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ABSTRACT

A design for assembly (DFA) method is used to analyze the existing design of parts of an electrical switch, and to reduce and re-design them, for the ease of automatic assembly. The procedure for the selection of suitable and economical assembly method is presented based on the Boothroyd & Dewhurst methods. Analysis of the initial design for manual assembly and the re-design for automatic assembly are presented. An algorithmic approach for simplified generation of all mechanical assembly sequences and selecting the good assembly sequences is presented with graphical representations. A work station needed for the automatic assembly is developed, which incorporates vibratory bowl feeders, an indexing machine and other equipment.

**DESIGN FOR ASSEMBLY: RE-DESIGN OF AN ELECTRICAL SWITCH FOR
THE EASE OF AUTOMATIC ASSEMBLY**

By

ACHYUTA REDDY PANNALA

**Thesis submitted to the Faculty of The Graduate School of New Jersey Institute of
Technology in the partial fulfillment of the requirements for the degree of Master of
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To My Parents

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Chapter 1

INTRODUCTION

In any manufacturing task, design is the first stage, and it is at this stage, that, the manufacturing costs are largely determined. The assembly process is the most important process which largely determines the manufacturing costs and labor requirements. Design for assembly or "automation friendly" design is concerned with defining product design alternatives which facilitate optimization of the product/process as a whole. For the improvement in productivity, design for ease of assembly must be given the highest priority. When automated assembly is considered one must determine whether the design of the product lends itself to such automation. The first step in assembly techniques is to identify the assembly process that is most likely to be economic for a particular product. Then the product can be designed for that particular process. The reason for early process selection is important, because manual assembly differs widely from automatic assembly in the requirements, it imposes on product design. An operation that is easy for a person may be impossible for a robot or a special purpose workhead, and operations that are easy for machines may be difficult for people [1].

Assembly cost depends crucially on product design, especially when high-speed dedicated assembly system is to be used. The suitability of a product for automatic assembly and the cost of assembly can both be assessed by systematically classifying features even when details of the assembly process are not known [10].

Production costs are minimized when design and production engineering are coordinated. That is, when the least costly production process is selected and the product is designed for that process. When a product is to be assembled automatically, the design can be assessed for suitability even before the details of

the assembly process are known. Design features can be classified and numerical ratings assigned to indicate areas where assembly can be made easier. Suitability of a product for automatic assembly can be determined by an analysis that consists of three major steps for each component part in the assembly:

- * Estimating the cost of handling the part automatically in bulk and delivering it in the correct orientation for insertion on an automatic assembly machine.

- * Estimate the cost of inserting the part automatically into the assembly and the cost of any extra operation.

- * Decide whether the part must necessarily be separate from all other parts in the assembly.

These three pieces of information can be combined to estimate the total cost of assembly and to estimate the "design efficiency" which is a numerical rating for the ease of automatic assembly [10].

When implementing the automation technologies, product design and automation design can no longer be treated as separate entities, but rather, must be integrated into one common activity. It is especially essential that interactions between product and process enter into consideration very early in the product design process. Product concept and automation decisions must be made in parallel in order to obtain an integrated manufacturing system optimally configured to satisfy both product and process needs.

Design for assembly is concerned with defining product design alternatives, which facilitate optimization of the product/process as a whole. Design for assembly involves the application of concisely stated design principles and guidelines to each decision making step [2].

The two main objectives of design for assembly studies are:

1. Reduce the number of parts.
2. Increase the ease of assembling the remaining parts.

1.1 FEW INSTANCES OF DESIGN FOR ASSEMBLY IMPLEMENTATION

Several major companies such as IBM, Dec, Xerox, and General Electric are using "design for assembly", and reporting material and labor savings of 25% to 30%. In RCA laboratories, video disc player's arm drive was developed for robotic assembly. The number of parts in this mechanism was reduced by 25% (from 12 to 9), and assembly time was reduced by 58 seconds, following the principles and guidelines of design for assembly.

At Satchwell Ltd., an immersion water heater controller was examined for automating the production process. Initially there were 21 component parts, out of which 14 were unsuitable for automatic assembly. The controller was then re-designed and simplified, using the information from the analysis. The new controller had 16 parts, of which only six were unsuited to automatic assembly. The process was automated even though some manual assembly remained [10].

In [14] it was discussed that, a water filter, with 12 parts was re-designed to 3 parts. 25% of the original manual assembly cost was eliminated by the new design.

Design for assembly method was used by 'Center for Flexible Manufacturing Research and Development' department of McMaster university, Hamilton, ON, Canada, to re-design a family of DC motors and reduced the number of parts from 56 to 18. The manual assembly time was reduced from 424.4 seconds to 171.0

seconds. The overall motor design efficiency was increased to 26.3% from 18.4% [15].

In IBM corporation, a paper feed mechanism was re-designed and the number of parts was reduced from 27 to 14. The re-design mechanism is now in production in the IBM plant in Austin, Texas. The original reason for re-design of this mechanism was, so that it can be assembled robotically. The resulting effort has produced an improved design for assembly manually, robotically or with fixed automation [16].

The above mentioned few examples of implementation of design for assembly methods clearly show that "design for assembly" has been an effective tool for product analysis and improved part design for assembly.

The electrical switch used for this project is currently manually assembled. The estimated number of parts produced per annum is 10,000,000. The high rate of production of these switches is motivation for the selection of this electrical switch as a candidate for automatic assembly. The existing design of many of the parts of the switch are analyzed and found not suitable for automatic assembly.

Design for assembly methods and principles are used to analyze each part of this switch and then the parts are re-designed for the ease of assembly, selection of suitable method for assembly, based on the 'Boothroyd & Dewhurst' methods is presented. The old design of the electrical switch is analyzed and compared with the analysis of the re-designed parts. Possible mechanical assembly sequences are generated and a method to select the good assembly sequences is presented. An automatic assembly work cell layout is designed, for the assembly of the re-designed parts of the switch.

Chapter 2

DESIGN PRINCIPLES AND GUIDELINES FOR AUTOMATIC ASSEMBLY

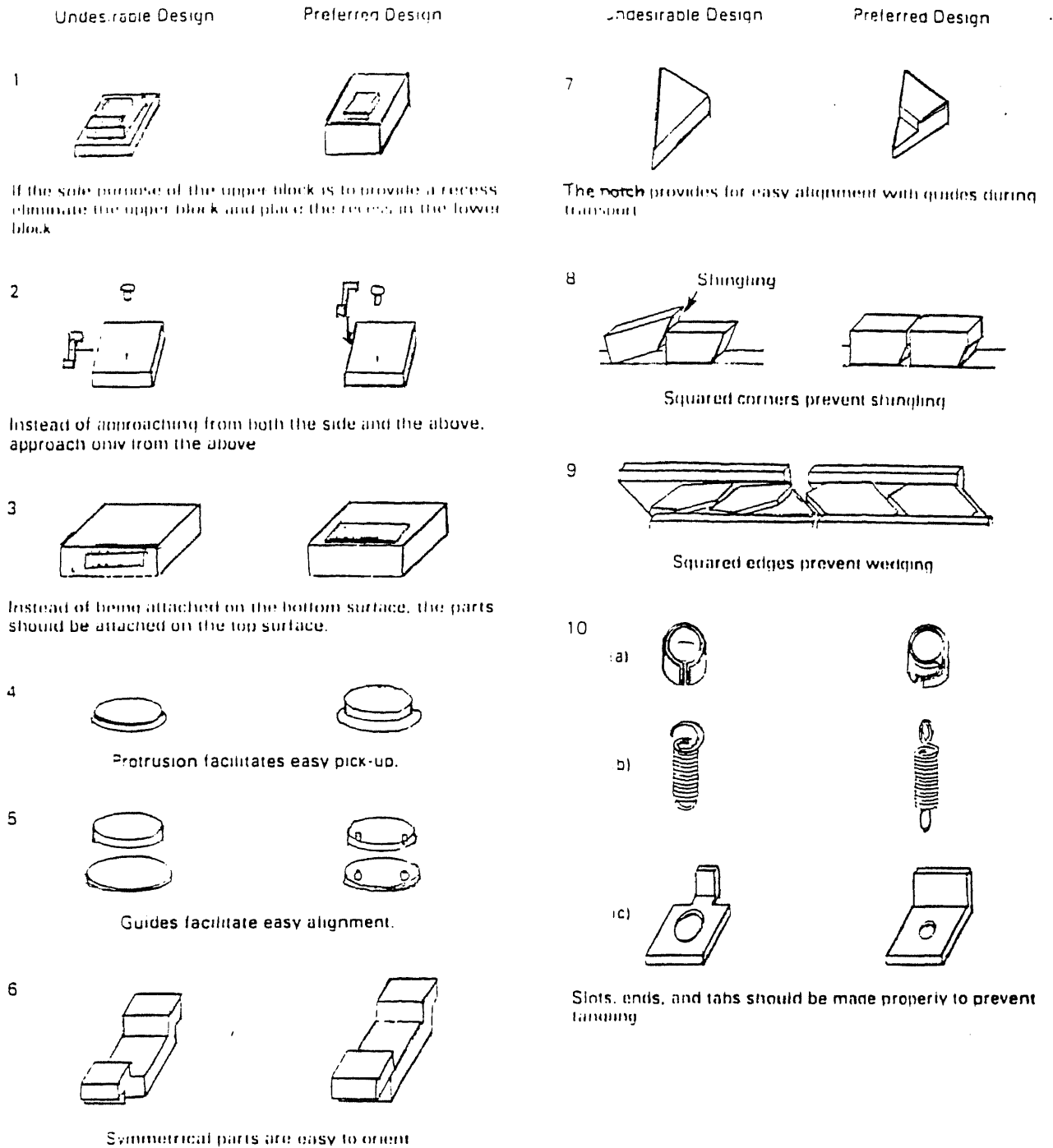
Products can be designed to fulfill the above said objectives, by following design approaches, techniques, tricks and design tips that have evolved out of automation experience which help show the way to good design for assembly. The great advantage of using concisely stated design for assembly principles and guidelines is that they explicitly state what is intuitively obvious to experienced designers and commonly used by good designers. Such a system of principles and guidelines therefore provide a firm basis upon which design knowledge can be expanded in a systematic way.

The following are the few guidelines for design for assembly suggested in [2] and [4] are summarized as follows:

1. Minimize the total number of parts.
2. Develop a modular design
3. Use standard components
4. Design parts to be multi-functional
5. Design parts for multi-use
6. Design parts for ease of fabrication
7. Avoid separate fasteners
8. Minimize assembly directions
9. Maximize compliance
10. Minimize handling
11. Provide unobstructed access

12. Fit parts with guide surfaces
13. Make the parts symmetrical
14. If symmetry is difficult to obtain provide asymmetrical features to facilitate part orientation.
15. Avoid parts which shingle
16. Avoid parts which wedge
17. Avoid projections holes or slots which cause tangling with identical parts during automatic feeding
18. Use trays, reels and strips or tubes and magazines for supplying different parts to the automated equipment.
19. Provide chamfers or tapers to facilitate parts mating.
20. Use snap-together parts wherever possible.
21. Design product to have parts assembled in a layering fashion so that pickup can be done easily and that stability of the parts during motion can be ensured.
22. Incorporate a one-handed adjustment when adjustment is necessary.

The above guidelines are illustrated in figure 1. These guidelines will be useful at any stage in the design process, but are most worthwhile if implemented in the initial stages of design.



continued

Figure 1, Design for Assembly: Guidelines

(Ref[6])

2.1 Applying the guidelines: The guidelines suggested for design for assembly and assembly automation should be thought as "optimal suggestions", which if successfully followed, will result in a more optimal, automation friendly design [2]. Use of the guidelines in this way helps to both assure a product design optimized for automated production and to delineate problem areas requiring special attention. Hints for creative application of the guidelines as well as insights to simulate innovative design are provided in the brief discussion of few guidelines follows. These guidelines are discussed in reference [2].

1. Minimize Total Number of Parts.

A part is a good candidate for elimination if there is 1) no need of relative motion, 2) no need for subsequent adjustments between parts, 3) no need of service or repeatability, and 4) no need for materials to be different. However, part reduction should not exceed the point of diminishing return where further part elimination adds cost and complexity because the remaining parts are too heavy, or too complicated to make and assemble, or are too unmanageable in other ways.

Perhaps the best way to eliminate parts is to identify a design concept which requires few parts. Integral design, or combining of two or more parts into one, is another approach. Besides the advantages given above, integral design reduces the amount of interfacing information required, and decreases weight and complexity. One piece structures have no fasteners, no joints, and fewer points of stress concentration. Conversely, structural continuity leads to high strength and lightweight.

Plastic is a major key to internal design. Plastic is available for making springs, bearings, cams and gear, fasteners, hinges, and optical elements. Brazed, welded or staked assemblies of stampings and / or machined parts can be made as one-piece P/M parts. Extrusions and precision castings as well as impacts are also good ways to eliminate subassemblies. Although switching to a different

manufacturing process may lead to a more costly part, experience with part integration has shown that a more costly process often turns out to be more economical when assembly costs are considered.

2. Develop a Modular design.

Design for modularity requires careful consideration of a variety of needs. To decouple the product from the automation, it is essential that stable groups be identified and that the interfacing information be specified in a way which facilitates the desired decoupling. Often, standardization of just a few dimensions is all that is needed to decouple product from process. In seeking to identify the minimum number of stable groups, it is useful to look at the distribution of functional requirements among different product models and lines to see if a particular function could be satisfied everywhere by one module. Looking for common problems within different models and product lines is another approach. A good design strategy is to keep the product generic for as long as possible during assembly by saving the specialized modules for last. If possible, the modules should be designed to add up to the final product thereby eliminating the need for a housing or other integrating structure.

3. Use Standard Components

Standard components require little or no lead time and are more reliable because characteristics and weakness are well known. They can be ordered in any quantity at any time. They are usually easier to repair and replacements are easier to find.

4. Design parts to be multi-functional

Combine function wherever possible. For example design a part to act both as a spring and a structural member, or to act both as an electrical conductor and structural member. An electronic chassis can be made to act both as an electrical

ground, a heat sink, and a structural member. Less obvious combinations of function might involve adding guiding, aligning, and/or self-fixturing features to a part to aid in assembly.

5. Design parts for multi-use

Many parts can be designed for multi-use. For example, the same mounting plate can be designed to mount a variety of components. Similarly, a spacer can also serve as an axle, lever, standoff, etc. Key to multi-use part design is identification of part candidates. One approach involves sorting all parts manufactured or purchased by the company into two groups consisting of 1) parts which are unique to a particular product or products and/or models. Each group is then divided into categories of similar parts. Multi-use parts are then created by standardizing similar parts. In standardizing the designer should sequentially seek to 1) category, and 3) minimize the number of design features within each variation. Once developed, the family of standard parts should be used wherever possible in existing products and used exclusively in new product designs.

6. Design of Parts for Ease of Fabrication

This guideline requires that individual parts be designed using the least costly material that just satisfies functional requirements (including style and appearance) and such that both material waste and cycle time are minimized. This is intern requires that the part be properly designed for the chosen process. Secondary processing (finish machining, painting, etc.) should be avoided whenever possible.

7. Avoid Separate Fasteners

Separate fasteners involve large amounts of information. Even in manual assembly, the cost of driving a screw can be six to ten times the cost of the screw. One of the easiest things to do is eliminate fasteners in assembly by using snap-fits. If fasteners must be used, cost as well as quality risks can be significantly reduced by

minimizing the size, number and variations used and by using standard fasteners whenever possible. Screws that are too short or too long, Separate washers, tapped holes, and round and flat heads should be avoided. Conversely, captured washers should be used for reduced part placement risk and improved blow feeding. For vacuum pickup, flat screw heads can be used.

8. Minimize Assembly Directions

All parts should be assembled from one direction. extra directions means wasted time and motion as well as more transfer stations, and fixture nets. This intern leads to increased cost, increased reliability and quality risks. The best possible assembly is when all parts are added in a top down fashion to create a z-axis stack. Multi motion insertion should be avoided.

9. Maximize Compliance

Because parts are not always identical and perfectly made, misalignment and tolerance stack-up can produce excessive assembly force leading to sporadic automation failures and/or product unreliability. Major factors affecting rigid part mating include part geometry, stiffness of assembly tool, stiffness of jigs and fixtures holding the parts, and friction between parts. To guard against this compliance must be built into both the product and production process. Designed-in compliance features include the use of generous tapers or chamfers for easy insertion, use of leads and other guiding features, and use of generous radii where possible. A clever trick, if possible, is to design one of the product components perhaps the largest, to act both as the part base (part to which other parts are added) and as the assembly fixture. In any case part base should be as stable and rigid as possible to improve insertion accuracy and simplify handling. Gravity is an extremely useful external effect which assists compliance and costs nothing. In addition to assisting with insertion, gravity is useful for feeding parts and for ejecting finished and defective product.

10. Minimize Handling

Parts should be designed to make position easy to achieve and the production process should maintain position once it is achieved. The number of orientations required during production equates with increased equipment expenses, greater quality risk, slower feedrates, and slower cycle times. To assist in orientation, parts should be made as symmetrical as possible. Orientation can also be assisted by designing in features which help guide and locate parts in the proper position. Parts should also be designed to avoid tangling, shingling, nesting in vibratory feeders.

To facilitate robotic part handling, provide a large, flat, smooth surface for vacuum pickup, or provide an inner hole for spearing, or provide a cylindrical surface or other feature of sufficient length for gripper pickup. Palletied trays and kitting are methods for supplying properly oriented parts to the assembly line.

Design in features which facilitate product and component packaging. Use standard outer package dimensions for feeding and storing.

Chapter 3

ECONOMICS OF ASSEMBLY : SELECTING THE SUITABLE METHOD

At the beginning stages of any product it is important to decide which type of assembly process is likely to yield the lowest cost. This decision has a major effect on the design because manual assembly differs widely from automatic assembly.

Choice of assembly mainly depends on the following four important factors:-

1. Cost of assembly
2. Production rate required
3. Availability of labor
4. Market life of product
5. Number of parts
6. Company investment policy

The cost of assembling a product is related both to the design of the product and to the assembly process used for its production. The product should be designed such that it can be economically assembled by the most appropriate process [1].

The six basic assembly processes discussed in [1] are:-

AI: Automatic assembly using special purpose indexing machines, work heads, and automatic feeders, one supervisor for the machine. When the number of parts in the completed assembly (N_a) are less than '6' (rotary indexing machine) and when $N_a > 6$ (in-line indexing machine).

AF: Automatic assembly using special purpose free transfer machines, workheads, and automatic feeders.

AP: Automatic assembly using manually loaded part magazines and a free transfer machine with programmable work heads capable of performing several assembly tasks.

MA: Automatic assembly using manually loaded magazines and a sophisticated two-arm robot with a special purpose gripper that can handle all the parts for one assembly.

MA: Manual assembly on a multistation assembly line. The transfer device is a free-transfer machine with one buffer space between each operator.

MM: Manual assembly with mechanical assistance. This system is the same as MA, but feeders or other devices are provided and the assembly time per part thereby reduced.

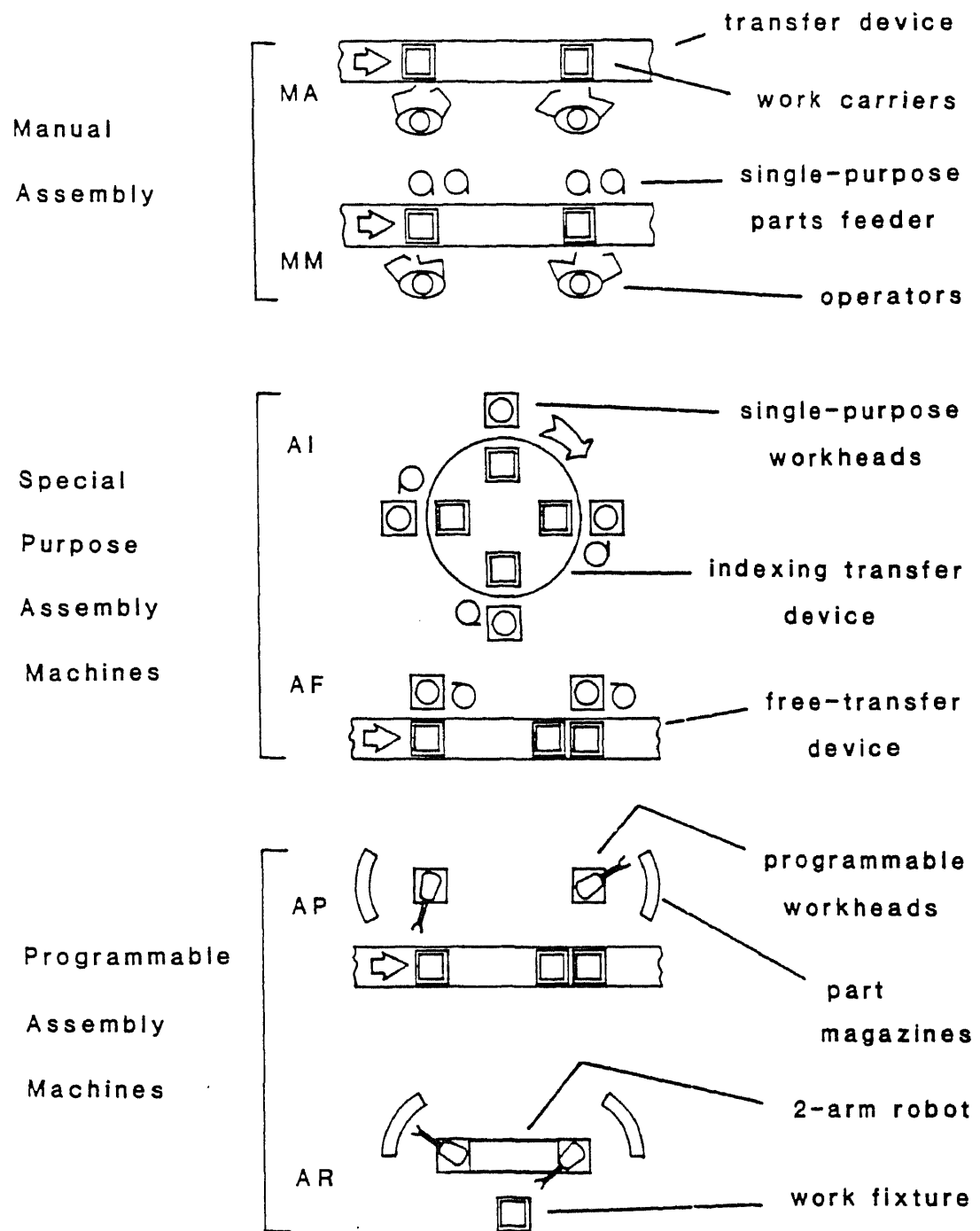


Fig 2. Basic Types of Assembly Systems
(ref: P.7, Design for Assembly handbook)

For the selection of the suitable assembly method for the re-designed electrical switch, the methods suggested by Boothroyd and Dewhurst in "Design for Assembly" handbook [3] are used: The charts provided in [3] and the methods to use the charts used for the analysis in selecting the suitable assembly method. A brief description of the choice of assembly system for re-designed electrical switch follows:

The new design of the electrical switch is consisting of 8 parts. It is assumed that '4' major design changes might take place during the first three years. The annual production volume is assumed to be 10,000,000 switches; and 2 switches are to be worked. As a matter of company policy, the amount that can be spent on an item of automation equipment, that will do the work of one operator on one shift is taken as \$40,000. This figure allows for the purchase of the equipment and all the engineering and debugging necessary before it is fully operational in the plant.

The annual cost one assembly operator is estimated to be \$20,000 including overheads.

STEP 1:

Obtain the investment factor, RJ from the following equation:

$$RI = (SH \times QE) / WA$$

where SH is the number of shifts worked,

QE is the capital equivalent of one assembly worker and

WA is the annual cost of employing one assembly worker.

In our example,

SH =2, QE=\$40,000 and WA=\$20,000

Thus, $RI = 2 \times 40,000 / 20,000 = 4$

STEP 2:

Select the appropriate row from the chart [1], For our example:

VS (annual production volume (shift) = 5 million

and NA = 8, so row number '1' can be selected.

STEP 3:

Select the appropriate column from the chart.

Taking (NT) Total number of parts available for building different product styles to be '8', and the total number of parts required (NA) 8, also (ND) number parts whose design is changed during the first three years, less than (NA). The total number of parts (assembling no major changes in the design of parts); column '1' can be selected.

The block designated '11' contains the letter AF/AI which represents special purpose machine assembly such as indexing transfer device or free transfer devices, with automatic feeders can be selected for the assembly of re-designed electric switch.

Chapter 4

EXISTING DESIGN OF THE ELECTRICAL SWITCH

The current design of the electrical switch consists of the following parts:

1. Sheet metal cover
2. Plastic cover
3. Metal part 1
4. Metal part 2
5. Switch
6. Spring
7. Base part
8. Rubber parts (2)
9. Rivets (2)
10. Screws (2)

The total number of parts in this design are thirteen.

Description of each part follows:

Sheet Metal Cover: Figure 3 shows the drawing of the metal cover. The main function of this aluminium metal strip is to cover the switch and it is riveted to the plastic cover and the base part, after all the parts of the switch are assembled. It also helps in fitting the whole switch inside the socket on the wall.

Plastic Cover: Figure 4 shows the drawing of plastic cover. This holds the switch and little grooves are provided in the inside, ignored to hold the metal parts. It covers inside parts and is riveted to the base part, and to the metal cover. Metal cover lies on the top of the plastic cover. If the assembly process is automated difficulties may occur in orienting this part, hence it needs design changes.

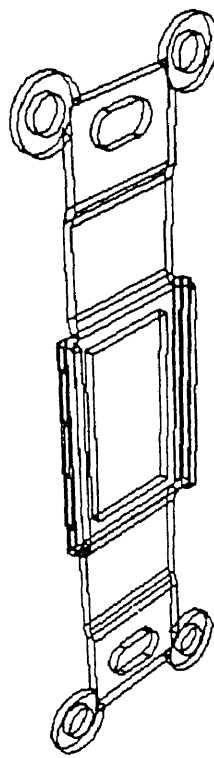


Figure 3, Sheet-metal Cover (Old Design)

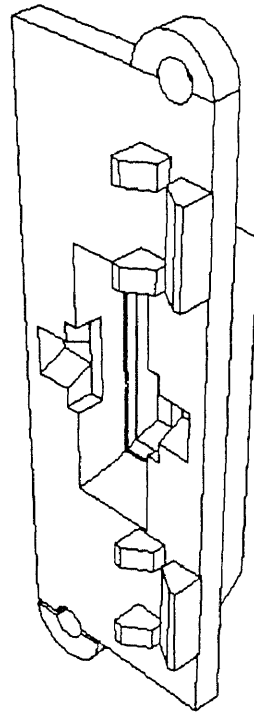


Figure 4, Plastic Cover (Old Design)

Metal Part 1: This is made out of stamping; and the metal used is brass. This part has got a projection and this projection is used for contacting the other metal part. This thin Sheet-metal part has an extrusion, and it will be matched with the groove of the base part. This part needs design changes, if the process is automated, as the base part is smaller, in area. It will be difficult for special purpose tool/robot to reach the correct location on the base part. Difficulties may arise in orienting the metal part correctly in to the groove of the base part.

Metal part 2: This is similar in shape to the shape of metal part 1. The only difference is, this has got a longer extrusion, than the previous one. When this part is correctly aligned and assembled in the base part, the longer extrusion comes into contact with the extrusion of metal part1, and it lies under the extrusion of the metal part1. This part also fits in to the groove provided in the base part. This part may take more time in correctly orienting and fixing it in the base part for manual assembly. Part should be assembled prior to the assembly of metal part 1, as it lies beneath the extrusion of metal part1. This part is also made out of brass sheet by stamping, and bending. This part also needs same design changes as the previous one.

Spring: A small coil spring is placed on the tiny extrusion provided inside the base part. The main function of the spring is to push the switch upside towards the plastic cover. One leg of switch lies on the spring, when it is assembled. Spring helps the switch to stay on 'ON' or 'OFF' position. This spring will not be secured after it is assembled. A grasping tool is necessary to keep it in it's position, in manual assembly. It will be a difficult task or impossible to assemble this if the process is automated.

switch: This is made of plastic, and it lies in the groove provided in plastic cover. Extrusion of this part enables the user to 'ON' or 'OFF' the electric connection. The other end of this part, has two separate projections. One is longer than the other. When this part is correctly assembled, the shorter projection (leg) lies on the longer extrusion of the metal part (2) and the other (longer) projection lies on the spring. As already explained the spring always forces the switch upwards.

The letters 'ON' and 'OFF' are embossed on two different sides of the switch. When the switch is pushed onto the OFF position, the shorter projection (leg) of the switch pushes the longer extrusion of the metal part downwards and thus the contact will be broken. The spring enables the switch to be on this position till it is pushed on to the 'ON' position. Whenever it is pushed on to the 'ON' position, the extrusions of the metal parts will come into contact.

If the process is automated, orienting this part will be a difficult task, as it has no symmetry in its shape. This part has to be redesigned, to get symmetrical features.

Base part: This is a rectangular box made of plastic. It has grooves to hold the two metal parts. It has provisions on one of its longer side to provide the exposure for the metal parts, so that electrical wires can be connected to them. The inner side of this part is complicated in shape, it is provided with grooves, slots, and extrusions to hold the metal parts and the spring. It acts as a base for all the parts and it covers the whole mechanism. This part is riveted to the plastic cover and Sheet-metal cover, after all the parts are assembled inside. Orientation of this part also might lead to difficulty as it has got many asymmetrical features in its design. This part also can be considered as a candidate for re-design.

Screws: The metal parts are fitted with one screw each. These screws enable the connection of electrical wires to the metal parts. It is assumed that the metal parts are already fitted with these screws, and they are not treated as Separate parts.

Rivets: Two Rivets are used to fix the Sheet-metal cover, plastic cover and the base part together, after all the parts are assembled inside. This riveting process may take longer time when compared to the assembly of other parts in manual assembly.

Rubber Parts: Two cylindrical rubber parts are inserted in the grooves of the base part, such that they come under the two ends of the switch. These small rubber cylinders help in preventing the noise, when the switch is used.

4.1 RE-DESIGN OF THE ELECTRICAL SWITCH

Re-design of the electrical switch for automatic assembly was done, mainly by following the Boothroyd & Dewhurst methods and the design rules for automatic assembly discussed in Chapter 1. In [3], Boothroyd & Dewhurst states under the topic "Estimating the minimum number of parts", that " it is important that the designer should always keep in mind that assembly costs will usually increase in proportion to the number of parts in the product. For this reason attention should be given to all parts in an assembly and an individual part should never escape scrutiny because of it's low intrinsic value. Small items such as Separate fasteners, clips, washers etc., which seem insignificant in themselves, can add enormously to assembly cost. In fact these items, as a group, can often account for the major part of the cost of assembly.

The above statements are equally valid for manual assembly, but the effect is more evident with automatic assembly since every part to be added requires a feeding and orienting device, a workhead, at least one extra work carrier, a transfer device, and results in an increase in the size of the basic machine structure. The elimination of a single fastener for example, could save \$20,000 or more in the cost of the assembly machine. Moreover, the resulting machine, because of the reduced number of workstations would generally operate with increased efficiency. It can be seen that an estimation of the theoretical minimum number of parts, for an assembly is a particularly important step. Assessment of all of the individual parts in the assembly ignored to obtain this number, takes place during the completion of the design for automatic assembly worksheet.

As each new part is added during assembly it is judged according to three simple criteria. If it satisfies one or more of the criteria then it is counted as a

Separate part. When these criteria have been applied to all the parts, the sum of the allowable Separate parts will then be the theoretical minimum.

The criteria are:

1. Does the part move relative to all other parts already assembled?
2. Must the part be of a different material or be isolated from all other parts already assembled? Only fundamental reasons concerned with material properties are accepted.
3. Must the part be Separate from all other parts already assembled, because otherwise necessary assembly or disassembly of other would be impossible?

If several identical parts are added to an assembly then the criteria should be applied to each one of them intern.

The criteria are intended to be applied objectively without regard to the apparent feasibility of eliminating parts or combining parts with others."

based on these statements, the criteria for theoretical minimum number of parts is applied on each part of the existing design of the electrical switch. The design rules stated in chapter 1 are also taken into consideration and few parts (total 5) are completely eliminated in the re-design and the other parts are changed in their design to achieve ease of assembly. Following is the list of the parts that are completely eliminated:

1. Rivets	(2)
2. spring	(1)
3.Rubber part (two reduced to one)	(1)
4.Sheetmetal cover	(1)
Total number of parts eliminated	<div style="border-top: 1px dashed black; border-bottom: 1px dashed black; display: inline-block; padding: 0 10px;">5</div>

Following is the description of each new part after re-design:

Cover: The new cover is the combined form of Sheet-metal cover and the plastic cover of the previous design. There is no necessity of the Sheet-metal cover to be Separate from the plastic cover, and it doesn't satisfy any of the three criteria stated earlier. The new cover can be manufactured in plastic instead of metal. In the new design the shape of the Sheet-metal cover comes on the top of the plastic cover, as shown in fig.5 ; The back side of the cover is also modified in the new design. The tiny extrusions, to locate the metal parts are eliminated, and two slots are made, to fit the metal parts in them. These changes are done ignored to ease the automatic assembly. If the metal parts are to be fitted in the base part as in the previous design, automating the process will become a difficult task, as the base part is smaller, for a special purpose tool, or robot to reach the correct location of the grooves, where the metal parts are fitted. Therefore we can fit the metal parts to the top cover, instead of fitting them in the base part.

The slots for metal parts are provided in a rectangular box shaped extrusion on the back side of the "new cover". Fig. 7, shows the cover after metal part is fitted in it's slot.

The slots are designed to have a groove on the top side and the metal parts are provided with extrusion, to match with these grooves. After the metal parts are inserted into the cover, the extrusion of the metal part will be correctly located in the groove of the slot and it prevents the metal part falling off from the slot. The groove in the slot and the extrusion of the metal part will act as a "snap fit" for the metal parts.

Metal parts 1&2: The re-designed metal parts are shown in the figures & , complicated extrusions are eliminated in the new design. The design changes are made such that,

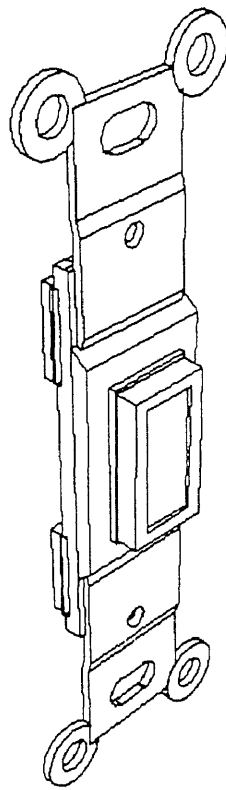


Figure 5, Re-Designed Cover (Sheet-metal cover & Plastic -covers are combined)

Front side view.

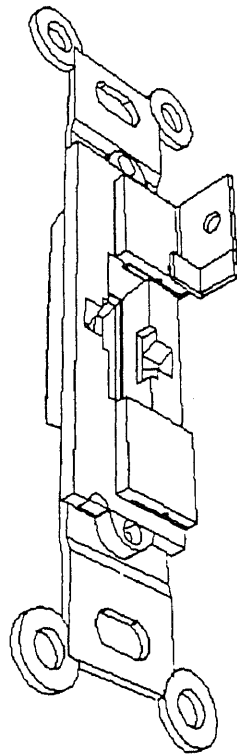


Figure 6, Re-Designed Cover (Back side view)

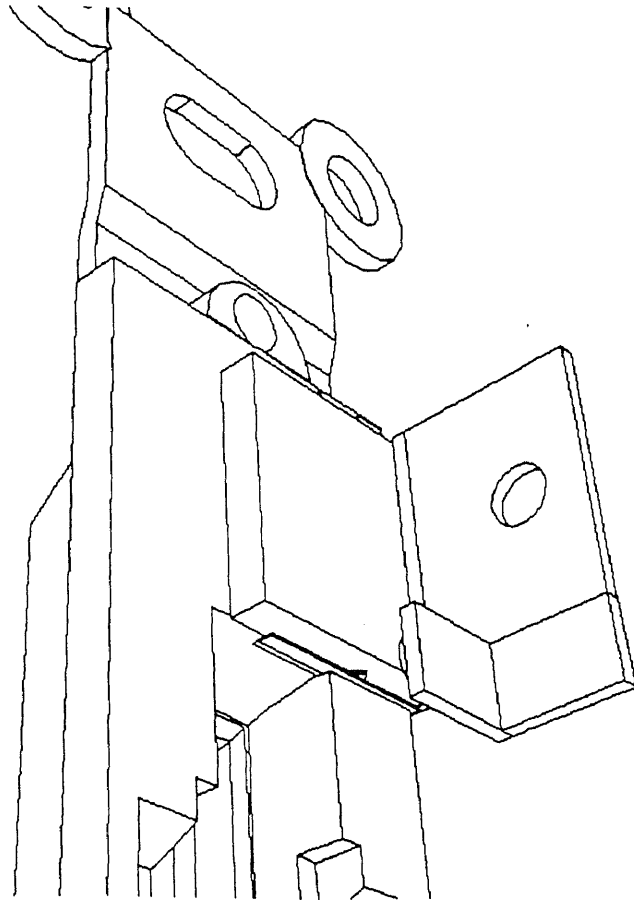


Figure 7, Re-Designed Cover (Metal part 1 fitted)

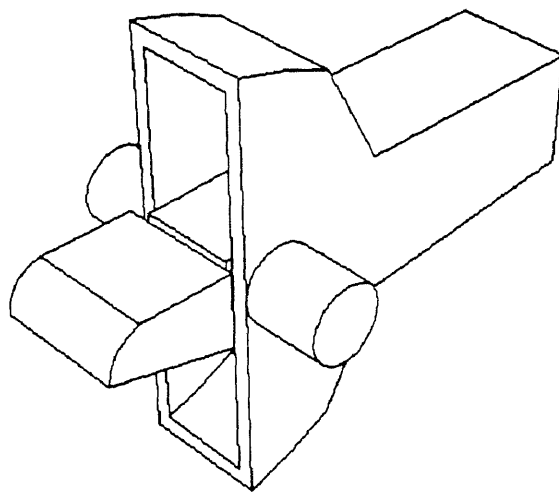


Figure 8 SWITCH (Re-designed)

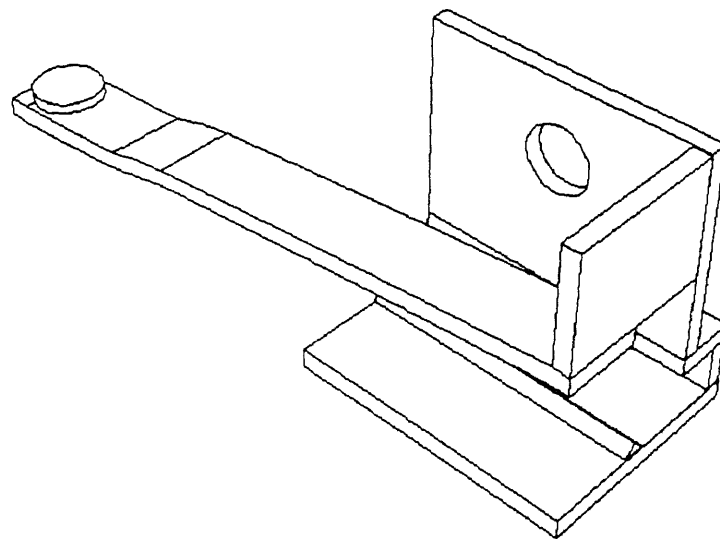


Figure 9, Metal Part 2 (Re-designed)

these parts can be inserted in the slots of the plastic cover as discussed above. In the old design, when the two metal parts are assembled, they will come in to contact and whenever the switch is put on "OFF" position, the leg of the switch pushes the strip (long extrusion) of the metal part2 downwards, so that the contact between the two metal parts will be broken.

The constraint here, for automating the process is, in automatic assembly, it is very difficult to assemble two parts if interference fit exists between them. This problem is solved in the new design, by designing the metal part2, such that the metal strip lies above the extrusion of metal part1, and it will not be in contact when these two parts are inserted into the cover. When the switch is pushed on to 'ON' position, the leg of the switch will push the metal strip downwards, such that it comes into contact with the extrusion of the metal part1.

The spring of the old design is eliminated by following the design principle, that "design parts to be multi functional" . As the metal strip lies above the extrusion of the metal part1, it always pushes the switch towards up and it acts as a leaf spring, and enables the switch to be on 'ON' or 'OFF' positions firmly. Thus the necessity of the Separate spring is eliminated completely, as the metal part 2 itself works as a spring and fulfills the same functions.

Rubber part: In the old design there were two small rubber cylinders, fixed in the grooves of the base part. The two ends of the switch touches the top surface of these parts, when it is on 'ON' and 'OFF' positions. This prevents the noise, when the switch is used. In the new design these two rubber cylinders are joined together and designed rectangular in shape. As the spring is eliminated. The space where the spring was placed in the base can now be used to fit this new rectangular rubber piece, which will help in preventing the noise when the switch is used. This new design, of the rubber part saves the time of assembly and this process can be easily automated.

Base Part: Since the metal parts are fitted in the cover, the complicated shapes of grooves are eliminated inside the base part. This part is re-designed to have two extrusion which fit in the holes of the cover, and which help in snap fitting the cover with the base part.

In the old design, there were two grooves to put the rubber parts in. As the two rubber parts are reduced to one rectangular part, the two grooves also are reduced to single groove. Modified design of base part is illustrated in fig. 10.

Switch: As the spring is eliminated in the new design symmetry can be achieved in the switch. In the old design there were two extrusions for switch (legs). The longer one rests on the spring and the shorter one rests on the long metal strip of the metal part 2. As the spring is eliminated the two legs are combined to a single leg which rests on the metal strip and pushes it down whenever the switch is on "ON" position. Figure 10 shows the re-designed switch symmetry has achieved about one axis in the new design and this helps in orienting the part correctly, during the assembly process.

Hence, the total number of parts of our example are reduced from 13 to 8. Here, it is assumed that the screws are already fitted to the metal parts and the list of the parts after re-design is:

1. Cover
2. Switch
3. Metal Part1
4. Metal Part2
5. Base Part
6. Rubber Part
7. Two Screws

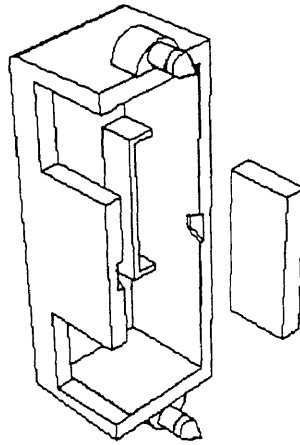


Figure 10, Base Part (Re-designed)

Chapter 5

ANALYSIS OF THE EXISTING DESIGN FOR MANUAL ASSEMBLY

The manual assembly of the electric switch (old design) is analyzed by following the procedure for the analysis of manually assembled products proposed by Boothroyd & Dewhurst in [3].

The method for analyzing the design to identify the features resulting in high assembly costs, and then to calculate the design efficiency is presented in the following steps.

STEP 1: The disassembled electric switch is assigned an identification number to each part, as it is removed starting with 1 for the complete assembly the numbers are shown in the analysis chart.

STEP 2: Referring to the design for assembly worksheet in [3] (figure 11) the work sheet has been completed.

STEP 3: Re-assembling the product is carried out, by first assembling the part with the highest identification number to the work fixture then the remaining parts are added one by one.

One row is completed for each part as shown in figure 11. The first row for base part of old design of electrical switch is completed as follows:

Column 1: The identification number of the part, the base part is "10".

Column 2: The operation is carried out once, hence "1" is entered.

Column 3: The two digit handling process code is generated from chart 2 of [3], figure 12, "Manual handling estimated times". The code generated is "00" because the thickness of the base part is 18.75mm, which is greater than 2mm, and the size (length) is 53.5mm which is greater than 15mm hence the code '00' is selected as the part is easy to grasp and manipulate.

Column 4: The handling time is obtained 1.13 seconds from chart 2 of [3] figure 12, which corresponds to the two digit code of "00".

Column 5: The assembly process code is a two digit number and it is obtained from chart 3 of [3] figure13, "Manual Insertion Estimated Times". For base part, this is coded as "00" as it is easy to align and position during assembly and it is assumed that it is not secured immediately as it is the base.

Column 6: The insertion time 1.5 seconds is obtained from chart 3 of [3], figure13, which corresponds to the two digit code of "00".

Column 7: The total operation time in seconds is calculated by adding the handling and insertion times in columns 4 and 6 of figure 11, and multiplying this sum by the number of repeated operations in column (2). i.e 1; in the case of base part and the number entered here for base part is 2.63 seconds.

Column 8: The total operation cost in cents obtained by multiplying the operation time in column 7 by 0.4; this figure is taken as a typical operator rate in cents per second [3], and the number obtained is 1.05 cents for the base part.

Column 9: The numbers in this column are entered by answering the following 3 questions to evaluate the minimum number of parts [3].

1. Does the part move relative to all other parts already assembled ?
2. Must the part be of a different material than or be isolated from all other parts already assembled ? only fundamental reasons concerned with material properties are acceptable.
3. Must the part be separate from all other parts already assembled because otherwise necessary assembly or disassembly of other parts would be impossible ?

If the answer to any of these questions is yes, then a "1" is placed in column (9). In case of multiple identical operations are indicated in column (2),, then the number of parts that must be separate is placed in column (9).

In case of base part, the answer for the above questions are:

1. No,
2. Yes,
3. Yes.

Hence, "1" is entered in column (9) of chart.

Further, the two rubber parts need not be separate, and they can be combined to be one. Even though the spring has relative motion, this is eliminated as the metal part 2 does the function of the spring switch also has the relative motion, so this is a separate part. Two metal parts are separate because they should be of a separate material (metal) to the material of the other parts (plastic) in order to provide electrical conductance. The steel metal cover, has no relative motion and this need not be a separate material hence this can be combined with the cover (plastic) and the whole part can be made out of plastic. Rivets can be removed by providing snap fits.

By following the procedure discussed above, all the remaining parts are analyzed by using the charts provided in [3] and all the columns are filled out for all the parts (rows) in the same fashion as it was done base part.

STEP 5: After all the rows are completed and figures in column (7) are all added, to get the total estimated manual assembly time which is 102.55 seconds for our example (electric switch) the figures in column (8) are added to get the total manual assembly cost which is 41.01 cents/assembly. The figures in column (9) are added to give the theoretical minimum number of parts which is '5'.

STEP 6: Finally the manual assembly design efficiency is calculated by using the equation $EM = 3 \times NM / TM$ [3].

Where EM = manual design efficiency,

NM = theoretical minimum number of parts,

TM = total assembly time.

Hence, $EM = 3 \times 5 / 102.55 = 0.014$ (14 percent).

Results of the analysis:

Thus the estimated design efficiency for the manual assembly of electric switch is 14 percent.

Cost of manual assembly = 41.01 / assembly.

And the approximate time required for manual assembly = 102.55 seconds.

DESIGN FOR MANUAL ASSEMBLY WORKSHEET

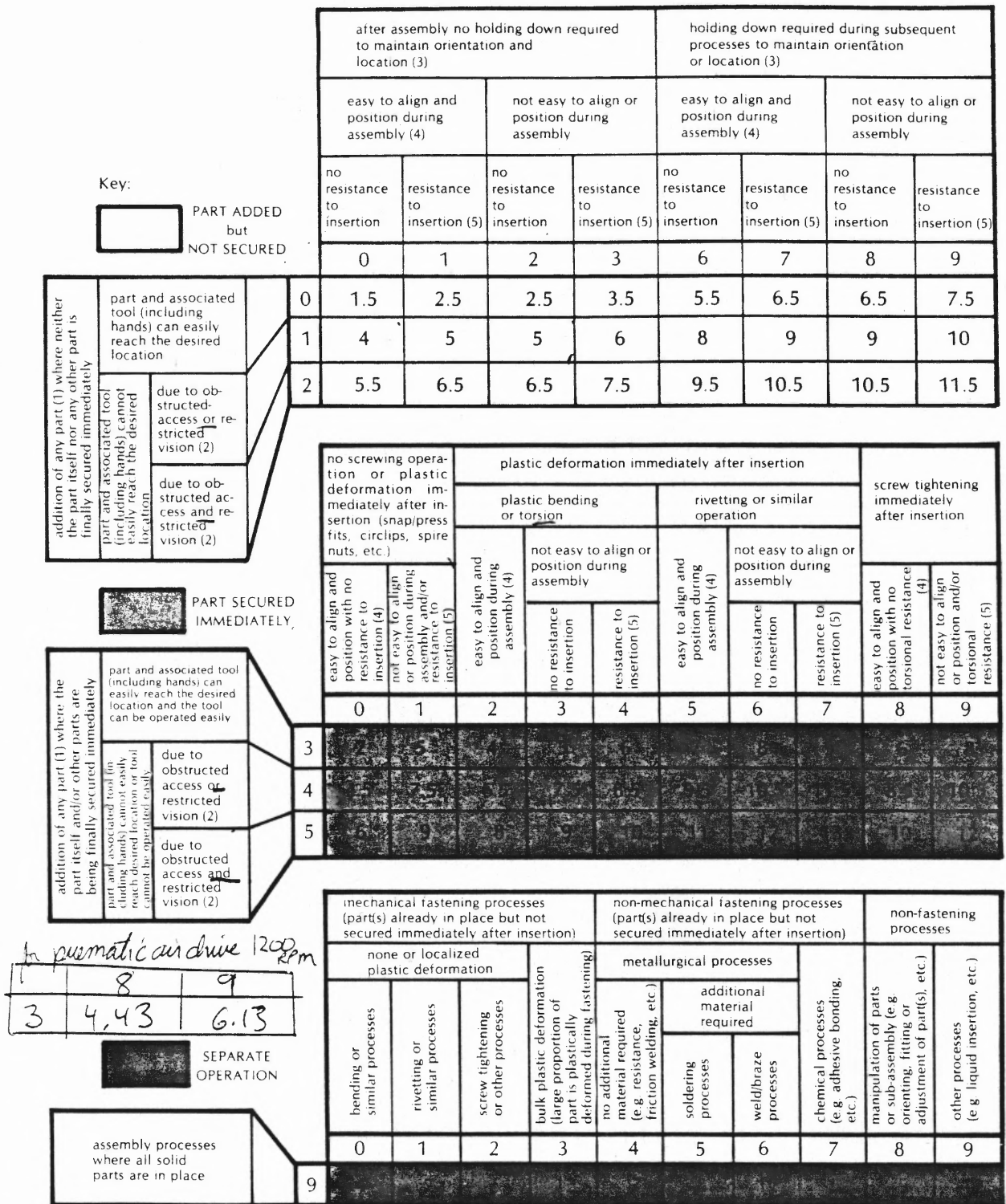
1	2	3	4	5	6	7	8	9	Name of Assembly
part I.D. No.	number of times the operation is carried out consecutively	two-digit manual handling code	manual handling time per part	two-digit manual insertion code	manual insertion time per part	operation time, seconds $(2) \times [(4) + (6)]$	operation cost, cents $0.4 \times (7)$	figures for estimation of theoretical minimum parts	
10	1	00	1.13	00	1.5	2.63	1.05	1	BASE
9	2	40	3.6	41	7.5	22.2	8.88	0	RUBBER PARTS
8	1	00	1.13	16	8.0	9.13	3.65	0	SPRING
7	1	86	5.25	44	8.5	13.75	5.5	1	METAL PART 2
6	1	86	5.25	44	8.5	13.75	5.5	1	METAL PART 1
5	1	00	1.13	06	5.5	6.63	2.65	1	SWITCH
4	1	00	1.13	06	5.5	6.63	2.65	1	COVER
3	1	00	1.13	06	5.5	6.63	2.65	0	SHEET METAL PART
2	2	40	3.6	91	7.0	21.2	8.48	0	RIVETS
						102.55	41.01	5	$\text{design efficiency} = \frac{3 \times \text{NM}}{\text{TM}} = .14$
						TM	CM	NM	

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Figure 11. Manual Assembly Work Sheet for Analysis

<p>Key:</p> <div></div> ONE HAND			parts are easy to grasp and manipulate					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	$(\alpha + \beta) < 360^\circ$	0												
	$360^\circ \leq (\alpha + \beta) < 540^\circ$	1												
	$540^\circ \leq (\alpha + \beta) < 720^\circ$	2												
	$(\alpha + \beta) = 720^\circ$	3												
<div></div> 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	$\alpha \leq 180^\circ$	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7		
	$\beta = 360^\circ$	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8		
	$\alpha \leq 360^\circ$	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9		
	$\beta = 360^\circ$	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10		
<div></div> TWO HANDS for MANIPULATION			parts present no additional handling difficulties				parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)							
			$\alpha \leq 180^\circ$		$\alpha = 360^\circ$		$\alpha \leq 180^\circ$		$\alpha = 360^\circ$					
			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		
<div></div> TWO HANDS or assistance required for LARGE SIZE			parts can be handled by one person without mechanical assistance								parts severely nest or tangle or are flexible (2)	two persons or mechanical assistance required for parts manipulation		
			parts do not severely nest or tangle and are not flexible											
			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)					
two hands, two persons or mechanical assistance required for grasping and transporting parts		9	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$				
			0	1	2	3	4	5	6	7	8	9		

Figure 12. Manual Handling-Estimated Times
(Ref: Design for Assembly Hand Book, P.32)



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CHART 3

Figure 13, Manual Insertion-Estimated Times (Seconds)
(Ref: Design for Assembly Hand Book, P. 34)

5.1 ANALYSIS OF THE RE-DESIGN FOR AUTOMATIC ASSEMBLY

The completion of the "automatic assembly work sheet is presented in the similar manner to that of the "manual assembly work sheet" , following the Boothroyd & Dewhurst method. The required production rate is assumed to be 80 assemblies per minute, and the total production required is assumed to be 10,000,000 assemblies per year. The assembly design efficiency is calculated at the end of the analysis after the chart for "automatic assembly analysis" is completely filled (fig 14), for the re-designed electrical switch.

the analysis is carried out by following these steps:

Step1: The assembly is taken apart and an identification number is assigned to each part, the complete assembly is given number '1', and the parts are numbered in the order of disassembly. Fig 14 shows the list of the parts and their ID numbers.

Step2: Re-assembly of the product is done beginning with the part with the highest identification number. All the rows of the work sheet for automatic assembly taken from [3], are completed for all the parts. The first row of the work sheet for the electrical switch is completed in the following way:

Column 1: The ID number of the parts, for the rubber part this is "7".

Column 2: The operation is carried out once. Hence "1" is entered here.

Column 3: The part feeding and orienting code is determined for the part using charts 4 to 7 of [3] (figs. 15-17).

For rubber part, this code is entered as "60002". From chart 4 of [3], (fig. 15) the first digit is obtained, this is taken as '6' because the rubber part is a non-rotational part, and it is considered to be a flat part, as the ratio between the length of the longest side ($A=22\text{mm}$), and the length of the intermediate side ($B=16\text{mm}$)

is less than '3', and the ratio between the length of the longest side ($A=22\text{mm}$) and the length of the shortest side ($c=4\text{mm}$) is greater than 4.

The next two digits in the code are taken to be '00' from chart 6, of [3] (fig 16). As the conditions $A > 1.1B$ and $B > 1.1C$ are satisfied for rubber part and also the part has 180 degrees symmetry about all three axes.

The last two digits in the code are entered as '02'. These are obtained from chart '7' (fig. 17), because the rubber part is small and non-abrasive, do not tend to overlap during feeding, not delicate, non-flexible, part will not tangle or nest, light and not sticky.

The same procedure is followed in generating the 'codes' for all the other parts and entered in the work sheet.

Column 4: Operating efficiency, is obtained from chart 6 of [3], as 0.8, which corresponds to '600' of the five digit code.

Column 5: Relative feeder cost for rubber part is 3 cents. It is obtained by adding the feeding cost (FC) (chart6) and additional feeder cost (DC) (chart7).

Column 6: The size of the rubber part is 22 mm and so the maximum feed rate from a standard feed rate is given by :

$$FM = 1500 \times 0.9 / 22 = 54.5 \text{ parts/minute. [3]}$$

Column 7: The assembly rate required is 40 per minute, ie. $FR = 40$, since this required rate is less than FM, the difficulty rating for automatic handling is given by,

$$DF = 60 / FR \times CR \text{ [3].}$$

$$DF (\text{for rubber part}) = 60 / 40 \times 3 = 3.30.$$

Column 8: The cost of feeding and orienting each rubber part is $CF = 0.03 \times DF = 0.09$ cents.

Column 9: The appropriate two digit code obtained from chart '8' of [3] (fig 19), is "30" for rubber part, because the part is secured immediately after it is assembled. It is inserted from vertically above, there is no screwing operation or plastic

deformation, easy to align and position. Similarly the two digit codes are generated using the same chart for other parts also.

Column 10: The relative workhead cost from chart 8 of [3] is, $WC = 1.2$ (corresponding to the code 30).

Column 11: $FR = 80$, and the difficulty rating for automatic insertion is $DI = WC$. Hence this column can be copied with the same values of column 10.

Column 12: The cost of insertion for rubber part, $CI = 0.06 \times DI = 0.072$ cents.

Column 13: The total operation cost for feeding and orienting the rubber part is the sum of the Separate costs per part for these two operations (column 8 and 12), multiplied by the number of simultaneous operations. Ie. $(2) \times \{(8) + (12)\}$, where the numbers in parentheses refer to the

data in these columns. In this case, the total cost obtained is 0.16 cents. Some calculation is done for the other parts, and the values are entered in this column.

Column 14: The theoretical minimum number of parts is already calculated, and all the parts in the new design are separate. Hence a '1' is entered in each row. And the total obtained is (NM) 6.

Step 3: The data is entered for all the other parts, following the same procedure and using charts, until the final assembly operation has been performed.

Step 4: The numbers in columns 13 and 14 are added to get the total cost of automatic handling and insertion CA and the theoretical minimum number of parts NM. For this example

$$CA = 2.56 \text{ cents and } NM = 6.$$

Step 5: The estimated design efficiency for automatic assembly, using the formula, $0.09 \times NM / CA$, is 0.21 or 21 percent.

Results of the analysis for automatic assembly:

(1) Cost of assembly = 2.56 per assembly.

(2) Design efficiency = 21 percent.

When these results are compared with the results of analysis of manual, it can be seen that, the cost of assembly is decreased from 41.01 to 2.56 cents. Therefore the total savings on each assembly is 38. cents. the design efficiency for assembly is increased from 14 percent to 21 percent.

DESIGN FOR AUTOMATIC ASSEMBLY WORKSHEET

1	2	3	4	5	6	7	8	9	10	11	12	13	14	required rate of assembly FR (per minute)	
part ID No	number of times operation is carried out simultaneously	five digit automatic handling code	orienting efficiency, OI	relative feeder cost, CR = FC + DC	maximum basic feed rate, FM	difficulty rating for automatic handling, DF	cost of automatic handling per part, (C) = 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	
7	1	60002	0.8	3	54.5	3.30	0.09	30	1.2	1.2	0.072	0.16	1	RUBBER PART	
6	1	73302	0.3	3	8.41	21.40	0.64	01	1.5	1.5	0.09	0.73	1	BASE	
5	1	62002	0.4	3	35.70	5.04	0.15	11	1.6	1.6	0.09	0.24	1	METAL PART 2	
4	1	66102	0.15	4	13.39	17.92	0.53	11	1.6	1.6	0.09	0.62	1	METAL PART 1	
3	1	70202	0.5	4	34.09	7.04	0.21	00	1.0	1.0	0.06	0.27	1	SWITCH	
2	1	61302	0.4	3	11.21	16.05	0.48	00	1.0	1.0	0.06	0.54	1	COVER	
<div> <div>Column 6</div> <div> $FM = 1500 \times \frac{1}{V}$ $V = \text{part size}$ </div> </div> <div> <div>Column 7</div> <div> $DI = \frac{CI}{TR} \times CR \text{ if } TR < FM$ $DI = \frac{CI}{FM} \times CR \text{ if } TR \geq FM$ </div> </div> <div> <div>Column 11</div> <div> $DI = \frac{CI}{TR} \times WC \text{ if } TR < (CI)$ $DI = WC \text{ if } TR \geq (CI)$ </div> </div>												2.56	6	<div> <div>design efficiency = $\frac{0.09 \times NM}{CA} = 0.21$</div> <div>CA NM</div> </div>	

Figure 14, Work Sheet for Automatic Assembly

(Ref: Design for Assembly Hand Book, p.87)

AUTOMATIC HANDLING

FIRST DIGIT

ROTATIONAL (1)	DISCS $L/D < 0.8$ (2)	0
	SHORT CYLINDERS $0.8 \leq L/D \leq 1.5$ (2)	1
	LONG CYLINDERS $L/D > 1.5$ (2)	2
NON-ROTATIONAL	FLAT $A/B \leq 3$ $A/C > 4$ (3)	6
	LONG $A/B > 3$ (3)	7
	CUBIC $A/B \leq 3$ $A/C \leq 4$ (3)	8

NOTES

1. A part whose basic shape is a cylinder or regular prism whose cross-section is a regular polygon of five or more sides is called a rotational part. In addition, triangular or square parts that repeat their orientation when rotated about their principle axis through angles of 120° or 90° respectively are rotational parts.

2. L is the length and D is the diameter or the smallest cylinder that can completely enclose the part.

3. A is the length of the longest side, C is the length of the shortest side and B is the length of the intermediate side of the smallest rectangular prism that can completely enclose the part.

Figure 15

(Ref: Design for Assembly Hand Book, Chart 4, P. 79)

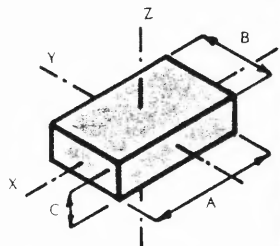
DATA FOR NON-ROTATIONAL PARTS (first digit 6, 7 or 8)

Key:

	OE	FC
6	0.7	1
7	0.45	1.5
8	0.3	2

first digit

		A ≤ 1.1B or B ≤ 1.1C (code the main feature or features which distinguish the adjacent surfaces having similar dimensions)							
		steps or chamfers (2) parallel to —			through grooves (2) parallel to —			holes or recesses > 0.1B (cannot be seen in silhouette)	other - including slight asymmetry (3), fea- tures too small etc
		X axis and > 0.1C	Y axis and > 0.1C	Z axis and > 0.1B	X axis and > 0.1C	Y axis and > 0.1C	Z axis and > 0.1B		
		0	1	2	3	4	5	6	7
part has 180° symmetry about all three axes (1)	0	0.8 1	0.8 1	0.2 1	0.5 1	0.75 1	0.25 1	0.5 1.5	0.25 2
		0.9 1	0.9 1	0.5 2	0.5 1.5	0.5 1	0.5 1.5	0.6 1	0.5 1
		0.6 1	0.5 1	0.15 2	0.15 1.5	0.5 1	0.15 1	0.15 1.5	0.15 2



code the main feature, or if orientation is defined by more than one feature, then code the feature that gives the largest third digit									
steps or chamfers (2) parallel to -				through grooves (2) parallel to -					
X axis and > 0.1C	Y axis and > 0.1C	Z axis and > 0.1B		X axis and > 0.1C	Y axis and > 0.1C	Z axis and > 0.1B		holes or recesses > 0.1B (cannot be seen in silhouette)	other - including slight asymmetry (3), fea- tures too small etc
0	1	2		3	4	5		6	7

part has 180° symmetry about one axis only (1)	about X axis	1	0.4 1 0.5 1 0.4 1	0.6 1 0.15 1 0.6 1	0.4 1.5 0.25 2 0.4 2	0.4 1 0.5 1 0.2 1	0.3 1 0.25 1 0.3 1	0.7 1 0.25 1.5 0.15 1	0.4 2 0.25 3 0.4 2	
	about Y axis	2	0.4 1 0.4 1 0.5 1	0.3 1 0.2 1 0.15 1	0.4 1.5 0.25 2 0.5 2	0.5 1 0.4 1 0.2 1	0.3 1 0.25 1 0.15 1	0.4 1 0.25 1 0.15 2	0.4 2 0.25 2 0.15 2	
	about Z axis	3	0.4 1 0.3 1 0.4 1	0.3 1 0.2 1 0.2 1	0.4 1.5 0.25 2 0.4 2	0.4 1 0.3 1 0.15 1	0.3 1 0.25 1 0.15 1	0.4 1.5 0.25 2 0.15 2	0.4 2 0.25 2 0.15 2	
part has no symmetry (code the main feature(s) that define the orientation) (4)	orientation defined by one main feature	4	0.25 1 0.25 1 0.15 1	0.15 1 0.1 1.5 0.14 1	0.15 1.5 0.24 2 0.15 1	0.1 1 0.2 1 0.1 1	0.15 1 0.1 1.5 0.05 1	0.1 1.5 0.15 2 0.1 1.5	0.1 2 0.15 3 0.08 2	
	orientation defined by two main features and one is a step, chamfer or groove	6	0.2 2 0.1 3 0.05 2	0.15 2 0.1 3.5 0.05 2	0.1 2.5 0.1 4 0.05 2.5	0.1 2 0.1 3 0.05 2	0.15 2 0.1 3.5 0.05 2	0.1 2.5 0.1 4 0.05 2.5	0.1 3 0.1 5 0.05 3	
	other - in- cluding slight asym- metry (3) etc	9								

Figure 16

(Ref: Design for Assembly Hand Book, P.84, Chart 6)

AUTOMATIC HANDLING — ADDITIONAL FEEDER COSTS, DC

FIGURES TO BE
ADDED TO FC,
OBTAINED FROM
CHARTS 5 OR 6

FIGURES TO BE ADDED TO FC, OBTAINED FROM CHARTS 5 OR 6					parts will not tangle or nest				tangle or nest but not severely				severely nest	severely tangle
					not light		light		not light		light			
					not sticky	sticky	not sticky	sticky	not sticky	sticky	not sticky	sticky		
					0	1	2	3	4	5	6	7		
parts are small and non-abrasive	parts do not tend to overlap during feeding	not delicate	non- flexible	0										
			flexible	1										
		delicate	non- flexible	2										
			flexible	3										
	parts tend to overlap during feeding	not delicate	non- flexible	4										
			flexible	5										
		delicate	non- flexible	6										
			flexible	7										

very small parts						large parts				
rotational			non-rotational			rotational		non-rotational		
L/D ≤ 1.5	L/D > 1.5	A/B ≤ 3 A/C > 4	A/b > 3	A/B ≤ 3 A/C ≤ 4		L/D ≤ 1.5	L/D > 1.5	A/B ≤ 3 A/C > 4	A/B > 3	A/B ≤ 3 A/C ≤ 4
0	1	2	3	4		5	6	7	8	9
parts are very small or large but are nonabrasive		8								

parts will not severely tangle or nest											severely tangle or nest
small parts					large parts		very small parts				
orientation defined by geometric features			orientation defined by non-geometric features		orientation defined by geometric features	orientation defined by non-geometric features	orientation defined by geometric features	orientation defined by non-geometric features			
non-flexible		flexible	do not overlap	overlap							
do not overlap	overlap										
0	1	2	3	4	5	6	7	8	9		
abrasive parts	9										


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CHART 7


Figure 17,(Ref: Design for Assembly hand Book, Chart7, P.85)

			after assembly no holding down required to maintain orientation and location (5)				holding down required during subsequent process(es) to maintain orientation and location (5)			
			easy to align and position (6)		not easy to align or position (no features provided for the purpose)		easy to align and position (6)		not easy to align or position (no features provided for the purpose)	
			no resistance to insertion	resistance to insertion (7)	no resistance to insertion	resistance to insertion (7)	no resistance to insertion	resistance to insertion (7)	no resistance to insertion	resistance to insertion (7)
			0	1	2	3	6	7	8	9

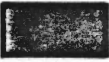
Key:

 PART ADDED but NOT SECURED

addition of any part (1) where no final securing is taking place (2)	straight line insertion	from vertically above	0	1	1.5	1.5	2.3	1.3	2	2	3
		not from vertically above (3)	1	1.2	1.6	1.6	2.5	1.6	2.1	2.1	3.3
	insertion not straight line motion (4)		2	2	3	3	4.6	2.7	4	4	6.1

 PART SECURED IMMEDIATELY

addition of any part (1) where final securing is taking place	straight line insertion	from vertically above	3	3	3	3	3	3	3	3	3
		not from vertically above (3)	4	4	4	4	4	4	4	4	4
	insertion not straight line motion (4)		5	5	5	5	5	5	5	5	5

 SEPARATE OPERATION

assembly process where all solid parts are in place or non-solids added or parts are manipulated	mechanical fastening processes (parts already in place)	none or localized plastic deformation			bulk plastic deformation (large portion of the part deformed)	non-mechanical fastening processes (parts already in place)			non-fastening processes	
		bonding or similar processes	rivetting or similar processes	screwing or other processes		metallurgical processes		chemical processes (adhesive bonding etc.)	manipulation of parts or sub-assembly (orienting, fitting, adjustment etc.)	other processes (liquid insertion etc.)
	0	1	2	3	no addition of material (friction or resistance welding, etc.)	additional material required	7			
						soldering processes	welding or brazing			
						4	5	6		

Figure 18

(Ref: Design for Assembly Hand Book, Chart 8, P.87)

Chapter 6

ASSEMBLY SEQUENCE PLANNING

In any manufacturing task, assembly plays a fundamental role. parts are designed and made to meet the specifications, and then are assembled to a configuration, that fulfills the functions of the final product of mechanism. The economic importance of assembly as a manufacturing process has lead to the extensive efforts to improve the efficiency and cost effectiveness of assembly operation.

The sequence of mating operations that can be carried out to assemble a group of parts is constrained by the geometric and mechanical properties of the parts, their assembled configuration, and the stability of the resulting sub-assemblies.

Determining The Assembly Sequence: Choice of assembly sequence and identification of sub-assemblies focus attention on somany aspects of product design, that they provide a natural launchpad for integrative detailed design. Assembly sequence studies require identification of potential jiggig and gripping surfaces, grip and assembly forces, clearances and tolerances, and other issues that must be accounted for inpiece part design. The reason for seeking a good assembly sequence are : Construction reasons such as access to fasteners or lubrication points. Similar considerations apply to ease of assembly, since some sequences may include some tricky part mates whose success may be doubtful or whose failure might damage some parts. There are quality control reasons, such as the ability to test the function of a sub-assembly or the avoidance of a sequence that installs fragile parts easily in the process. Some sequences might not offer the opportunity to test some function until it is buried beneath many other parts, making re-work expensive.

There are process reasons, some sequences may not allow a part to be jigged or gripped from an accurately made surface, making assembly success doubtful. Some sequences may require many unproductive moves such as fixture or tool changes or the need to flip a sub-assembly over. Flipovers may be unavoidable, but sequences may require flipping before the sub-assembly is fully fastened together, risking the possibility that it will dis-assemble spontaneously unless extra fixtures are provided. Flipovers may be easy for people but difficult, awkward, or costly for machines because of extra axes and control needed. Thus a sequence without flips may be sought if automatic assembly is a goal. Along with this, there are production strategy reasons, such as being able to make some sub-assemblies to stock, since they are common to many models, so that final assembly to order can be done quickly on only the remaining parts [4].

An Algorithmic Approach for Assembly Sequencing:

A systematic method for algorithmically generating all physically possible assembly sequences can be used to generate the possible assembly sequences for the re-designed electric switch. In an assembly the preconditions can be thought of as feasibility conditions for the execution of the operation and the acceptability of the resulting state. This algorithmic approach, introduces a hierarchy of such feasibility conditions to reduce the complexity of the geometric and physical reasoning that must be carried out for sequence generation. Once assembly is characterized by a network of nodes(parts), and lines(liaisons), names are associated with these two sets of elements, for example, part names with the nodes and liaison numbers with the lines subsequently, any assembly step is characterized by the establishment of one or more of the liaisons of the assembly. Thus completion of assembly from start can be characterized by a (punctuated) string of numbers representing, in same sequence, all of the liaisons of the assembly [5].

This study is based on the work of 'Bourjolt' and Thomas L. De Fazio & Daniel E. Whitney [5]. The assembly sequence generation involves characterizing the assembly by a graph in which nodes represent parts and lines between nodes represent relations or liaisons between parts, either as connections or contacts [5]. This method does not precisely create assembly sequences but rather creates liaison sequences. Instead of parts, liaisons are used in each sequence. Sequences are generated by answering the following two questions for each liaison. According to De Fazio and Whitney, the number of liaisons is related to the number of parts by:

$$n-1 < l < \frac{n^2-n}{2}$$

Where n = number of parts,

l = number of liaisons.

Hence, for the electric switch case, for ($n = 6$) parts, there are between 10 and 30 questions. Each of the following questions are addressed to each of the liaisons.

*Q1: What liaison(s) need be done already to allow doing liaison1?

*Q2: What liaison(s) need be left undone to allow doing liaison(i)?

Answers are in the form of precedence relations between liaisons and/or logical combinations of liaisons. Liaison sequences are directly generated from the answers. The starting state is that of disassembly. 'state' refers to the state of establishment of liaisons. Assembly proceeds from state to state by adding a part or a sub-assembly to another established. The imaginary path associated with part or sub-assembly is called assembly state transmission or a "state transmission". each state can be represented by a box with a list of numbers representing established

liaisons, and state transmissions may be represented as lines connecting boxes. The starting state is represented as a box with no entries.

Liaison sequences can be generated by scanning the liaison list and the answers for those liaisons which are not preceded by any one of these liaisons may serve as the first liaison. All possible subsequent liaisons can be found out by again scanning the liaison list, the precedence relations, and any other constraints imposed on the assembly will generate another rank. If no state is shown more than once, two or three ways of getting to a state will occur. Its representation will have two or three state transmissions (lines) entering it. In this fashion the 'finish' state can be approached by following the algorithmic approach until all the liaisons have been established. The ranks will be numbered orderly. Zeroth rank will represent the un-assembled starting state, first rank for the prospective first liaison and so forth. We can see that there will be as many ranks as parts, since $l > (n-1)$, a single liaison is necessarily established per state transmission only for assemblies where $l = (n-1)$. For those assemblies, where $l > (n-1)$, some state transmissions involve establishing two or more liaisons.

In the electrical switch case, there are six parts. The list of the parts is given below:

- 1) Cover
- 2) Switch
- 3) Metal Part1
- 4) Metal Part2
- 5) Rubber Part
- 6) Base Part

Fig 19, shows the liaison diagram for assembly

The liaison diagram is the first step in generating the family of liaisons or assembly sequences. The constraints for the assembly are:

- 1) The switch should be assembled to the cover (liaison1), before the metal parts are inserted into the cover.
- 2) Rubber part should be assembled to the base, before cover is fitted to the base.
- 3) Switch, rubber part, metal parts should be assembled before the base is fixed to the cover.

Here, $n = 6$ (number of parts),

$l = 5$ (number of liaisons),

$l = (n-1)$.

Thus, we may anticipate that no multiple establishment of liaisons will occur during any single part assembly move.

The next step will be to answer the two questions above mentioned.

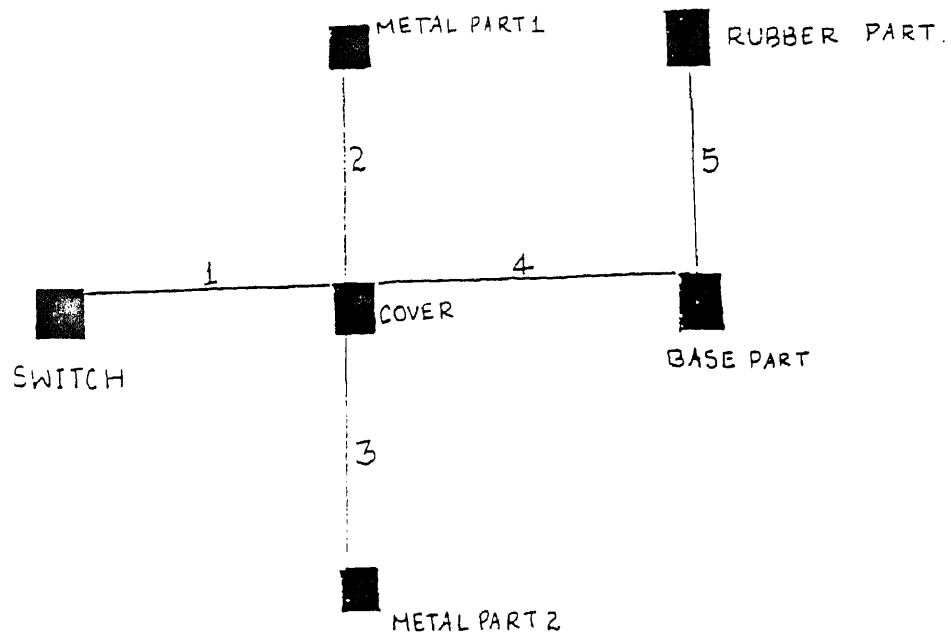


Figure 19

Liaison Diagram for Electrical Switch Assembly sequence

Q1) What liaison must be done prior to doing liaison (i)?

Answers:

For $i = 1$, 'nothing' precedes the switch to the cover.

For $i = 2$, L1 (liaison1) should be done before metal part1 is fixed. The reason behind this is once metal parts are fixed we cannot put switch in the cover.

Therefore, $1 \rightarrow 2$.

For $i = 3$, L1 should be done before metal part2 is fixed for the above said reason.

Therefore, $1 \rightarrow 3$.

These two relationships can be combined by:

$1 \rightarrow (2 \text{ and } 3)$.

Comment: For liaisons 2 and 3, either of the liaisons can be

followed, 2 and 3 does not precede each other, but liaison 1, precedes for both the liaisons 2 & 3.

For $i = 4$, Liaisons L1, L2, L3 & L5 should be done prior to doing L4.

Therefore, $(1 \text{ and } 2 \text{ and } 3 \text{ and } 5) \rightarrow 4$.

For $i = 5$, nothing precedes the rubber to base.

Q2) What liaisons must be left to be done after doing liaison 'i'?

For $i = 1$, liaisons 2 and 3 and 4.

Comment: Metal parts must be left to be done, before fixing the switch, and cover should not be fixed to the base.

Therefore, $1 \rightarrow (2 \text{ and } 3 \text{ and } 4)$.

For $i = 2$, L4 must be left to be done, because, once base is fixed to the cover, metal parts cannot be fixed.

Therefore, $2 \rightarrow (4)$.

For $i = 3$, L4 must be left to be done for the above said reason.

$3 \rightarrow (4)$.

For $i = 4$, Nothing.

Comment: Cover will be fixed to the base after all the liaisons are done.

Hence nothing must be left to be

done.

For $i = 5$, L4 must be left to be done, because once base is fitted to the cover, rubber part can't be fixed.

$5 \rightarrow (4)$.

In summary, the following relations result from answering the above 10 (21) questions.

$1 \rightarrow (2 \text{ and } 3)$,

$(1 \text{ and } 2 \text{ and } 3 \text{ and } 5) \rightarrow 4$.

The next step is to algorithmically generate sequences of the liaisons subject to the previous constraining relations. Fig. 20 shows the graphical representation of the possible sequences. In fig each box representing a state contains five cells, each representing a liaison, one through five from left to right, within the box. A blank cell implies that the corresponding liaison is not established while a marked cell implies that the corresponding liaison has been established. Lines connecting the boxes represent the possible state transitions. The wholly blank box in the zeroth rank represents the wholly unassembled starting state, and the wholly marked box in the fifth rank represents the wholly assembled or finish state. Each path through the diagram starting at the top and moving along lines through succeeding ranks to the bottom represents a valid liaison sequence.

11 liaison sequences can be verified by counting. A simple procedure for counting how many sequences there are, involves working upwards answering and recording for each state in each rank, the question "from this state, how many paths to the last rank are there?" . The answer to this question for the single state in the zeroth rank is the number of valid liaison sequences.

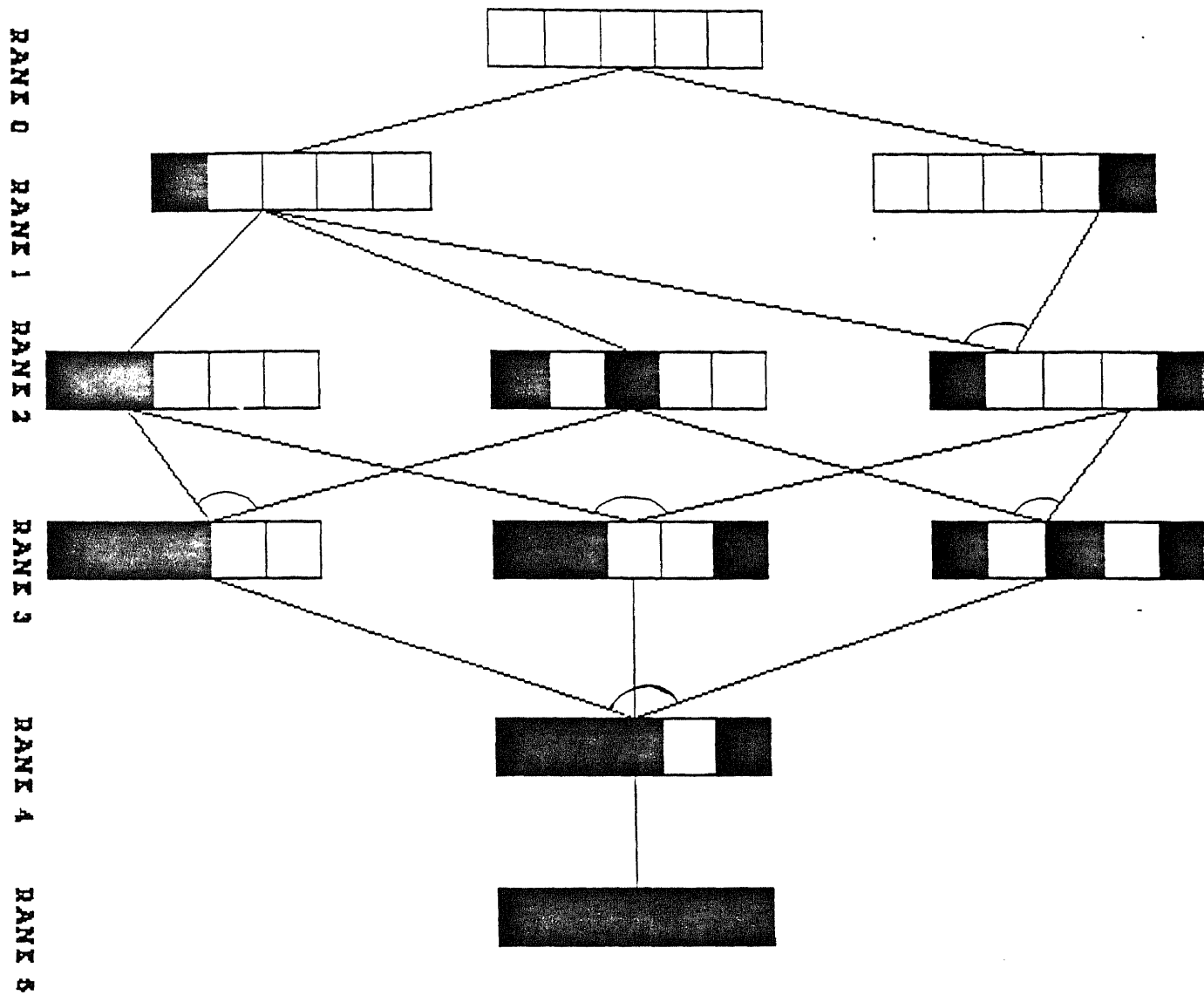


Figure 20

Graphical Representation of Possible sequences for The Assembly of Electrical
Switch

6.1 CHOOSING GOOD ASSEMBLY SEQUENCE

Having the means to generate all of the physically possible sequences of assembly of a complicated sub-assembly or assembly allows us to choose the best assembly sequence.

The entire procedure of liaison sequence analysis yielding the viable assembly sequences, followed by the winnowing to one or few assembly sequence candidates, is represented in fig. 21 , [2]. The winnowing process can be judgmental, qualitative, quantitative, or a combination of these and can follow any or several of paths, as shown in figure.

Assembly moves may be eliminated when an acceptable alternative path exists and the move in question is difficult to accomplish or puts a part or parts at risk of damage. Second, we can eliminate unacceptable assembly states the equivalent of eliminating corresponding nodes or boxes from the assembly-sequence graph. Assembly states may be eliminated when an acceptable alternative path exists and the state in question is awkward, unstable or conditionally unstable under assembly conditions, or requires undue time, cost or equipment to maintain it between assembly moves.

One can enforce any of several assembly-sequence constraints. Such constraints can be arbitrary and may be based on his/her's own concept of good practice. In the electrical switch case, we can reduce the assembly sequences to five (5), after eliminating few states by following the above discussed methods. Fig shows the reduced number of sequences, and any one of it can be followed to assemble the switch.

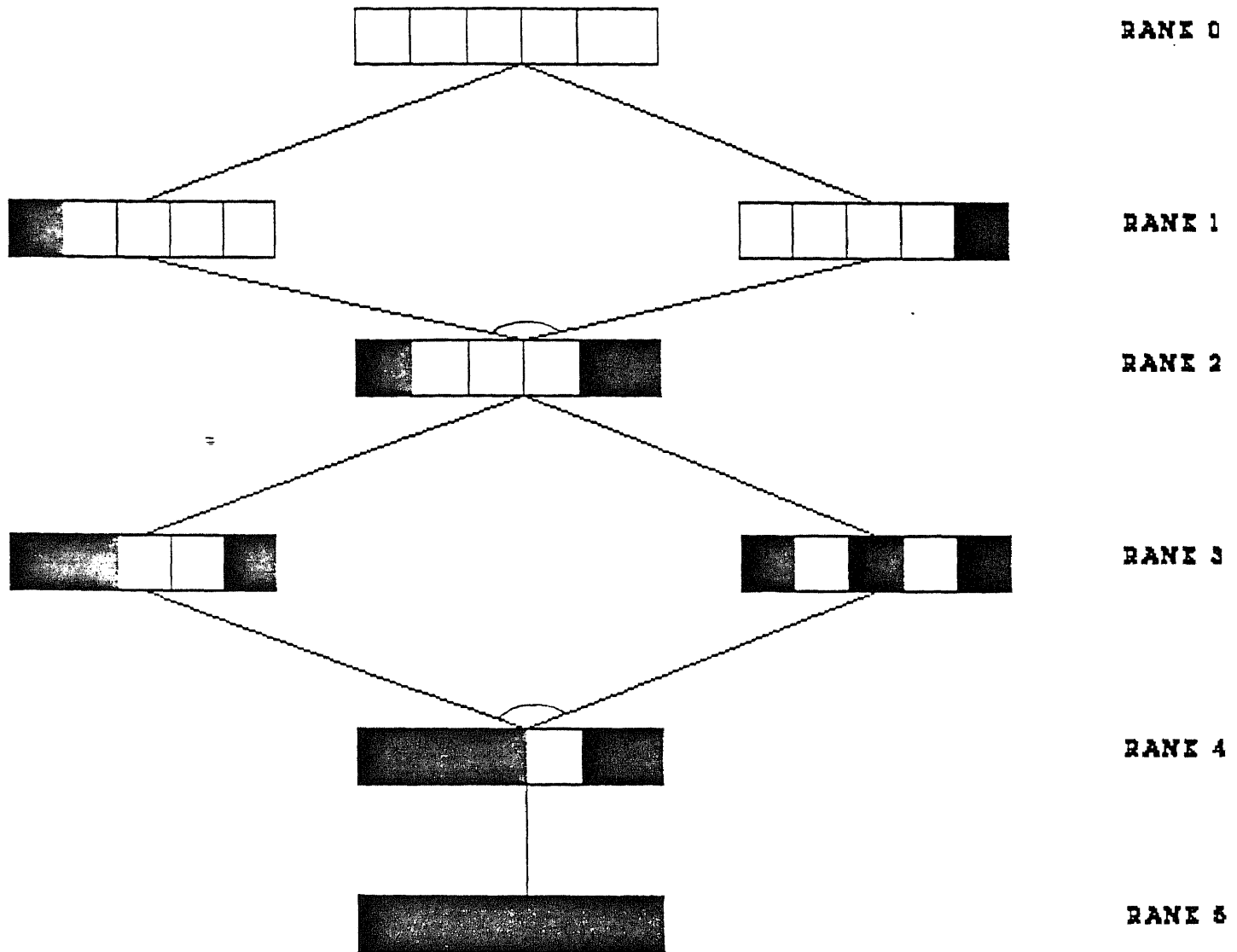


Figure 21
Graphical Representation of Good Assembly Sequences

Chapter 7

AUTOMATIC ASSEMBLY WORK CELL

In this chapter, it is discussed about the layout and function of assembly work cell for the re-designed electrical switch. Fig 22, shows the schematic diagram of the work cell. The estimated equipment required in the automatic work cell are listed below:

- 1) Vibrating feeder for plastic cover
- 2) Magazine for switches
- 3) Feeder for metal part 1
- 4) Feeder for metal part 2
- 5) Indexing machine
- 6) Feeder for base parts
- 7) Feeder for rubber parts
- 8) Hydraulic insertion mechanism
- 9) Conveyors
- 10) Bin for final assemblies.

Assembly Process: The vibratory feeder for plastic covers can be arranged with guide ways, such that the plastic covers can be oriented correctly. They should be passed on to the conveyor, orienting the part upside down. The conveyor can be designed to have a groove in the middle, and this should exactly match with the slot of cover, while it carries the cover.

The switches can be manually loaded into magazines (upside down), one over the other. Vibrating feeder also can be used to orient them. These magazines should be arranged with a stopper, which stops the switches falling down. The stopper should be opened, whenever the plastic cover comes under the magazine, so

that the switch falls down correctly into the slot. No insertion mechanisms are required as this is a simple assembly. After the switch falls into the slot of the cover, stopper should be closed immediately , till the next cover comes under the magazine. The stopper should allow only one switch at a time. Co-ordination is very important between the conveyor speed and opening and closing of stopper. The cover and switch assembly next passes to an indexing machine, where, metal part1 & 2 will be inserted into the cover. As soon as the cover comes to the indexing machine , it will be loaded into the grooves provided on the indexing plate, and it will be rotated to the conveyor from the feeder for metal part1. A hydraulic insertion mechanism can be used to insert the metal part1 into the groove provided on the side of the cover.

Same mechanism can be used to insert metal part2 into the cover when the cover is assembled with metal part1 and rotates to the feeder for metal part2 on indexing machine . After the switch and the two metal parts are assembled to the cover , it can be passed on to the insertion mechanism, where it will be assembled to the base part.

Simultaneously when the above said operations are being carried out , rubber parts can be fixed in the base part in a separate branch of the work cell as shown in figure. Rubber parts can be feeded by vibrating feeder , and they can be inserted into the base part. After this assembly, the base part should be flipped over and passed to the insertion mechanism where it will be assembled with the cover . The conveyor which carries the base part should be placed over the conveyor, which carries the covers assembled with other parts. A hydraulic mechanism can be used to press the base part from the top, so that it will be snap fitted with the cover.

This finishes the final assembly and the assemblies can be passed to a bin and a conveyor, where they will be collected. Co-ordination and timing adjustment in

between all the equipment and machinery is necessary for successful assembly in this work cell.

In place of vibratory feeders for covers , metal parts 1 & 2 , base parts and rubber parts , manually loaded magazines can be used to reduce the cost of machinery. In place of hydraulic insertion mechanisms , any other suitable mechanisms can be used to assemble the parts.

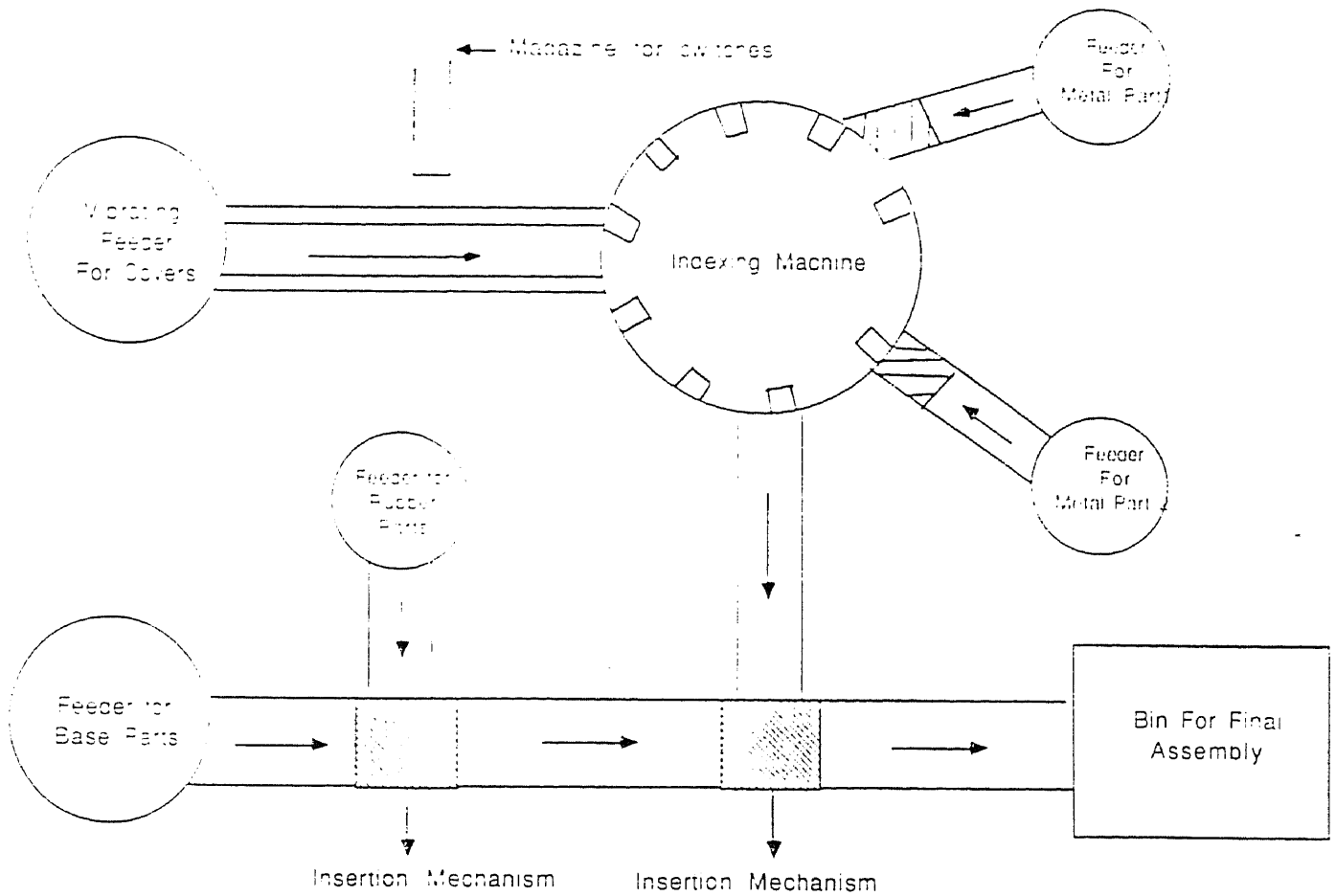


Figure 22, Automatic Assembly Work Cell Design for The Assembly of Electrical Switch

CONCLUSIONS

Design for assembly has been an effective tool for product analysis and improved part design for assembly. The efficiency of design of the product for automatic assembly depends both on the features of the design of the product and the required assembly rate. Assembly cost depends crucially on product design. The suitability of assembly can both be assessed by systematically classifying the product design features, even when the details of the assembly process are not known.

In the currently designed electrical switch, parts are analyzed and found, to be not suitable for automatic assembly. These parts are re-designed and reduced in number from 13 to 8. The analysis showed that the cost of assembly of old design for manual assembly is 41.01 cents, and the cost of assembly of re-designed switch for automatic assembly is 2.56 cents per switch. The product design efficiency is increased from 14% to 21%, by the re-design. Time of assembly can be tremendously decreased if proper equipment is used in the automatic assembly work cell.

Perhaps the main contribution of the present work is the demonstration that, the principles of design for assembly can be applied successfully and with significant potential economic gains to simple, high volume everyday products such as the electrical switch, we are all familiar with.

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