharge Ball
48.	Baffle - Pump Well
49.	Needle & Seat Assembly
50.	Float Assembly
51.	Hinge Pin - Float Assembly
52.	Rod - Primary Metering (2)
53.	Spring - Primary Metering Rod (2)
54.	Insert - Float Bowl
55.	Insert - Bowl Cavity
56.	Screw - Connector Attaching
57.	Mixture Control (M/C) Solenoid & Plunger Assembly
58.	Spring - Solenoid Tension
59.	Screw - Solenoid Adjusting (Lean Mixture)
60.	Spring - Solenoid Adjusting Screw
61.	Spring - Pump Return
62.	Pump Assembly
63.	Link - Pump
64.	Throttle Postition Sensor (TPS)
65.	Spring - TPS Tension
66.	Filter Nut - Fuel Inlet
67.	Gasket - Filter Nut
68.	Filter - Fuel Inlet
69.	Spring - Fuel Filter
70.	Screw - Idle Stop
71.	Spring - Idle Stop Screw
72.	Idle Stop Solenoid & Bracket Assembly
73.	Bracket - Throttle Return Spring
75.	Idle Speed Control & Bracket Assembly
76.	Screw - Bracket Attaching

THROTTLE BODY PARTS

(Not all parts appear on all models.)

No.	Part Name
77.	Throttle Body Assembly
78.	Gasket - Throttle Body
79.	Screw - Throttle Body
80.	Idle Needle & Spring Assembly (2)
81.	Screw - Fast Idle Adjusting
82.	Spring - Fast Idle Screw
83.	Tee - Vacuum Hose
84.	Gasket - Flange

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Figure 1.b. Exploded View Parts Description

2. DESCRIPTION OF ASSEMBLY

The General Motors Rochester Products model E2ME Dualjet carburetor is the product under study. This report is concerned with the parts circled in figure 1.

The Float Bowl Assembly (#44) was oriented horizontally on the table and served as the base part. The rest of the parts were picked by the robot from fixed points and were inserted or located in the correct position on the Float Bowl Assembly. See figure 2. The behavior of each part during assembly was observed and it is recorded below.

2.1 Bowl Cavity (#55)

This insertion caused no problems. It had to be positioned accurately as did the rest of the parts, but this was not difficult.

2.2 Needle and Seat Assembly (#49)

It was assumed that the seat was preassembled. Therefore only the insertion of the needle was performed by the robot. The pull clip located on the needle needs to be hooked over the edge of the flat on the float arm facing the float pontoon. See figure 3a. In the current design the pull clip can lose its orientation easily. Also, the end of the clip will not allow a snap-type of fit by the flat on the float. The proposed redesign is to secure the position of the clip such that the curved end will face the float, be bent so that a snap fit will result and the shape of the clip will hold the float in position after insertion. See figure 3.b.

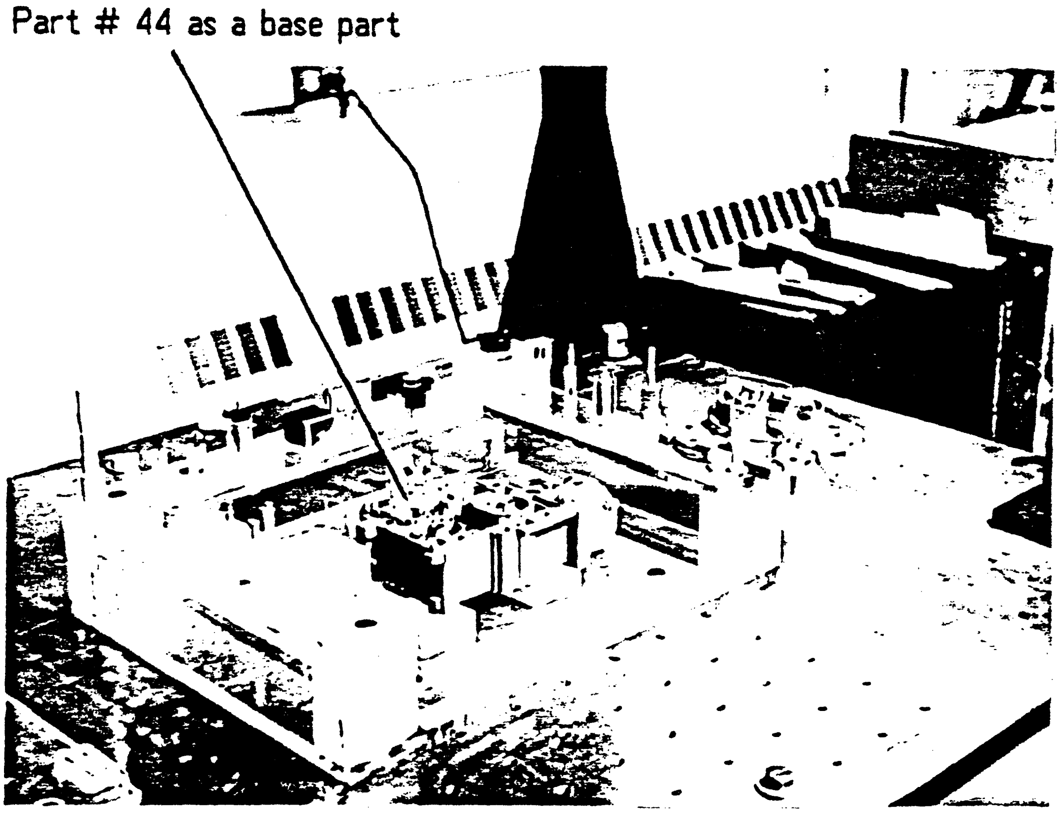
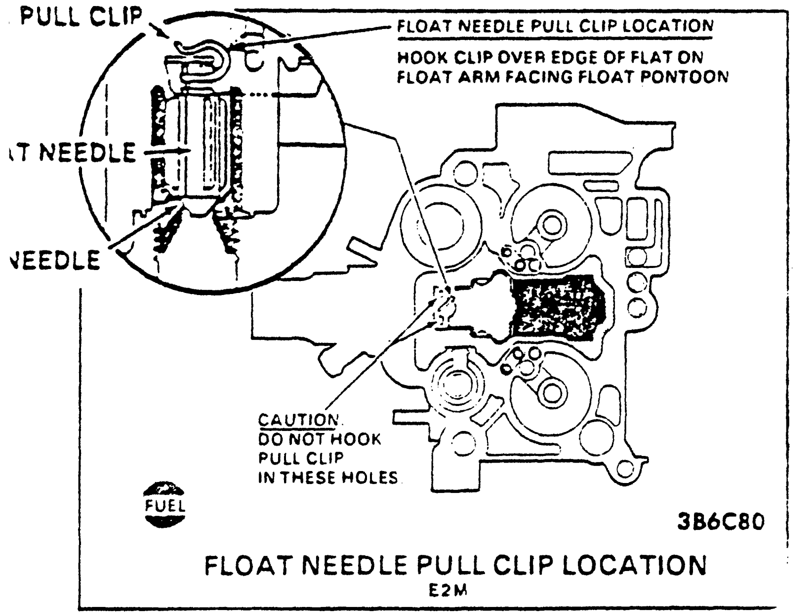


Figure 2. Experimental Setup



ure 3.a. Original Pull Clip Design And Location

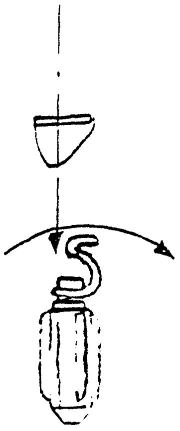


Figure 3.b. Suggested Pull Clip Design, Please Note The Proposed Sn
Fit Motion Of The Clip Redesign

2.3 Ball-Pump Discharge (#46)

The placing of this part was quite straight-forward and consisted of dropping it at a minimal height above the discharge hole. See figure 4.

It was observed that at high robot speeds and higher dropping heights the operation failed, because the part either hit the side walls or bounced back.

2.4 Retainer-Pump Discharge Ball (#47)

The placing of this part was performed by the robot but special tooling was required to complete the screw operation. In this case it was done manually. This part also behaved the same as the Pump Discharge Ball at high speeds and locations of drop. See figure 4.

2.5 Baffle-Pump Well (#48)

The tapered shape of this part allowed no failure in the insertion process.

2.6 Spring-TPS Tension (#65)

Since this spring was rigid enough, handling did not create any problems and the operation succeeded all the time.

2.7 Throttle Position Sensor (TPS) (#64)

This was the first of the parts which had wiring on it, by which two parts were connected. Since the wiring was short and rigid enough, the part which was free in the air did not lose much of its orientation and the operation never failed. This is not the case in later assembly operations.

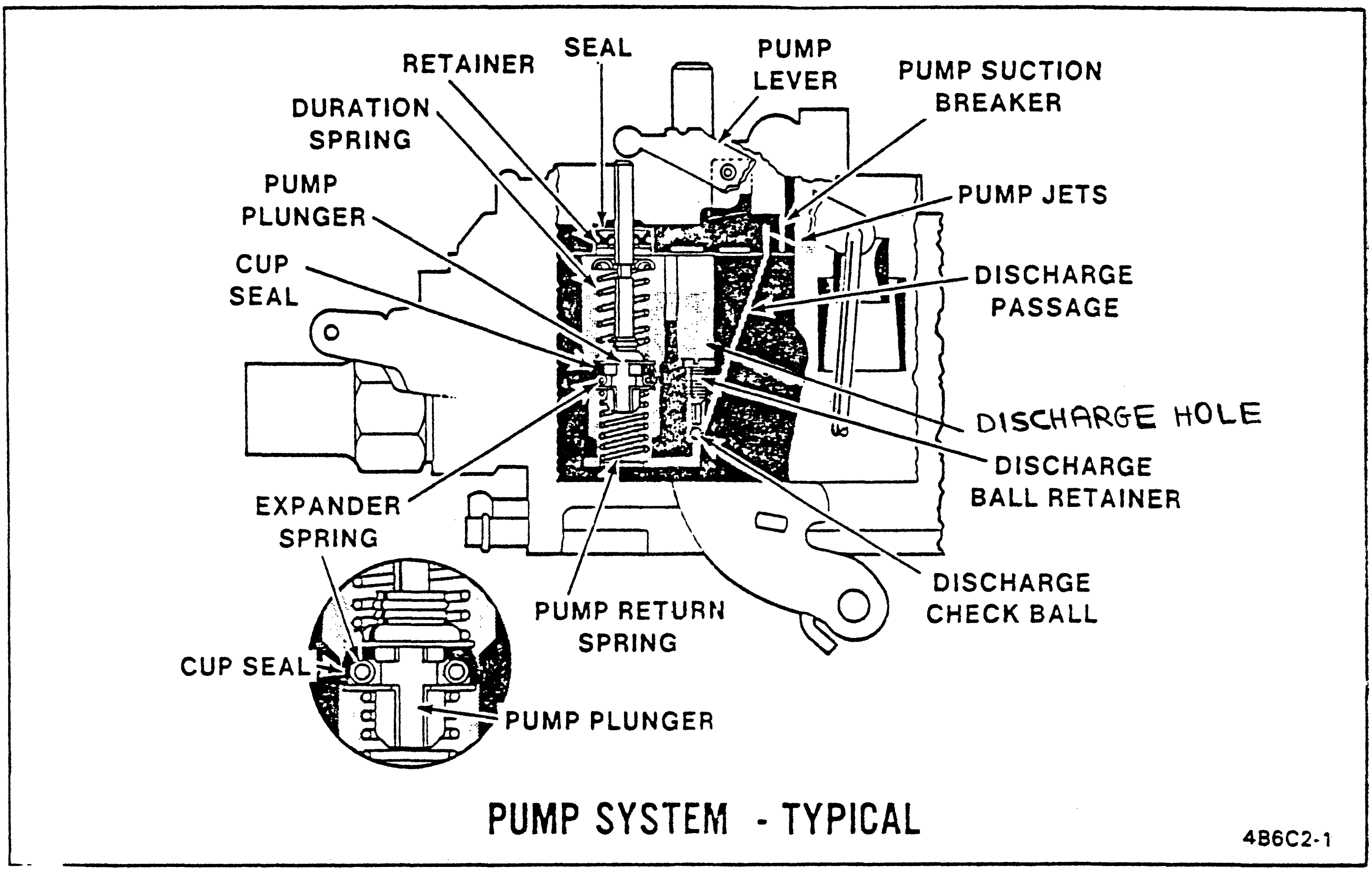


Figure 4. Location Of Discharge Ball And Ball Retainer

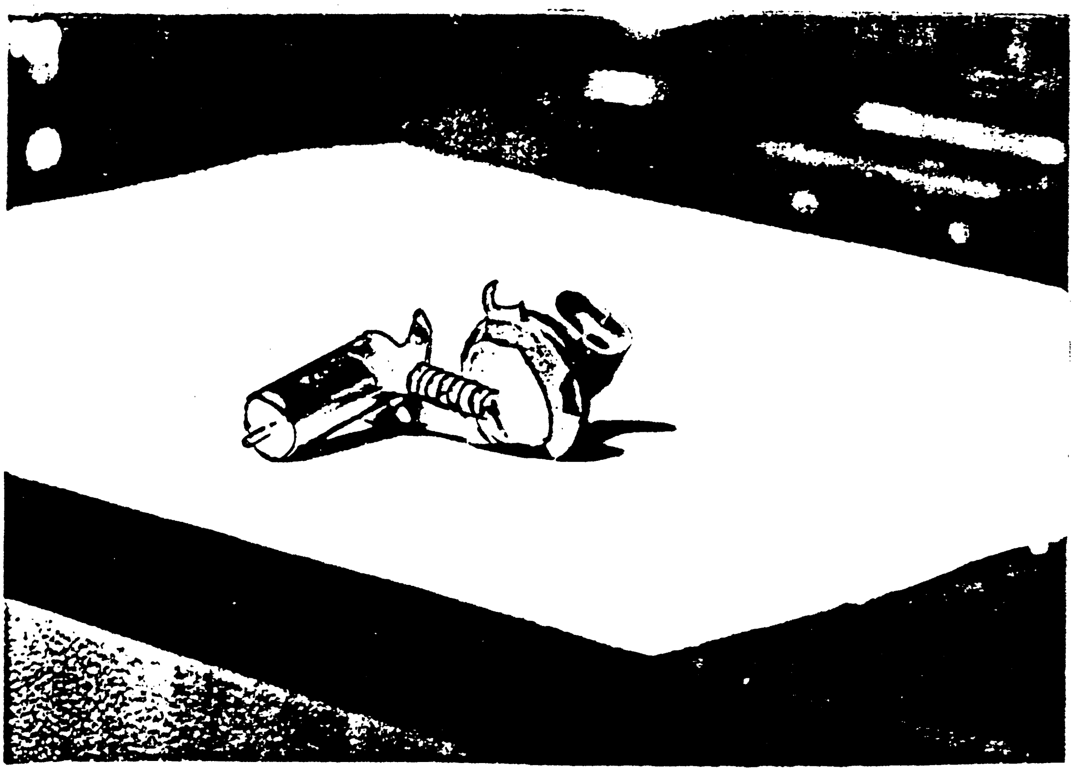


Figure 5. Modified Mixture Control Solenoid

2.8 Spring-Solenoid Tension (#58)

This was another part that had to be drop-inserted. Due to its short length and high height of drop, successful placement of this spring almost never succeeded. It was realized that at higher speeds of operation, the percent success increased. Also, because of the existence of the Solenoid Adjusting Spring (#60) this spring can be eliminated from the assembly.

2.9 Spring-Pump Return (#61)

This spring was simply dropped to its hole. To achieve vertical orientation it was then pressed down by a special tool.

2.10 Spring-Solenoid Adjusting Screw (#60)

This operation never failed. Ideally a spring having a flat end would be a better design since it would not tangle easily and would stay vertical.

2.11 Hinge Pin (#51)

Insertion of the hinge pin to the float was very difficult because of close tolerances. By tapering the end of the hinge pin this difficulty was overcome. Also due to vibration of the robot arm, the hinge pin would not stay at its proper position after being inserted. Irregular layer of some glue applied to the pin provided the friction necessary for keeping it at its location.

2.12 Float Assembly (#50)

As long as the hinge pin did not lose its orientation on the float, this insertion succeeded.

2.13 Mixture Control Solenoid (#57.a)

This part was impossible to position since two parts were connected by flexible wiring and orientation of the part which was not held by the gripper was lost easily. A more rigid bridge made of epoxy and a spring enabled the operation to be performed. The bridge provided enough rigidity to keep the part at the right position and enough flexibility for adjustment of the solenoid. See figure 5.

2.14 Screw-Connector Attaching (#56)

Like the rest of the screws this one also required special tooling. Due to improved rigidity of solenoid need for this screw disappeared. When the solenoid was inserted it did not lose its orientation as it used to. Also the pressure exerted by Air horn Assembly (#1) secured the solenoid's position.

2.15 Screw-Solenoid Adjusting (#59)

This screw also required special tooling. Because of its fine threads, it would be very difficult to screw it in with the robot.

2.16 Insert Float Bowl (#54)

Insertion of this part succeeded most of the time. Because of its light weight, friction caused at the time of insertion happened to keep this part from full drop-insertion once in a while.

2.17 Spring (#57.b)

This spring was helix shaped, very soft, and fitted tightly to the mixture control solenoid from the small end. To perform the operation, the bigger end was fitted to the mixture control solenoid. At slow speeds the number of success was higher. This is due to the fact that inertia force was lower.

2.17 Rod-Primary Meetering (#52)

Since the contact area between the gripper and the part was only a point or a small line, it was very easy for this part to shift left and right in the gripper. A suggested redesign is to increase the line of contact or provide as much of a flat surface as possible for handling purposes. Due to gradual decrease in its diameter it allowed easy insertion to part #53. See figure 6.

2.18 Spring-Primary Meetering Rod (#53)

This spring was also helix-shaped, very soft and tight-fit to #52. An attempt was made to insert part #52 into part #53 at the feeding point, before insertion of both into the base part. After #52 was inserted to #53, transportation of the two parts required proper handling of spring, since it would fall due to vibration in the robot arm. Also, because the spring was soft and helix shaped, proper handling was not possible without damaging the spring. For these reasons, the helical springs were replaced with normal cylindrical coil springs. These provided the advantages of being symmetrical for feeding and handling purposes and also created enough contact points for proper gripping.

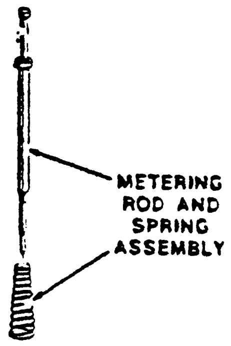


Figure 6. Metering Rod And Spring Assembly

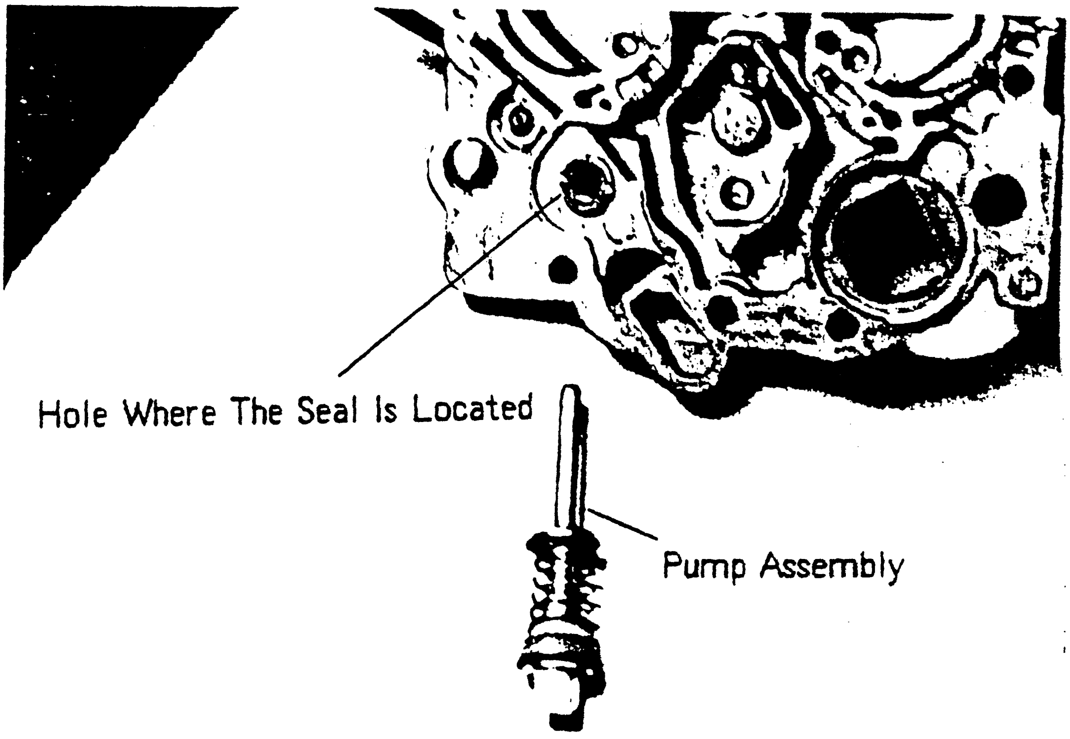


Figure 7.a. Pump Assembly And The Hole It Is Inserted

2.19 Solenoid Plunger (#57.c)

Handling and insertion of this part caused no problems.

2.20 Pump Assembly (#62)

Throughout the assembly a person would think that after #61 was inserted, the next step is to put part #62 on top of it. This could not have been done since #62 would lose its position easily and would not allow proper insertion to part #1.

Surprisingly the current design precluded this difficulty. A seal (#16) in part #1 provided the friction necessary to hold part #62 to part #1 during the insertion of part #1 to the rest of the assembly. Part #1 were picked first by the robot and lowered down when the hole that #16 is located aligned vertically with #62. Then both parts were treated as a subassembly and inserted to #1. The only necessary modification was to taper the end of #62 for easier insertion. See figure 7.

2.21 Air Horn Assembly (#1)

This part didn't provide enough surface for proper handling. By means of gluing two plexiglass flat surfaces, this problem was also overcome.

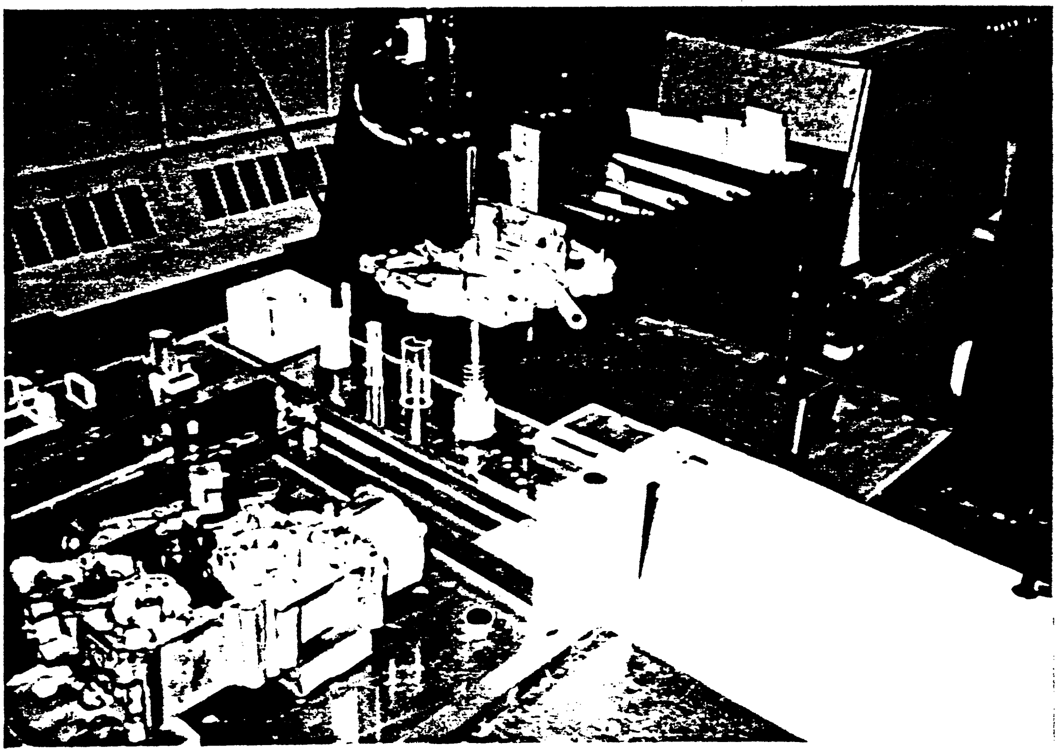


Figure 7.b. Pump Assembly Insertion

3. ASSEMBLY EVALUATION BASED ON UMASS (Boothroyd) SYSTEM.

3.1 Generation of Worksheet for Automatic Assembly

The completion of the "Automatic Assembly Worksheet" (figure 8) was done with respect to the suggested steps in the "Design for Assembly Handbook" [1].

The existing version of the assembly was taken apart and an identification number was assigned for each part. Then the product was re-assembled beginning with the part with the highest identification number. Each row of the worksheet was completed. When doing so it was assumed that all the parts met the UMASS feeding criteria. The last two digits of column three (Automatic Handling and Feeder Costs) were filled based on the author's best judgement.

Column 1, Worksheet ID number of the Bowl Cavity is 22.

Column 2, operation is carried out only once, therefore 1 is entered.

Column 3, the five digit automatic handling code is determined from charts 4 to 7, [1]. In this case it was determined to be 17480.

Columns 4, 5, PE = 0.05 and CR = 1 were determined from the five digit code and the charts.

Column 6, Maximum feedrate from a standout feeder is given by FM = 1500 x OE/Y, where Y is the maximum size (in mm) of the part under consideration.

Aside from columns 9 and 10, the rest of the columns were filled by applying formulas shown on the worksheet. Chart 8, [1] was used for Columns 9 and 10.

required rate of assembly FR (per minute): 2

Name of Assembly: Carburetor Sub-assembly

1 part I.D. No.	2 number of times operation is carried out simultaneously	3 five-digit automatic handling code	4 orienting efficiency, OE	5 relative feeder cost, CR = FC + DC	6 maximum basic feed rate, FM	7 difficulty rating for automatic handling, DF	8 cost of automatic handling per part, CF = 0.03 x DF	9 two-digit automatic insertion code	10 relative workhead cost, WC	11 difficulty rating for automatic insertion, DI	12 cost of automatic insertion per part, CI = 0.06 x DI	13 operation cost, cents (2) x [(8) + (12)]	14 figures for estimation of theoretical minimum parts	Name of Assembly
22	1	17480	0.05	2.5	2.0	75	2.25	00	1.0	30	1.8	4.05	0	Bowl Cavity (55)
21	1	22066	0.75	6.0	86.5	180	5.4	00	1.0	30	1.8	7.2	1	Needle Seat Assy (49)
20	1	10002	0.7	3.0	210	90	2.7	01	1.5	45	2.7	5.4	1	Ball-Pump Discharge (46)
19	1	21000	0.9	1.0	84.3	30	0.9	39	1.8	54	3.2	4.1	1	Retainer-Pump Discharge Ball (47)
18	1	61546	0.7	5.0	38.8	150	4.5	00	1.0	30	1.8	8.1	1	Baffle - Pump Well (43)
17	1	20015	0.9	6.0	61.3	180	5.4	30	1	30	1.8	7.2	1	Spring-Tps Tension (65)
16	1	27406	0.27	5.0	10.12	150	4.5	11	1.6	48	2.88	7.38	1	Throttle Position Sensor (64)
15	1	10016	0.7	6.0	80.8	180	5.4	00	1	30	1.8	7.2	0	Spring-Solenoid Tension (58)
14	1	20016	0.7	6.0	28.7	180	5.4	92	0.8	24	1.44	6.8	1	Spring-Pump Return (61)
13	1	20016	0.9	4.0	122	130	5.4	00	1	30	1.8	7.2	1	Spring-Solenoid M[illegible] [illegible] (60)
												64.3 CA	8 NM	design efficiency = $\frac{0.09 \times NM}{CA}$ =

Column 6: $FM = 1500 \times \frac{OL}{Y}$, Y = part 'size'

Column 7: $DF = \frac{60}{FR} \times CR$ if $FR < FM$; $DF = \frac{60}{FM} \times CR$ if $FR \geq FM$

Column 11: $DI = \frac{60}{FR} \times WC$ if $FR < 60$; $DI = WC$ if $FR \geq 60$

Figure 8.a

1	2	3	4	5	6	7	8	9	10	11	12	13	14	required rate of assembly FR (per minute) 2
part I.D. No.	number of times operation is carried out simultaneously	five-digit automatic handling code	orienting efficiency, OE	relative feeder cost, CR = FC + DC	maximum basic feed rate, FM	difficulty rating for automatic handling, DF	cost of automatic handling per part, CF = 0.03 x DF	two-digit automatic insertion code	relative workhead cost, WC	difficulty rating for automatic insertion, DI	cost of automatic insertion per part, CI = 0.06 x DI	operation cost, cents (2) x [(8) + (12)]	figures for estimation of theoretical minimum parts	Name of Assembly
12	1	27402	0.27	4.0	76.9	120	3.6	12	1.6	48	2.88	6.48	1	Hinge Pin (51)
11	1	81222	0.4	4.0	7.39	120	3.6	03	2.3	69	4.14	7.74	1	Float Assembly (50)
10	1	27479	MANUAL ASSEMBLY									8.12	1	Mixture Control Stud (57.a)
9	1	21002	0.9	3.0	103.8	90	2.7	39	1.8	54	3.24	5.94	0	Screw Connector Attaching (56)
8	1	22002	0.15	3.0	25.6	90	2.7	39	1.8	54	3.24	5.94	1	Screw - Solenoid Adjusting (59)
7	1	86526	0.05	6.5	1.92	203	6.09	02	1.5	45	2.7	8.79	1	Insert - Float Bowl (54)
6	1	15076	0.6	8	45	240	7.2	03	2.3	69	4.14	11.34	1	Spring-Solenoid Plunger (57.b)
5	2	22022	0.25	4	20.8	120	3.6	02	1.5	45	2.7	12.6	2.	Rod-Primary Metering (52)
4	2	25076	0.6	8	4.68	240	7.2	02	1.5	45	2.7	19.8	2	Spring-Primary Metering (53)
3	1	17402	0.24	4	9.0	120	3.6	00	1	30	1.8	5.4	1	Solenoid-Plunger (57.c)
												98.09	11	design efficiency = $\frac{0.09 \times NM}{CA}$ =
												CA	NM	

Column 6 $FM = 1500 \times \frac{OL}{Y}$

Y = part 'size'

Column 7 $DF = \frac{60}{FR} \times CR$ if $FR < FM$

$DF = \frac{60}{FM} \times CR$ if $FR \geq FM$

Column 11 $DI = \frac{60}{FR} \times WC$ if $FR < 60$

$DI = WC$ if $FR \geq 60$

Figure 8.b

required rate of assembly FR (per minute): 2

Name of Assembly: Pump Assembly (6?)

part I.D. No.	number of times operation is carried out simultaneously	five-digit automatic handling code	orienting efficiency, OE	relative feeder cost, CR = FC + DC	maximum basic feed rate, FM	difficulty rating for automatic handling, DF	cost of automatic handling per part, CF = 0.03 x DF	two-digit automatic insertion code	relative workhead cost, WC	difficulty rating for automatic insertion, DI	cost of automatic insertion per part, CI = 0.06 x DI	operation cost, cents (2) x [(8) + (12)]	figures for estimation of theoretical minimum parts
2	1	22002	0.75	3	16.54	90	2.7	02	1.5	45	2.7	5.4	1
												168.0	20
												CA	NM

design efficiency $= \frac{0.09 \times NM}{CA} =$ 0.0107

Column 6: $FM = 1500 \times \frac{OI}{Y}$

Y = part 'size'

Column 7: $DF = \frac{60}{FR} \times CR$ if $FR < FM$

$DF = \frac{60}{FM} \times CR$ if $FR \geq FM$

Column 11: $DI = \frac{60}{FR} \times WC$ if $FR < 60$

$DI = WC$ if $FR \geq 60$

Figure 8.c

1	2	3	4	5	6	7	8	9	Name of Assembly
part I.D. No.	number of times the operation is carried out consecutively	two-digit manual handling code	manual handing time per part	two-digit manual insertion code	manual insertion time per part	operation time, seconds (2) x [(4) + (6)]	operation cost, cents 0.4 x (7)	figures for estimation of theoretical minimum parts	
10	1	83	5.6	38	6	11.6	8.12	1	Mixture Control Solenoid
						TM	CM	NM	

design efficiency = $\frac{3 \times NM}{TM}$ =

Figure 8.d

For further explanation of how the worksheet was completed it is suggested that the reader refer to the Design for Assembly Handbook [1]. Please note that figure 7 is the author's completion of the worksheet; others might rate the parts and complete the worksheet differently.

3.2 Assessment of Boothroyd Data.

3.2.1 Potential for eliminating the parts.

It is seen from the worksheet that the present design of the parts yields a very low efficiency of 1.07 percent for automatic assembly. Zeros in column 14 suggest that either parts can be eliminated or joined with other parts. The bowl cavity (ID 22) can be molded together with the mixture control solenoid corrector. This will result in elimination of one part from the assembly as well as a reduction of total assembly time.

Spring-Solenoid Tension (ID 15) can be eliminated from the assembly, since the Spring-Solenoid Adjusting screw serves the same purpose.

Screw-Connector Attaching (ID 9) can also be eliminated since the cover (ID 1) exerts enough pressure on the solenoid connector, to keep it in its place.

3.2.2 Potential for improving automatic handling and assembly.

Cases where manual handling is necessary, or where the operation cost is high, requires improved design for automatic assembly. Cases where very soft helix spring were used (ID #4 and #6) created handling problems. Also, cases where parts didn't provide enough contact surface (ID #5) caused misalignment problems.

Some of the parts were very hard to insert due to close tolerances. The Hinge pin (ID #12) was one of these.

For springs, the ideal shape is symmetric with ends closed. For parts which can not be held easily because of small contact area it is suggested to have more flat surfaces. To decrease the effect of close tolerances, ends of the parts should be tapered.

4. DISCUSSION AND CONCLUSION

In Sections Two and Three we observed that our analysis correlates fairly well with the Boothroyd approach. Data generated for the Boothroyd system were substantially based on personal best judgement. This is due to the fact that the Boothroyd approach has some limitations for automated assembly. But it did show the importance of using a design for assembly method. The Boothroyd system's limitations on part properties related to this experiment are listed below. The evaluation does not account for:

I - Parts which are connected by wires and are free to lose their orientation with respect to each other.

II - Parts, which are made of two or more separate parts and can rotate or slide with respect to each other.

III - Springs, which are not symmetrical and are very soft.

Based on the problems encountered, the following guidelines should be additionally considered in design for automated assembly:

1. Do not include sliding or rotating features on parts. This is due to the fact that during transportation or insertion of these parts necessary orientation is very difficult to achieve.
2. Eliminate helix-shaped, soft springs to ease the difficulty involved in handling and transporting such parts because of minimal contact area and limited gripping force.
3. Avoid tight-fitting springs.
4. Allow enough contact area for proper handling of parts.

5. Do not use flexible wiring between parts or use only sufficiently rigid wiring when absolutely necessary.

6. Try to evolve a single part design for parts which do not move with respect to each other. This may require expensive castings or moldings, but it can reduce the costs of assembly.

7. Provide tapered ends or chamfers for easy insertion.

8. Eliminate exceedingly lose-fit insertion-type subassemblies to enable the proper transportation of the parts without being affected by vibration of robot arm or inertia forces.

9. Consider using rubber seals etc. for vertical transportation of parts as in the case of pump assembly by pump plunger seal. This will create more subassemblies and will insure that parts being inserted will stay vertical to the plane of insertion.

10. Avoid using fine threaded, unnecessarily long screws.

Since design for automated assembly methods are in the process of being developed, experiments with relatively complicated parts have an important role in determining the problems encountered in automated assembly. The Carburetor Subassembly was such an example. Rules developed throughout this experiment are believed to be helpful to designers and to developers of automated assembly methods.

REFERENCES

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