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MODERN ASSEMBLY CONCEPTS AND APPLICATIONS

SUBMITTED TO THE UNIVERSITY OF CAPE TOWN IN
PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE IN
ENGINEERING (MECHANICAL).

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AUTHOR: PELAYO OMOTOSO

SUPERVISORS: PROF. A. SASS

MR. B. REED

I, Pelayo Olawale Percy Omotoso, submit this thesis in partial fulfilment of the requirements for the degree of Master of Science in Engineering. I affirm that this thesis has been written by me, and that it is a record of my own work and research. It has not been presented in any previous application for a higher degree. All quotations are indicated and the sources of information are specifically acknowledged by means of references.

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SYNOPSIS

This project introduces, and demonstrates assembly concepts that are helping to change the nature of industrial production. The emergence of Concurrent Engineering as a production process ideal is being fuelled in part by some of these assembly concepts.

The idea for the project stems from a course on Design for Manufacture and Assembly, which the author of this thesis attended in 1999. From there, a lot of the work done in the area of assembly has been researched. The understanding of the theory conveyed in this document is based on this information.

The second part of the development of this project is the result of the development of a Manufacturing Technology Centre at the University of Cape Town, and the university's increasing association with the production industry. This association prompted engineers at the Gabriel shock absorber factory to approach the university with a production problem associated with their assembly process. The nature of the problem was such that it was ideal for academic study.

This project has been shaped to apply a number of assembly technologies while aiding the people at Gabriel S.A. in finding a suitable solution to their production problem. The result has been an enriching academic study that is presented in the document, and the development of a new assembly facility at Gabriel S.A. that should be integrated into their production process early in the year 2001.

The work presented here represents a half thesis (20 credits). As part of the fulfilment of the Masters programme at the University of Cape Town the author has also completed the following courses making up an additional 21 credits:

An introduction to Finite Elements (AMU502Z); Engineering Software Design and Development (AMU504Z); Manufacturing Technology and Process Design (MEC544Z); Mechanical Engineering Project (MEC551Z).

The author also took part in an internship programme (a joint effort between the University of Cape Town and The Cummins Engine Company). For the six-month period between 09/1999 and 03/2000 the author interned as a Project Engineer at Sytech, a division of the Cummins Engine Company. During this time the author became familiar with aspects of engineering, including fluid power controls, electrical controls, instrumentation, electrical panel layouts, fluid schematic drawings, electrical schematic drawings, customer communications, pricing negotiation, project management, scheduling, assembly support and system debug. He attended formal courses on Engine familiarisation, Fundamentals of Engine Performance and Design for Manufacture and Assembly. The author managed a number of projects independently, including the manufacture of the Smart Oil consumption cart (which included some Value Engineering) and the Cummins Mid-range Engine plant fuel modules.

The author also presented two papers in the year 2000. The first, titled *An introduction to Concurrent Engineering as the most effective tool for growth in the South African Industry*, was presented at the M3 conference at the University of Cape Town. The second one, titled *Developing Flexible Manufacturing and Concurrent Engineering in the South African Manufacturing Industry*, was presented at the 1st annual conference of the Rapid Product Development Association of South Africa (RAPDASA) at the CSIR (council of Scientific and Industrial Research).

1 INTRODUCTION

Industrial assembly is part of the production system. The basic outline of a production system involves the realisation of a need; the design of a product to fulfil that need; the manufacture of the components of the product and the subsequent assembly of the product; finally followed by the marketing of the product. This is illustrated in Figure 1.1.

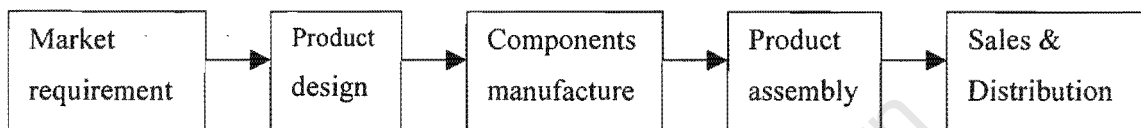


Figure 1.1: Diagram shows the flow in a basic production system.

This project focuses on industrial assembly, which is specific to production systems and the production industry. As such all references to assembly in this document refer only to industrial assembly.

Assembly involves the mating and joining of components or subsystems to realise the final product. Many products require assembly. Some products have hundreds of components, and consequently have complex assembly processes. Others have only a few parts and therefore require more simple assembly processes.

1.1 The role of assembly in production systems

When a product is an amalgamation of a number of parts (not just a single entity), the assembly process is required. A product is broken into components for three main reasons:

1. The product's function requires a number of parts. Some products require independent relative motion of parts, or parts of different physical properties, thus

requiring different materials. These requirements necessitate assembly in the production process.

2. A product composed of components might be more efficiently produced or more economical to produce. A design engineer will use standard parts in a product, as it is economical to do so, even when this means the product would require assembly. The maintainability of a product can also give rise to the need for unit components since there are parts of some products that are more prone to wear. Isolating these parts, allows the rest of the product to be re-used.
3. Social factors can also be a determining factor. Aesthetic considerations in design can necessitate assembled products.

Assembly can take up to 50% of the production time and accounts for 20% of the unit production cost [1]. These statistics indicate the relative importance of assembly.

Figure 1.2 is a further illustration of these facts.

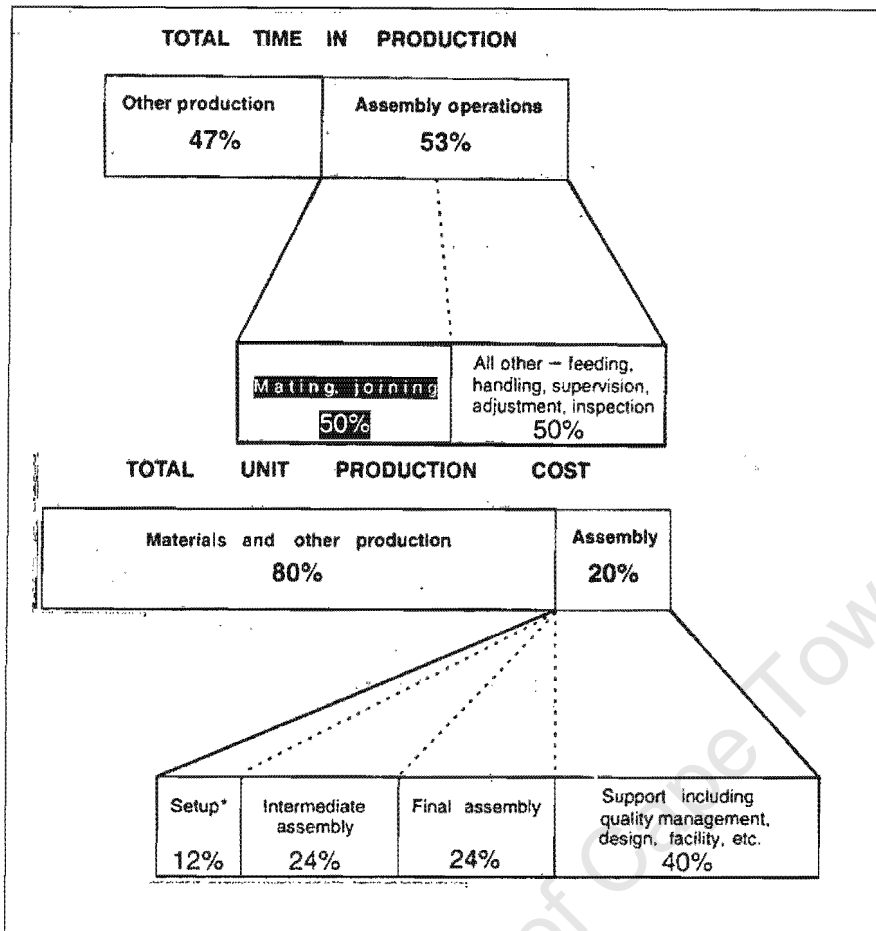


Figure 1.2: Charts showing the percentage resources, in production time and cost, dedicated to the assembly process.

Source: *Industrial Assembly* [1].

The focus on understanding the assembly process and the potential cost saving opportunities that follow from this is on the increase. While design and manufacturing processes are well understood, knowledge of the assembly process is still limited. Evidence of this can be seen in the dearth of modelling tools that exist to simulate and predict assembly. Such knowledge would help create an understanding of assembly and improve assembly systems. This is important since products that are costly to assemble may not be competitive in the marketplace.

1.2 The changing face of assembly

The production industry is a dynamic one. The need for a competitive advantage to ensure sales boosts the development of technologies and strategies. The influence of new technologies that are developed as a result of this process can change the way future products are developed. The assembly process is no different in this respect. To fully appreciate this, one only needs to consider the effect of the mass production lines in the early decades of the twentieth century, or the recent effects of the development of the SCARA (Selective Compliance Arm for Robotic Assembly) robot on electronic assembly.

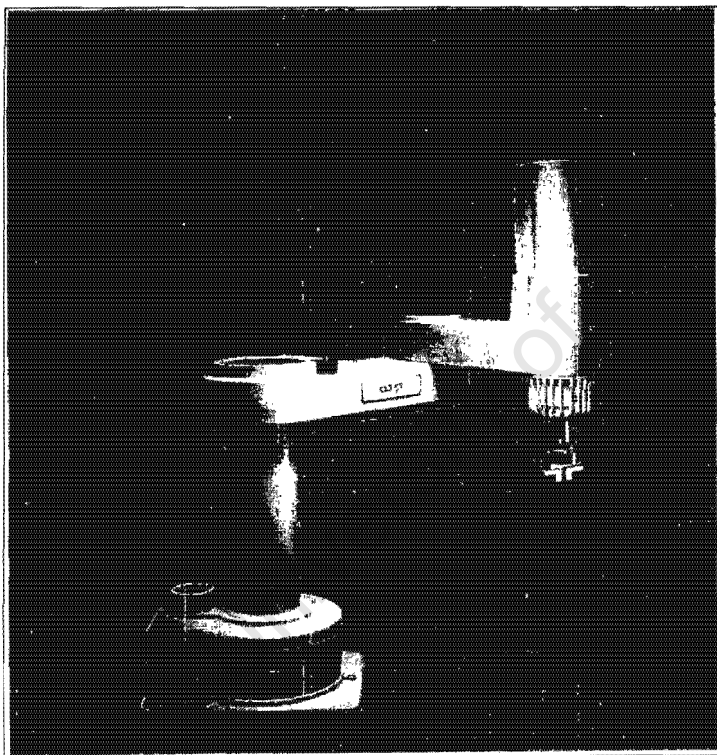


Figure 1.3: A SCARA robot.

Source: *Fundamentals of Modern Manufacturing* [10].

Today assembly focuses on concepts such as flexibility, product design and expert systems for assembly sequence generation and planning. This document highlights

some developments in the area of assembly and demonstrates their application. Specifically the changes in product design and assembly design are investigated.

Of particular interest is the effect of modern assembly technology on the development of products. Today there is a greater emphasis than ever before on an integrated production process which functions seamlessly. This is the doctrine of Concurrent Engineering. This project demonstrates that products being produced in our markets today would have different characteristics, had they been developed using modern techniques. This is done using a case study, the details of which are presented in the next chapter. A product manufactured in South Africa is re-engineered and the results compared with the original product to demonstrate the improvements in the product. The project also shows how modern assembly technology can be taken advantage of to solve practical difficulties in existing assembly processes using the same product as in the case study briefly described above.

1.3 Thesis outline

1.3.1 Main objectives

1. To demonstrate the effect changes in assembly strategy and technology has on product design and assembly.
2. To show how modern assembly strategy and technology can be used to solve assembly problems.

1.3.2 Thesis layout

The layout of the thesis has been designed to guide the reader through the process of research and the approach the author has taken to meet the objectives outlined above. The introductory chapter (Chapter 1) aims to orientate the reader as to the nature of the project and its subject matter. Chapter 2 introduces the case study and the product

that is the subject of this project. Chapter 3 introduces the fundamentals of the assembly process, while Chapter 4 highlights the areas of modern assembly theory that are relevant to the project. The next two chapters deal with the main objectives of the project: The effect of modern assembly theory on product development is discussed in Chapter 5. Chapter 6 deals with the problem of using modern assembly technology to solve practical assembly problems. Some conclusions are posed in chapter 7, along with a view to the future.

1.3.3 Project limitations and constraints

1. The major limiting factor is that the project involves a product that has been designed and is in production. As such it is not possible to disrupt the production process in any way.
2. No product changes can be made in practice.
3. The solution relies on the author's understanding of Gabriel S.A. and its products, and the author's ability to access relevant documentation on production at the company.

2 COMPRESSION HEAD VALVE CASE STUDY

A compression head valve is a component in a motor vehicle shock absorber. The South African division of Gabriel Shock Absorbers approached the University of Cape Town to help them correct some difficulties they were experiencing in the production of certain types of compression head valve, which they produced. The difficulties had resulted in an undesirably slower pace in the assembly of compression head valves. This was affecting some of their shock absorber assembly lines (these difficulties are detailed in section 2.4). Upon examining the situation at Gabriel S.A. the potential for this project was discovered. The process at Gabriel fit the criteria for a thesis project such as this one for a number of reasons:

1. The component involve has a simple assembly process. This meant that basic assembly tasks and characteristics were easy to isolate and examine.
2. The nature of the difficulties experienced at Gabriel S.A. with the assembly of the compression head valve is such that they are not severe enough to pose a substantial threat to their overall production. As such there is less pressure for an immediate solution. This allows for the opportunity to use the case study as an academic project. The nature of the difficulties is also clear and easily distinguishable.

2.1 The compression head valve as a shock absorber component

In order to fully appreciate the context of the assembly difficulties are Gabriel S.A., it is important to understand the function of the compression head valve in the shock absorber.

Shock absorbers form part of the suspension system of a vehicle. A shock absorber's primarily function is to ensure good vehicle road holding characteristics. It does this

by dampening out the shock loads the vehicle experiences due to unlevelled roads. One type of shock absorber consists of two cylinders, one inside the other. These are called twin tube shock absorbers. Transferring a fluid from one cylinder to the other through spring-loaded valves dampens shock loads. One such valve is the compression head valve. It is positioned at the interface between the two cylinders. The valve acts as a restriction to the flow of fluid from one cylinder to the other. The nature of this restriction primarily dictates the damping characteristics of the shock absorber.

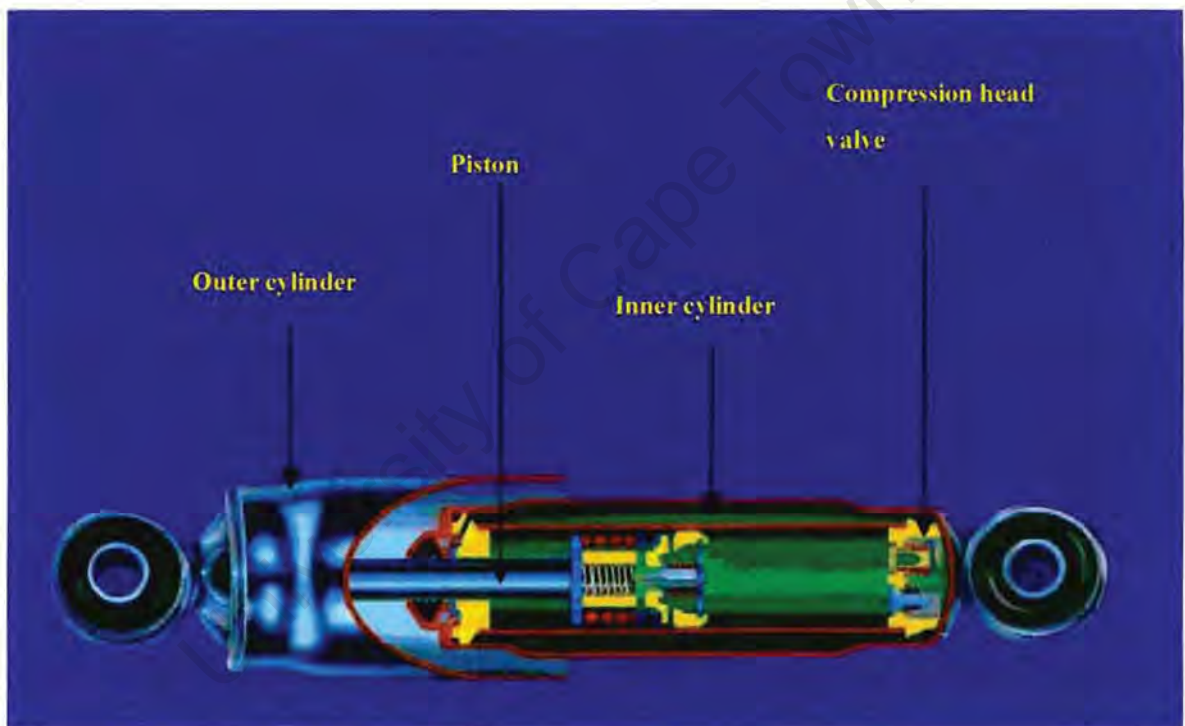


Figure 2.1: A section through a Gabriel twin-tube shock absorber.

Source: Gabriel suspension guide [21].

Gabriel manufactures a variety of shock absorbers that require a compression head valve. The company has switched to a compression head valve that relies on the stiffness of thin discs for their valving characteristics, rather than conventional springs. The reason for this is that these discs are simpler to manufacture, and easier

to assemble. This method of valving also allows for greater flexibility in the valving characteristics resulting from various disc combinations. The cost of producing the flat disc is comparatively less than the cost of winding springs. Gabriel's production target for disc compression head valves is one thousand a day. The disc compression head valve is the subject of this project. Henceforth when the compression head valve is referred to, it is this type of valve that is being referred to. The theory behind the functioning of the valve is attached as Appendix A.

2.2 Compression head valve parts and their functions

The variety of Gabriel's production strategy requires that they produce shock absorbers with varying damping characteristics. Most of these changes can be achieved by varying the thickness and number of the discs in the compression head valve. An understanding of the various parts of which the compression head valve is composed, and how these parts contribute to its function is important, as it provides the context around which the assembly system must work.

2.2.1 Components of the compression head valve

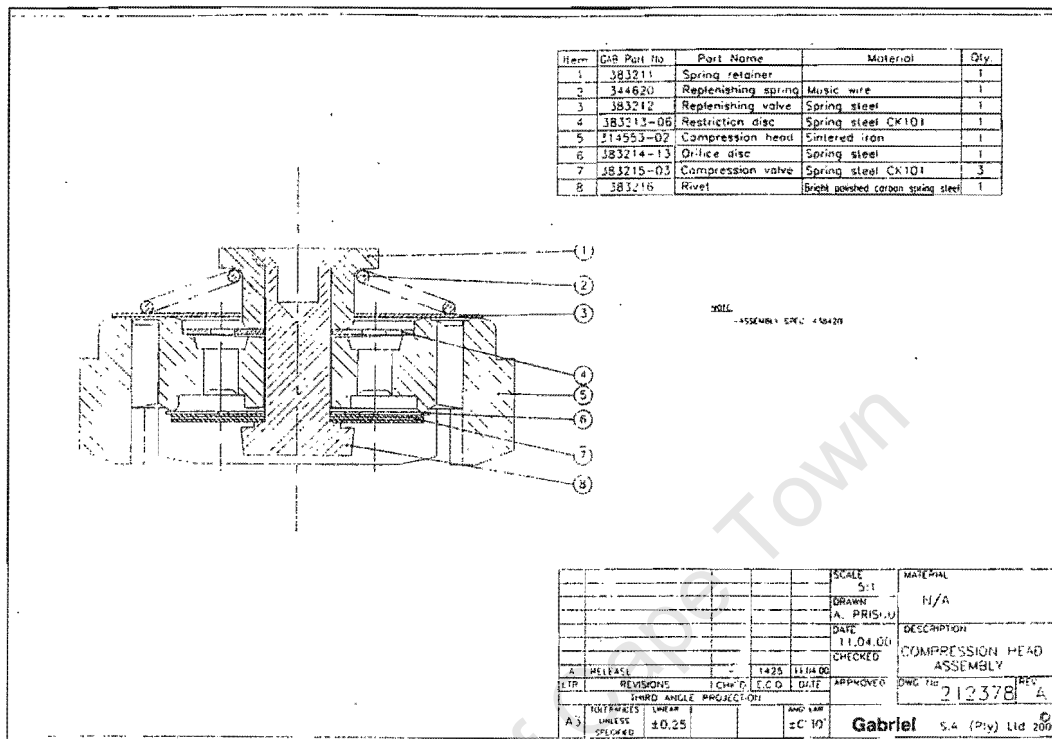


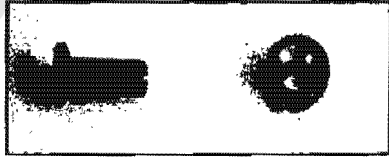
Figure 2.2: Sectioned assembly drawing of the compression head valve.. Source: *Gabriel S.A. drawing office.*

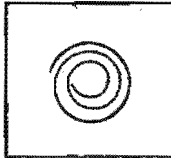
The compression head valve is composed of 8 parts. These include a spring, a rivet and retainer, a housing called the compression head, and 4 different disc types (see Figure 2.2). These discs are all less than 0.3mm in thickness. The characteristics of each part are discussed below¹.

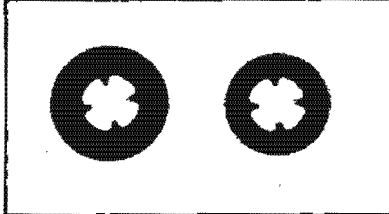
¹ The compression head valve is oriented such that the order of components – from top to bottom – is the retainer, the spring, the replenishing valve, the restriction disc, the compression head, the orifice disc, the compression discs, and the rivet. In this document, most of the components are referred to, relative to the position of the compression head. Thus the rivet, and the orifice and compression discs are *below* the compression head, while everything else is *above* it.

Different types of discs are arranged on either side of the compression head. The set of discs on top of the compression head are used to restrict the flow of shock absorber fluid from the outer cylinder to the inner cylinder (This occurs during the extension stroke or rebound), while the ones on the bottom work when fluid flows in the opposite direction (as would occur during the compression stroke). Variations in the characteristics of the discs are typically in the form of a change in thickness or a change in the number of holes in the disc. The diameter of most of the discs does not vary for differently configured compression head valves. However some compression head valves are smaller than others (the size is determined by the size of the compression head). The compression head valves with the smallest diameter require some discs to be smaller than normal.

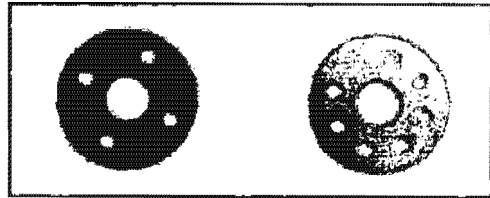
- The rivet and retainer: The retainer and rivet form the topmost and bottommost part of the assembly respectively. They function as the fastener on the assembly, and are standard to all compression head valves of this type. There is no fastener variation.


- The replenishing valve spring: The spring is responsible for keeping all the parts in contact, preventing leaks between components. It also aids the replenishing valve in metering fluid flow while the shock absorber is on the rebound. The spring, like the fasteners, is a standard part.


- The replenishing valve: This disc controls the flow of shock absorber fluid from the outer to the inner cylinder. Most of the compression head valves have a replenishing valve that is 28mm in diameter, however the smaller ones have a smaller replenishing valve, which is 25mm in diameter. No other variation is applicable to this component.

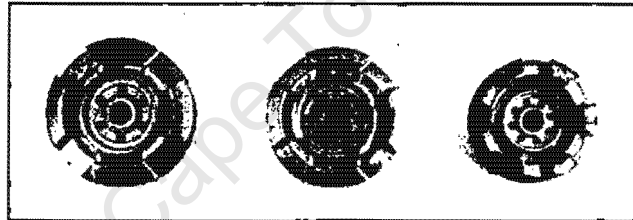


- The restriction disc: The restriction disc has a diameter of 17.5mm. This is standard for all compression head valves including the smallest ones. The



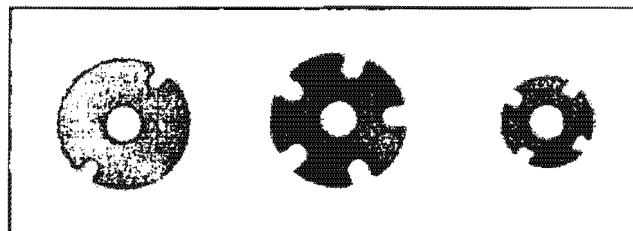
restriction disc has a number of circumferential holes the fluid must flow through during compression (i.e. flow from the inner to the outer cylinder). This restriction has a negligible effect on the flow at low velocities, but offers a large resistance to the flow of shock absorber fluid at high velocity. It is thus able to damp out sudden impact loading on the suspension of a vehicle. The resistance is adjusted by varying the number of holes in the restriction disc.

- The compression head: This sintered metal piece is the largest component of the compression head valve, and therefore forms the housing around which the assembly is built. The retainer, the spring, the replenishing valve and the



restriction valve all locate on top of the compression head. All other components fit below it. There are three different sizes, ranging from 35mm to 29.2mm. The smallest size requires a number of different sized discs.

- The orifice disc: This disc has small slots in the side of it. At low velocities, fluid flows through these orifices. As the velocity increases, the resistance offered to the flow



becomes too great for any fluid to flow through. The amount of resistance the orifice disc offers depends on its number of circumferential slots. A smaller orifice disc is necessary for the smallest type of compression head valve. It is 16.5mm in diameter. All other compression head valves have an orifice disc with a 21mm diameter.

- The compression disc: These are a number of flat discs, located below the orifice disc. As many as six compression discs can be used in a single compression head valve. When the



resistance offered by the orifice disc is too high (in response to the high fluid velocity), the fluid exerts a pressure on the surface of the compression discs below the orifice disc. When sufficient pressure develops, the discs are deformed to allow fluid to flow, and thus relieve the pressure. The compression discs act like a relief valve, the characteristics of which depend on the stiffness of the discs. Stacking discs increases the resistance due to their higher combined stiffness. Four different thicknesses of discs (0.1mm, 0.15mm, 0.2mm and 0.3mm thick) can also be chosen from, however, a compression head valve can only use one thickness of disc for part control purposes. The smallest size compression head valve has compression discs that are 14.5mm in diameter. All other compression head valves have discs that are 19mm in diameter.

The components of the compression head valve all functioning together, produce a particular damping characteristic. By selecting from the various components described above, the damping characteristics can be adjusted to any desired level.

2.3 The compression head valve assembly

Presently the compression head valve is assembled manually. Two assembly stations exist for this process, each with a compression head riveting machine for the fastening operation, and an assembly operator. The assembly is done upside down on the riveting machine. This is because the shape of the compression head is such that, when placed upside down, the orifice and compression discs placed on it form a stable assembly unit, and can be transported as a single piece. This is not true of the components on top of the compression head, as they are unsupported by the shape of

the compression head. Therefore, they are free to slide off during transporting. The rivet is placed in the upper jaw of the machine. When the assembly has been placed into the machine, the assembly worker activates the machine, which lowers the rivet to fasten the parts together. The details of this process are discussed below.



Figure 2.3: The compression head valve assembly cell.

2.3.1 The existing assembly process

The assembly workers have found that the most effective method for assembling the compression head valve is by having an initial subassembly of the compression head and the discs below it (the orifice and compression discs) in the assembly, and then joining everything together on the riveting machine. The subassembly is done away from the machine on a palette. This is shown in Figure 2.4.



Figure 2.4: The subassembly palette. Thirty subassemblies can be done at a time on these palettes.

The subassembly palette has ten pegs, each long enough to hold three compression heads. The assembly operator assembles all thirty subassemblies, before continuing with the overall assembly. This is important since the assembly operator avoids confusion by assembling only one configuration of discs (recall that the valving characteristics are determined by the disc configuration). This means that there is a minimum batch size of thirty for each configuration, thus there is a limit on the flexibility of the current assembly system. The subassembly takes roughly half of the total assembly time.

The other parts of the compression head valve are assembled in the riveting machine as shown in the figure below:

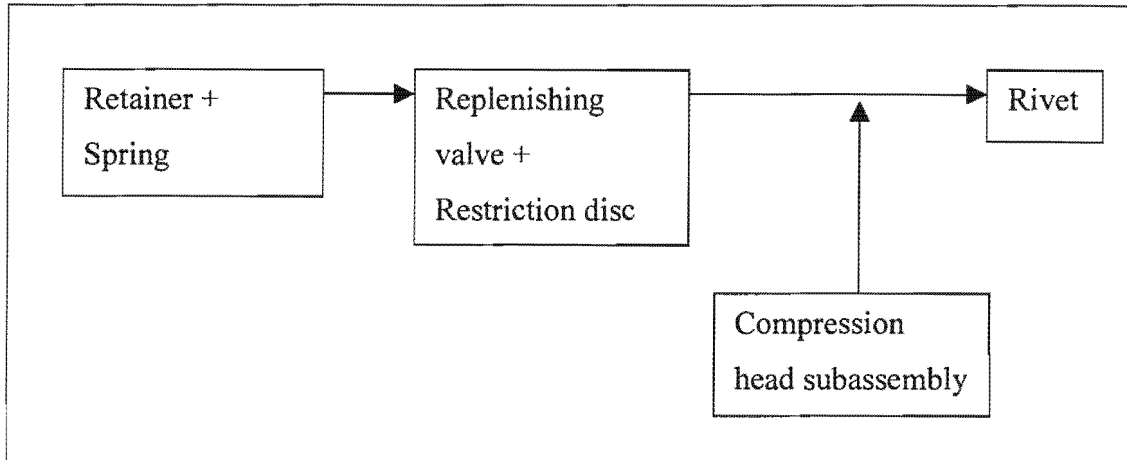


Figure 2.5: The Compression head valve assembly steps. The compression head subassembly is composed of the compression head, the compression discs and the orifice disc.

2.4 Compression head valve assembly difficulties

To meet the current production levels with the present number of assembly workers and assembly stations requires the assembly workers to work overtime regularly. The production demands on the compression head valve assembly stations is expected to increase as Gabriel plans to double production in 2001. As such, something must be done to increase the productivity of the compression head valve assembly station in the most efficient manner. The engineers at Gabriel S.A. believe that the cost of installing assembly aids (in the form of automation) for the current number of assembly workers would be more cost effective than employing additional assembly workers to meet production. Part of the reasoning behind this is that the current compression head valve assembly process has a number of characteristics that make it difficult to keep up a high productivity level over the course of a full day. Simply employing additional staff will not solve such productivity difficulties. As such the engineers at Gabriel S.A. require a solution that addresses a number of productivity difficulties. As an initial step to formulating a solution, the compression head valve and its assembly process were examined to find existing design or process weaknesses.

2.4.1 Compression head valve design related difficulties

It is important to note that the compression head valve was designed to fulfil its function as well as to satisfy a number of production criteria (e.g. flexibility). In this respect it is very successful. The fact that the product could have been designed better for assembly takes nothing away from this.

The area that causes most of the difficulty is the handling of the parts. The discs are so thin that they are difficult to pick up, and difficult to separate (If each disc is 0.1mm thick, a pile 100mm high contains a thousand discs). Ensuring that the correct numbers of discs are being assembled can take a significant amount of time. In addition the spring's function necessitates a design that is prone to tangling. Tangled springs take time to untangle, and this slows down the assembly process. But these are all manual operating problems, due to the manual assembly process. It would be expected that the assembly process would be changed to an automated one to resolve these issues. However the compression head valve has not been designed for automated assembly. While the product does have a single axis of assembly, there is no base component on which to locate all the other parts, and the parts on top of the compression head are not located until the fastening operation.

2.4.2 Compression head valve assembly process related difficulties

The assembly process is such that it is quicker to assemble the compression head valve with a subassembly stage. The subassembly is done away from the riveting machine, therefore when an assembly worker is busy with the subassembly stage of the assembly process the machine utilisation is reduced to zero. The only way to avoid this is to include a subassembly worker. This is undesirable since it would mean that the compression head valve assembly requires two workers instead of one.

The manner in which the subassembly is presently done limits the flexibility of the assembly process.

These problems are not severe enough to stop production, but they have a significant effect on the cost of producing a compression head valve. Any feasible solution to these problems would ease the present production difficulties and improve productivity.

2.5 Compression head valve assembly productivity

The productivity of the current assembly process is affected in part by the limit it places on the flexibility of what would otherwise be an inherently flexible process. The difficulties associated with the handling of discs can affect the quality of the components produced. This can happen when two discs that have adhered to each other are mistaken for a single disc. This mistake can only be picked up after the shock absorber has been completely assembled and tested. It therefore costs a great deal more labour time than the time taken to assemble the compression head valve. In addition to the time the assembly operator can waste in ensuring that the correct numbers of discs are used, the springs can tangle, causing additional time wasted in untangling them. The compression head valve assembly can take up to sixty five seconds to complete. This duration takes into account the time spent on the compression head valve subassembly². The engineers at Gabriel S.A. and staff involved in the compression head valve assembly process believe that the assembly time could be reduced significantly.

² It was difficult to get permission to conduct an independent study of the assembly process to get a more exact idea of the time taken because the assembly operators are very sensitive about time studies being conducted. This figure comes from an estimate based on a day's production, and the hours taken to meet that target for the day. The figure was also discussed with the team leader who found it to be a reasonable estimate.

3 THE ASSEMBLY PROCESS

3.1 Factor influencing assembly

Because assembly is one of the later processes of production, it is largely dependent on the production processes that occurred before it. The most important of these are the design and the manufacture process. Their influence can be understood by examining what aspects of the product are critical to each process. The design process is most concerned with the functionality of a product and its parts, while the manufacturing process is concerned with the geometry and material required for a part. The assembly process is involved only with the relationship between features of the various parts of a product. These features are a result of the selected manufacturing process, and their relationships are based on tolerances, dictated by the design of the product. This means that the determination of the cost of the assembly process is shared between the design, manufacture and assembly engineers. In fact research has shown that most of the cost of a product (between 70% and 80%) are committed to during the design phase of production [3]. This is largely due to the fact that the designer decides the form of the product.

Apart from being influenced by other aspects of the production process, assembly is also dependent on a number of external factors. The key factors are listed below:

3.1.1 Availability of resources

A resource in the industrial context is any source of overhead that can be used during production. This is typically seen in terms of capital, labour, materials and machinery. Resources influence the set up of the manufacturing organisation. Choices made on production methods, including assembly, take resource availability into account.

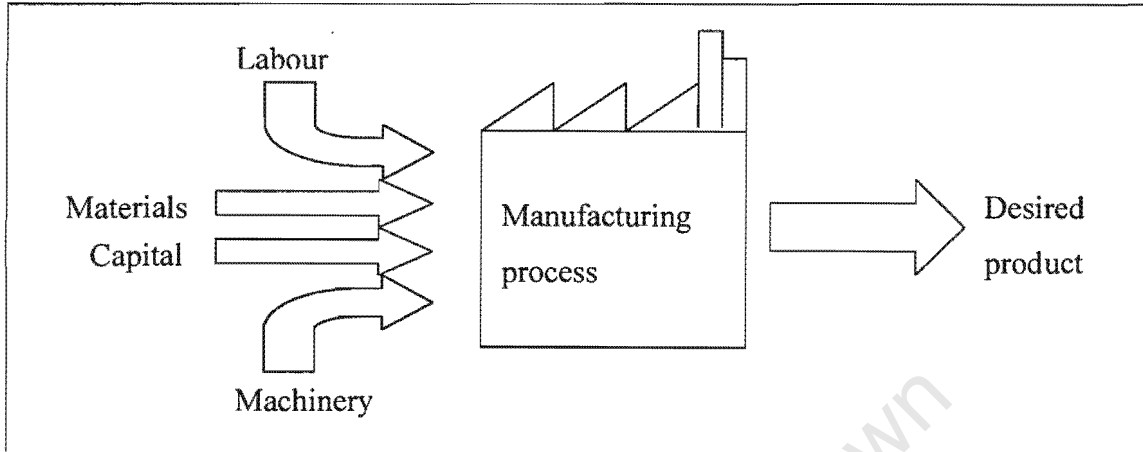


Figure 3.1: Resource requirements for product manufacture.

Labour and machinery are associated with the maturity of the local industry. In broad terms, the more developed the local industry is, the easier it is to find skilled labour, and machinery based on cutting-edge technology. The level of capital available is usually specific to the manufacturing organisation and its source or method of financing. Material resources on the other hand, depend on the regional location of the organisation.

The assembly process also takes up floor space in the factory. The cost of this space is easily determined. Space being used by an assembly process is considered a capital investment in the process. As such, compact assembly processes are favoured.

3.1.2 Production requirements

The assembly process must satisfy the requirements of production. Factors like production volume, product variation, and product complexity must be matched to the assembly properties. Decisions taken about the assembly process should be geared towards satisfying a production requirement.

3.2 Basic assembly theory

The assembly process can be explained in terms of a framework based on the level of product information required. The characteristics of the assembly process can be based on the batch size of production, on the structure of the final product, or on its components. This framework is illustrated in Figure 3.2 below.

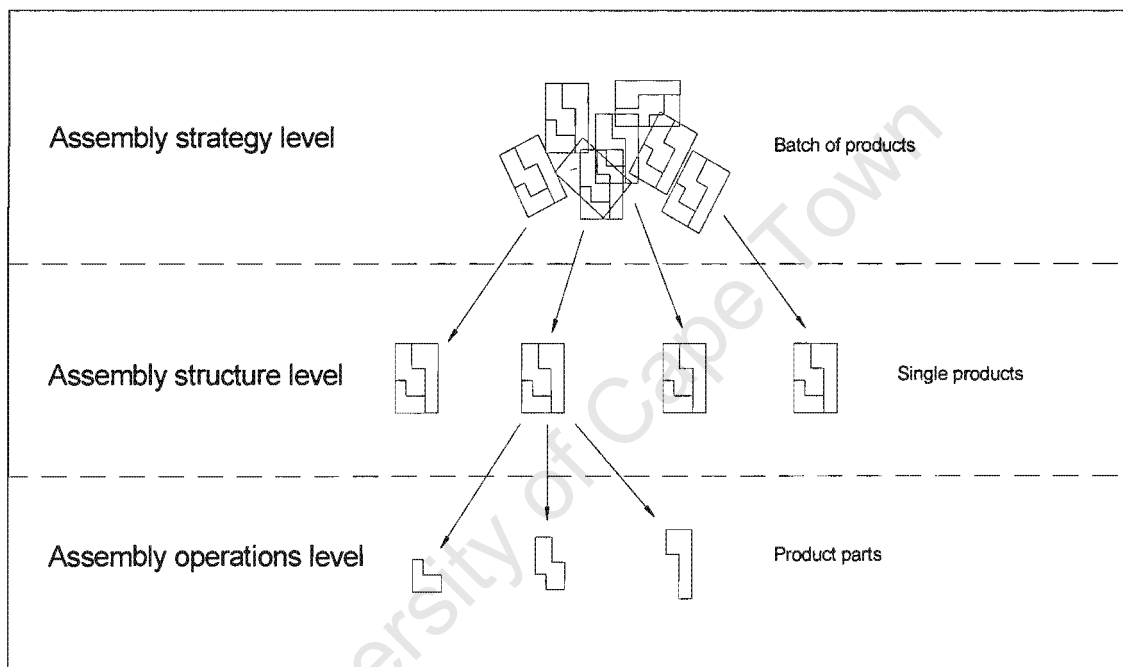


Figure 3.2: Figure illustrating the hierarchical nature of the levels of an assembly process.

3.2.1 Assembly strategy

At this level, decisions made about the assembly process are based on the expected volume and rate of production, and the batch sizes for production runs. When considering batch sizes, it is customary to speak of small-batch (1-100 units), batch (over 100 units) and mass (over 100 000 units) production. The batch size is based on the nature of expected customer demand.

The following aspects of assembly are characteristics of the assembly strategy level:

1. Method of assembly

Selecting the optimum assembly method requires knowledge of the capabilities and limitations of the various methods measured in relation to the restraints imposed on the production by required production rates and batch sizes. Assembly is typically classified according to what or who is responsible for putting the product together.

Broadly assembly can be classified into three methods:

- Manual assembly: Human workers perform the assembly operations. Typically low production volumes, and a high degree of product variation is associated with this method. The capital required for this process is low, but it is labour intensive. Manual assembly is normally only economical for small-batch production.
- Flexible automation assembly: The mechanical equipment that performs the assembly operations in flexible assembly can be reprogrammed for a variety of similar products. The variation allows the manufacturer to be flexible to the specific demands of customers. It also means that the manufacturer is able to adapt to quickly changing market conditions. However this variance also requires small batch or medium batch production with short production runs to be economical for all products in that family. More detail is given about Flexible Assembly in section 4.3.2.
- Fixed automation assembly: The mechanical equipment that performs the assembly operation has been built specifically for that product. Any change over for a different product results in a long downtime period. The capital investment for this method is high, and is thus best suited for mass production and long production runs with a fixed rate of production. The longevity of the product lifecycle makes the capital investment economically viable.

In most cases machines are faster and more accurate than human assembly workers, and work better with heavy components. The human assembly worker is more flexible and is able to make decision related to changing work conditions, which might lead to faulty production for automated assembly units. All these factors have to be considered when selecting an assembly method. The chart labelled Figure 3.3 shows the strengths and weaknesses of the three methods in various functions.

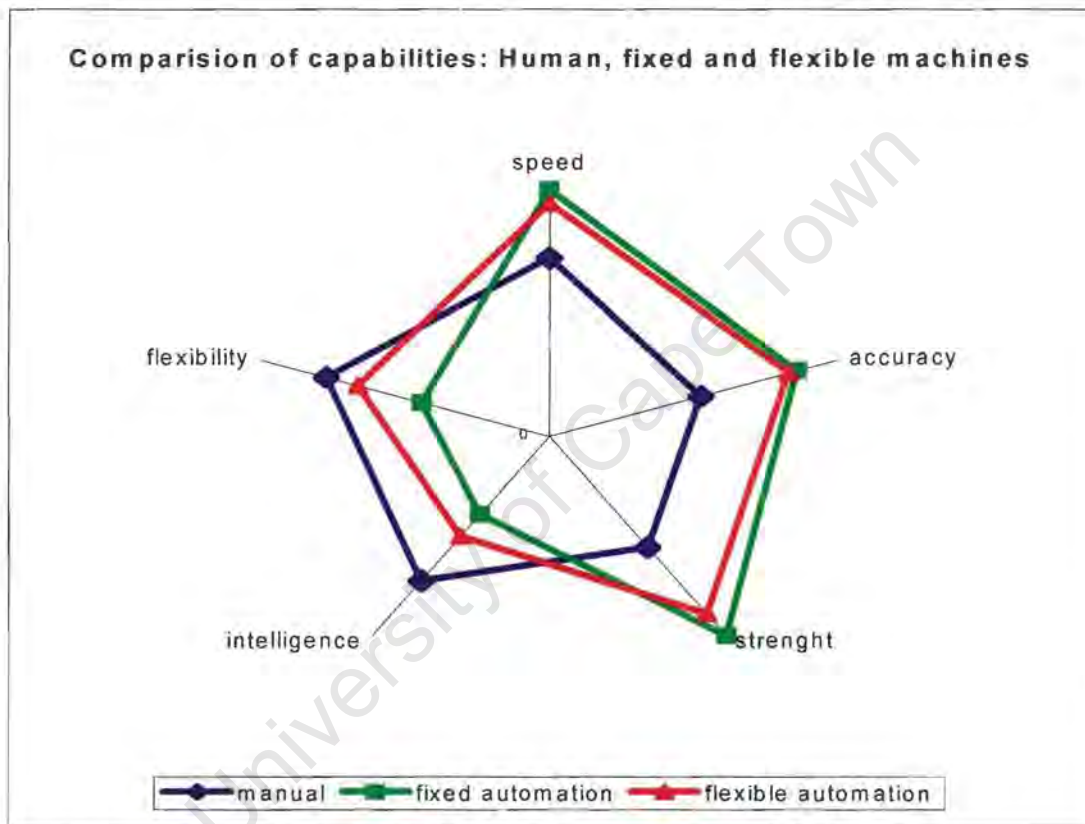


Figure 3.3:Chart showing a relative weighting of the capabilities of the three methods of assembly in a number of critical areas as selection criteria.

These capabilities affect the suitability of an assembly method for different types of production. Usually the method of assembly can be selected once the production volume, batch size and product variation is known. Figure 3.4 shows the optimal assembly method for the various batch sizes.

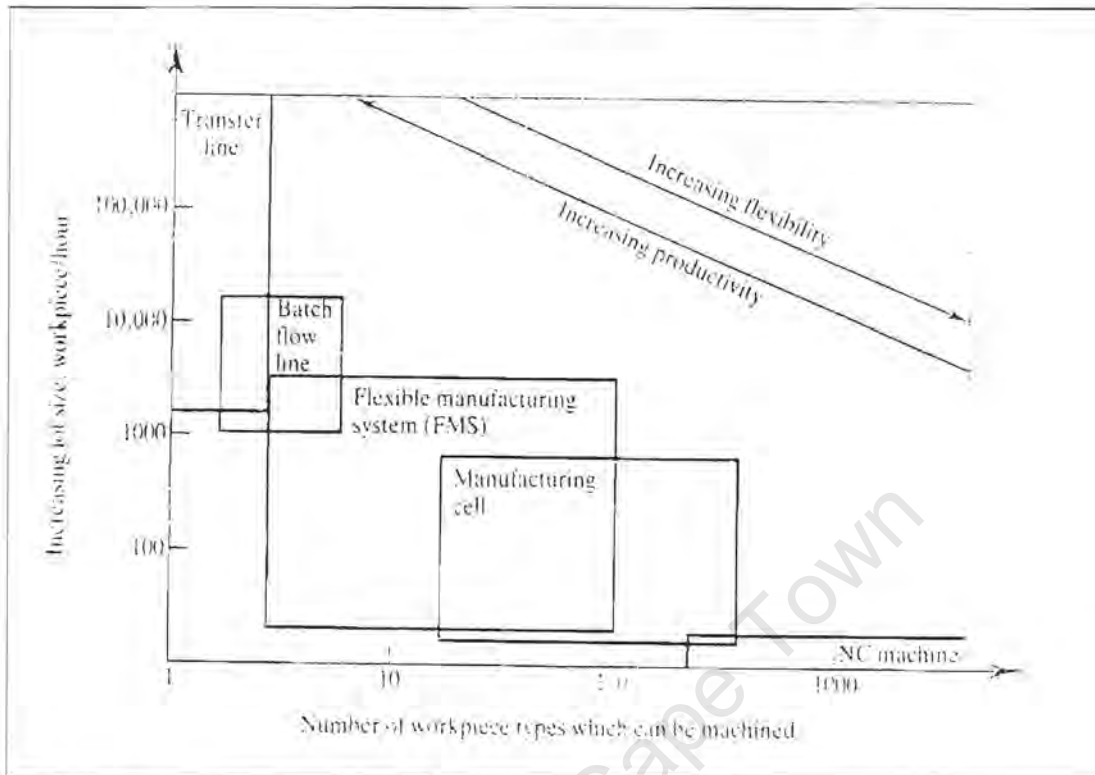


Figure 3.4: Figure showing the different manufacturing methods and the optimal application of each method.

Source: *Computer-Aided Manufacturing* [11].

Assembly automation typically involves pneumatic devices (where heavy loads are handled, hydraulic systems are used instead) or mechanisms (e.g. cams and linkages) to carry out assembly operations

2. The assembly system

An assembly process has an associated assembly system. This is the configuration of the assembly stations, or the logistics of physically realising the desired assembly method for a particular product. The choice of equipment must also be considered. Typically the important criterion here is the flow of product. The system can be set up so that the product flow is down an assembly line or at an assembly cell. The

configuration of an assembly line depends on the batch size of the product. Linear assembly lines are well suited to mass production. Workstations can also be set up in a circular or oblong arrangement. Such set ups are used for smaller batch sizes, or for subassembly.

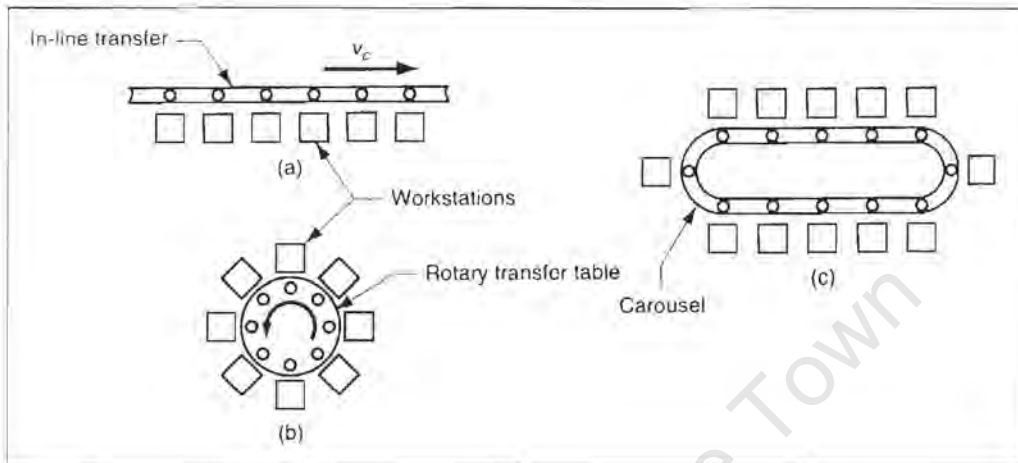


Figure 3.5: Types of assembly layout.

Source: *Fundamentals of modern manufacturing* [10].

3. Transportation and storage

This concerns the manner in which the assembly process interfaces with the production phases that occur immediately before the assembly process, or immediately preceding the assembly process. The method of transporting the part being assembled must be considered. Transfer lines or conveyors are economical, and thus used wherever possible. Automatically Guided Vehicles (AGV) are used in fully automated assembly processes, where heavy components must be transferred, or where long distances separate assembly stations. The storage of components can affect the ease of assembly. If parts are not carefully racked, sorting or orienting of parts might be required at the assembly station. Such operations can waste time and can therefore be costly. Figure 3.6 shows an example of the difference transportation and storage can make to the assembly process.



Figure 3.6: Two examples of storage methods of cylinder head valves. The picture shows the problems with the storage method on the right hand side.

Source: *Concurrent design of product and process* [2].

Transfer of the completed assembly, as well as the storage should be such that the operator on the final assembly station need perform no additional tasks. Assembly that takes place on a palette is desirable in this regard since palettes can double as storage racks.

3.2.2 Assembly structure

1. Constraints on assembly

The sequence and the relationship between assembly operations have to be well thought out to ensure assembly efficiency. Two types of constraints are involved in determining the sequence of assembly.

- Physical constraints: This is closely related to the structure of the product, since it places physical restrictions on what order the product is assembled. Parts must be assembled within a housing, for instances, before a cover restricts access. The product might require different orientations to assembly some components.
- Practical constraints: A variety of practical constraints exists, with respect to complexity of the process and optimisation of the number of stages needed to assemble the product. An example is that when a number of identical parts have to be mounted, it is unproductive to interrupt this sequence for mounting of other parts.

A number of sequence options usually exist, which satisfy the assembly constraints. For fixed automation there is no value to having more than one sequence option, because the assembly system is designed and optimised for one fixed sequence. Sequence options, however, might mean that a manual assembly process could be designed to allow for different preferences of assembly workers, where such preferences might allow for more efficient assembly. Flexible automated assembly can also use these options to channel the flow of the product differently in the event of a machine failure, or machine maintenance, or reconfiguration downtime. Despite this, typically in all assembly methods, only one sequence is chosen.

The choice of the assembly sequence is critical because it commits the assembly process to certain requirements. Usually the sequence defines the need for subassemblies, jigs and fixturing mechanisms. It also plays a role in the factory layout in terms of the floor space needed for the defined sequence.

2. Representing assembly sequence information

Documenting proposed assembly sequences in an elegant and concise manner allows for easy comparison and re-planning sequences. It also provides an unambiguous written record of the structure of the assembly process. However assembly sequence generation can be a tedious task to accomplish manually. This is because assemblies

with as few as 10 parts can have hundreds of feasible sequences, and all must be considered in order to ensure that the optimum sequence has been chosen. Algorithms for ensuring that all sequences are considered have been developed. They include the LASTD (Layered Assembly State Transition Diagram) [4], which can be defined as a parts-oriented approach. Bhaskare and Newton [5] argue that a sequence generation method based on the assembly tasks required is more in keeping with the way process planners work. De Fazio and Whitney [2] developed an algorithm based on the 'liaisons' between parts being assembled. A schematic representation of the process it follows is given in Figure 3.8. Other assembly sequence representation methods include Petri Nets, which are gaining favour in assembly processes. Petri Nets consists of a set of conditions (the states that the objects can be in), and a set of events (the assembly operations). The assembly sequence is shown through the transfer of tokens (assembly objects or components). An example is shown in Figure 3.7.

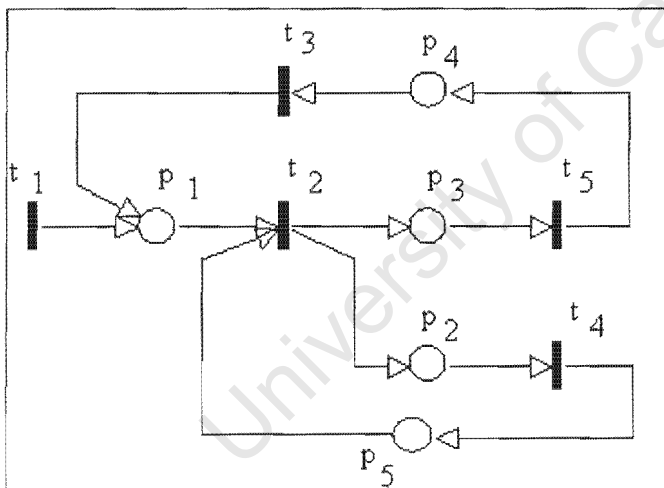


Figure 3.7: Petri Net example.

Source: *Architecting Information Systems* [24].

The strength of Petri Nets lies in its versatility in modelling systems with concurrency and parallelism³. Assembly tasks strive for greater parallelism since it requires less lead-time. Computer simulations with Petri Nets have contributed to the popularity of the Petri Nets.

Computer aided assembly sequence generation forms part of the Computer Aided Process Planning (CAPP) process. Computer based systems strive for greater integration between assembly modelling, Design for Assembly and assembly process planning [14]. Most of these are computer systems.

Assembly process planning results in assembly sequence plans that can be used for production. The plans must consider the need for subassemblies and the effective overall efficiency. Simultaneous assembly of different components of the product can be done using subassemblies, thus speeding up the process. Good methods for generating an assembly sequence follow extensive steps that are broad enough for any application. There are situations in which subassemblies are undesirable, especially since each subassembly requires stability as a stand-alone unit. However a report by Reijers suggests that large subassemblies are also avoided with 90% of the subassemblies studied containing less than twenty-three parts [18].

³ Concurrency refers to a number of assembly operations carried out at the same time (basically the extent to which the assembly process can be divided up into subassemblies). The extent of this division is the level of parallelism of the assembly process.

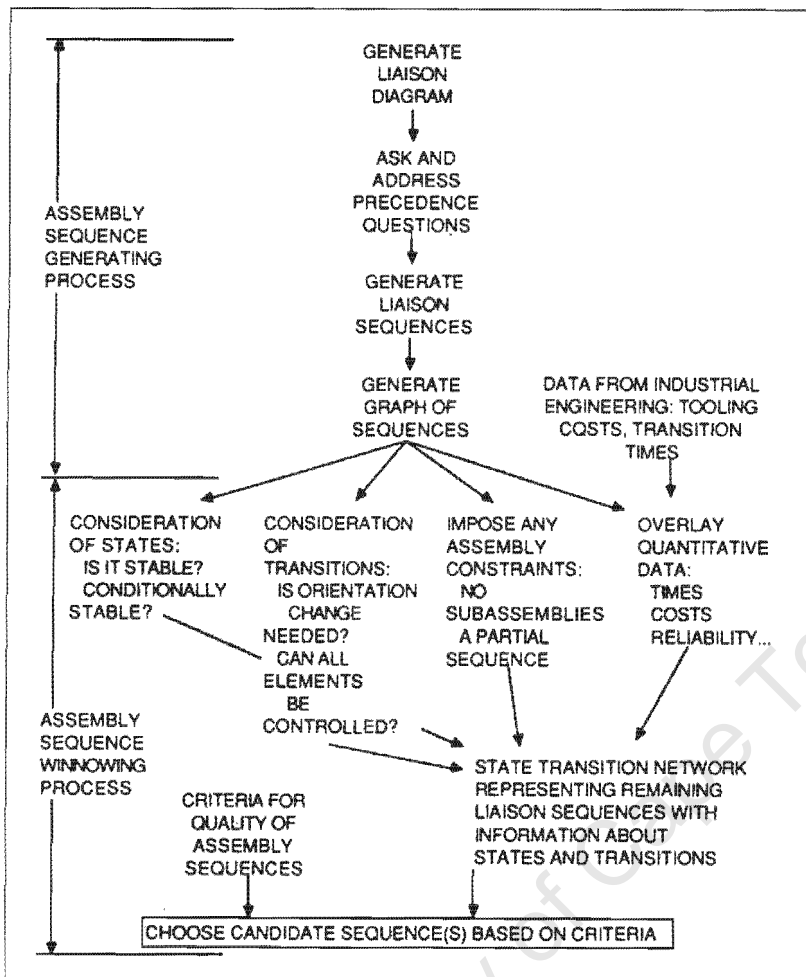


Figure 3.8: Assembly sequence generation algorithm.

Source: *Concurrent design of products and process* [2].

The efficiency of the assembly process depends on the number of workstations, machines or workers, and the time taken to assemble the product to the required quality standard.

3.2.3 Assembly operations

The mechanics of putting a product together involves a number of operations. Parts must be transported to assembly workstations where they are required. This task can be done by conveyors, walking beams, bowl feeders etc. or the parts can be

transported on skids or in containers. The method of transportation affects the way in which the part is presented at the workstation. Presentation of parts should be such that no operations other than the assembly tasks need be performed. The location and orientation of the part is particularly important in this regard. Jigs or fixtures can be used to ensure proper location during assembly. Some transport systems can be used to orient parts for easy assembly (A vibratory bowl feeder is a good example of this). In other cases gates or deflectors can be built into the assembly operation to ensure proper part presentation.

The mating task can take up as much as 80% of the total assembly time [6], and occurs in three stages. It starts with a pick-up or handling operation, followed by a rapid motion operation and finally a feed or insertion operation. Part handling considerations differ significantly, depending on the assembly method involved. For manual assembly methods, motion economy is important in the determining the assembly operations. Manual assembly processes should be designed such that the worker uses as few motions as possible in assembling a part. An emphasis is placed on using both hands during assembly operations to achieve a combination of tasks simultaneously. For automated handling processes, careful planning should be done to ensure only simple motion paths are required involving the least degrees of freedom possible. This is because automation costs escalate rapidly as the degrees of freedom of the automated machinery increases. The main objective is to minimise redundant motions to reduce assembly time. Wherever possible handling, feeding and orienting difficulties are avoided. Self-locating and self-fastening features are integrated onto the components to achieve this aim. The rapid motion operation follows the pick-up of a component. During this operation the assembly parts are brought into close proximity. Any orientation required is done at this stage. Next is the feed or insertion operation, during which the assembly task is realised. Automated assembly units interact using sensors to ensure proper mating of parts. A basic catalogue of sensors is shown in Figure 3.9.

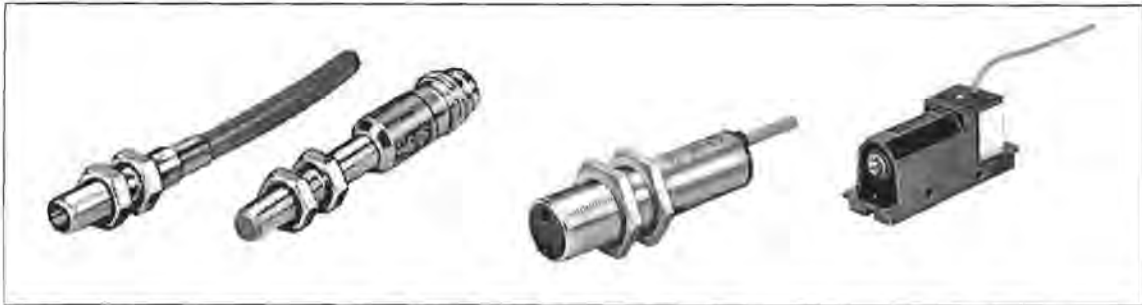


Figure 3.9: Some examples of (from left to right) proximity switches, a optical sensor and a pressure switch.

Source: *Festo pneumatic catalogue* [20].

Once the task of the workstation is complete, the product being assembled is passed onto the next station via the assembly transport system.

The tolerance to which parts are made is critical in the assembly operation stage. The importance of the tolerances designed into products lies in its influence on the ease of assembly. Products designed with tolerances that are tighter than necessary are more difficult to assemble. Often this leads to unnecessary rejection of parts during assembly. If the tolerances are not tight enough, the quality of production suffers. Determining the tolerances for a particular product is a concurrent design issue, requiring engineers from all stages of production.

3.3 The importance of the assembly process

All phases of the production process are important. Assembly can no more be done in isolation than can design or manufacture. The nature of production is such that trade-offs between stages are necessary to develop the best product possible. For example, making a product easier to assemble might make the parts more costly to manufacture.

3.3.1 Production efficiency

Production efficiency can be seen as a measure of the effective use of production resources. The measure of this is in terms of cost and the time spent on a process. Assembly does not usually cost as much as the other stages of production, and typically does not take as much time. But processes like manufacture are optimised for the particular product, and therefore costs are minimised relative to the requirements of the product. Assembly processes in industry however, are not well optimised, and take more resources than is really necessary for the particular product. With manufacturing organisations strive increasingly harder for more cost-cutting measures assembly is becoming a prime focus.

3.3.2 Understanding the production process

The fact that the assembly process is not well-understood means there is scope for improving production. Any insight gained into the nature of the assembly process affect the way a product is designed and manufactured, because assembly is integrative. Computer-Aided assembly models could play a key role in production. Already software for assembly process planning, and design for assembly aids are having marked effects on industry. In an article in *Plastics World*, Carl Kirkland introduces Design for Assembly by saying “It saves Ford Motor Co. \$700 per vehicle and reduces Ford’s manufacturing costs by 30%...and by using it NCR Corp. will save \$1.1 million in total lifetime manufacturing labour costs for its new model [which will be assembled] in 75% of the time of a previous model with 85% fewer parts.” [19]. It is clear that the potential for more production savings through a greater understanding of the assembly process is being realised.

3.3.3 Modern trends in the production market

Manufacturing comprises of technical and economic processes that convert resources into products for sale. Success is measured by profit, i.e. the economic achievements

of the product. International trade restrictions are being reduced. The global marketplace, in which products manufactured in Hong Kong compete on an equal footing with products from local industry. Competition is fierce; companies survive today by offering more to their customers, responding faster than the competition and taking advantage of cutting-edge technology. Thus products today are more diverse than they have been in the past. An example of this is the increasing number of automotive vehicle categories available to the customer. Companies are more flexible to the needs of customers. This has led to a change in the development of assembly processes. Today a lot of money is spent on flexible assembly systems (FAS). More products are manufactured with some degree of automation. The drive in industry is to increase the flexibility of automation to cater for a wider product range. Some products are also developed, because the technology exists to produce parts that are easier to assemble. The increasing role of plastics (plastic components are generally easier to produce than components in other materials) is testament to this change. The need to be more technologically advanced than the competition has fuelled the development of new technologies. Products have a shorter shelf life as they quickly become outdated. This means that new products must be produced quickly. Product designs must be easy to manufacture and easy to assemble, so that these processes take as short a time as possible.

4 MODERN ASSEMBLY THEORY

Concurrent Engineering is a new buzzword in industry. The concept refers to the goal of simultaneously developing products and their production processes. More significantly Concurrent Engineering is a quality initiative that aims to give everyone involved a stake in the development of a product, and a better understanding of the multi-disciplinary critical parameters for that product. The idea is that this knowledge be translated into a higher quality product. For the purposes of this project, modern assembly theory is any assembly strategy or method that is geared towards the ideal of a fully integrated production process through Concurrent Engineering.

Changes in the production process, that have been as a result of assembly related research, have impacted on two areas of production in particular. The assembly process itself is better understood today. As a result of this, there is scope for optimising the process. This rationalisation of the assembly process is a major focal point for optimising industrial production. The other area of impact is the design of products, and its impact throughout the production process. Through an integrated design process, features of products and the overall design strategy can be geared towards easy assembly.

4.1 The integrated production process

The factors discussed in section 3.3.3 above are starting to force production industries to rethink the way they develop products. One aspect about the conventional process of product development process has become glaringly obvious: It alienates the various specialisations within the industry, by setting objectives specific to particular specialisations along the product development process, independent of other specialisation that might play a later role in the process. This leads to a disjointed process that suffers a breakdown at the interfaces of the various specialisations. The

mistakes that are made as a result of this affect the quality of the final product. Concurrent Engineering is a quality initiative that results from shared information and expertise within a design team composed of members that represent the various stages of the production process. It allows for the breaking down of information barriers, with everyone from the design engineers to the production engineers contributing their expertise to the development of the best possible product. In this way the responsibility for the development of a product and the quality of production is shared. Design problems are more likely to be discovered and corrected early in the development process, before production begins. The result is that in Concurrent Engineering the time-to-production (or development lead time) can be greatly reduced, as is the overall cost of developing the product (see Figure 4.2). In the more traditional engineering design process, tasks are parcelled out into various engineering departments, with different, sometimes conflicting objectives. This leads to a system in which each department works towards its objective, and then passes on the project to the next one, in a manner akin to throwing it over a wall (The various departments therefore have little or no interaction). This is showing in Figure 4.1.

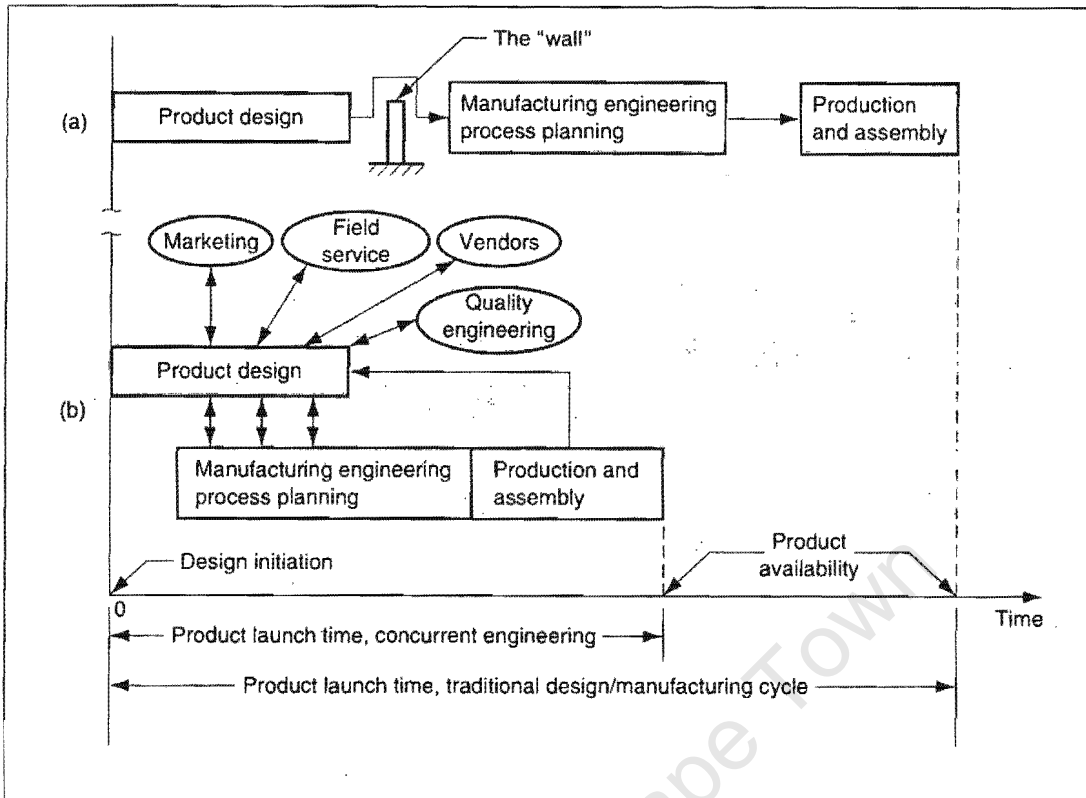


Figure 4.1: Diagram showing the differences between traditional engineering design (a) and concurrent engineering (b). The design process in concurrent engineering involves a design team, and an iterative approach which overlaps the various design stages. The result is that the product launch time can be much shorter for a Concurrent Engineering process.

Source: *Fundamentals of Modern Manufacture*.

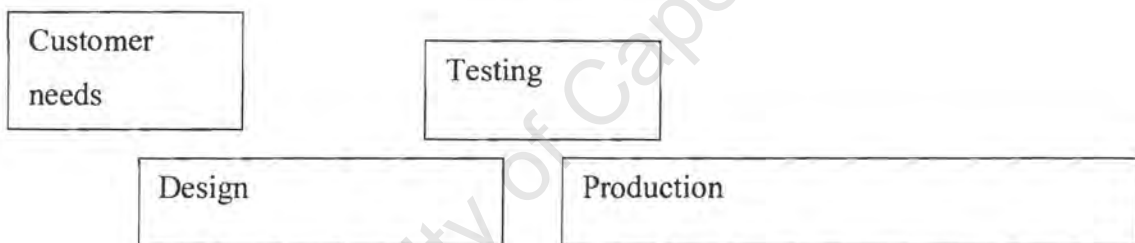
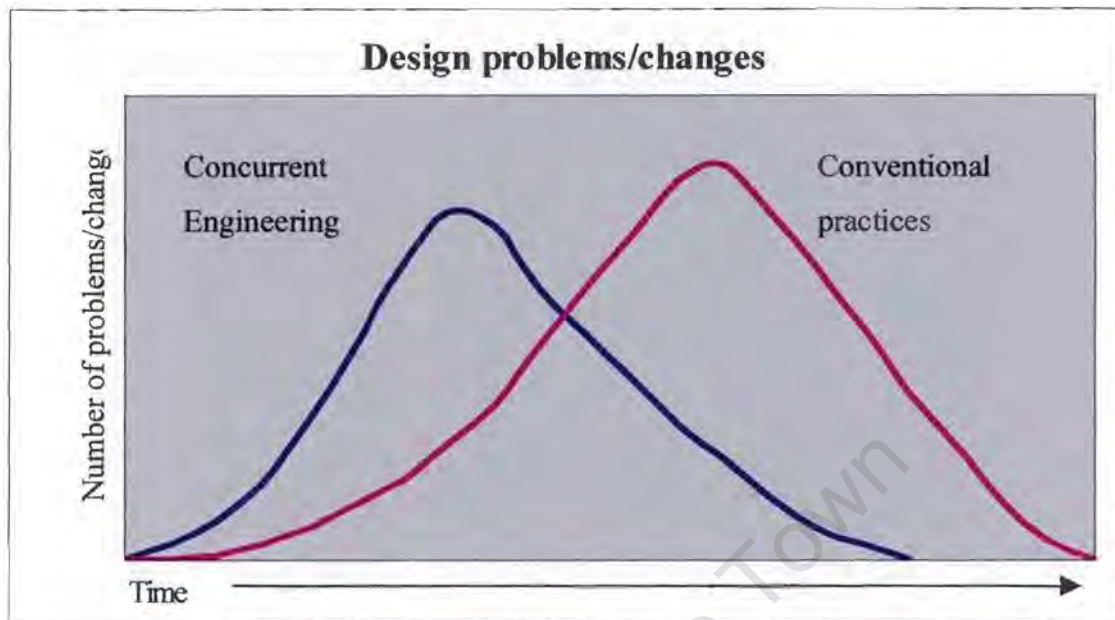


Figure 4.2: In Concurrent Engineering design problems are usually discovered early therefore a feasible design is settled on before production begins. The later a design change must be made, the more time it takes, and the more expensive it is. In this way Concurrent Engineering can save on both time and money.

But implementing Concurrent Engineering is not easy. This is because Concurrent Engineering is a system that allows a company to use modern industrial technology to achieve production goals. These technologies include Flexible Manufacturing Systems, Group Technology, Design for X (where X can be manufacturing, assembly, life-cycle, environment, quality etc.), Computer Aided Manufacturing and Design (CAD/CAM) to name a few. However the approach a design team takes in terms of the technologies the team chooses to use, and the manner in which the team

chooses to use these technologies, depends on the goals of the design team. For this reason the implementing of Concurrent Engineering might have a completely different form, based on different technologies in different industries. The success of the implementation thus depends on the design teams ability to understand the product development goal, the resources available to them, and the advantages and drawbacks of applying particular technologies. These technologies can be grouped depending on the stage of the production process in which they are applicable. In this chapter, only technologies associated with the assembly process (directly or indirectly) are discussed.

4.2 Rationalising the assembly process

In the introductory chapter of this thesis, the potential for cutting costs and improving production quality that existed in the optimisation of the assembly process was established. The rationalisation of the assembly process is one key focus of Concurrent Engineering. Rationalisation can be achieved through a number of methods. These methods can be grouped into three topics: Assembly automation, rationalisation through assembly employment, and product design for assembly. These are discussed below.

4.3 Modern assembly automation

When compared to the design and manufacturing processes, the assembly process is limited in automation and computer aid. Studies in the automotive industry show that between sixty and ninety percent of the manufacturing process is automated, while for assembly processes [1] the figure is closer to fifteen percent. Industrial mechanisation, and subsequent automation of the assembly process lag behind the other processes for a number of reasons:

1. Assembly is highly product specific with a high variability in the nature of assembly operations. Therefore standard solutions are difficult to develop.

2. As the final stage of production, a large amount of variability is built into the assembly process in practice, to allow for any errors higher up the production process, and last minute adjustments for the continuously changing market. This made fixed automation more difficult to implement for assembly processes.
3. Assembly automation has been economically difficult to justify until recently.

Today, a variety of different automated options are available for assembly processes, differing in the degree of automation and the complexity and flexibility of the assembly system. This has allowed for the automation of low to medium volume assembly processes with smaller batch sizes in comparison to the systems developed in the past.

4.3.1 Degrees of automation

Studies have shown that about 50% of the actual assembly time is spent on the joining of parts [1] (See Figure 4.3).

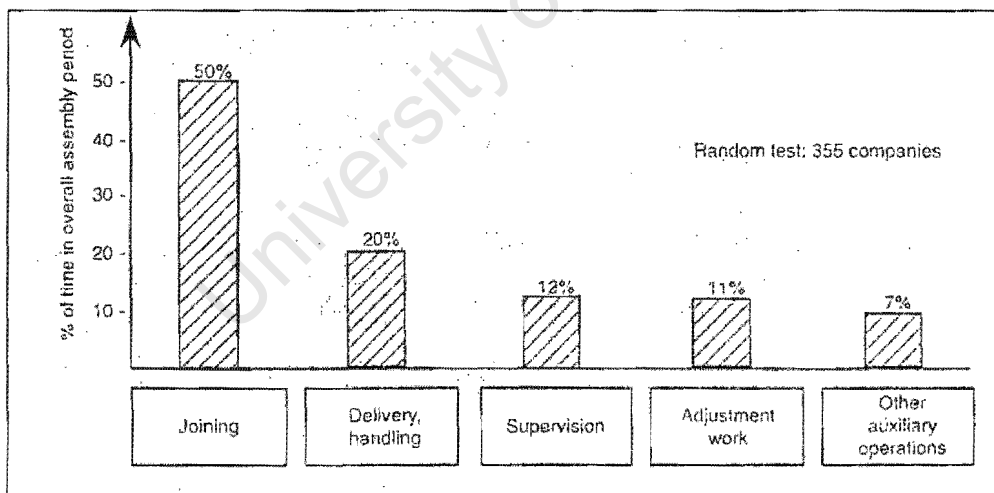


Figure 4.3: Percentage of assembly time spent on various assembly operations.

Source: *Industrial assembly* [1].

The significance of this is that the distribution of time on assembly operations is varied. Therefore there is a need to prioritise the implementation of automation. Rationalisation strives to achieve the highest possible gain in productivity at the least possible cost. Fully automated processes are inflexible and expensive to construct. Fully manual processes are slow and inconsistent. Typically what is needed is a production environment somewhere between these two extremes. The nature of automation is such that the cost of automating some assembly operations is higher than others. Also, in different cases, the increase in productivity gained as a result of automating the various assembly operations varies. In deciding what degree of automation is required, the nature of the assembly system being designed and the targeted area of the assembly process to be automated must be considered. Thus automation can be prioritised on the basis of these two factors. A good example is to consider a process with complex part interactions or geometries that makes automation of the mating or joining operation costly. Here benefits can still be gained from automating the transfer, sorting or inspection of parts that would otherwise require the attention of an assembly operator. This frees up the operator to concentrate on the mating tasks. This is known as semi-automation. It is particularly useful in emerging industries, where capital is limited.

The costs of a fully automated system have to take into account the maintenance and capital costs (including the power required for the system), which can be significantly greater than the personnel costs involved in a fully manual process. In some cases this cost can effectively short circuit any productivity gains. However, the costs associated with varying degrees of automation are such that it is possible to determine an optimum automation level. This is shown in Figure 4.4.

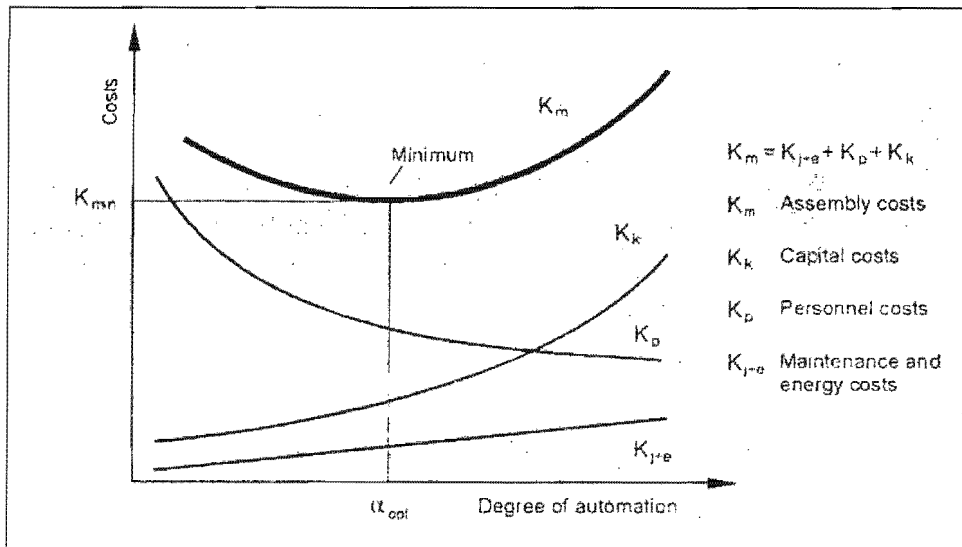


Figure 4.4: Assembly cost as a function of degree of automation.

Source: *Industrial assembly* [1].

It is important that a good semi-automation system leaves the possibility for further change in the level of automation required by the assembly process. This leaves the process engineers with the flexibility to make changes in response to the changes in the production industry.

4.3.2 Flexible Assembly Systems

Dynamic changes in industry have rendered many machines obsolete today. In the past, it took several years for a machine to reach a point where replacing it would yield more favourable returns on the investment than continuing to use it. Today, the reduction in the market life of many products means that this is no longer the case. As such assembly systems must be designed with allowances for product variability. The advent of Flexible Manufacturing Systems (FMS) has thus allowed more assembly processes to be automated (Recall the need for flexibility as one of the factors hindering assembly automation as point two in section 4.3). Medium to low volume batch production can now be automated using FMS. So extensive has been the use of

FMS in assembly that they are now called Flexible Assembly Systems (FAS). Unlike Fixed Automation, the justification for capital expenditure is not based on the expected life of one product, since the FAS can assemble variations of product families that are yet to be introduced into production.

Flexible Assembly Systems allows for a family of products to be assembled using the same system. As new product variants are introduced, the nature of FAS is that the system is able to accommodate the assembly of the new product. A host computer controls the system such that real-time assembly scheduling allows the system to cope with machine breakdowns or sudden changes in demand.

1. Components of Flexible Assembly Systems

- The assembly robot: Assembly stations are characterised by the equipment used in the mating and joining tasks. While other equipment can be used, robots are the primary choice because they are easily programmable to suit the various assembly configurations required. The basic types of assembly robots are shown in Figure 4.5.

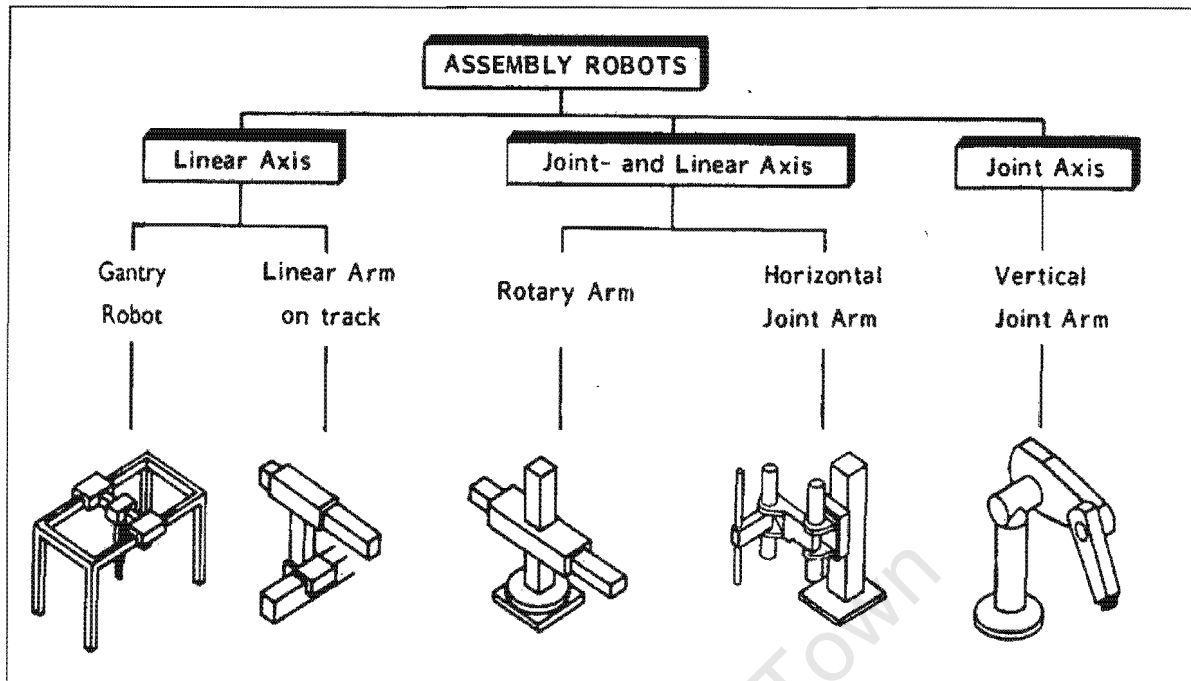


Figure 4.5: Classification of assembly robots.

Source: *Industrial assembly* [1].

- High demands are made on the repetitive accuracy, the process speed the possibility of producing sensor signals and the ease of use of the programming language. The kinematic construction of the assembly robot, in terms of motion, must usually have from four to six degrees of freedom to carry out the various assembly tasks [1]. In particular the need for greater dexterity is driving research into assembly robots. The combination of this and form recognition sensors are used to allow robots to retrieve components from bins, and align them as necessary before assembling the part. This eliminates the need for devising mechanisms to orientate components for assembly.
- The transportation or material transfer device: Conveyors, palletes, bowl feeders etc. are some of the usual transfer devices used in automation. For FAS an increasingly used method of transportation are Automatically Guided Vehicles (AGVs). AGVs load and unload palletes at Flexible Assembly Stations or Cells.

An automatic storage and recovery system for components and final assemblies allows the transportation system to be fully computer controlled.

- The computer controller: Process orders, assembly sequencing and process monitoring are all done by the controlling computer system of the FAS. With large systems, the programming required for such a computer controller can become quite extensive. The complexity of the software involved can constrain the long-term flexibility of the system [6]. In large FAS (50 or more stations or cells) one solution involving the decentralisation of computer control is called the *heterarchical* approach. In this system, the transporting system (e.g. palletes) has a processing unit with memory and a radio. The same is true of the machines that make up the various manufacturing cells. This allows the machines to essentially *bid* for the jobs that depend on the machines workload and configuration. The pallette makes the decision as to which bid to accept. Upton's description of this type of system is from a FMS point of view, but the same system could work for assembly operations involving a large number of assembly stations.

2. Types of Flexible Assembly Systems

The complexity of the assembly system is one way of classifying FAS. Typically Flexible Assembly Stations or Cells are small units comprising or a maximum of four robots. When these cells are incorporated into a larger assembly framework, the result is a Flexible Assembly System. The linking of Flexible Assembly Cells can be either rigid (e.g. a conveyor system that links the cells in a given order) or flexible involving AGVs. The latter method ensure greater flexibility. FAS can be in the form of a Flexible Assembly Line where assembly robots are connected via a linear conveyor system. The advantage of this system is that it has a high ratio of price to efficiency (i.e. easy to develop an efficient system compared to other assembly layouts). This is partially due to the simplicity of the transport system, and the fact that the costs of assembly robots (especially SCARA robots which are typically used in these systems) have reduced over the last few years.

4.4 Assembly employment

4.4.1 Reconciling automation and employment of labour

While automation has its advantages, it has gained a reputation as a job destroyer. Machines can usually accomplish a large number of tasks far more efficiently than humans. A machine can be used to replace a number of human workers in production processes, and especially automation where the tasks are mundane and repetitive. It is important that this aspect of automation is never ignored. Social issues such as this one affect the lives of a lot of people and can damage credibility of an industry, or cripple production with retaliatory strikes and mass action. There are arguments that automation creates jobs in the industry of machinery production, and that keeping a company competitive through automation helps retain jobs for the workers in that company. These arguments however, do not address the issue of retrenched workers. Our local industry is such that labour costs do not demand alternative means of production (as is the case in nations with more established industries). A social responsibility to upgrade the skill levels of the workforce in tandem with the production processes rests with the manufacturer. The reality of the industry is that the workforce becomes more costly as skills increase, in line with technology. The industry is therefore unable to support as many workers as it did previously.

4.4.2 Manual assembly workstations

While automation can be applied to the assembly of a large number of products, there are still some aspects of assembly that are best done manually. These usually involve bulk or limp materials, the visual inspection of the assembly operator (the operator is said to have an *eye* for the task) and a relatively unstructured set of requirements. An example of such a system involves the assembly of fuel injector plungers and the nozzle on a Fuel Systems production line. The close tolerances involved are extreme, but relative, involving a match of injector and nozzle. This takes a skilled operator which makes it difficult to use machines for the operation. Such manual workstations

development focuses on the ergonomics of the station, and the equipment needed to perform the required assembly operations. Such ergonomic considerations include the need for adjustability of the work surface to suit the height of the assembly operator, and to increase comfort and efficiency. The work should also be easily repositioned to accommodate changes in posture that occur in the normal course of work. The assembly stations should also be designed to accommodate use by disabled operators. Factors such as wheelchair access are important in this regard.

Motivating assembly teams is also a priority in ensuring optimal productivity. Creating a working environment that is easily adaptable to suit the assembly operator helps boost motivation. The rigidity and lack of freedom of the paced assembly line work that is typical of assembly work is considered detrimental to productivity in the long run. Alternatives that are being experimented with include job rotation, autonomous cell groups and employee empowerment. All these aim to reduce the level of monotony involved in the assembly work and give the assembly operators the incentive to make decisions about their working environment that would lead to better productivity. They also promote the assembly operator's awareness of their responsibilities to the quality of their products, generating some ownership on the part of the assembly operators.

4.4.3 The Human-Automation Hybrid assembly system

The fear that automation would spell the end of the necessity for human operators in the assembly process has been proven to be unfounded. Today, even in highly automated systems, humans still play critical roles. While the dream of an assembly process without the intervention of humans remains the goal for a lot of researchers, some are embracing the inherent practicality of developing flexible systems that function with both human operators and automated machinery. An example of such a system is shown in Figure 4.6.

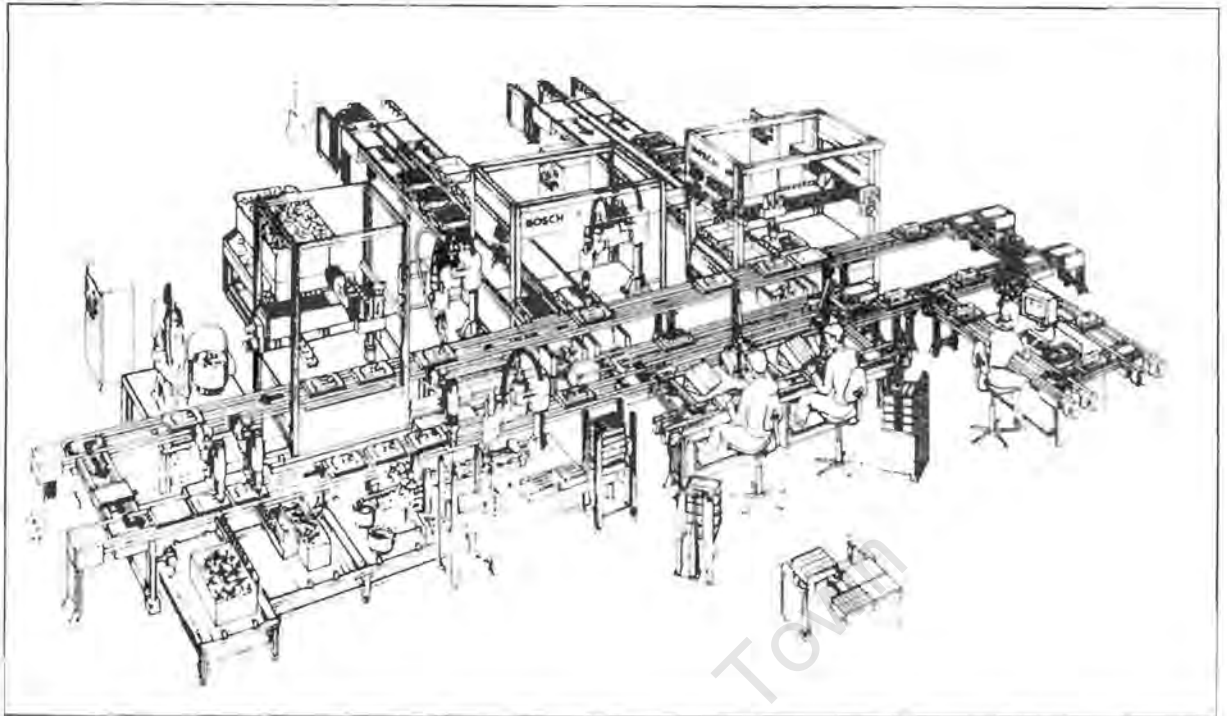


Figure 4.6: An example of a hybrid assembly system. The figure shows assembly operators working on the same line as a number of assembly machines.

Source: *Industrial assembly* [1].

Often this type of system forms the most economical approach to upgrading older assembly systems in need of newer technology to boost efficiency. This ensures that the transitions are easier for the production staff (Operators and Managers alike have misconceptions about the resulting effects of automation that can prove harmful to the production process if unchecked). The fact that the productivity of these systems can prove comparable to that of fully automated systems (see section 4.3.1 above) continues to inspire research in the area.

4.5 Product design

The area of product design is perhaps the area where assembly optimisation has had the largest impact (An illustration of this is shown in Figure 4.7). This is because the

cost of any revisions to the product changes from erasing lines on a CAD drawing during design, to discarding a batch of products and ordering new materials during manufacture or assembly. While the difference for a single product (typically only a couple of seconds) might seem inconsequential at first, when the total production run is considered, the cost difference can become a substantial fraction of the projected profits. As such there is a greater emphasis on developing product designs to ensure easy manufacture and assembly.

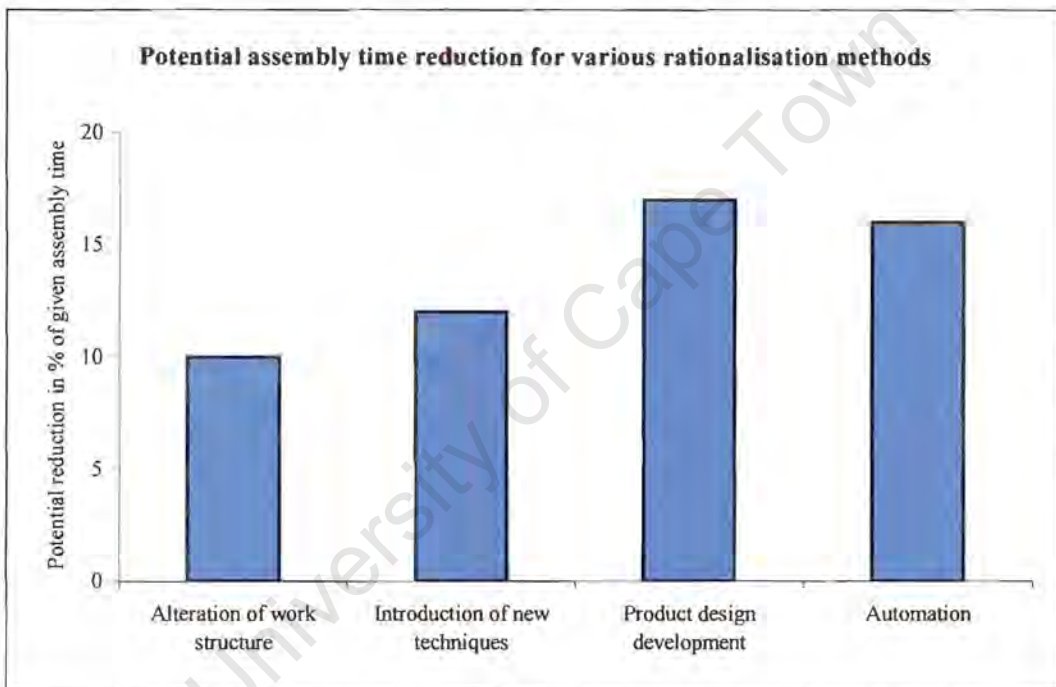


Figure 4.7: Rationalisation impact of various areas influencing assembly.

Data source: *Industrial assembly* [1].

The reason for this is that a large percentage potential for savings is that most of the cost commitment (about 70% thereof) of the product is done at the design stage [3]. The reason this is not intuitively obvious is that the actual cost of the design stage is not an overwhelming total of the overall cost of developing the product (typically in the region of 15%). This is illustrated in Figure 4.8.

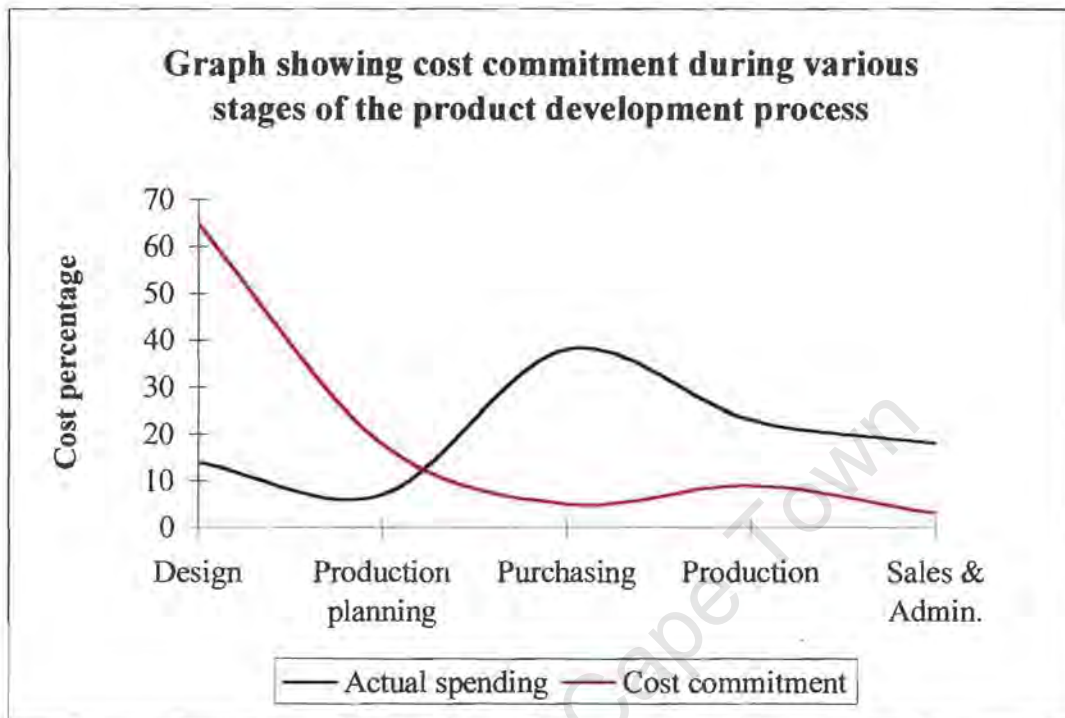


Figure 4.8: Cost impact during various stages of product development.

Source: *Introduction to Design for Manufacturing and Assembly* [12].

Thus, by spending more time on the design of a product to ensure that it is easy to assemble, the cost of the overall development process can be reduced. This is called Design for Assembly (DFA). It has developed from the Design for Manufacture (DFM) principles first developed in 1975 by the Hatachi Corporation in a system they called the Assemblability Evaluation Method (AEM). The term Design for Manufacture was first used for a system developed by Boothroyd and Dewhurst in 1979. This system is arguably the most widely known and used DFM system in industry today. Boothroyd and Dewhurst now call their system Design for Manufacture and Assembly (DFMA). These systems are used to evaluate product Design for Assembly. However, today DFA is used in much broader terms to incorporate all design rationalisation that leads to an easier assembled product. These

include Group Technology (GT), Computer Aided Design (CAD) systems and the addition of Artificial Intelligence (AI) to CAD systems.

4.5.1 Group Technology

Group Technology (GT) is a rationalisation approach based on commonalities among parts and processes. This approach allows industries to save time and money by using common parts in a range of their products, with emphasis on modular components and the development of a family of products. In this sense, by developing Group Technology, industries allow for the development of a Flexible Assembly System to assemble their products, with all the associated quality and productivity advantages.

Group Technology also provides a classification and coding system that proves to be a consistent method for part identification based on both product design and process characteristics. Such classification allow for easy integration of modular components into new products. The resulting standardisation in product design allows for a more focused quality initiative within the industry. An additional benefit is the increase in capacity of the existing production facilities through use of a cellular layout. GT requires good communication between design and manufacturing personnel to be successful. It is an effective in CAD-CAM integration and is a major part of Concurrent Engineering.

4.5.2 Product Design for Assembly

Design for Assembly techniques can be used to analyse the product being designed, or to develop the assembly system being designed, or both simultaneously. The objective of Design for Assembly is to facilitate the development of a product that is easy to assemble. The ease of assembly of a product requires that the product have as few parts as possible, and that the remaining parts have simple features.

- Part reduction: Fewer parts lead to fewer workstations, less time dedicated to assembly and a reduced inventory of parts. Generally fewer parts mean less of everything since nonexistent parts cost nothing to make. Part reduction is therefore highly desirable. A product has a theoretical minimum number of parts, based on its function and the production process. This minimum can be deduced by asking the following questions of each part of the assembly:
 - a) Does this part move relative to its surrounding parts?
 - b) Does it have to be made of a different material from that of surrounding parts?
 - c) Is this part necessary to facilitate the manufacture or assembly of other parts?These are called the motion, material and manufacturing criteria. The part is a candidate for elimination if it does not fulfil any one of the above functions. Parts can be eliminated by combining them with other parts, or by redesigning the product such that the part becomes unnecessary.
- Product simplification: Complex features usually require additional machining. When these features are used to relate product components, the assembly operations involved in the process usually requires more time, machinery and/or manpower. It is thus desirable to simplify the product for assembly using assembly-orientated construction principles. Such principles encourage the design of a modular product. This means that the product is built from standard subassemblies that are common to a range of products. Standardising on common parts, processes and assembly methods across a number of product models permits the use of higher volume production processes, resulting in lower production cost. An optimised design should also have a large base component on which to secure the other parts and provide a frame around which to build the product. The product should be built along a primary axis (usually vertical), stacking components above each other with the aid of gravity. This is particularly crucial where robotic assembly is concern, because complex orienting operations require multiple degrees of freedom, and thus more expensive robots.

1. Facilitating easy assembly operations

These guidelines are meant to make the assembly operations for a product easier. They can be classified in terms of the type of assembly operations they involve. It is important that assembly costs eliminated by the following DFA guidelines are not incurred as machining or other such costs due to the complexity of the resulting product features or process requirements.

- Design for easy insertion: When mating parts are in the form of a hole and a peg, the design should be such that the peg fits in the hole without jamming in the quickest way possible. Investigation has shown that parts designed for a top downward method of insertion (i.e. working with the aid of gravity) are easier to assemble than those that are designed for sideways or down upward method of insertion [7]. The choice of material also plays a role in the ease of insertion. Components involved in insertion operations should be made out of rigid materials, and not floppy, rubbery materials, because the components would require support during insertion, which could waste time.
- Design for easy fastening: The choice of fastener used to secure parts in assembly influences the time taken to assemble the product. Designs should be such that the need for fasteners is minimised. This can be done by incorporating the fastening mechanism into the mating components. A snap-fit is a good example of such a design. Where common mechanical fasteners are necessary, the fastener that requires the least amount of time during assembly should be chosen. Figure 4.9 shows the relative cost of different fasteners.

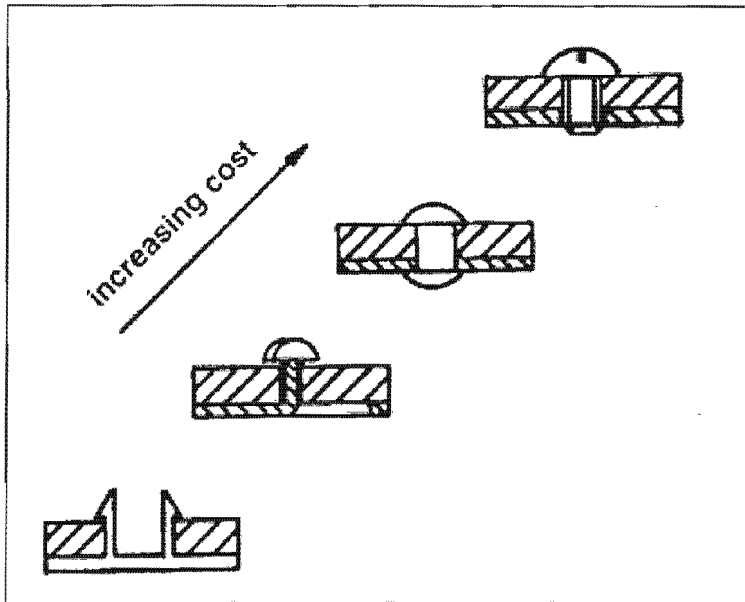


Figure 4.9: Figure showing the relative cost penalties for different types of fasteners, increasing in expense from snap fitting to plastic bending to riveting to screwing.

Source: *Product Design for Manufacture and Assembly* [3].

- Design for easy handling: Part handling includes the pick up, orientation and transportation of parts during the assembly process. These activities can take up as much as 80% of the total assembly time [7]. Parts that are difficult to pick up should be avoided. The Figure 4.10 illustrates a number of part types that are difficult to handle.

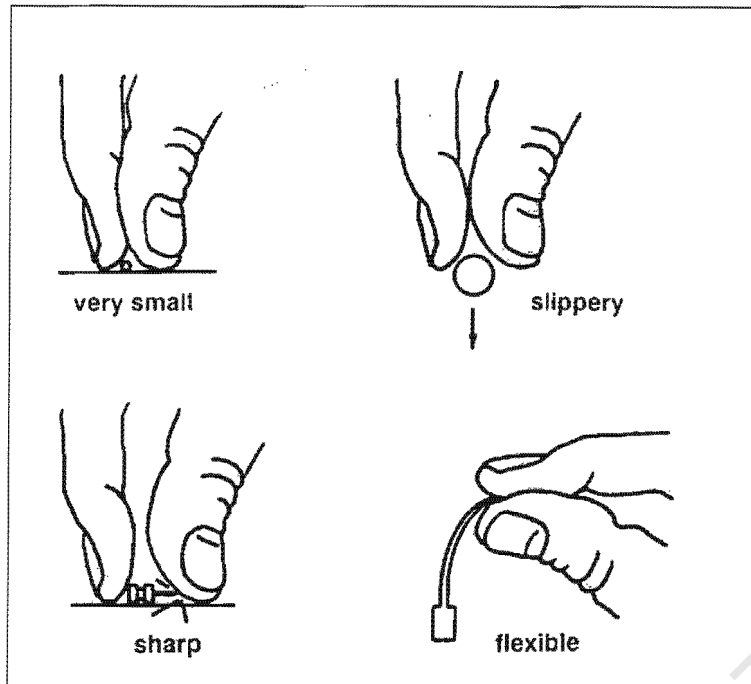


Figure 4.10: Types of handling difficulties.

Source: *Product Design for Manufacture and Assembly* [3].

- In addition, parts that are either very small or very large, or that are hazardous to the handler should be avoided. Symmetrical parts are desirable since they require no orienting operations for assembly. Where symmetry is unachievable, parts should have pronounced asymmetry to ensure correct assembly orientation.

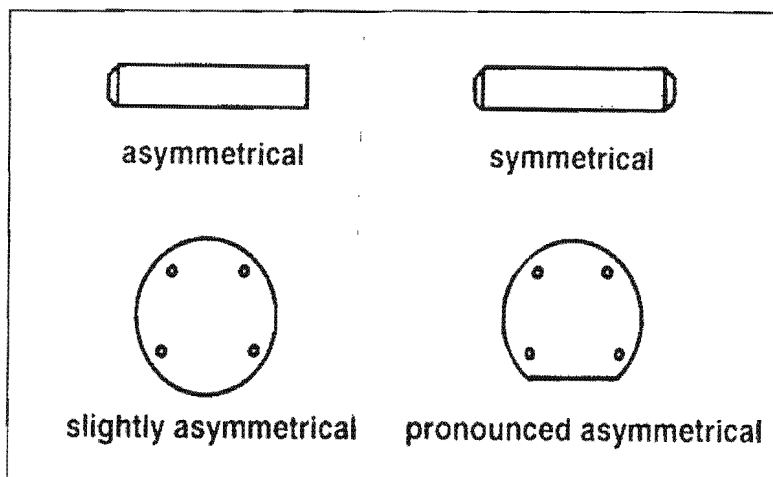


Figure 4.11: Figure showing objects with varying degrees of symmetry.

Source: *Product Design for Manufacture and Assembly* [3].

Large or heavy parts should be avoided where possible, since they require additional transportation infrastructure. Similarly small, delicate parts should also be avoided since they require great care in transporting.

Often assembly practices differ, depending on the assembly method being applied. DFA can be used to facilitate easy manual or automated assembly.

2. DFA: manual assembly

An important factor to consider in manual assembly is motion economy. This is even more important than in automated assembly since human workers are typically slower in the long term. Manual assembly processes should be designed such that the worker uses as few motions as possible in assembling a part. Including two-handed operations to achieve a combination of tasks simultaneously where possible can help make this possible. Parts assembled manually should have clearances to minimise resistance to insertion, and prevent jamming. Designs should be such that parts locate themselves before the worker releases them. Part location is also important to ensure

that an assembly worker is not required to hold a part in place. This unnecessarily uses a hand that could have started another assembly task.

3. DFA: robot/automated assembly

Handling of parts is of critical importance in automated assembly. Careful planning of the assembly process should ensure good motion economy with simple motion paths. This allows the use of simpler automation systems or robots. It is good practices to avoid sensors where possible. When applicable, use simple contact sensors rather than the more expensive vision systems. When robot or automation features such as sensors or additional motion axes are justifiably necessary, ensure that they are used optimally. Often some other tasks can be improved using these additional abilities. In automobile engines, for example, a sensor is used to determine the speed at the flywheel. This is necessary to give a speedometer reading, however the sensor can also be used to monitor speed for traction control.

4. Design efficiency using DFA

A design team is usually faced with a choice of product designs, from which to choose the best design. But what makes one design better than another? Usually the issue is even more complex because one design would have a different advantage, from a production standpoint than another. An assembly design might be easier to handle, but require more fasteners than another. The only method of distinguishing the two designs is by quantifying the design with a comparable rating system. Most Design for Assembly methodologies can give a quantitative measure of the time and costs required to assemble a product. The advantage of this is that design teams have a real measure of the extent to which they are improving their design during the iterative process of product development. They can also use this rating to compare their product to others in the industry. This can help to highlight the strengths and weaknesses of their designs, relative to that of the competition. Typically different DFA systems use different evaluation methods, however they are very similar. The

section below shall briefly outline the basics of design efficiency as applied in DFMA.

5. Concepts in Design Efficiency

DFMA breaks down the time taken to join a component to an assembly into the handling time, and the insertion time required for that component. The difficulty associated with the assembly of any component has to do with the ease of handling and insertion for a component. This document has already dealt with these in point 1 of section 4.5.2 above. DFMA proposes that the dimension and symmetry features of a part play the greatest role in determining the ease of assembly. These are defined in the following manner:

- Part dimensions: Every part can be enclosed totally by the co-ordinates of its largest dimension along all relevant axes. This is called the part envelope. Typically Cartesian or Cylindrical co-ordinate systems are used to describe objects. Therefore part envelopes are either rectangular or cylindrical in nature. The longest side of a part envelope is called the size of the part, and the shortest side of the part envelope is called the thickness of the part. The effect of part thickness and size on assembly time is shown in Figures 4.12 and 4.13.

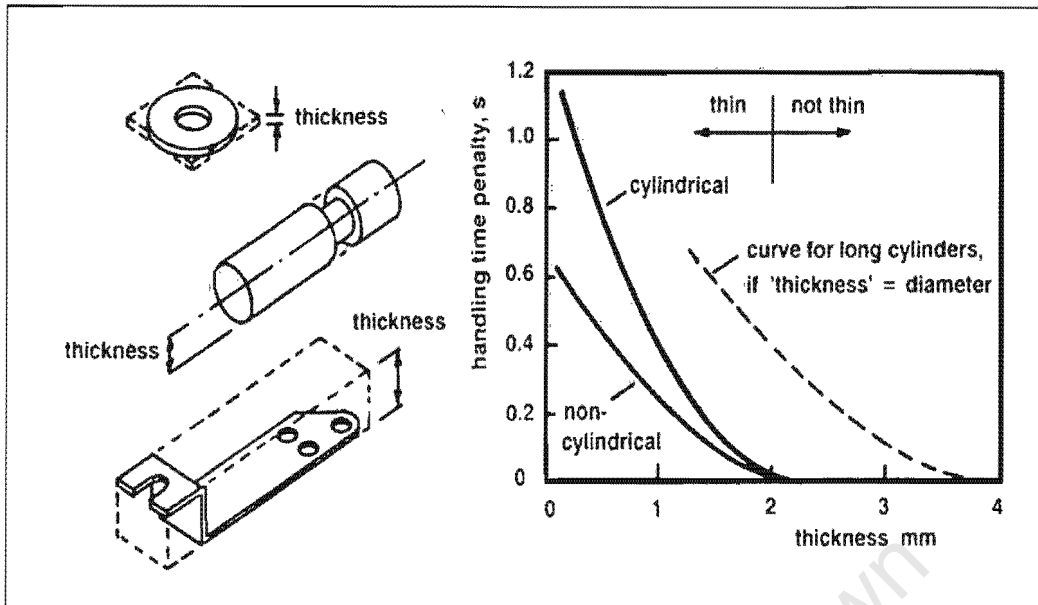


Figure 4.12: The effect of thickness on assembly time.

Source: *Product Design for Manufacture and Assembly* [3].

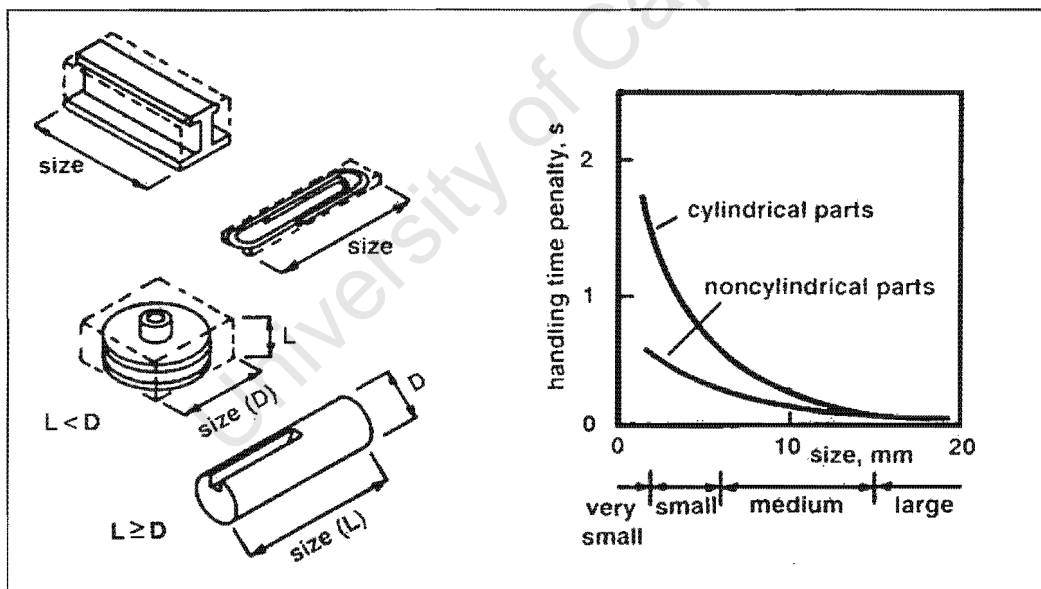


Figure 4.13: The effect of size on assembly time.

Source: *Product Design for Manufacture and Assembly* [3].

- Part symmetry:** Symmetry is described in reference to axes of rotation. The central axis of a part is defined by the axis of insertion during assembly. A part can display symmetry when rotated on an axes perpendicular to its axis of insertion. This is called alpha symmetry. Symmetry around an axis parallel to its axis of insertion is called beta symmetry. The angle through which a part must be rotated in order to insert into an assembly is its degree of symmetry. A part shaped like a drawing pin for example has 360° alpha symmetry and 0° beta symmetry. Some examples are shown below.

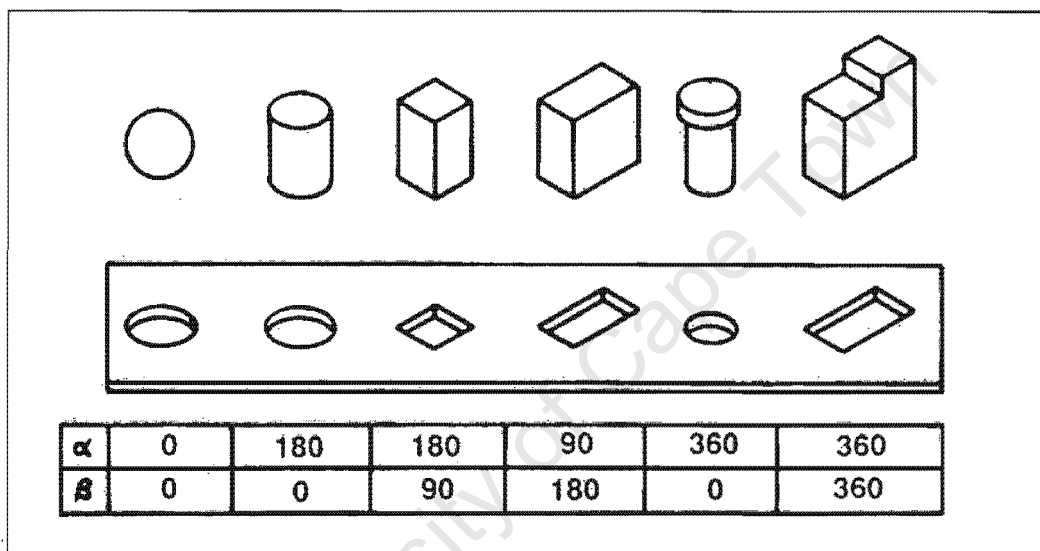


Figure 4.14: Some examples of parts and their α and β symmetry.

Source: *Product Design for Manufacture and Assembly* [3].

6. The evaluation method

The method of evaluating the efficiency of the product design differs for different DFA systems. Most are based on an index or database of assembly and product information, which a real product is compared to using specially formulated tables. The result is therefore a relative term, based on information gathered about a number of assembly characteristics that tries to represent all the possibilities available, while being specific enough to allow for the discerning of individual product

characteristics. A simple example of this is the AEM, which is used to determine the difficulty of an assembly process by means of a 100-point index. The evaluation indices are then correlated to an assembly cost. This enables designers to make reasonable cost estimations at the initial design stages. Unacceptably high assembly costs lead to the rethinking of the assembly strategy. By iteratively applying AEM, designers can improve the design. The AEM method is shown in Figure 4.15.

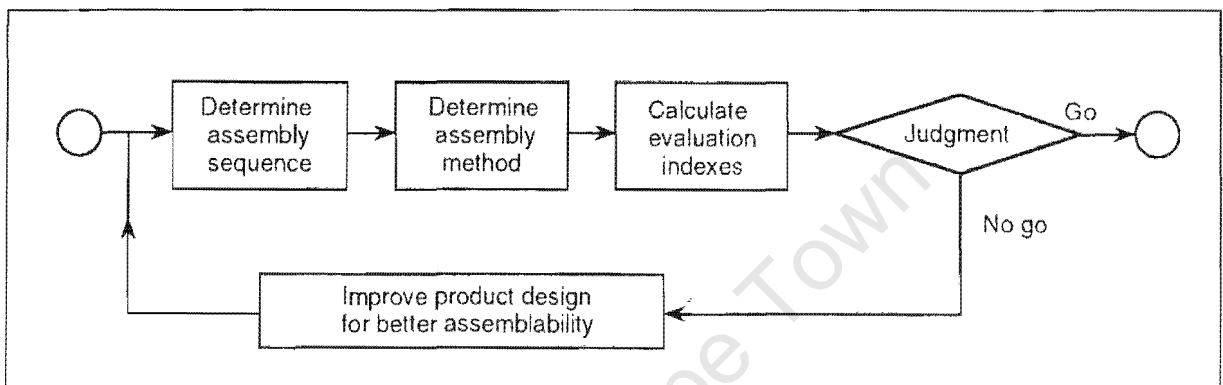


Figure 4.15: An algorithmic description of the Hitachi AEM Design for Assembly method.

Source: *Introduction to Design for Manufacturing and Assembly* [12].

The Boothroyd and Dewhurst DFMA system that shall be used in this project evaluates using databases of assembly operations (mainly part handling and insertion) based on time study experiments done in the late '70's and early 80's. The tests are concerned basically with the determination of an ideal which other products are measured against. For manual assembly processes, this ideal is based on the time it takes to assemble each component. Therefore the design efficiency is given by the

formula $E_{ma} = \frac{N_{min} t_a}{t_{ma}}$ where E_{ma} is the design efficiency; N_{min} is the theoretical

minimum number of parts; t_a is the basic assembly time for one part (In an ideal product this is 3 seconds) and t_{ma} is the actual assembly time taken for the particular product being evaluated according to the DFMA chart. For automated processes more emphasis is based on the cost of the assembly operations since this is more crucial

here than for manual processes. Therefore Boothroyd and Dewhurst evaluate the different assembly methods are evaluated differently, using separate databases and formula. However the databases have been developed such that the results are comparable. A full description of the different processes is given in Appendix B. When applied correctly, the results can point a designer towards the most cost effective assembly method and an effective design to take advantage of this method.

It is important to understand the meaning of the numerical results of the Design for Assembly evaluation. This is because the results must be put into context for them to satisfy any real objectives. The question is whether there is a design pass or fail percentage that results from the evaluation. For instance is a design that gets a rating of 45% considered to be a 'bad' design, while one with a rating of 55% is 'good'? Can every product be designed so as to get ratings about 50% or 80%? Unfortunately the answers are not simple. The reason is that different products have different design criteria, and are therefore subject to different factors that affect the DFA rating of that product. For instance, it might be possible to produce portable CD players with a DFA rating of up to 65%, while it may only be possible to develop automobile gearbox assemblies with ratings around 45%. This means that a well-designed gearbox assembly will score lower than an equally well-designed CD player. Each product has its own *acceptable range*, and is therefore only really comparable to a similar product. A more important distinction to make is that the importance of the numerical results of the evaluation, is that it provides a figure to be bettered by the development engineers. Any modifications can be tested, and considered positive improvements, provided that the result of a secondary DFA evaluation yields a higher score than the original one. If an initial design had a rating of 30% before modifications, and a rating of 41% after modifications, the design engineers can discern that the modifications made to the product have made it easier to assemble.

It is a good idea to bear in mind at this point that while DFMA has great value in aiding the design process, the method does have a number of drawbacks. One of these

is that the use of databases limits its scope and flexibility. Such limitations include the failure to take into account characteristics from the assembly structure level such as subassemblies. Instead DFA focuses solely on the assembly operations level.

7. Concurrent Engineering and Design for Assembly

Design for Assembly is an engineering tool that can be used to develop a Concurrent Engineering framework in the manufacturing industry (as explained before).

Concurrent Engineering is an approach to product development that allows the breakdown of information barriers to maximise the use of the expertise of the design team in producing the best product possible. Concurrent Engineering is a system that uses engineering tools to improve product quality. It requires a new mental attitude to production; A shared responsibility for the development of a product and the quality of production.

It is often difficult to classify what is a successfully developed and implemented Concurrent Engineering framework. The steps towards developing a Concurrent Engineering production system are not laid down in any rulebook. Many companies are often frustrated by failed attempts at implementing Concurrent Engineering. Often the problem is a resistance to change to an unproven system. This should not come as a surprise according to Gary S. Vasilash since "...[The] industry has been 'enculturated' to work separately and sequentially." He says the effect is that "the mindsets [of design and manufacturing engineers] are different." [8]. Implementing Concurrent Engineering by starting with DFA helps ease the transition process and illustrates the merits of the system. This is because Design for Assembly is concerned with the beginning phase of product development. It is thus easy to determine its effect on the products without having to consider any previous production method. It also provides the foundation for the integrative product development approach that is the cornerstone of the Concurrent Engineering framework. The results of DFA also speak for themselves. The level of improvements typically associated with the implementation of DFA is an unambiguous indicator of the impact Concurrent

Engineering can have on production. This is enough to boost enthusiasm for Concurrent Engineering. An essential feature of Concurrent Engineering is that when it is supported by management, and the production team, its implementation is more likely to lead to more efficient production.

4.5.3 Computer Aided Design Systems and Artificial Intelligence

The integration of DFA methods into CAD/CAM software is one of the focal areas of research today. While there are computer systems to facilitate DFA (Boothroyd and Dewhurst DFMA has a DFA software component), they are not CAD programmes. CAD programmes face practical difficulties associated with the integration of DFA. These include the limited accuracy of CAD systems in modelling robot assembly systems. The development of a user friendly, more effective programme that can act as a geometric modeller and an assembly task simulator is the kind of software that is required. Some commercial CAD programmes that include a DFA function are available (e.g. ICAD®).

Artificial intelligence techniques adds decision support capabilities to CAD software. This can help advise designers on possible product modifications. The advantages of AI are that it allows the designer to have less extensive training in DFA; and reduces the chance of error and increases design quality. Techniques for introducing AI include rule-based knowledge systems, fuzzy logic, neural networks knowledge systems and feature-based assembly design.

5 CASE STUDY: THE EFFECTS OF MODERN ASSEMBLY THEORY ON PRODUCT DESIGN

The influence of some modern assembly theory is such that the effects have been felt throughout the production industry. Design for Manufacture and Design for Assembly are changing the way many companies develop products, and can account for significant savings for production companies. The strengths of DFMA are such that when older product designs, which were considered to be efficient at the time, are analysed, the method is still able to suggest significant improvements. An example of this is sited in the redesign of a General Electric (GE) self cleaning oven door, which “Everyone thought [it] ... was a marvellous work of art ... [only to discover] ... that it was a turkey [i.e. clumsy design].” according to Paul Misegades, then Manager of equipment services engineering and advanced services [8].

In an attempt to qualify exactly what improvements are gained using modern assembly processes, the Design for Assembly theory was applied to the redesign of the compression head valve and its assembly process. It is important to note here that the results of this process represent the abilities of the technological processes currently available, and have no social or economic basis (These social factors have little scientific theory, and as such the scope for defining them is beyond the requirements of this project). There is also no evidence supporting the need for the implementation of such technologies from a customer demand point of view. There is also no intent by Gabriel S.A. or the University of Cape Town to develop this exercise any further than is done in this project.

The task here is to develop a comparative product in light of modern technologies. The diagram below shows the areas of the product development process, which will be focused on, and the techniques used.

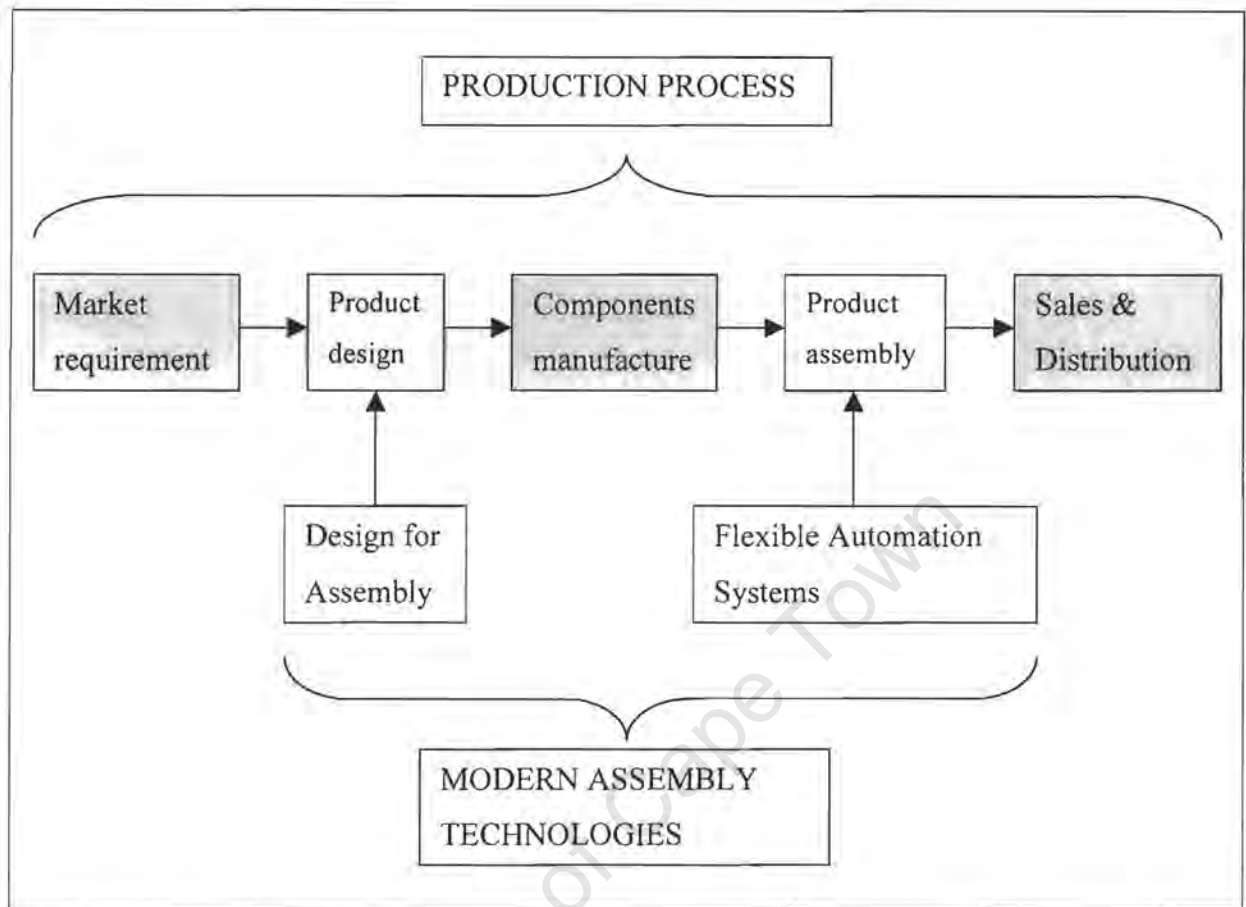


Figure 5.1: Figure showing the areas of focus in the redesign of the compression head valve.

Design for Assembly makes assembly one of the initial criteria of the design process (apart from the usual form and function criteria). This exercise uses DFA to develop a product that can be assembled using Flexible Automation Technology. Flexible Automation allows for the introduction of new product designs or variations, and enables efficient assembly through real-time computer monitoring. The compression head valve lends itself well to automated assembly. Although the current design does not have a base component, the product can easily be designed to include one, as well as a top-down assembly process. The system of using disc variation to change the characteristics of the valve is a method of modular production that is in keeping with the ideals of Group Technology. It is possible to restructure the compression head

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valve assembly area to allow for a Flexible Assembly Cell. A typical layout of such a cell is shown in the figure below. This would of course have to be part of a factory-wide automation drive.

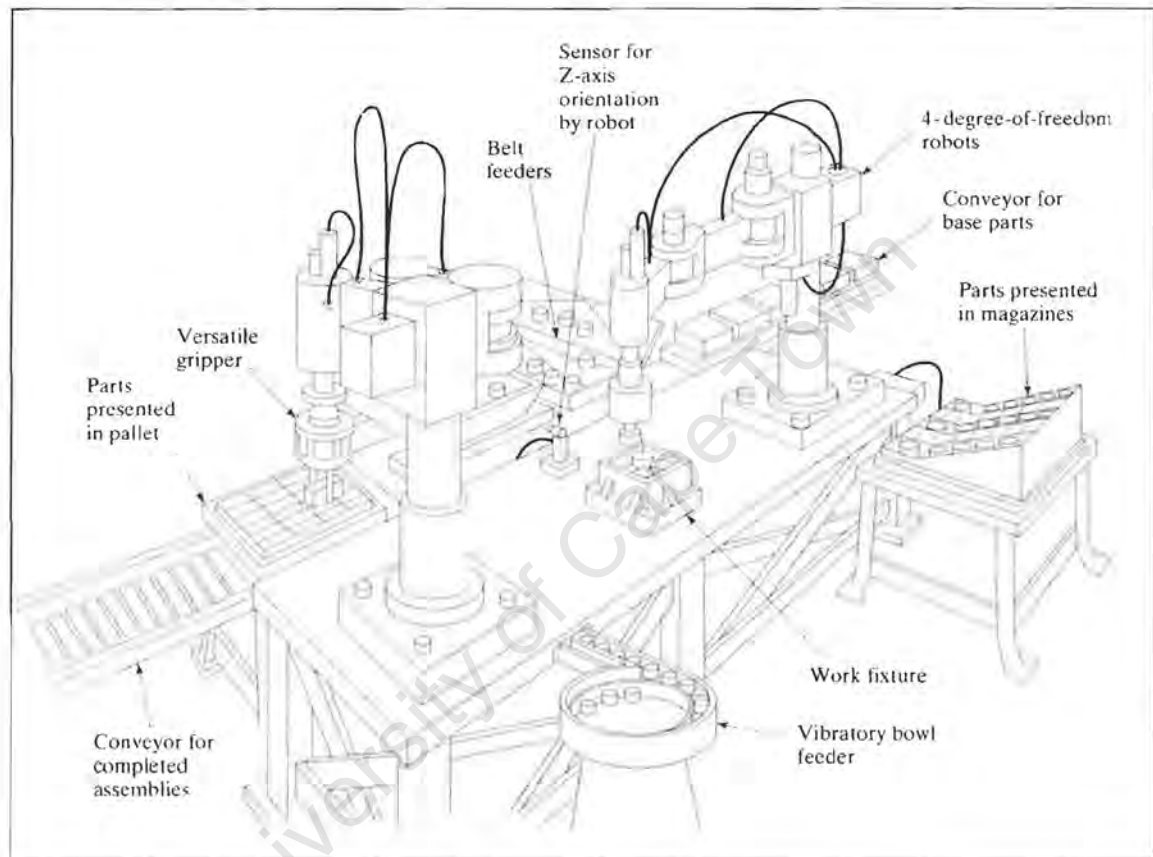


Figure 5.2: A typical layout of a FAC.

Source: *Manufacturing engineering and technology* [21].

5.1 Evaluating the current compression head valve design

The DFA design evaluation provides a good method of assessing the efficiency of an ongoing product design. It also gives a numerical method of comparing two similar products. For this reason it provides a good starting point for this exercise. The current compression head valve design shall be evaluated using the Boothroyd and

Dewhurst Design for Manual Assembly technique. The result is shown in the table below. An explanation of the process used to generate the data in the columns is presented in Appendix B.

DESIGN FOR MANUAL ASSEMBLY WORKSHEET									
1	2	3	4	5	6	7	8	9	Name of Assembly
Part ID No.	# times operation performed 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) x [(4)+(6)]	Operation cost, relative 1.0 x (7)	Figures for estimation of theoretical minimum parts	Compression head valve assembly
10	1	11	1.8	00	1.5	3.3	3.0	0	Retainer
9	1	83	5.6	00	1.5	7.1	7.1	1	Spring
8	1	09	2.98	08	6.5	9.48	9.48	1	Replenishing valve
7	1	09	2.98	08	6.5	9.48	9.48	0	Restriction disc
6	1	10	1.5	06	5.5	7.0	7.0	1	Compression head
5	1	09	2.98	00	1.5	4.48	4.48	1	Orifice disc
4	6*	09	2.98	00	1.5	26.88	26.88	1	Compression disc
3	1	10	1.5	00	1.5	3.0	3.0	0	Rivet
2	1	-	-	91	7.0	7.0	7.0	0	Riveting process
						77.72	77.72	5	DE = 19.3%
						TM	CM	NM	= (3 X NM)/TM

Figure 5.3: DFA evaluation for manual assembly on compression head valve design.

*Maximum number possible.

The evaluation of the present compression head valve gives a design efficiency (DE) rating of 19.3%. Here NM is the theoretical minimum number of parts; TM and CM represent the actual assembly time taken and the cost equivalent. The assembly of the

compression head valve is faster (and therefore more efficiently) when one compression valve is required. For this scenario, the efficiency increases to 27.1%. The low efficiency is mainly as a result of the handling difficulties the assembly operators experience during the assembly process. Other problems that contributed to the assembly inefficiency are discussed in the next section.

It is important to note, when judging a component on the basis of its efficiency rating, that an efficiency rating is not a test that a product can score 100% on. Instead it is a quantifiable benchmark for making improvements (This was detailed previously in section 4.5.2). The value of the rating is that it gives a number that the redesigned compression head valve can be measured against.

5.2 Analysing the DFA evaluation results

Often the results of a DFA evaluation, when analysed correctly, can point to the weaknesses in the design of a product. The value of this is that by highlighting these areas, the designer can work towards a goal in any further redesigns.

5.2.1 Redundant parts

DFA is particularly focused on eliminating parts. When the three criteria for doing so (see section 4.5.2) are applied to the compression head valve three parts are eliminated (parts with '0' in column 9 of the table above).

The fasteners (rivet and retainer) involved in any assembly process are always candidates for elimination. The most efficient manner of fastening components from an assembly point of view is to build the function into other components.

The restriction and orifice disc have very valuable functions in ensuring the proper valving characteristics of the compression head valve. However there is nothing preventing these components from being integrated into other components of the compression head valve. The compression head itself offers a restriction to flow, in the same way the restriction disc does, but without the required variety. If a greater

variety were added to the compression head's restriction capabilities, it would negate the need for a separate restriction disc.

The analysis suggests that five parts are the theoretical minimum possible.

5.2.2 Component handling difficulties

The reason this project was devised was because the people at Gabriel S.A. noticed a problem associated with the handling of parts. In the analysis this is also plainly obvious, as five out of eight components have associated handling difficulties (an '8' in column 3 of the table above denotes a handling problem). Designing these difficulties out of the product would go a long way towards improving assembly efficiency.

5.2.3 Component location problems

When a component is not located properly, care has to be taken to ensure that it is properly oriented and positioned. This costs time and is thus undesirable. The design of the compression head valve is such that the location of the replenishing valve and the restriction disc on the spring is not secure.

5.3 Developing a new compression head valve

A summary of the problems associated with the compression head valve is that there are too many components, most components are difficult to handle and improperly located. Because the decision to develop a robotic assembly system has been taken, the issue of locating parts is very important. As such the new compression head valve design must have a base component onto which all other components locate. A top-down assembly process is also crucial. The use of automation eliminates a large proportion of the handling difficulties. However springs are still notoriously difficult to handle using automation.

The operating characteristics of the compression head valve make the issue of a base component the most difficult one. Because fluid has to flow both from inner tube to outer tube and from the outer tube to the inner tube of the shock absorber it makes more sense from a functional point of view, to have a large component in the middle of the compression head valve with discs on either side of it. The need for a base component means a system similar to the one shown in Figure 5.4 below must be developed.

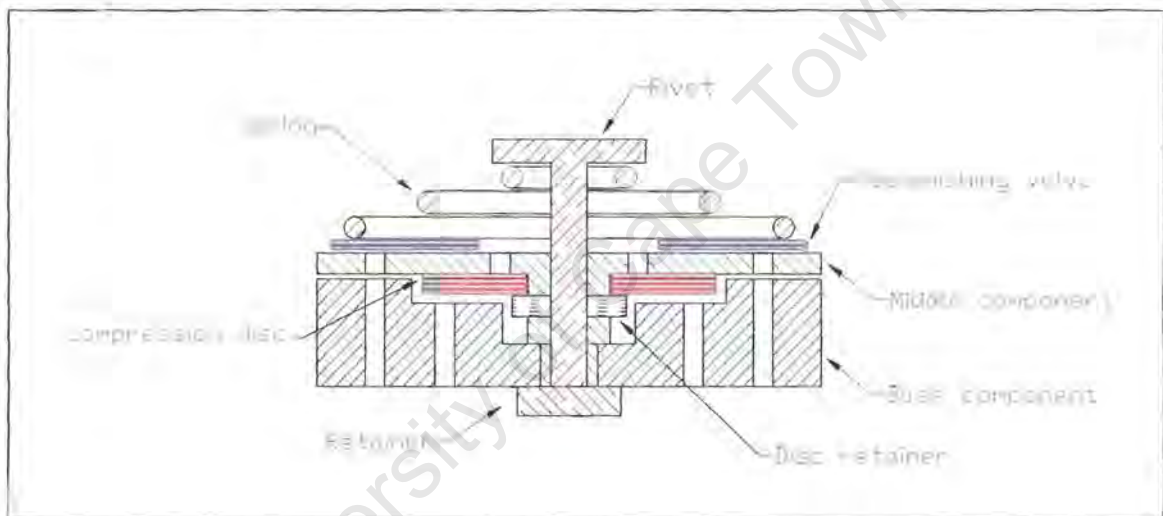


Figure 5.4: A possible redesign of the compression head valve that includes a base component.

The problem with this is that it contradicts the goal of minimizing parts. In fact such a configuration adds an extra part to the compression head valve. It also does nothing to solve the problem associated with handling springs.

By analysing the workings of the disc valves it was determined that if this method of valving is used to check the flow of shock absorber fluid in both directions, then the configuration of compression head valve must include a large component with discs on either side of it. This points to the need to replace the disc valve operation in one

of the flow directions with another valve mechanism. Recall that the disc valve mechanism works on a cantilever system. Another type of disc system is also currently in use at Gabriel S.A. The valve is comprised of a disc on a seat. The fluid pressure pushes the valve off the seat, allowing flow from one cylinder to the other. This is illustrated in the figure below.

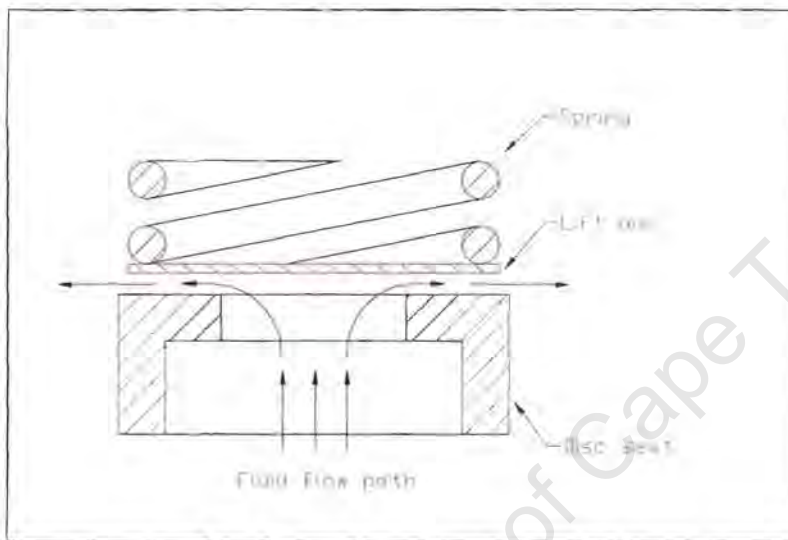


Figure 5.5: Basic operation of lift disc valve. Fluid forces the spring upward against the spring resistance.

The lift disc still requires a seat. The valving system being developed is such that it might require components between the seat and the disc. One way of doing this is by making the disc thicker, with an inclined circumference on which it is seated. This is illustrated in the figure below.

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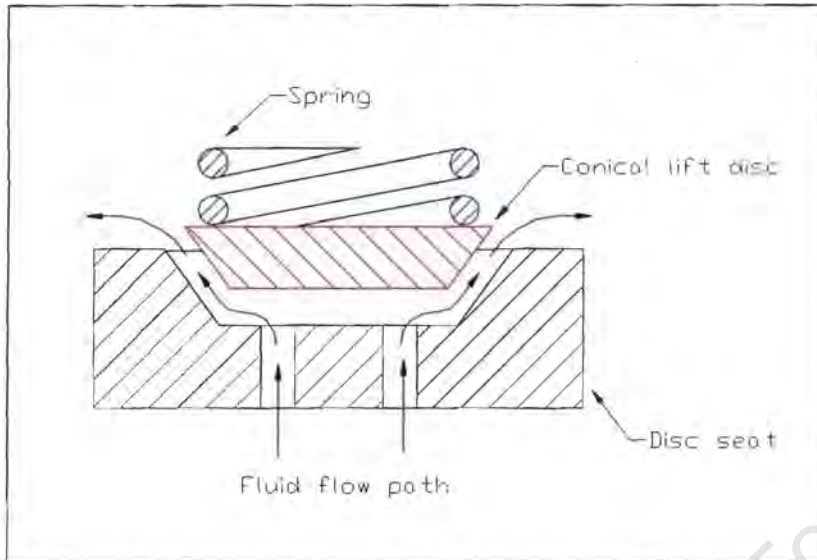


Figure 5.6: The conical disc means that only circumferential contact with the disc seat is required.

By putting these ideas together a new compression head valve was designed. Figure 5.7 illustrates the new configuration.

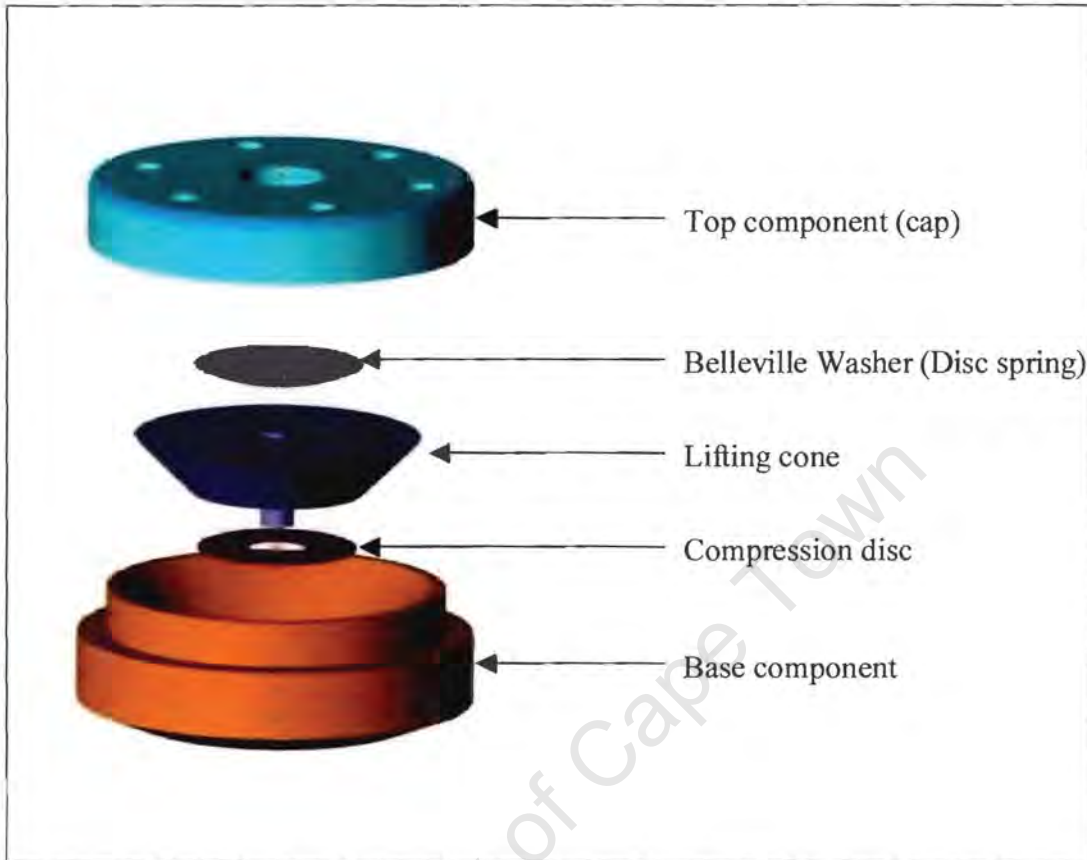
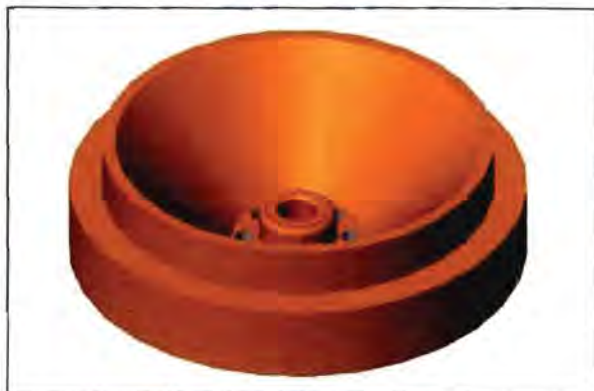


Figure 5.7: Exploded view of the redesigned compression head valve design.

5.4 New compression head valve parts and their functions

- The base component: It is press fitted to the top component to fasten the valve components together. The base has locating features for the discs and the lifting cone. The lifting cone has a lower extension that fits into a central hole in the base



component. The compression discs are located on a shoulder on the base

component, similar to the shoulder on which the compression discs sit on the present compression head valve. The sides of the base are conical to provide a seat for the cone component. The outer dimensions of the base component are identical to that of the present compression head valve, ensuring that the redesigned compression head valve would fit in the shock absorber without need for modifications of any other parts. Eight circumferential holes in the bottom of the component allow shock absorber fluid to flow through from one cylinder to another.

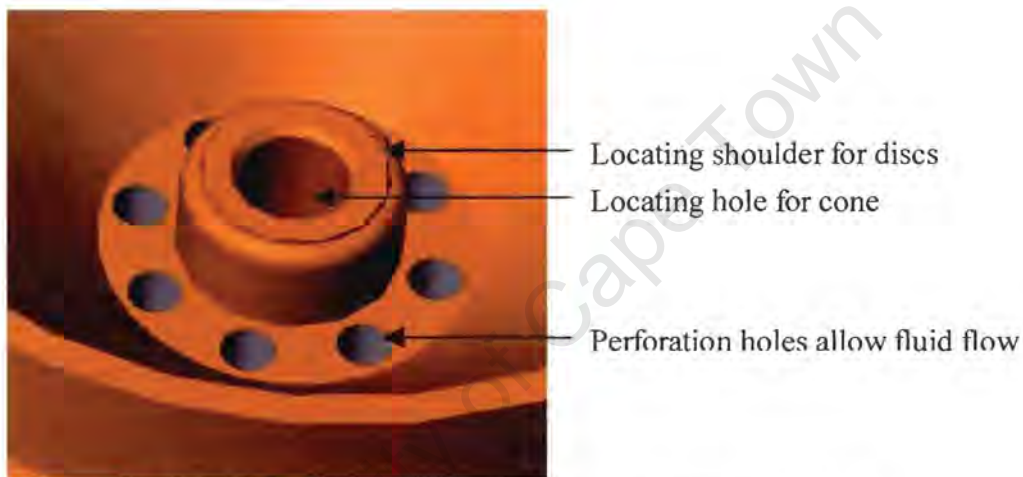


Figure 5.8: Figure showing some important features of the base component.

- The compression disc: This component has been retained in the new design, because the knowledge of its valving characteristics gives a higher degree of confidence in the new design, without the need for extensive testing. The compression discs function as it did in the original design. However the discs in this design would not be metallic, but made out of a plastic or polymer material. The use of metal in the present design is for cost reasons and does not serve any functional purpose since the discs function depend solely on stiffness and durability. Substituting a low cost polymer (with the appropriate stiffness and



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durability properties) eliminates the tendency of discs to adhere to one another, or to magnetise. It also allows greater variation in the stiffness properties of the disc. Since there is more variation, there is less need for the extensive stacking of discs, as in the previous design. This design would allow for a maximum of two discs (if unavoidable) in an assembly.

- The lifting cone: The cone replaces the function of the replenishing valve. When fluid flows from the outer to the inner cylinder, it pushes the cone up against the disc spring. This creates a small gap between the



cone and the walls of the base component, thus metering the flow of fluid. The cone angle is 45° . This allows for sufficient contact to ensure a good seat, but is greater than the angle (between 10° and 30°) that would result in the locking together of the cone and the base component (this angle is commonly used in cutting tools). When fluid is flowing in the opposite direction, the cone is pressed against its seat, allowing no flow through that path. Instead the fluid flows through circumferential holes in the cone, and exerts a pressure on the surface of the compression disc below. The cone has a locating feature for the disc spring.

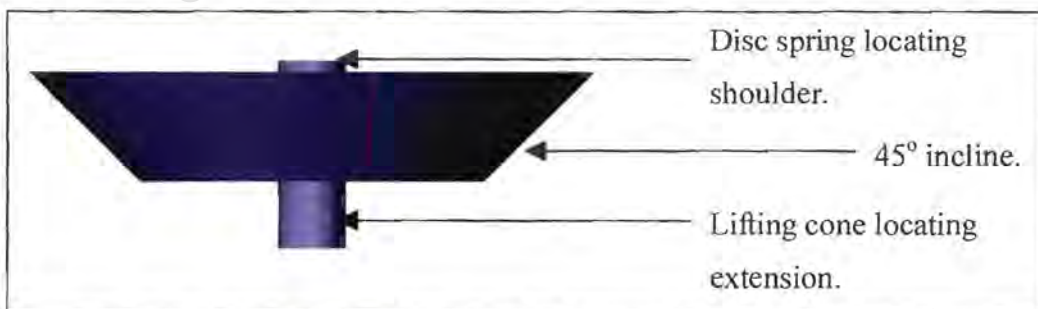


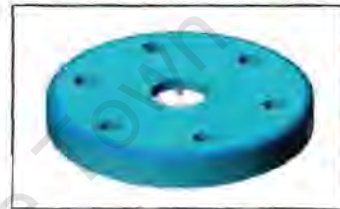
Figure 5.9: Figure showing some important features of the lifting cone.

- The disc spring: Replaces the function of an ordinary spring in the present compression head valve. It is pre-loaded by the press fit of the top



and bottom components to ensure that the components stay in contact. The disc spring also provides the resistance to the motion of the lifting cone. The extent of this resistance is based on the desired valving characteristics. The variation in resistance of the disc spring can be developed using a variety in thickness.

- The top component: Forms the fastening component, together with the base component. A number of compression head valves exist in production that relies on press fits. If necessary snap features can be added to the base and top



parts (e.g. a groove in the base and a lip on the top component) to ensure mating. The holes in the top component allow for the free flow of fluid in both directions.

5.5 Evaluating the new compression head valve design

The redesigned compression head valve was evaluated using the Boothroyd and Dewhurst Design for Automatic and Robot Assembly technique. The result is shown in the table below. An explanation of the process used to generate the data in the columns is presented in Appendix B.

DESIGN FOR ROBOT ASSEMBLY WORKSHEET									
1	2	3	4	5	6	7	8	9	Name of Assembly
Part ID No.	# times operation performed consecutively	Robot insertion code	Relative robot cost, A_r	Additional relative cost, A_g	System operation time, T_p	Time penalty for gripper or tool change, T_g	Total system time (2)x[(6)+(7)]	Figures for estimation of theoretical minimum parts	Compression head valve assembly
6	1	00	1	0	2	0	2	1	Compression base
5	2	20	1	0.05	2	4	12	1	Compression disc
4	1	00	1	0	2	0	2	1	Seated valve
3	1	00	1	0	2	0	2	1	Disc spring
2	1	00	1	0	2	0	2	1	Compression head
			1	0.05			20	5	200,000
			A_{rmax}	A_g			T_a	NM	Total batch size, T_b

Figure 5.10: DFA evaluation for robot assembly on redesigned compression head valve design.

The total relative assembly cost is given by $C_t = [C_a A_r C_r T_a + (C_a A_g + D_f)] 10^5 / T_b$

while the theoretical relative minimum cost is given by

$$C_t = (2C_a C_r NM + D_f) 10^5 / T_b$$

Where C_a = Cost of standard assembly robot with two arms, each having 4 degrees of freedom.

C_r = Cost of using non-dedicated equipment of unit value.

D_f = Total cost of parts magazines and work fixtures used with the assembly system.

Because this is a relative comparison, the values of C_a and C_r can be seen in relative terms as unimportant. The typical values used here are 150 and 0.003 respectively. D_f

is related to the number of parts in the system. Here for C_t a D_f of 5 shall be used, and for C_i a D_f of 4 shall be used, to indicate the potential for a better system ideally.

Therefore $C_t = 10.75$ and $C_i = 4.25$. Hence the Design Efficiency (DE) = 39.5%. For only one compression disc the efficiency climbs to 45.2%. The improvement amounts to just under twice the efficiency of the current system.

The weaknesses in the redesign are also easy to spot. The choice to stay with discs as the valving system costs dearly. However the intention here is to develop a feasible product design. As such, straying too far from the current system presents too many unanswered questions, which would be impossible to engage without practical prototyping and testing. By staying with disc valves (despite their penalties) a higher design of confidence is gained in the feasibility of the new design.

6 CASE STUDY: IMPROVING EXISTING SYSTEMS USING MODERN METHODS

One of the aims of this project is to solve some of the assembly problems that are hampering the production process at Gabriel S.A. The nature of the production requirements at Gabriel S.A. is such that this has to be done with minimal disruption to the production of compression head valves. This means two things; any modifications cannot interfere with the continuing production of compression head valves, and the planned modifications should be implemented without the need for extensive set-up durations or orientation of the existing workforce. The reason for this is that production volume is crucial to the operation at Gabriel S.A. and cannot be put in jeopardy. As such the only solutions that are acceptable in this context are those that are relatively risk free in terms of their effect on the continual production of compression head valves, and is cost effective. A solution such as the one proposed in the previous chapter requires a complete change of the compression head valve and thus the manner in which it is assembled. While this is demonstrably more effective in the long run, it does require a great deal of set-up time. In addition, considerable research has to be done to understand the valving characteristics of the new design. A marketing drive would also be required to ensure customer confidence in the new product. This amounts to a considerable investment, which is not quite justified when considering that the nature of the production difficulties is not critical. Instead, what is required is an assessment of the compression head valve and its assembly process in order to determine the source of the problems. Often it is possible to find solutions that require little invested resources, yet yield significant improvements. Such a solution is ideal in this case.

6.1 Assessing the compression head valve assembly

A systematic way of addressing the difficulties associated with the compression head valve assembly is to divide these difficulties into those that are design related and those that are assembly related (as done in section 2.4). For convenience, the difficulties are summarised below:

- The design related difficulties: Some parts of the compression head valve are designed such that they are difficult to handle.
- The assembly related difficulties: The machine utilisation (and hence productivity) of the assembly process is not optimal.

The method proposed in Chapter 5 dealt with the difficulties generated by the design of the part. The argument for this (and the underlining premise of DFA) is that if the part was designed 'correctly' the set of difficulties associated with the assembly of the part would fall away. While this has been adequately demonstrated, the investment associated with it makes the solution impractical for the set of difficulties experienced at Gabriel S.A. Indeed, any attempt to change the design of the compression head valve would require extensive research into the effects of these changes. This would have an associated cost in terms of time and money. Therefore it is more practical to deal with difficulties related to the assembly of the component.

The productivity of the current assembly method is low. Productivity is usually an issue in manual processes. Often automation is used to increase the productivity of a process. Relieving an assembly operator of some of the operator's tasks is one way in which automation can be used to increase productivity. Fully automating the compression head valve assembly process is not a practical solution. One reason is that the product has not been designed for this process, and therefore some product modifications (however slight) are required to make automation cost effective. The cost and the set-up time required also make the investment in a fully automated compression head valve assembly unit more than Gabriel S.A. is willing to make.

However it is possible to automate only certain areas of the assembly process. A partially automated assembly workstation can be designed to improve the productivity of the compression head valve assembly.

6.2 Selecting areas for partial automation

A partial automation system begs the question as to what areas of the assembly cell would be automated. The answer lies in the aim of the proposed solution. Here, the aim is to realise as significant an improvement as possible while committing as few resources as possible. Therefore it is required that a minimal degree of automation results in the elimination of most of the current assembly difficulties. Analysis of the process has shown that the area of concern involves the compression head valve subassembly. One solution is to remove the subassembly. However, this is not the most convenient of solutions, and does not result in an assembly process that is easier than before. A better solution results from automating the subassembly part of the compression head valve assembly. The reason for this is that this relatively simple change solves a number of difficulties at once. Firstly it is unobtrusive; it does not change the current assembly sequence, the current operators or the current machinery being used. It simply relieves the assembly operator of the subassembly duty.

Because the automated cell works on the subassembly and the assembly operator works on the main assembly simultaneously, the productivity is increased, and production demands can now be met. Additionally, by automating the subassembly, the need for the assembly operator to handle most of the discs is reduced. The automated cell is handling a top-down assembly process with a large base component, and does not have to handle the spring component, which could prove difficult. This solution is also cost effective requiring very simple components. All of this amounts to a partial automation cell that is ideally suited to the compression head valve assembly.

6.3 Developing automated mechanisms for the subassembly process

The subassembly involves the placing of compression valves and an orifice disc on the compression head (the number of compression discs depends on the valving characteristics required). Assuming that the assembly operator loads and unloads the compression heads as required, the tasks of the automated cell is two fold. Firstly it has to have some means of transporting the compression heads from the load/unload area (where the part can be accessed by the assembly operator), to a working area, away from the assembly operator, where discs can be loaded as required. Secondly it must have a mechanism in place for presenting a single disc and loading it onto the compression head.

6.3.1 Transporting the compression head

The need to move the compression head is necessary from a safety standpoint. Having the mechanisms of the cell operating in the same space as the assembly operator, leaves room for accidents. However, since the compression head must be transported, any advantage that might be derived from this must be exploited. One such advantage is the development of a modular automated cell. The compression head can be moved between a number of cartridges, each containing a particular type of disc. Each cartridge places only one disc on the compression head (If the valve requires four compression discs and one orifice discs the compression head would receive discs from five different cartridges). Therefore all cartridge systems perform the same operation and can be controlled together. An effective method of doing this is by placing the compression head on a rotation table.

6.3.2 Presenting and loading the discs:

By deciding on a modular system, the task of developing a mechanism for presenting discs and loading them onto the compression head is simplified. As soon as a single and reliable mechanism is developed, it can be used for all discs.

Methods of loading vary widely from bowl feeders to gravity fed systems. The task here is to choose the most suitable, and most cost effective method for this particular application. The criteria for this selection are that firstly the disc should not be contaminated in any way during the process. The discs are washed in Trichloroethylene (a cleaning agent) before being transported to the assembly station. It is important that the discs remain clean, as any foreign particles could affect the performance of the valve. Therefore this is a valve performance criterion. The other criterion is the requirement for absolute precision of the mechanisms ability to load one and only one disc every time.



Figure 6.1: Can you tell which of these is a stack of two discs and which is not?

Here there is no room for error, since if two discs are placed instead of one, the valving characteristics change dramatically. This can therefore be called the precision criterion.

The valve performance criterion rules out any methods that might require magnets or a fluid medium to load or present the discs. The discs are ferrous, but can easily become magnetised. Once this happens, the discs attract iron fillings and particles in

the air. These particles can affect the valving characteristics. The performance criterion also eliminates any mechanisms that might lead to a change in the physical properties of the discs such as bending, scratching or warping, or a change in the metallic properties of the discs, such as would occur at high temperatures. This leaves the option of a vacuum suction cup. Because of the central hole in all the discs the vacuum would have to be generated along an annular area of the discs. A picture of such a cup is shown below in Figure 6.2.



Figure 6.2: Pneumatic suction cup.

The suction cup would be mounted on two cylinders. One cylinder would move vertically to allow for the picking up and placing of discs by the suction cup. The other would allow the suction cup to move laterally between the rotation table, and the area where the discs are presented to it. A picture of the proposed system is shown in Figure 6.3.

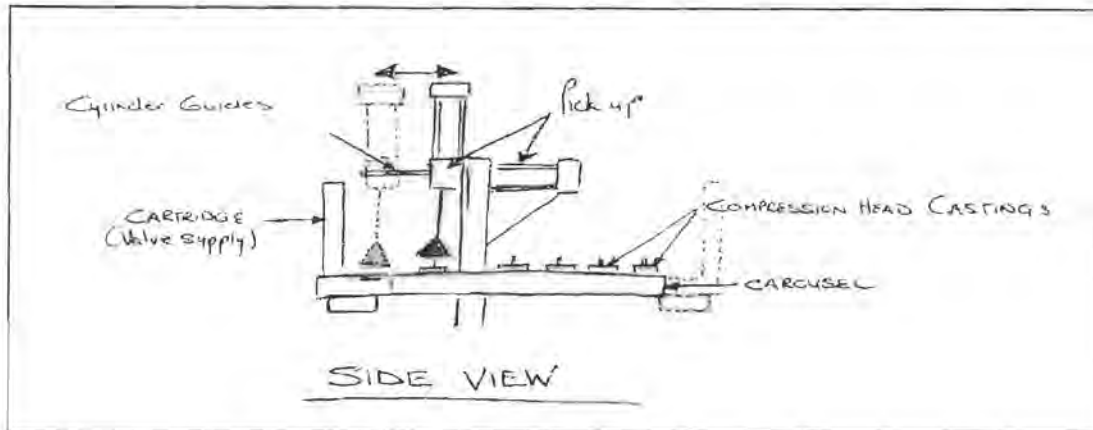


Figure 6.3: Concept drawing showing cylinder motion.

The precision criterion requires an active mechanism for separating discs. As such a gravity fed process would not be ideal. Bowl feeders also do not guarantee separation of discs and therefore must also be eliminated. The precision criterion allows only for mechanisms that can demonstrate that the process of presenting and loading, allows for only a single disc to be handled at a time. One solution is to stack the discs at an angle. An annular suction cap can be used to pick up the top disc from the stack while blowing air through the central hole in the disc. Because the discs are slightly offset from one another, air blown through the centre of the top disc would push the disc directly below it downward, resulting in the separation of the discs. The concept is illustrated in Figure 6.4.

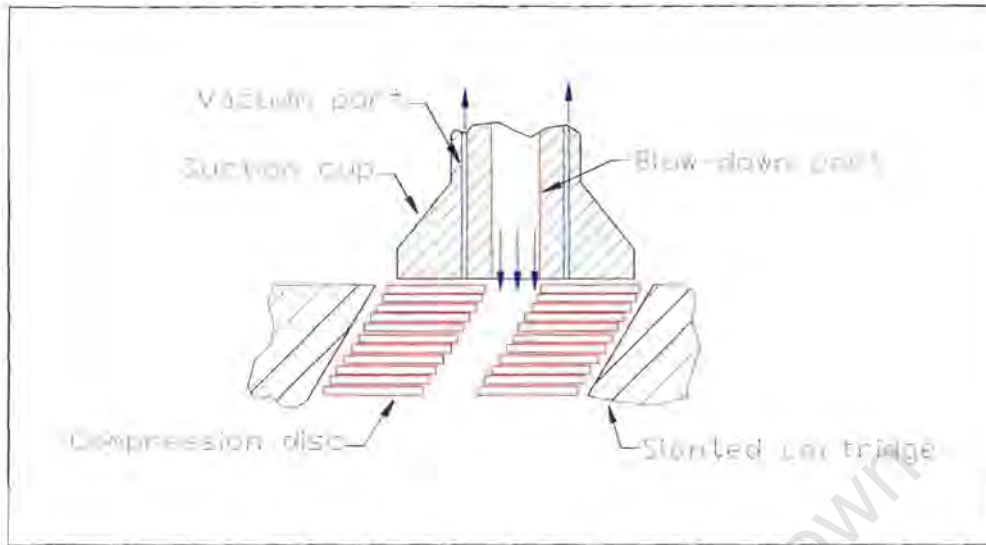


Figure 6.4: Slanted disc cartridge concept.

While theoretically sound, this concept has potential weaknesses. The first of which is the angle at which the discs must be stacked is critical. Tests performed showed that an angle in excess of 45° is required. At such an angle, the movement of discs by means of a pressurised cylinder below the stack might not be consistent. In addition the area of the underlying disc exposed to the blow down jet of air is minimal. It is worth noting that when discs adhere to one another, they can be separated either by sliding them apart or by pushing/pulling them apart (i.e. applying a shear force or a normal force respectively). The force required for separation is least when the discs are slid apart. Since the method proposed above requires a push separation, and the available contact area is minimal, a high-pressured jet of air would be required. When all these are considered, along with the fact that the method leaves some room for error (no matter how well it is set up), it is clear that this is not the most favourable method.

A more preferable method would involve the sliding of discs over each other. In this method, the discs that are not required to be placed are restricted from moving laterally. A cutout in the cartridge allows the disc required to slide out. The initial

system developed worked by sliding the bottom disc from a stack out to an area where it could be picked up by the suction cup. It was made up of two cylinders, a sliding probe and a cartridge. One cylinder controlled the vertical movement of the probe while the other controlled its horizontal motion. The mechanism made use of the central hole in the discs as a pick-up point. Mechanisms had now been developed to carry out all the tasks of the subassembly, and their operation is conceptually satisfactory. A drawing of the system is show in the figure below.

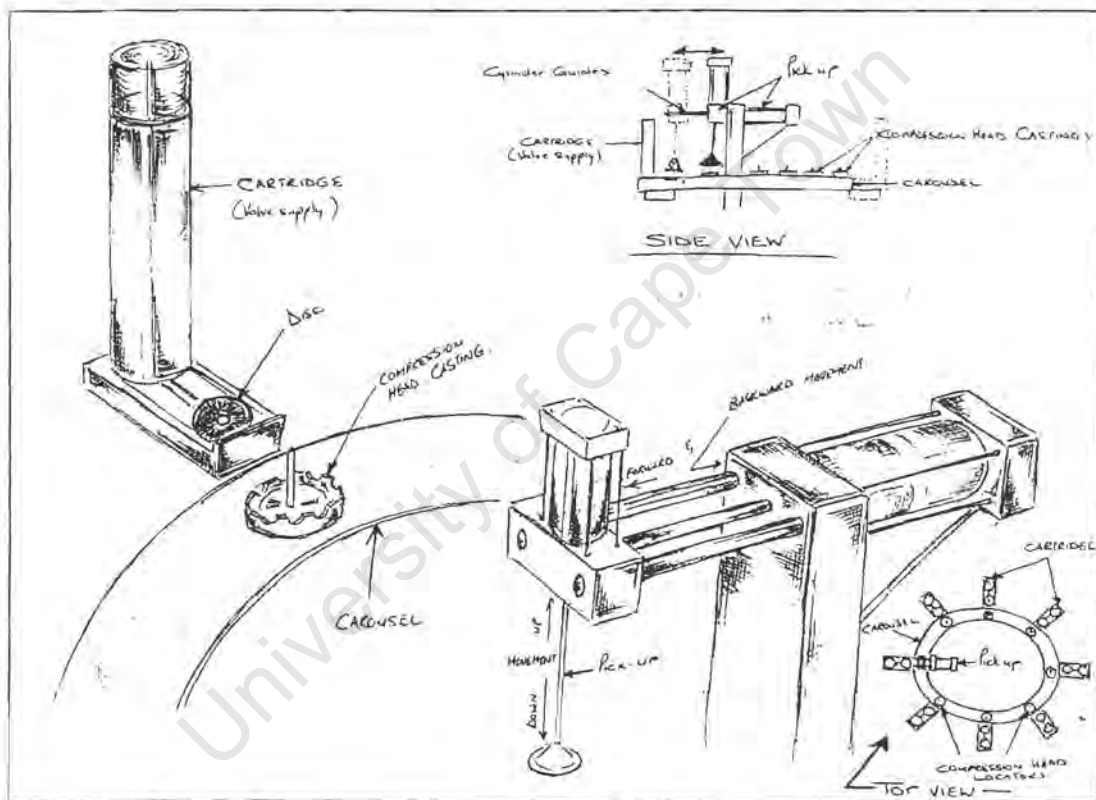


Figure 6.5: Resulting concept drawing.

6.2 Final modifications to the automated assembly cell

Developing the mechanisms is only part of the process. These mechanisms have to be integrated, and a sequence has to be developed that ensures the smooth running of the

assembly cell. During the process of developing an operation sequence, an opportunity was realised for simplifying the mechanisms. To illustrate the point, Figure 6.6 shows the proposed sequence. Events that are placed side by side occur simultaneously.

EVENT SEQUENCE		
1	Rotating table indexes, moving the compression head.	Vertical cylinder actuates, bring the slider into contact with the bottom disc on the stack.
2	The Horizontal cylinder extends, moving the bottom disc out of the stack to a convenient pick up point.	The horizontal cylinder on which the suction cup is mounted moves out towards the pick up point.
3	The suction cup moves downward, the vacuum is activated which picks up the disc.	
4	The suction cup moves back to the indexing table where the disc is placed on the compression head.	The slider is retracted, and the cycle starts again.

Figure 6.6: Proposed sequence of assembly events.

A look at the sequence reveals that there is a duplication of motion as both the presenting system (the slider) and the loading system (the suction cup) has vertical and horizontal components of motion. Fundamentally the nature of the system requires the slider to have a lateral component of motion to allow for the sliding of discs. The suction cup requires a vertical component of motion to allow for the picking up and placing of discs. All other components of motion are redundant, and can consequently be eliminated. The resulting system is shown in Figure 6.7.

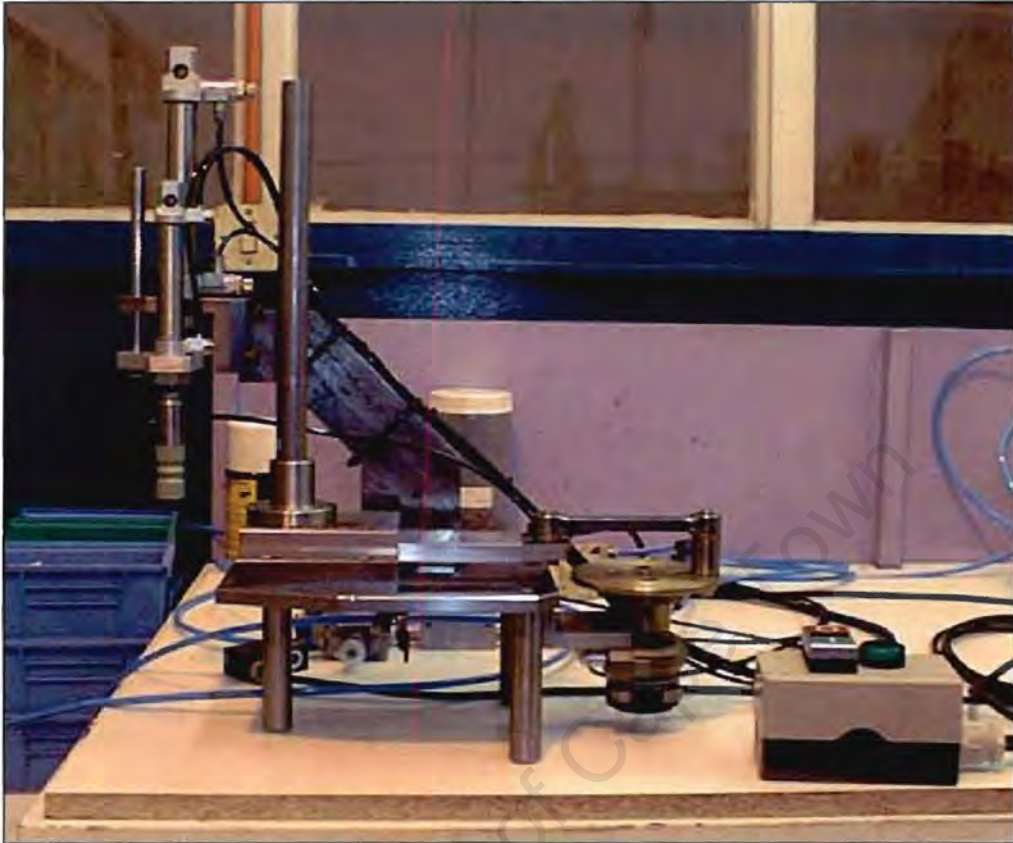


Figure 6.7: Final disc presentation mechanism.

The layout of the final system was then decided. The maximum number of discs that can be placed on one compression head is seven (six compression discs and one orifice disc. See Chapter 4). Therefore there must be seven or more disc presenting modules. The decision was taken to have nine disc presenting modules arranged circumferentially around the compression head indexing table, with an area from where the assembly operator can load and unload the components. The system layout is shown in Figure 6.8.

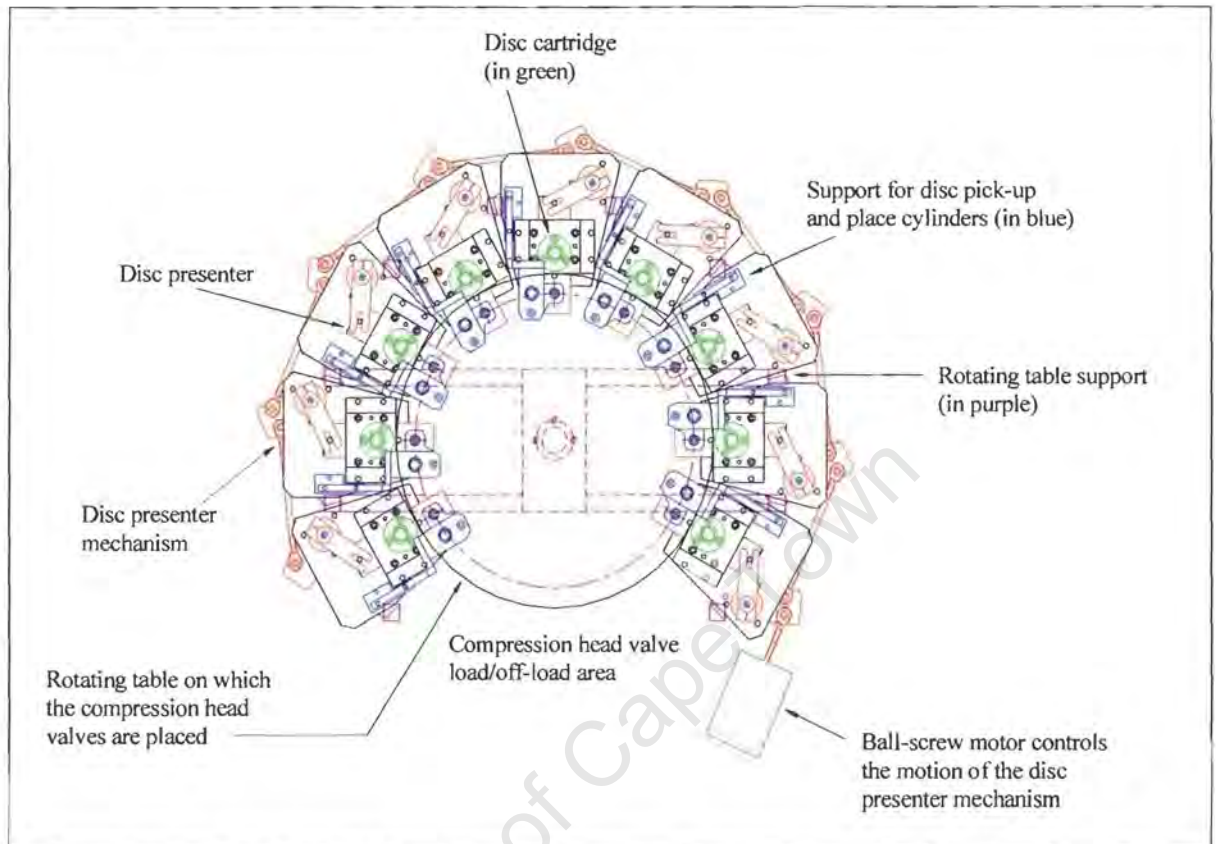


Figure 6.8: Overhead view of assembly cell layout.

6.5 Control and pneumatic design of the automated assembly cell

Essential to the sequence planning for an automated cell is the electrical and pneumatic systems. The pneumatic system is shown in Figure 6.9.

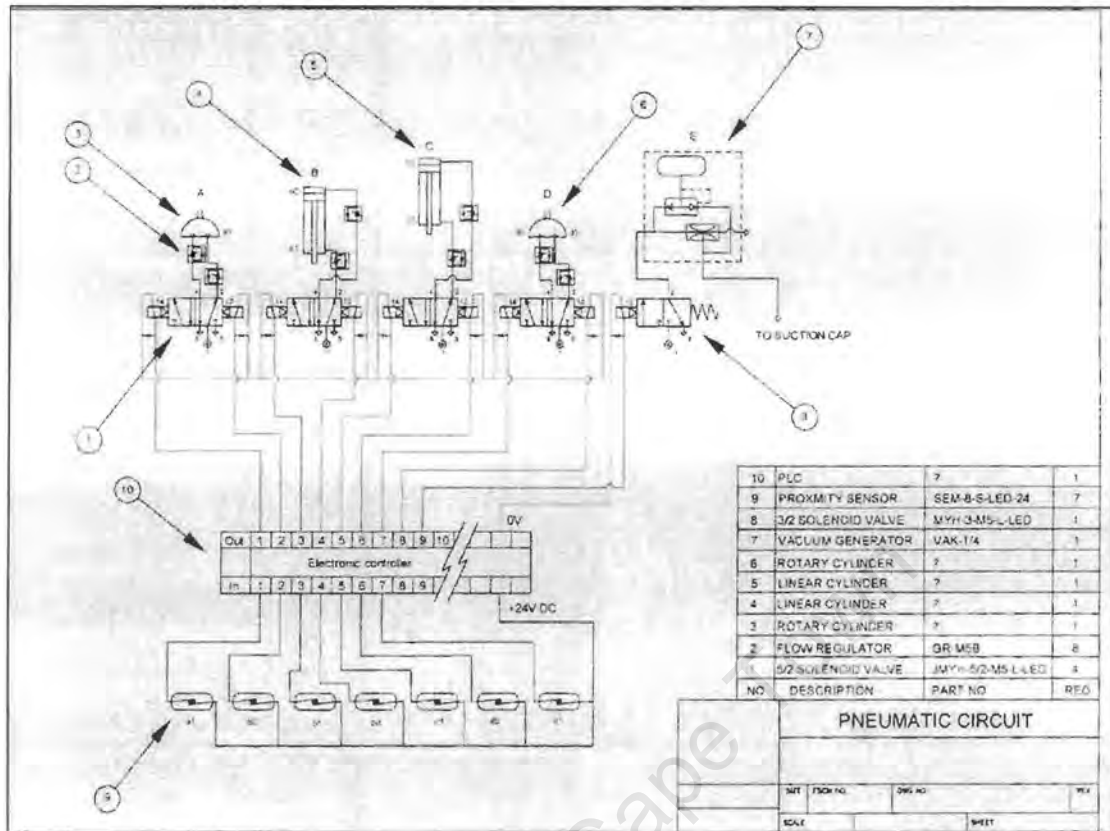


Figure 6.9: Pneumatic unit diagram.

Notice that only one unit component of the assembly cell is shown here for simplicity. The overall system is a duplication of this unit.

6.5.1 Assembly PLC sequence options

The assembly sequence for a unit of the assembly cell along with the associated PLC ladder diagram is shown in Figure 6.10.

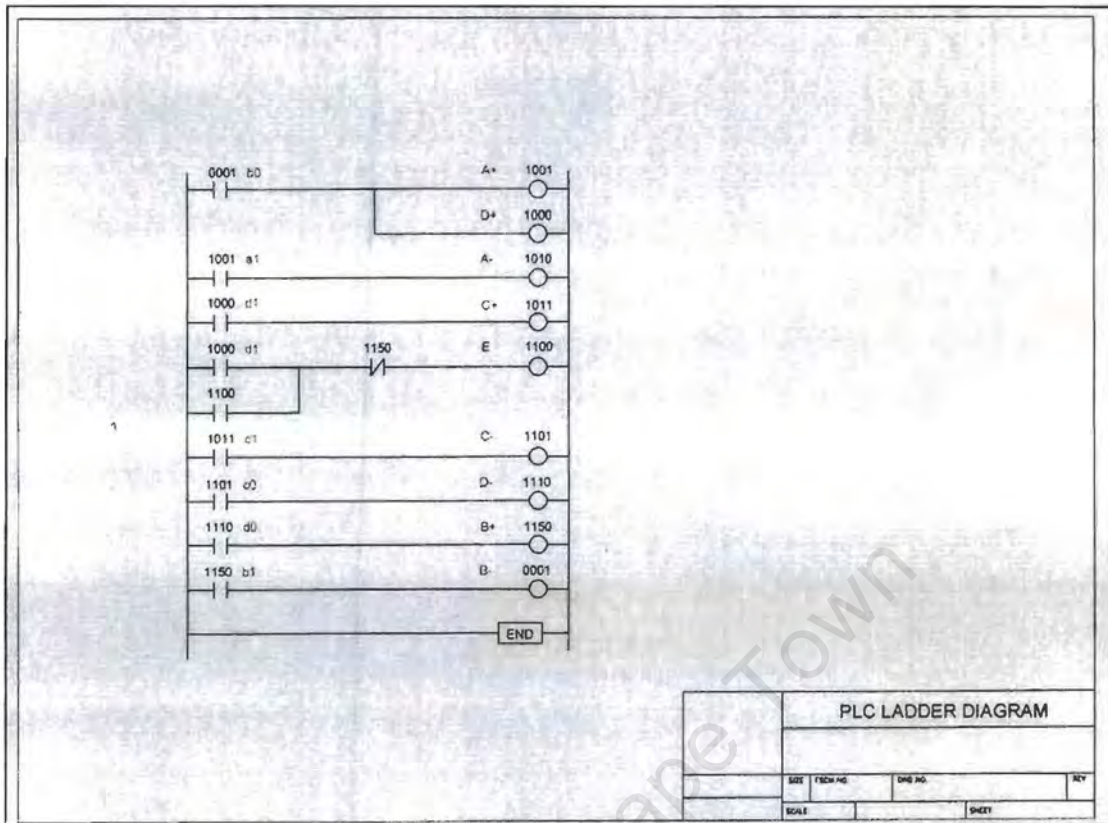


Figure 6.10: PLC unit diagram.

The associated flow chart for a unit station is shown as Figure 6.11.

Case study: improving existing systems using modern methods

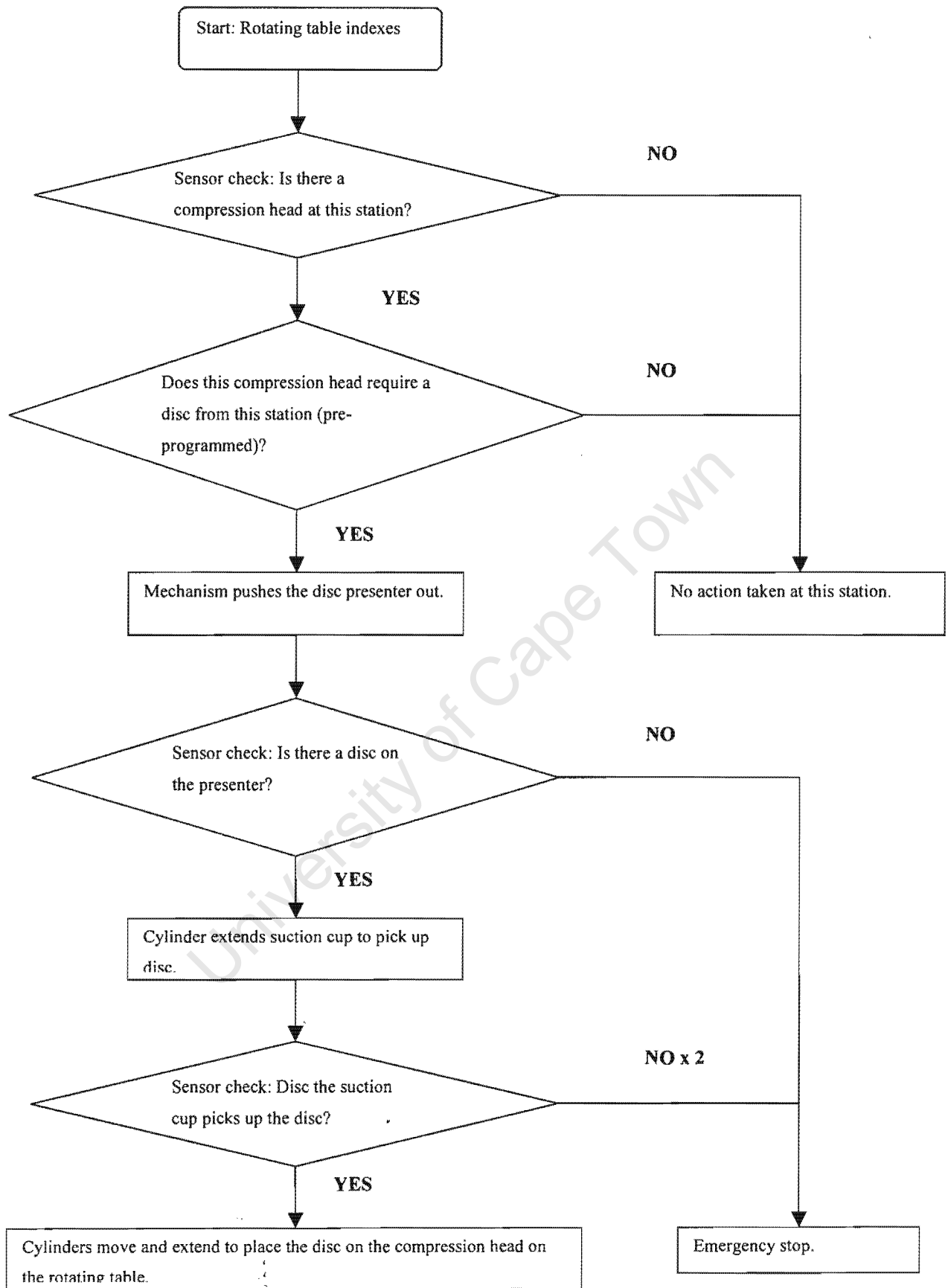


Figure 6.11: Unit station flowchart.

However the development of a sequence for the whole system has to take into consideration start-up, shutdown modes. This is because when the assembly cell is started up, the rotating table is not full of compression head components. The system has to recognise this and initiate a start-up phase until such time as all nine stations can present discs. The reverse is applicable on shutdown. A system flowchart demonstrating this is shown in Figure 6.12.

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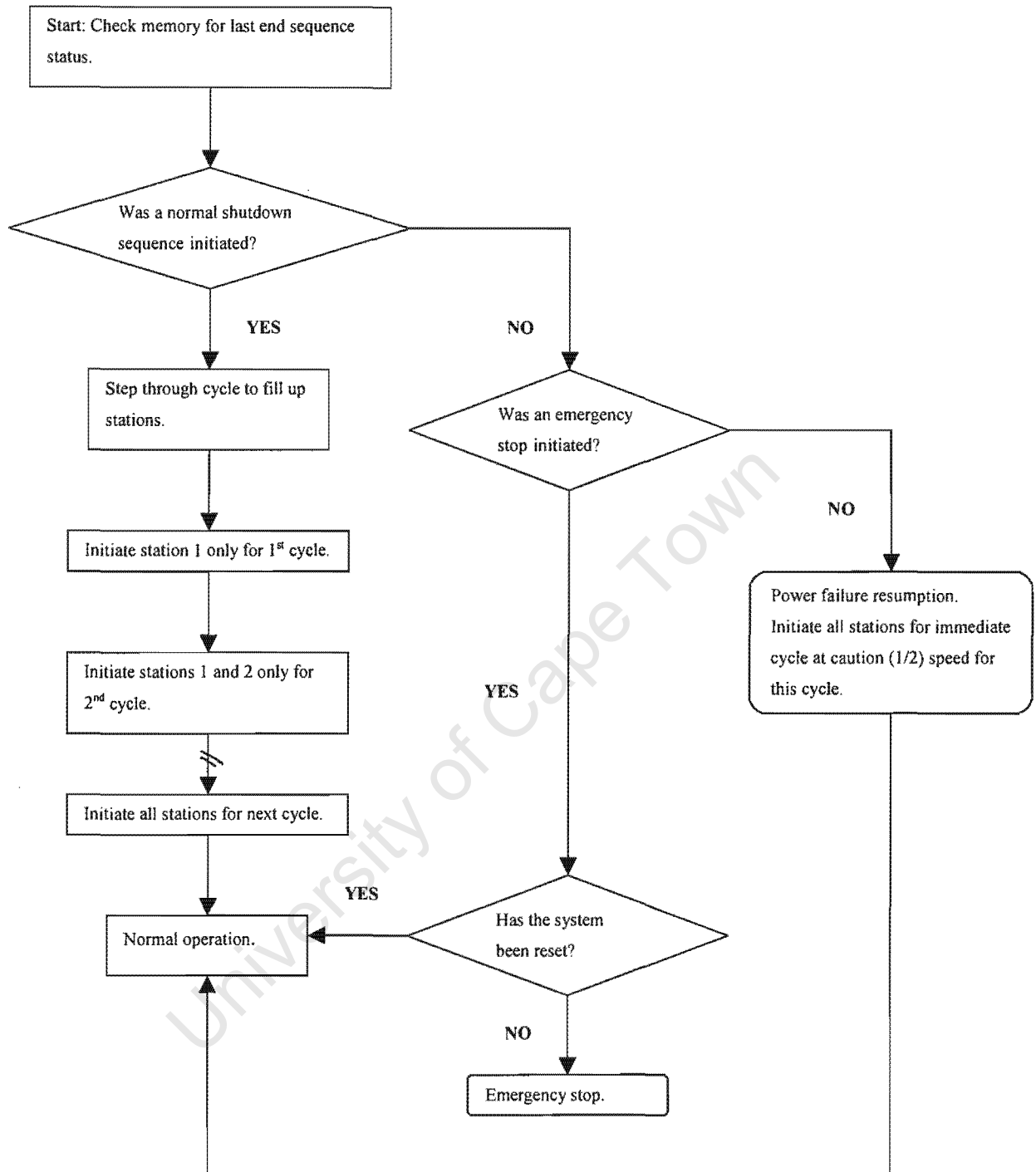


Figure 6.12: Flowchart showing sequence initiation.

6.6 Evaluating the new assembly cell

While the final assembly cell has not been completed and put into operation yet, certain characteristics can be drawn from the performance of the prototype mechanism, and the design goals for the system. The essential test of the new system is how well it provides solutions to the problems. From a subjective point of view, this question boils down to how easy the system is to use. The reduction in the workload of the assembly operator is a quantifiable measure of this. Since the subassembly process took about half the total assembly time, it can be argued that the workload has reduced by half. However the quality of the work done by the assembly operator can be expected to increase since the tasks that have been left to the operator are easily done manually. The flexibility of the overall system has increased due to the elimination of the thirty-part batch subassembly restriction. Any number of any variations can now be assembled.

6.6.1 Productivity evaluation

The productivity of the assembly cell can be assessed using a number of different criteria. The first is of course the time taken to assembly a component. The prototype has demonstrated the ability to place discs in five seconds using timers in the sequence rather than the sensors that will be used in the final assembly cell. This suggests that this time can be further reduced. It can be conservatively assumed that the remaining assembly tasks for the assembly operator would take half the total time as the previous system without the subassembly time included. This is about twenty seconds of manual assembly time. Therefore a total assembly time of twenty five seconds is a reasonably conservative estimate for the final system. The elimination of the problem associated with mistakenly placing two adhered discs instead of one improves the overall quality, although the percentage improvement is difficult to establish since detailed quality information is considered priority information at Gabriel S.A. The flexibility of the system is also improved, since the new system has no minimum batch size requirement. Most of the system parts are standard with only

the disc presenter mechanism and disc cartridge being specific to different diameters or thickness of discs. As such provision has been made to use the system on any similarly designed product (Following the successful integration of this system, the manufacturing engineers at Gabriel S.A. have suggested using it for a similar product in their production process).

6.6.2 Cost evaluation

Gabriel intends to build two of the assembly cells developed above, to meet its production demands. The budget breakdown for the systems is given below:

BUDGET AREA	COST BREAKDOWN (R)	FINAL COST (R)
Design and Prototype	12000	12000
Manufacture of machined components	38000 x 2	76000
Pneumatic components	13000 x 2	26000
PLC control software and hardware	11000 x 2	22000
Manufacture of tooling	17500 x 2	35000
Manufacture of support structure	6500 x 2	13000
Assembly	5000 x 2	10000
Total		194000

The machine would save Gabriel the cost of two additional assembly operators at R19.50 an hour for each operator, for 41.5 hours a week (1992 hours per annum). This adds up to R77688 per annum. Therefore the payback period on the machines would be approximately 2.5 years. This number is below the 3-year maximum payback period required at Gabriel. As such the assembly cells are economically justifiable.

7 CONCLUSIONS AND FUTURE OUTLOOK

The assembly process is different today, as a result of the drive towards a fully integrated production process. This thesis has shown how this change manifests itself in the design of a product, and the process of assembly of that product.

7.1 Concurrent Engineering

In Chapter 4 the advantages of Concurrent Engineering were highlighted. New technologies in industry today are aimed at realising the goal of a fully integrated industrial process. The focus of technology in the past has been on enabling the various disciplines within the production process to function efficiently. Concurrent Engineering shifts the focus to enable efficient interfacing between the various disciplines. The assembly process is useful in this regard because it is inherently inter-disciplinary. That is to say that the assembly process is a reflection of the processes that occurred before it such as the design and manufacturing stages of the production process. As Concurrent Engineering continues to draw lines of influence between the different production disciplines, the assembly of the product shall continue to be the critical checkpoint of a fully integrated process.

7.2 Product design

The influence of assembly theory on product design is changing the way products are developed. The Design for Assembly has been shown to easily account for a hundred-percentage increase in efficiency using the compression head valve as an example. Since the efficiency evaluation represents a measure of the time (and thus the cost) committed to assembling a product. This example verifies the assertion of the literature, in terms of the potential savings to be gained from DFA.

Modular products are an industry wide phenomenon. These are normally manifested in product families, or distinct brand characteristics throughout a product range. The driving factors behind establishing modularity is that it aids in the flexibility of machining and assembly systems. Flexible Assembly Systems allow for cost effective assembly of low to medium batch and volume products, since the justification for the machine need not be based on the projected volumes for a single product, but rather the whole range of products of that type.

7.3 Integrating automation into existing assemblies

Given the changes that are occurring in product design (and indeed in the overall production environment) to enable easier assembly, the question concerning the ease of automating older products was addressed in this thesis. The results show that while full automation is extremely difficult to attain in older products, semi-automation of the assembly process is a relatively easier process. The process of identification of areas for possible automation was demonstrated using the compression head valve, and a new assembly system was developed for the product. The advantages of the new system can be summarised as follows:

1. A reduction in assembly time from about sixty five seconds to about twenty five seconds.
2. A 66.6% increase in the riveting machine utilisation.
3. The elimination of the need for an additional assembly operator for the compression head valve subassembly.
4. A reduction in the difficulty of the work done by the assembly operator, due to the elimination of handling difficulties.

7.4 Future outlook

The success of the exercise to improve the productivity of the compression head valve assembly process at Gabriel proves that there is a means of applying modern

assembly concepts to older products. The new assembly cell was developed in such a way, as to accommodate a further transition to a more sophisticated assembly machine, should the production team at Gabriel deem this to be necessary.

There is need to explore further, the link between understanding the assembly process, and developing a fully integrated production system. Computer Aided Assembly tools will contribute a great deal to this process. The scarcity of Computer Aided Assembly tools is reflected in the inability of the author to obtain a full assembly computer tool for the purposes of this project (A demo for the DFMA tool suite was obtained from the internet). In the future, the level of access to these tools would determine the extent to which a DFA test can be taken, especially when it is considered that these tools will be integrated with CAD, FEM and process simulation software.

A fully integrated production process is getting closer to becoming a reality. It is the belief of the author that a well understood, and modelled assembly process would be a step closer to the realisation of this goal.

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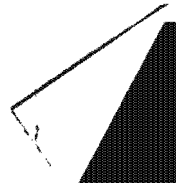
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APPENDIX A

Description of the valving characteristics of double cylinder shock absorbers from a Gabriel manual.

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How a shock absorber works

Based on a description of Gabriel shock absorbers fundamental workings in a internal guidebook titled Arvin: Shock absorber basics.

The operation of a hydraulic shock absorber is based on two physical principles:

1. Fluid (as used in a shock absorber) is practically incompressible.
2. Forcing fluid through a restriction requires energy, and this energy is exponentially proportional to the rate at which the fluid is forced through the restriction.

Collapsing or extending a shock absorber forces the fluid through a variety of passages (valving) inside the shock absorber. The shock absorber performs its function of damping suspension oscillations because the fluid resists being forced through the valving inside. As the fluid passes through the valving, the kinetic energy (motion) of the suspension is converted into thermal energy (heat) in the fluid. This heat is then transferred through the body of the shock and dissipated into the atmosphere around the shock absorber.

Since the energy required to force the shock absorber's fluid through the restriction is exponentially proportional to the rate at which it is forced through the restriction, the shock absorber is velocity sensitive. As the shock is stroked at higher speeds, its resistance to motion increases.

The force produced by a shock absorber in response to the velocity of motion is the most important characteristic of a shock absorber. Shock absorbers are characterised by their force output (typically expressed in pounds or Newtons) at a given velocity (in inches/second or meters/second). Shock absorber valving can be tuned to provide different force vs. velocity characteristics to suit various application needs. A typical force vs. velocity plot for a shock absorber is shown below.

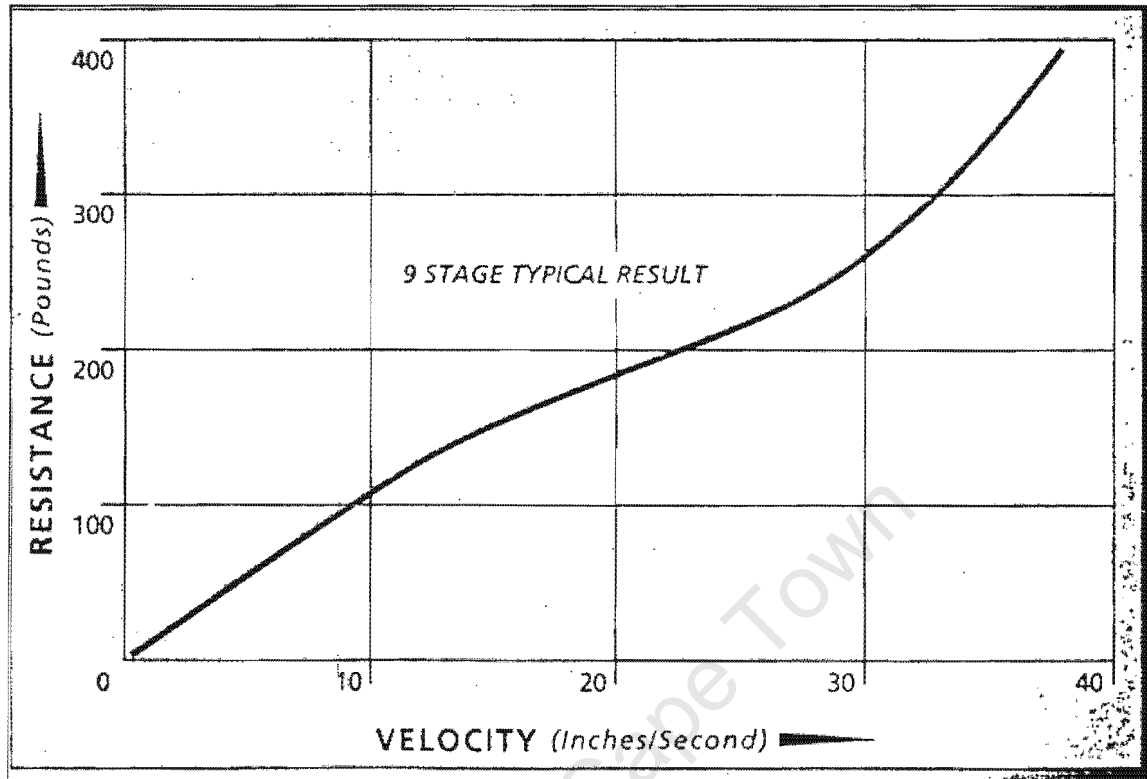


Figure A: A typical force vs. velocity graph for a twin-tube shock absorber.

To further understand the operation of a shock absorber, the basic stages of its damping operation require analysis:

The effects of orifice control on damping characteristics

The orifice control is usually a very small slot in the piston which fluid must flow through at lower velocities. Other components to the valving contribute little if any toward control at these velocities. As the velocities increase the control levels available from the orifice become too high requiring the next stage of control to come into effect. See the figure below for an illustration of the effects of the orifice control.

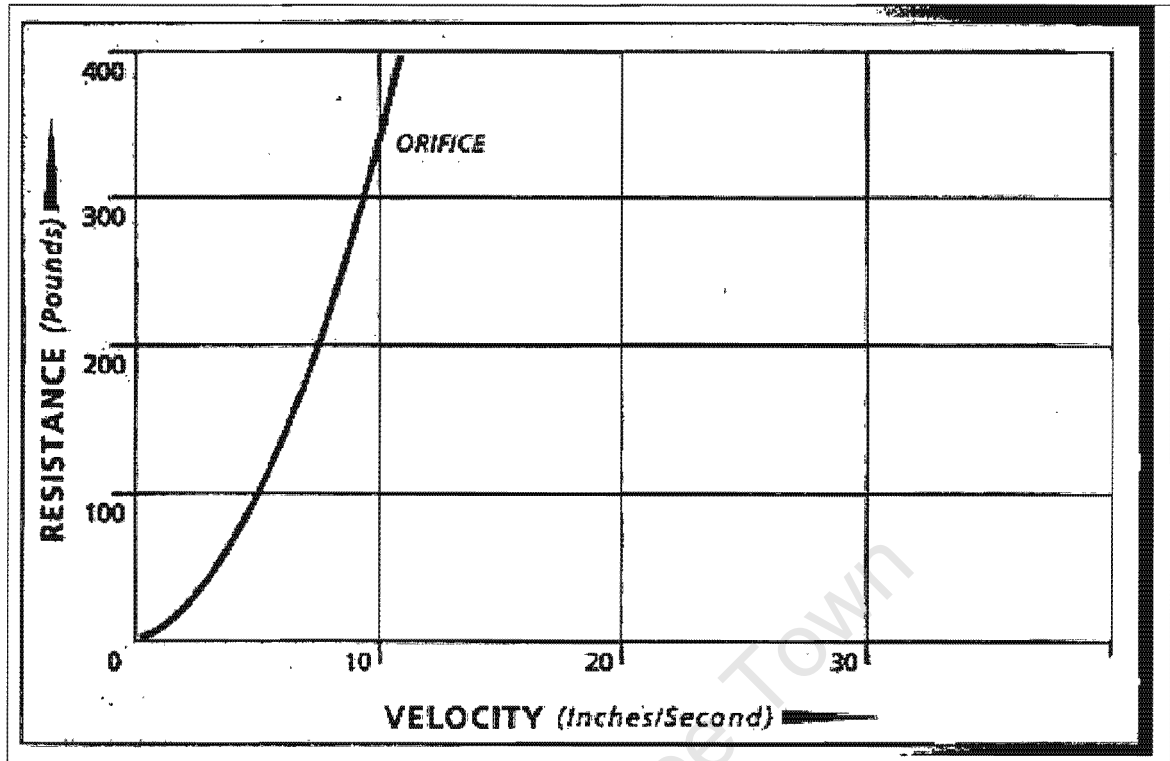


Figure B: Figure illustrating the effects of orifice control on shock absorber damping characteristics.

The effects of bypass on damping characteristics

To relieve the shock absorber of the high forces generated by the orifice, a valve is inserted into the system. During low velocities the valve is held in place by a spring. When sufficient pressure develops, the valve forces the spring to back off and the valve opens. The spring is selected in the shock tuning (valving) process. See the figure below for an illustration of the effects of the bypass valve.

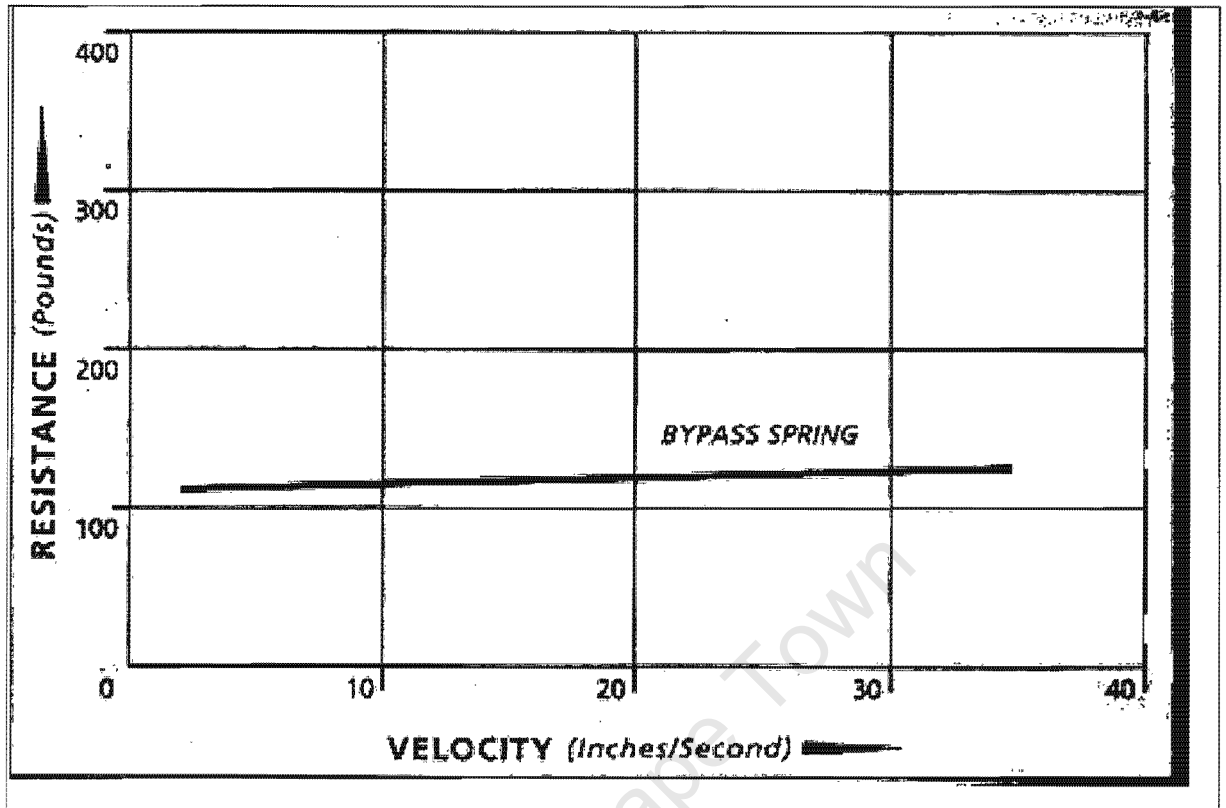


Figure C: Figure illustrating the effects of bypass on shock absorber damping characteristics.

The effects of restriction on damping characteristics

Shock absorbers on vehicle suspensions require high control forces at higher velocities. To meet this requirement, additional restriction to fluid flow is added to the design “upstream” of the orifice and blow off spring. This additional restriction has negligible effect at low velocities while being able to snub effectively at higher velocities. See the figure below for an illustration of the effects of restriction.

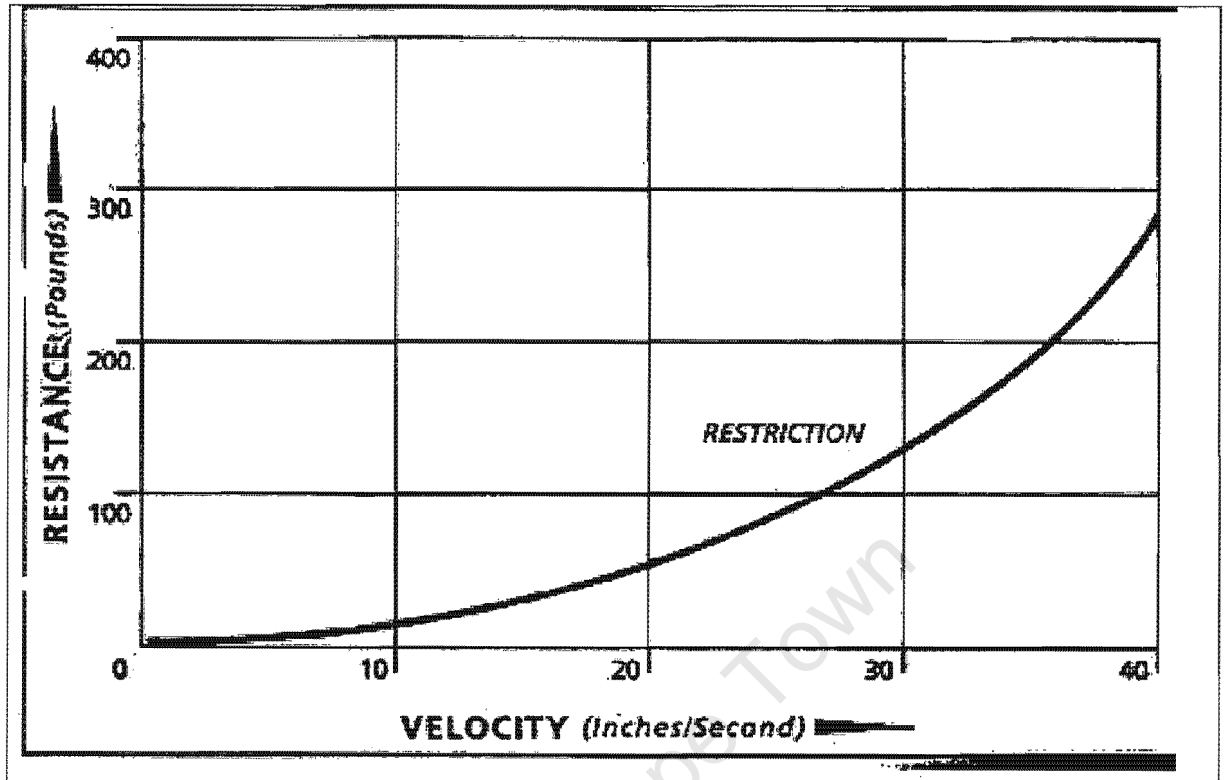


Figure D: Figure illustrating the effects of restriction on shock absorber damping characteristics.

The combined resultant damping characteristics

The orifice and restriction phases of the valving create force levels which increase exponentially with increase in velocity while the blow off acts in a more linear (nearly constant) manner. The combination of the above components allows for a control of varying degrees at all velocities. This effect would not be possible without the harmony that all generate when interacting. The combined effect is illustrated below.

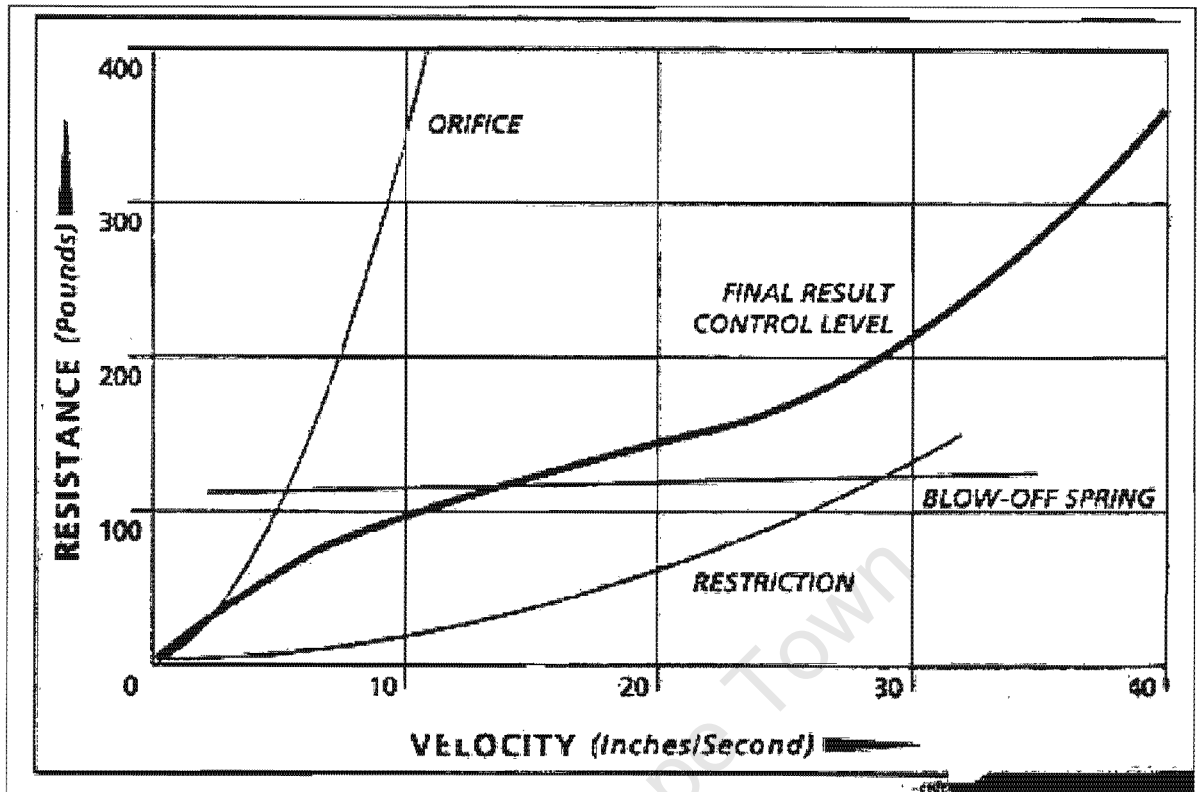


Figure E: Figure illustrating the combined effects of the various damping methods on the overall damping characteristics of a shock absorber.

The disc compression head valve

The spring and replenishing valve regulate flow as the shock absorber is extending. The extension usually does not involve as high forces as in the collapsing of the shock absorber, therefore this disc and spring system is all that is required. When the shock absorber is collapsing, fluid is forced through the restriction disc and onto the orifice disc. At low velocities fluid can flow out through slots in this disc. At high velocities, fluid creates sufficient pressure to cantilever the orifice disc and the compression valves below it, to create a greater area for flow.

APPENDIX B

1. An explanation of the Boothroyd and Dewhurst DFA method for manual assembly.
2. An explanation of the Boothroyd and Dewhurst DFA method for robotic assembly.

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Design for assembly: manual assembly

*Based on the article **Design for Assembly: Manual Assembly** published in Machine Design in 1983 by G. Boothroyd and P. Dewhurst.*

Design analysis

The first step in the analysis is to obtain the best information available on the product. Useful items are engineering drawings, exploded three-dimensional views, an existing version or prototype. The second step is to take the assembly apart, or imagine how it might be done. The complete assembly is assigned identification number 1. As each part is removed from the assembly, it is assigned an identification number in sequence. If the assembly contains subassemblies, they should be treated as “parts” first, then analysed separately later, or analysed together. The third step is to reassemble the part with the highest identification number to the work fixture, then add the remaining parts one by one. As the product is reassembled, data on the handling, assembly and operation cost are entered on a worksheet. This data is taken from the tables shown Figure F and Figure G.

MANUAL HANDLING – ESTIMATED TIMES (seconds)

		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	size > 6 mm	size ≤ 6 mm			
Key		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	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98				
	$360^\circ \leq (\alpha + \beta) < 540^\circ$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38				
	$540^\circ \leq (\alpha + \beta) < 720^\circ$	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7				
	$(\alpha + \beta) = 720^\circ$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4				
parts can be grasped and manipulated by one hand but only with the use of grasping tools	$\alpha \leq 180^\circ$	$0 \leq \beta \leq 180^\circ$	parts need tweezers for grasping and manipulation								parts need standard tools other than tweezers	parts need special tools for grasping and manipulation				
		$\beta = 360^\circ$	parts can be manipulated without optical magnification				parts require optical magnification for manipulation									
	$\alpha = 360^\circ$	$0 \leq \beta \leq 180^\circ$	parts are easy to grasp and manipulate	parts present handling difficulties (1)	parts are easy to grasp and manipulate	parts present handling difficulties (1)	parts are easy to grasp and manipulate	parts present handling difficulties (1)	parts are easy to grasp and manipulate	parts present handling difficulties (1)	parts are easy to grasp and manipulate	parts present handling difficulties (1)				
		$\beta = 360^\circ$	thickness > 0.25mm	thickness ≤ 0.25mm	thickness > 0.25mm	thickness ≤ 0.25mm	thickness > 0.25mm	thickness ≤ 0.25mm	thickness > 0.25mm	thickness ≤ 0.25mm	thickness > 0.25mm	thickness ≤ 0.25mm				
	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7					
	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8					
	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9					
	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10					
	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)	$\alpha \leq 180^\circ$	$\alpha \leq 180^\circ$	parts present no additional handling difficulties				parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)								
			$\alpha = 360^\circ$	size > 15 mm		size ≤ 15 mm		size > 15 mm		size ≤ 15 mm		size > 6 mm		size ≤ 6 mm		
$\alpha = 360^\circ$		$\alpha \leq 180^\circ$	0	1	2	3	4	5	6	7	8	9				
		$\alpha = 360^\circ$	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7			
two hands, two persons or mechanical assistance required for grasping and transporting parts	TWO HANDS required for LARGE SIZE	$\alpha \leq 180^\circ$	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				parts are heavy (> 10 lb)									
	$\alpha = 360^\circ$	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)	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)	parts are easy to grasp and manipulate	parts present other handling difficulties (1)					
		$\alpha \leq 180^\circ$	$\alpha = 360^\circ$	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$	$\alpha \leq 180^\circ$	$\alpha = 360^\circ$					
	9	2	3	2	3	3	4	4	5	7	9					

Figure F: Classification, coding and database for part features that affect manual handling time (in seconds).

MANUAL INSERTION – ESTIMATED TIMES (seconds)

		after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)						
		easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly				
		no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)			
Key		0	1	2	3	6	7	8	9			
addition of any part (1) where neither the part itself nor any other part is finally secured immediately	part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5		
	due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10		
	due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5		
addition of any part (1) where the part itself and/or other parts are being finally secured immediately	part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	0	1	2	3	4	5	6	7	8	9	
	due to obstructed access or restricted vision (2)	3	2	5	4	5	6	7	8	9	6	8
	due to obstructed access and restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
5	6	9	8	9	10	11	12	13	10	12		
assembly processes where all solid parts are in place	mechanical fastening processes (part(s) already in place but not secured immediately after insertion)	none or localized plastic deformation		bulk plastic deformation (large proportion of part is plastically deformed during fastening)		no additional material required (e.g. resistance friction welding, etc.)		non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)		non-fastening processes		
	bending or similar processes	0	1	2	3	4	5	6	7	8	9	
	riveting or similar processes	0	1	2	3	4	5	6	7	8	9	
screw tightening (6) or other processes	0	1	2	3	4	5	6	7	8	9		
metallurgical processes	0	1	2	3	4	5	6	7	8	9		
additional material required	0	1	2	3	4	5	6	7	8	9		
soldering processes	0	1	2	3	4	5	6	7	8	9		
weld/braze processes	0	1	2	3	4	5	6	7	8	9		
chemical processes (e.g. adhesive bonding, etc.)	0	1	2	3	4	5	6	7	8	9		
manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of parts), etc.)	0	1	2	3	4	5	6	7	8	9		
other processes (e.g. liquid insertion, etc.)	0	1	2	3	4	5	6	7	8	9		
9	4	7	5	3.5	7	8	12	12	9	12		

Figure G: Classification, coding and database for part features affecting insertion and fastening (in seconds).

Also entered is an estimate of the potential for eliminating the part or combining it with another part.

When reassembly is complete, data from the worksheet are summed to give the total estimated manual-assembly time and cost, as well as the theoretical minimum number of parts in the product. Finally, the manual-assembly design efficiency is obtained

from $E_m = \frac{3N_m}{T_m}$ where E_m = design efficiency; N_m = minimum number of parts, and

T_m = total assembly time. This equation compares the estimated assembly time for an assembly containing the theoretical minimum number of parts, each of which can be assembled in the “ideal” time of three seconds. This ideal time is based on the assumption that each part is easy to handle and insert, and that about one third of the parts are secured immediately on insertion with well-designed snap-fit fasteners.

Unfortunately, there is no broadly applicable guideline for satisfactory design efficiency. The assumption that all parts in the assembly are easy to handle and insert is impossible to meet in many products. At one extreme, complex electromechanical products that require extensive wiring and gasketing tend to have low design efficiencies, even when well designed. Many companies making such products have decided that design efficiencies around twenty to thirty percent are quite acceptable. At the other extreme, simple products such as pneumatic piston assemblies with few parts can have design efficiencies as high as ninety percent. Ultimately, experience with a range of similar products is the only way to decide on an acceptable efficiency.

Generating the data

The most critical step in the design analysis is the reassembly, where data are generated for possible redesign. For the purpose of reassembly and data generation,

never assume that one part is grasped in each hand and joined, and then placed in the assembly. One row on the worksheet must be completed for each part as it is added in turn to the assembly.

Reassembly starts with the part having the highest number, 10 for the retainer of the current compression head valve assembly. The identification number is entered in Column 1 of the worksheet. The operation is carried out once so "1" is entered in Column 2. A two digit handling code is found on a chart (shown below), which also shows an estimated time for manual handling. Since the retainer can be easily handled in one hand, has a combined α and β symmetry of 360° , and has a thickness and size of greater than 2mm and between 6mm and 15mm respectively, the relevant handling code is "11". The code is entered in Column 3 of the worksheet and the corresponding handling time (in this case 1.8s) in Column 4. The assembly code and insertion time are found from a second chart (shown below). Since the retainer is easy to align with no obstructions or resistance to insertion the relevant insertion code is "00". The assembly code is entered in Column 5 and the insertion time (1.5s) in Column 6. The total operation time in seconds is calculated by adding the times in Column 4 and 6 and multiplying by the number of repeat operations in Column 2. This result is entered in Column 7.

The total operating cost in cents is obtained by multiplying the operation time in Column 7 by a factor (in this case 1. The factor represents the cost of each assembly second. Therefore a better estimate can be substituted if this information is known by the company) and entered into Column 8. For the retainer this value is 3.3. Probably the most critical entry on the worksheet is the theoretical minimum number of parts, entered in Column 9. This is based on the three elimination criteria questions detailed in section 4.5.2. If the answer to any of these questions is yes, then the component cannot be eliminated a "1" is placed in Column 9. If the answer to all of them is no, then the component is a candidate for elimination and a "0" is placed in Column 9. In the compression head valve, the retainer need not move relative to any part, and need

not be made out of a different material. Therefore a “0” can be placed in Column 9 for the retainer. The restriction discs can also a candidate for elimination following the three criteria. This process is carried out for all the parts in the assembly. The complete worksheet shows that the estimated manual assembly time is over seventy seconds, while ideally it should be closer to fifteen (5 parts x 3 seconds). Following the formula given above, the design efficiency is 19.3%. The complete worksheet is shown as Figure H.

DESIGN FOR MANUAL ASSEMBLY WORKSHEET									
1	2	3	4	5	6	7	8	9	Name of Assembly
Part ID No.	# times operation performed 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) x [(4)+(6)]	Operation cost, relative 1.0 x (7)	Figures for estimation of theoretical minimum parts	Compression head valve assembly
10	1	11	1.8	00	1.5	3.3	3.0	0	Retainer
9	1	83	5.6	00	1.5	7.1	7.1	1	Spring
8	1	09	2.98	08	6.5	9.48	9.48	1	Replenishing valve
7	1	09	2.98	08	6.5	9.48	9.48	0	Restriction disc
6	1	10	1.5	06	5.5	7.0	7.0	1	Compression head
5	1	09	2.98	00	1.5	4.48	4.48	1	Orifice disc
4	6*	09	2.98	00	1.5	26.88	26.88	1	Compression disc
3	1	10	1.5	00	1.5	3.0	3.0	0	Rivet
2	1	-	-	91	7.0	7.0	7.0	0	Riveting process
						77.72	77.72	5	DE = 19.3%
						TM	CM	NM	= (3 X NM)/TM

Figure H: DFA evaluation for manual assembly on compression head valve design.

Design for Assembly: robot assembly

*Based on the article **Design for Assembly: Robots** published in Machine Design in 1984 by G. Boothroyd and P. Dewhurst.*

Products intended for robotic assembly can be analysed in much the same way as those intended for manual assembly. The product is assembled, and each part or subassembly in the product is analysed to determine the cost and time required to add it to the assembly. In addition the part is examined to see whether it can be eliminated or combined with some other component. The results guide redesign, indicating where additional effort is most likely to cut production costs.

The database is different from that of manual assembly and can vary depending on the number of robots in the assembly station. An example of a database for robot assembly is shown in Figure I.

PART SECURED IMMEDIATELY

Addition of any part where fast securing is taking place			Straight line insertion		From vertically above		Not from vertically above		Insertion not straight line motion		No screwing operation or plastic deformation immediately after insertion (snap or press fits, etc.)		Plastic deformation immediately after insertion						Screwing immediately after insertion	
											Plastic bending			Rivetting or similar plastic deformation			Easy to align and position in resistance to screwing		Not easy to align or position and/or resistance to screwing	
											Easy to align and position		Not easy to align or position (no features provided for the purpose)		Easy to align and position					
											Easy to align and position	No resistance to insertion	Resistance to insertion	Easy to align and position	No resistance to insertion	Resistance to insertion	Easy to align and position	No resistance to insertion	Resistance to insertion	
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	
3	1.2	1.9	1.6	2.4	3.6	0.9	1.4	2.1	0.8	1.8										
4	1.3	2.1	2.1	3.2	4.8	1	1.5	2.3	1.3	2										
5	2.4	3.8	3.2	4.8	7.2	1.8	2.8	4.2	1.6	3.6										

Part added and secured immediately		Force or torque levels within robot capability								Special workhead operation Robot positions part	
		Part can be gripped and inserted using standard gripper or gripper used for previous part				Part requires change to special gripper					
		Snap or push fit		Push and twist or other simple manipulation		Snap or push fit or simple manipulation		Screw fastening or nut running			
		Self-aligning	Not easy to align	Self-aligning	Not easy to align	Self-aligning	Not easy to align	Self-aligning	Not easy to align		
0	1	2	3	4	5	6	7	8	6		
3	1.0 0.55	1.0 0.6	1.0 0.7	1.0 0.75	1.0 0.6	1.0 0.65	1.0 0.7	1.0 0.8	1.0 1.15		
4	0 0	0 0	0 0	0 0	1.5 0.7	1.5 0.7	1.5 0.7	1.5 0.7	4.0 0.7		
5	1.5 0.55	1.5 0.6	1.5 0.7	1.5 0.75	1.5 0.6	1.5 0.65	1.5 0.7	1.5 0.8	1.5 1.15		
6	0 0	0 0	0 0	0 0	1.5 0.7	1.5 0.7	1.5 0.7	1.5 0.7	4.0 0.7		
7	1.5 1.05	1.5 1.1	1.5 1.15	1.5 1.2	1.5 1.05	1.5 1.1			1.5 1.6		
8	0 0	0 0	0 0	0 0	1.5 0.7	1.5 0.7			4.0 0.7		

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Fig. 3.6 Design for assembly data samples: (a) relative workhead cost for automatic insertion; (b) time and cost (in seconds; cents) for a single-station, two-arm robot system (table entries: top left – relative robot cost; top right – relative effective basic operation time; bottom left – relative additional gripper or tool cost; bottom right – relative time penalty for gripper or tool change) (courtesy of Boothroyd Dewhurst Inc.).

Figure I: Database samples showing (a) the relative workhead cost for automatic insertion and (b) time and cost (in seconds) for a single-station, two-arm robot system (Table entries: top left - relative robot cost; top right - relative effective basic operation time; bottom left – relative additional gripper or tool cost; bottom right – relative time penalty for gripper or tool change).

Design analysis

The analysis system shows the effect of design decisions on the cost of robotic assembly. The system can be updated easily, so that changes in the cost, speed, or cycle time can be factored into the analysis.

The robot used as the basis for cost comparison has two arms, each with four degrees of freedom. These are X, Y, Z, and translation and wrist rotation about the Z-axis, which is at right angles to the work fixture. Wrist rotation is essential to enable the robot to orient rotational parts about their axes of insertion. The relative cost of the robot arms needed to assemble a particular product is then determined by the difficulty of the insertions. It is affected mainly by the degrees of freedom needed to carry out the insertion.

In the analysis, a relative robot cost, A_r , is assigned to each separate insertion operation. The extra cost of special grippers or tools, A_g , is then added to the largest value of A_r . Time estimates are made under the assumption that the assembly system has enough compliance to facilitate part insertions. The compliance may be built into the robot wrist, the work fixture or both. Also, either the robot gripper or the work fixture is assumed to have sensors that detect the presence of parts and verify insertion. With these capabilities, stoppages caused by faulty parts do not present the major problems often encountered with dedicated automatic assembly systems and need not be included in time estimates.

The present generation of robot arms typically takes three seconds to move, grasp, orient, return to the work fixture, and insert a part. Normally one robot arm inserts a part while the other grasps and moves the next part. The minimum time between part insertions is thus 1.5s. To allow for delays caused by interactions between the arms, the analysis assumes that the system time, T_p , for assembling a part with no assembly problems is 2s. To carry out a gripper change, insert a part, and return to the original gripper, one arm typically spends 9s instead of 3s. In the worst case, the other arm

will only insert one part during this time. Thus two parts have been added in 9s instead of the usual 4s. In the best case, the other arm inserts two parts during the course of the gripper change. To accommodate these extremes, an average time penalty, $T_g = 4$ is used in the analysis, giving a total of 6s per part instead of 2s.

In many assembly operations one part must be held down while the next part is added. If one robot arm must hold down a part while the other inserts a second part, then the system time for one part is lost. In general, then if both arms are required, the system time for that part is 4s.

Generating the data

Parts are numbered in the reverse order, so entry on the worksheet starts with the highest numbered part. In Column 1, enter the identification number of the part. In the case of the redesigned compression head valve, the base component this identification number is "6". In Column 2, enter the number of times the insertion operation is repeated for parts of that type. Next determine the appropriate two-digit insertion code from the insertion chart shown below, and enter the code in Column 3. Since the base component is assembled straight from the top and is self-aligning, the insertion code is "00". The chart gives the relative robot cost, A_r , additional relative cost, A_g , system time for the operation, T_g , and the time penalty for a tool or gripper change, T_p . These values are entered into Columns 4 through 7 respectively. For the base component, these values are "1", "0", "2" and "0" respectively. Next determine the total system time for the operation by multiplying the number in Column 2 by the added value from Column 6 and Column 7. Enter this value in Column 8 (this adds up to "2" for the base component). If the part must be separate enter "1" in Column 9; if not, enter "0". The base component cannot be eliminated therefore "1" is entered in Column 9. This process is repeated for all the other parts.

When the nine columns have been completed for every part in the product, total assembly cost and design efficiency can be calculated. Add the numbers in Column 8 to find estimated total time, T_a . Add the numbers in Column 5 to find the relative cost of additional grippers and robot tools, A_g . Take the largest number in Column 4 as the relative robot cost, A_{rmax} . Add the number of parts in Column 9 to find the theoretical minimum number of parts, N_m . These numbers are used to find the total cost per assembly from $C_i = [C_a A_r C_r T_a + (C_a A_g + D_f)] 10^5 / T_b$

Where C_a = Cost of standard assembly robot with two arms, each having 4 degrees of freedom.

C_r = Cost of using non-dedicated equipment of unit value

D_f = Total cost of parts magazines and work fixtures used with the assembly system

Because this is a relative comparison, the values of C_a and C_r can be seen in relative terms as unimportant. The typical values used here are 150 and 0.003 respectively. D_f is related to the number of parts in the system. Here for C_i a D_f of 5 shall be used. For the redesigned compression head valve $A_{rmax} = 1$, $A_g = 0.05$, and $T_a = 20$. This gives a total cost per assembly of $C_i = 10.75c$.

The theoretical minimum number of parts is the sum of the figures in Column 9.

Therefore $N_m = 5$. The "ideal" design has this number of parts. Each of these parts can be assembled in the basic system time of 2s and none requires a special gripper or tool. The cost of this ideal design is therefore $C_i = (2C_a C_r N_m + D_f) 10^5 / T_b$. Here for C_i a D_f of 4 shall be used, to indicate the potential for a better system ideally.

Therefore $C_i = 4.25c$. This works out to a design efficiency of 39.5%. The completed worksheet is shown as Figure J.

DESIGN FOR ROBOT ASSEMBLY WORKSHEET									
1	2	3	4	5	6	7	8	9	Name of Assembly
Part ID No.	# times operation performed consecutively	Robot insertion code	Relative robot cost, A_r	Additional relative cost, A_g	System operation time, T_p	Time penalty for gripper or tool change, T_g	Total system time (2)x[(6)+(7)]	Figures for estimation of theoretical minimum parts	Compression head valve assembly
6	1	00	1	0	2	0	2	1	Compression base
5	2	20	1	0.05	2	4	12	1	Compression disc
4	1	00	1	0	2	0	2	1	Seated valve
3	1	00	1	0	2	0	2	1	Disc spring
2	1	00	1	0	2	0	2	1	Compression head
			1	0.05			20	5	200,000
			A_{rmax}	A_g			T_a	NM	Total batch size, T_b

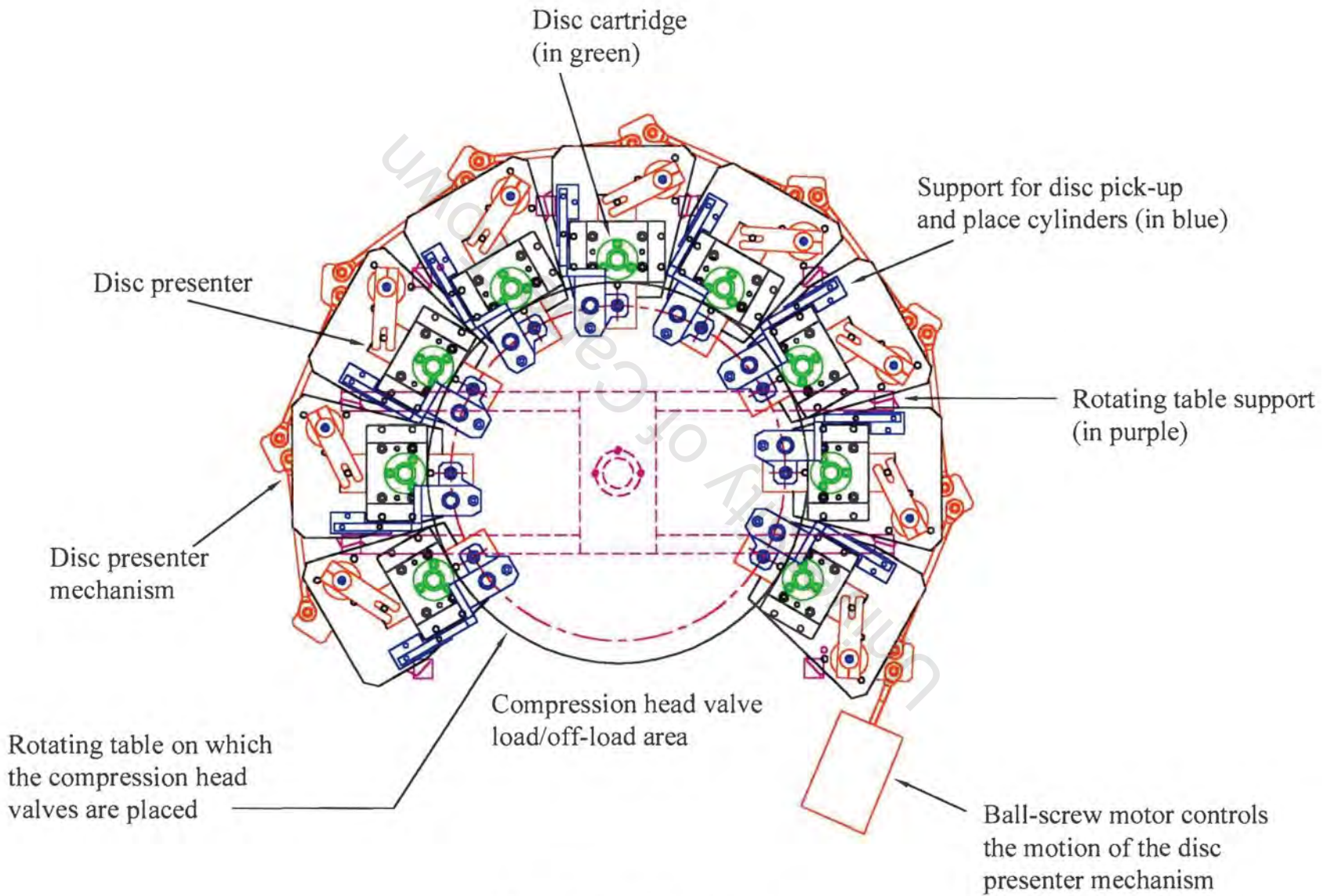
Figure J: DFA evaluation for robot assembly on compression head valve design.

APPENDIX C

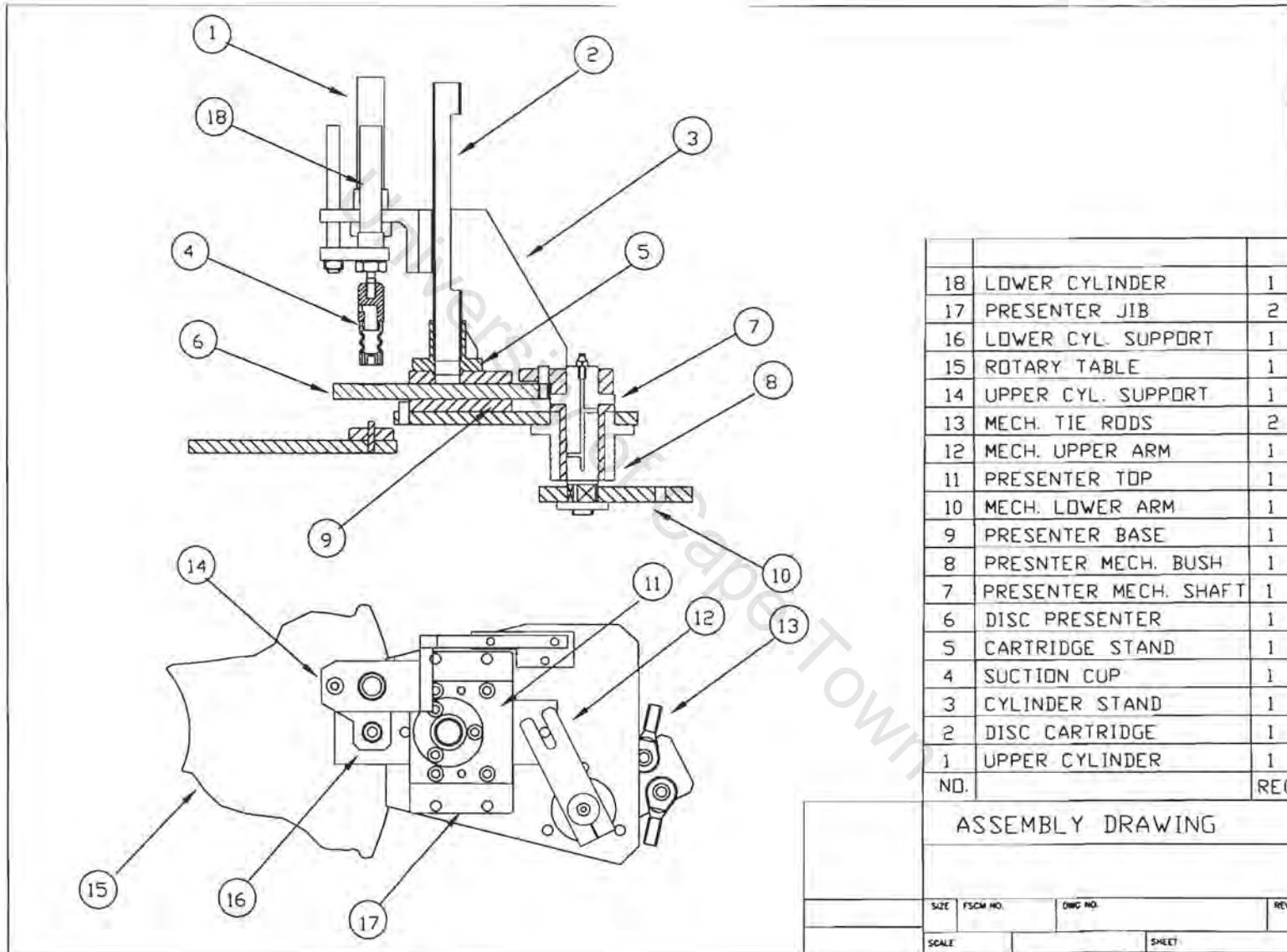
Design drawings for the new compression head valve assembly cell.

These drawings were done in AutoCAD 2000, and have been fitted to A4 size here for convenience. A disc containing copies of the AutoCAD files is included.

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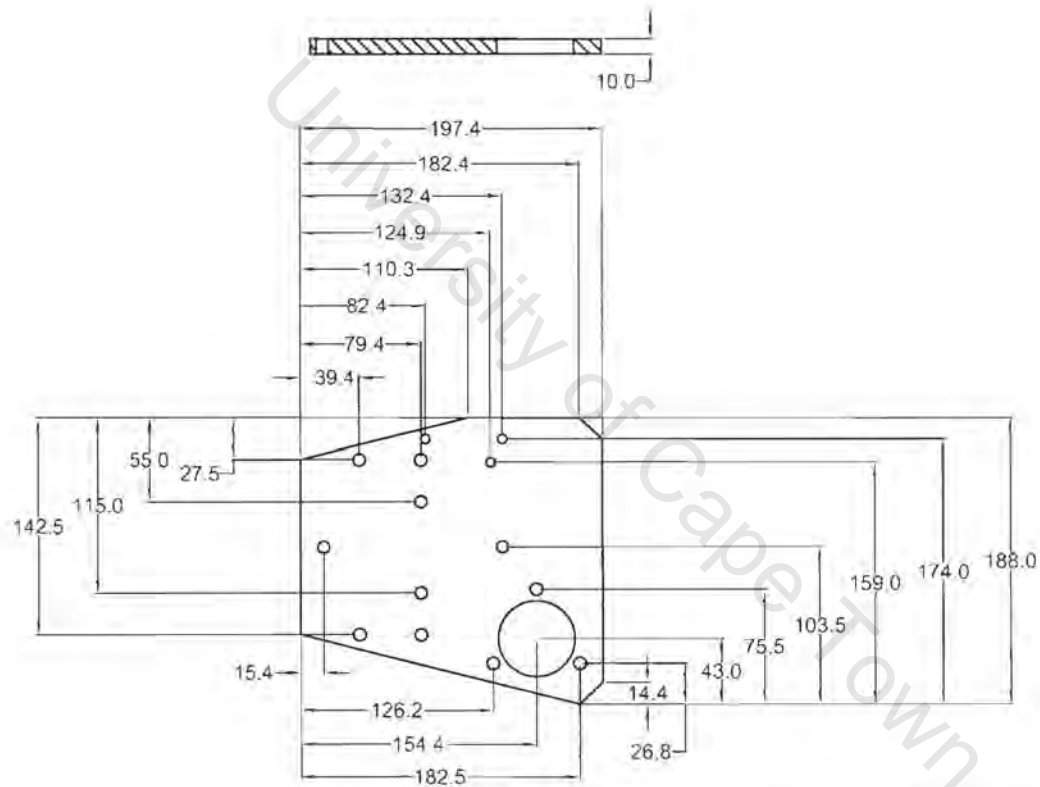
ASSEMBLY CELL LAYOUT



18	LOWER CYLINDER	1
17	PRESENTER JIB	2
16	LOWER CYL. SUPPORT	1
15	ROTARY TABLE	1
14	UPPER CYL. SUPPORT	1
13	MECH. TIE RODS	2
12	MECH. UPPER ARM	1
11	PRESENTER TOP	1
10	MECH. LOWER ARM	1
9	PRESENTER BASE	1
8	PRESENTER MECH. BUSH	1
7	PRESENTER MECH. SHAFT	1
6	DISC PRESENTER	1
5	CARTRIDGE STAND	1
4	SUCTION CUP	1
3	CYLINDER STAND	1
2	DISC CARTRIDGE	1
1	UPPER CYLINDER	1
NO.		REQ.

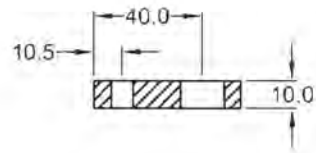
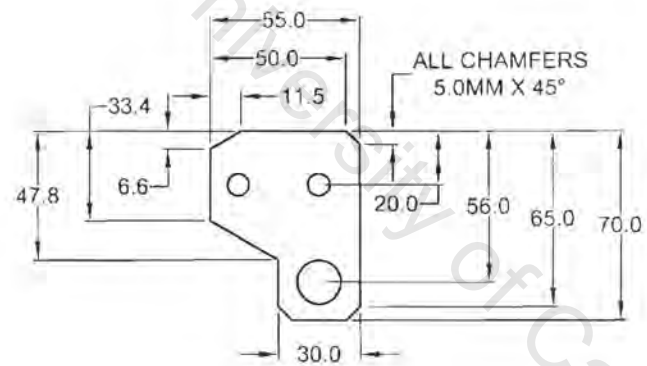
ASSEMBLY DRAWING

SIZE	FSCH NO.	DWG NO.	REV
SCALE		SHEET	



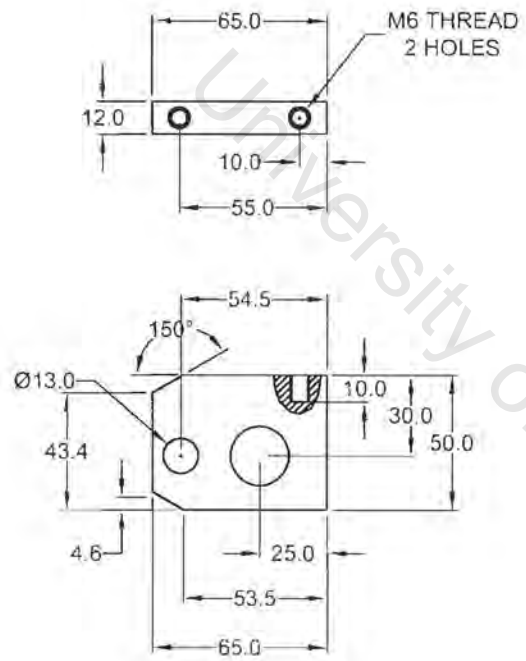
COMPONENT BASE PLATE

COMPONENT BASE PLATE			
SIZE	FSCH NO.	DWG NO.	REV
SCALE	SHEET		



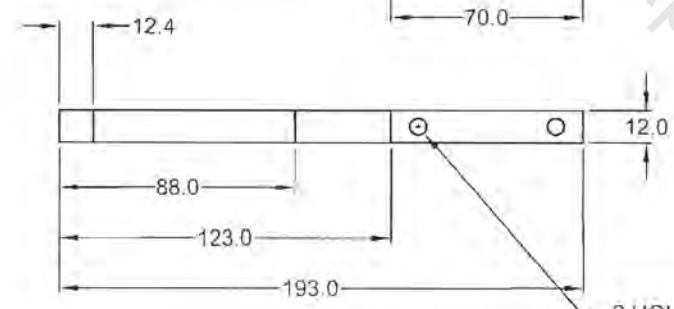
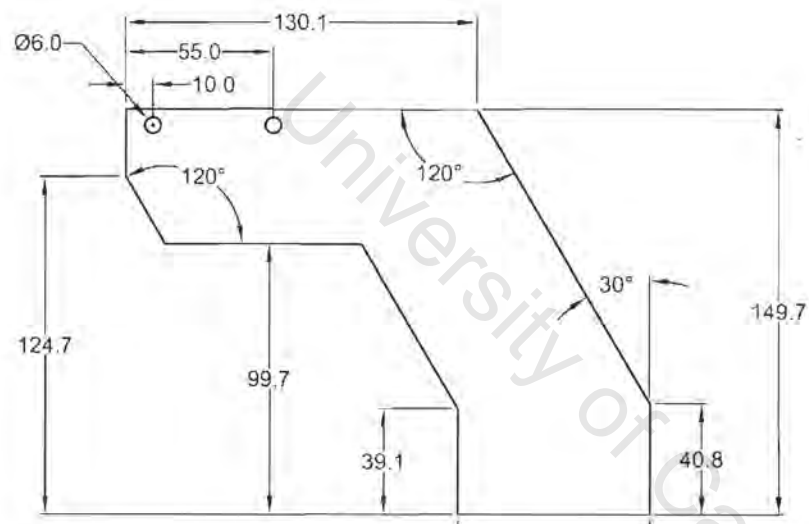
MATL: ALUM.

LOWER CYLINDER SUPPORT			
SIZE	FIG. NO.	DRG. NO.	REV.
SCALE			SHEET



MATL: ALUM.

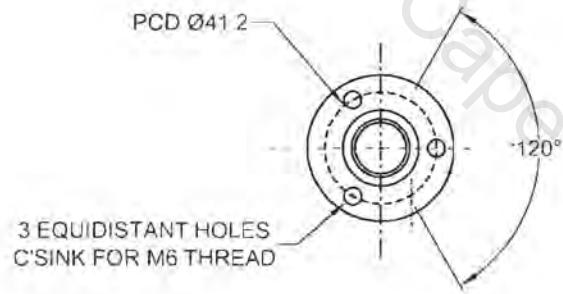
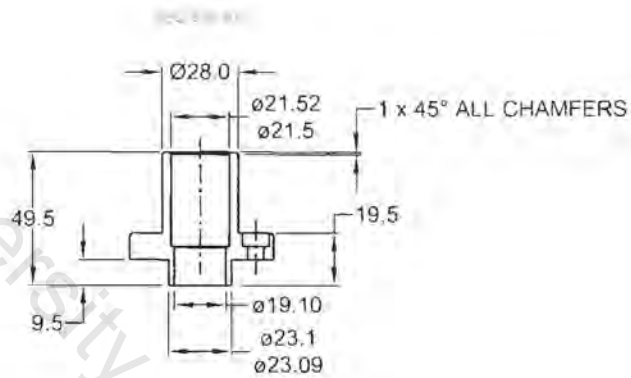
UPPER CYLINDER SUPPORT			
SIZE	FSCH NO.	DRG NO.	REV
SCALE	SHEET		



MATL. ALUM

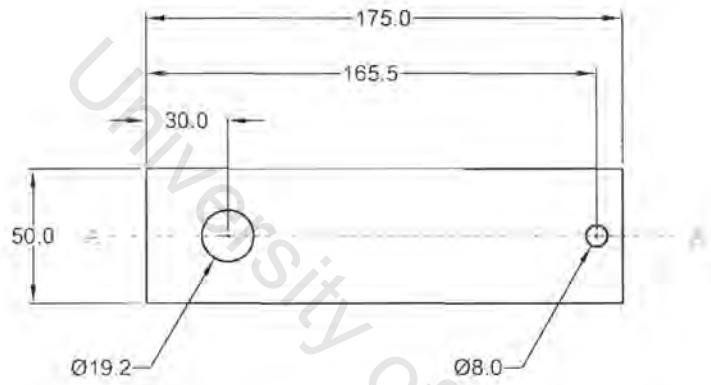
CYLINDER STAND			
SIZE	FSCH NO.	DWG NO.	REV
SCALE			SHEET

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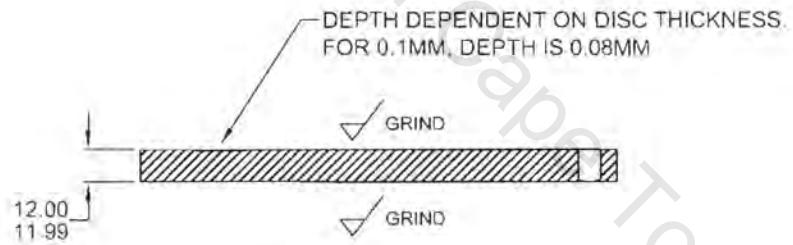


MATL: MILD STEEL

DISC CARTRIDGE STAND			
SIZE	FIG. NO.	DRG. NO.	REV.
SCALE			SHEET



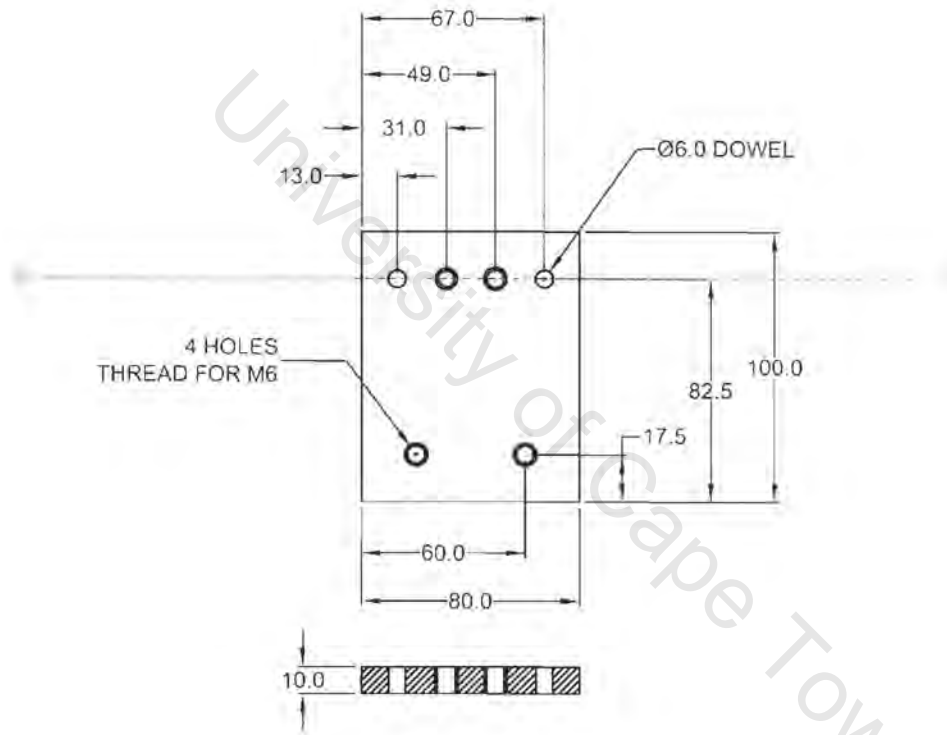
8.00 MM DOWEL PIN



SECTION AA

MATL: MILD STEEL

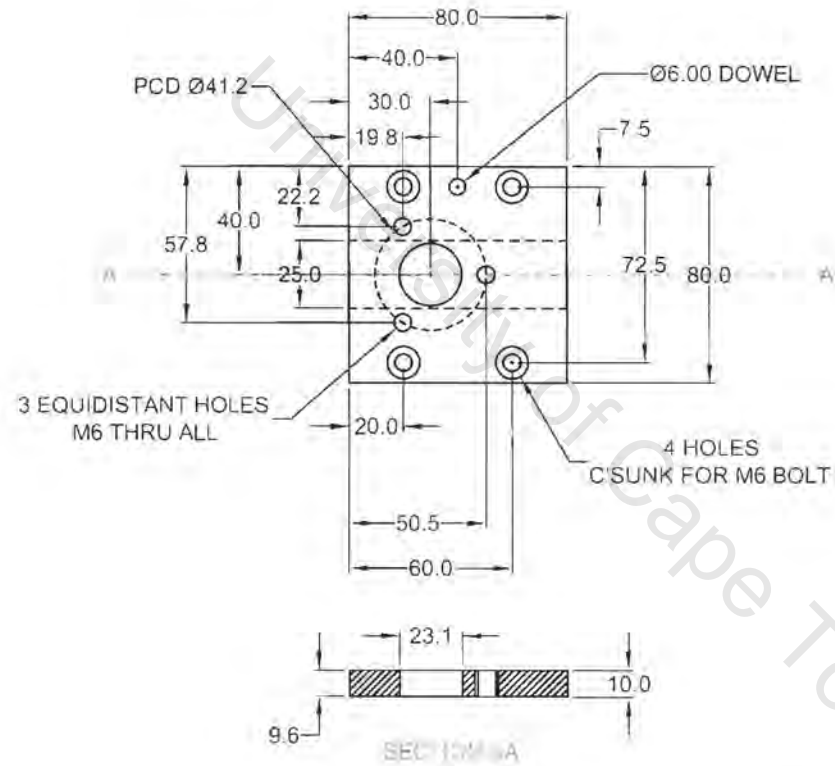
				DISC PRESENTER			
SIZE	FIG. NO.	DWG. NO.		REV.			
SCALE				SHEET			



SECTION AA

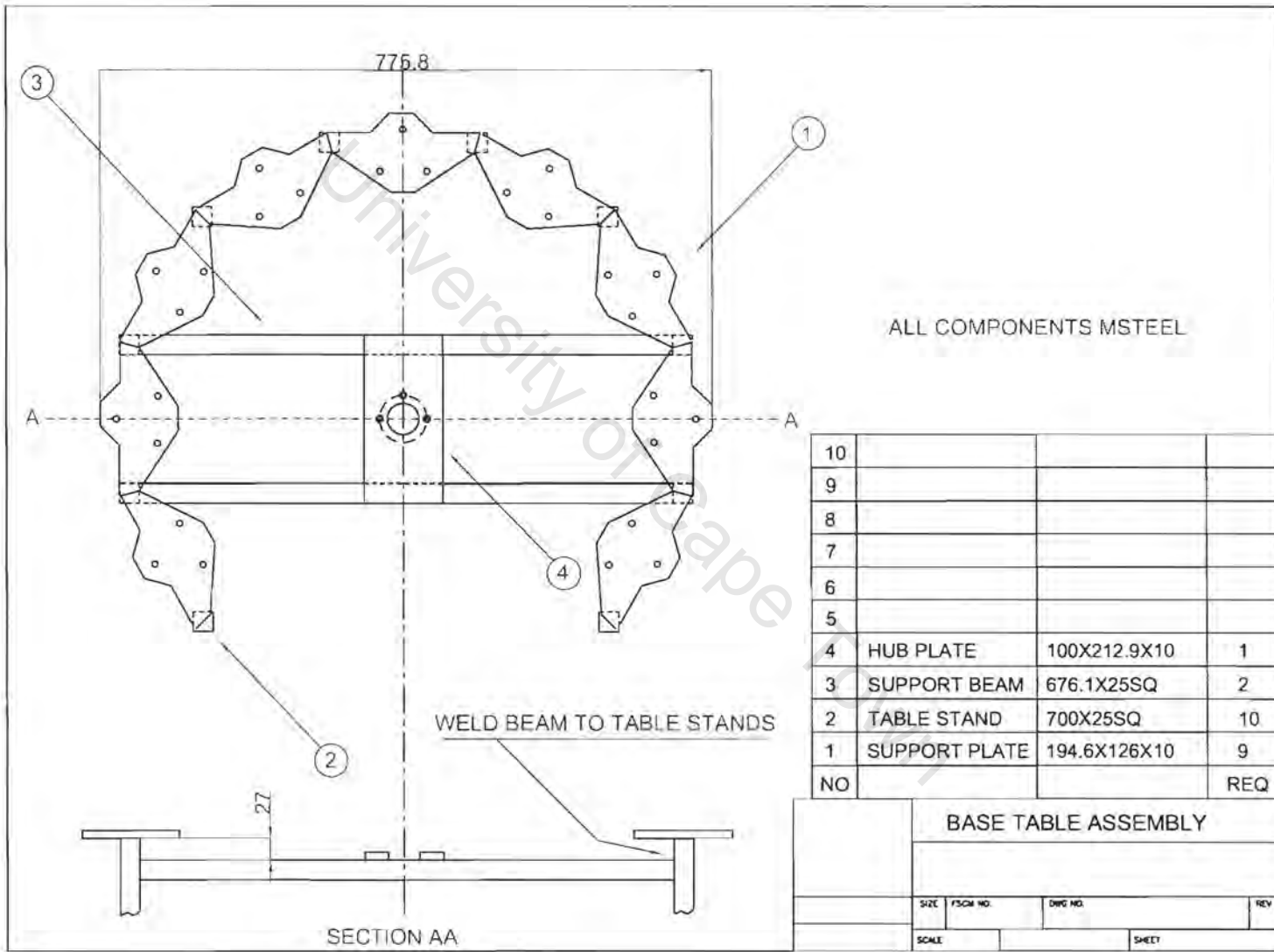
MATL. MILD STEEL

PRESENTER BASE			
SIZE	FSOM NO.	DWG NO.	REV
SCALE	SHEET		



MATL: PHOSPHOR BRONZE

PRESENTER TOP			
SIZE	FSCH NO.	DWG NO.	REV
SCALE			SHEET

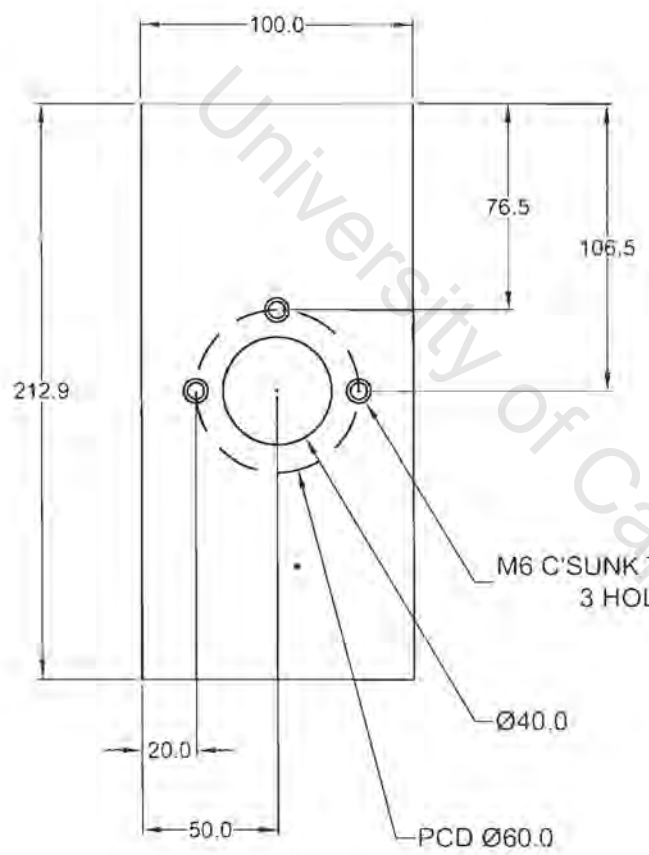


ALL COMPONENTS MSTEEL

10			
9			
8			
7			
6			
5			
4	HUB PLATE	100X212.9X10	1
3	SUPPORT BEAM	676.1X25SQ	2
2	TABLE STAND	700X25SQ	10
1	SUPPORT PLATE	194.6X126X10	9
NO			REQ

BASE TABLE ASSEMBLY

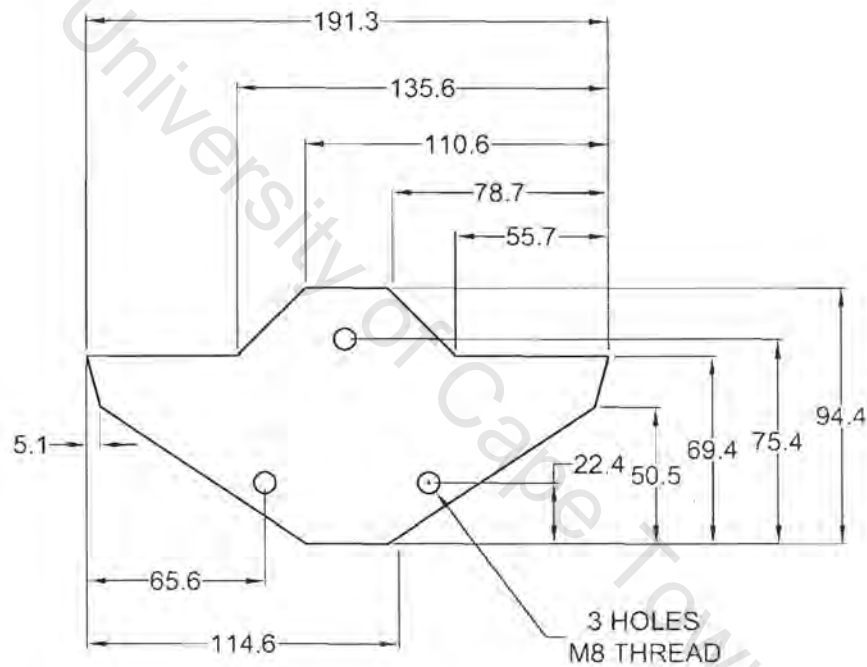
BASE TABLE ASSEMBLY			
SIZE	FSCH NO.	DWG NO.	REV
SCALE		SHEET	



M6 C'SUNK THRU ALL 3 HOLES

10MM THICK MSTEEL PLATE

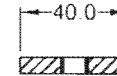
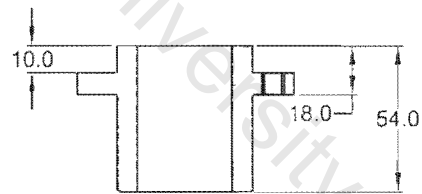
ROTARY TBL. MOUNT			
SIZE	TSCHM NO.	DRG NO.	REV
SCALE	SHEET		



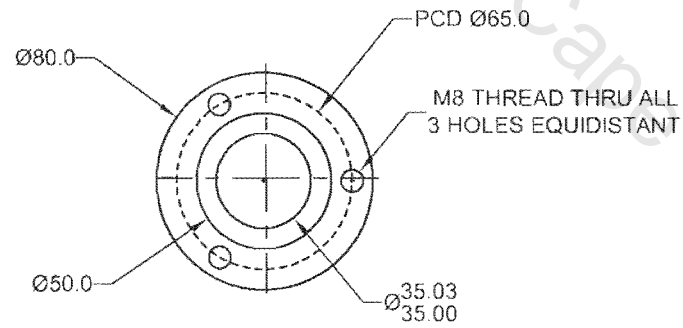
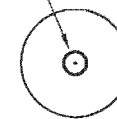
NOTE: WRT ANGULAR DIMENSIONS THIS COMPONENT IS SYMMETRICAL ABOUT THE VERTICAL AXIS.

NEEDED: 9 OFF X 10MM THICK MSTEEL

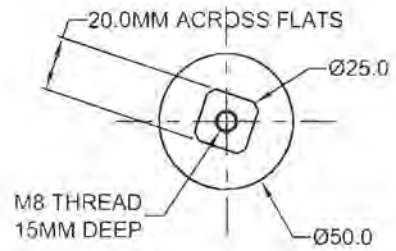
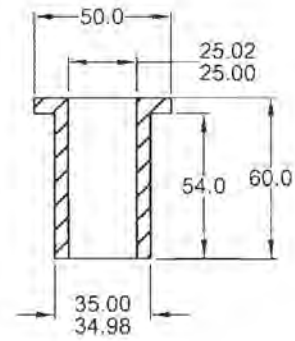
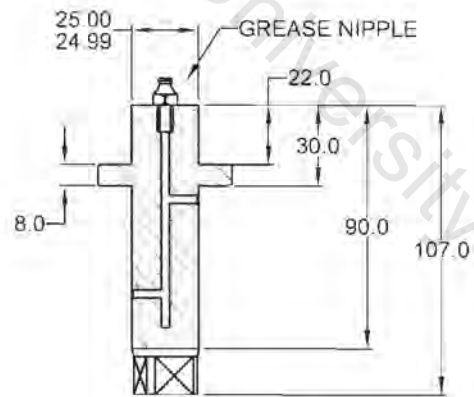
COMP. BASE PLT. MOUNT			
SIZE	FSCH NO.	DWG NO.	REV
SCALE			SHEET



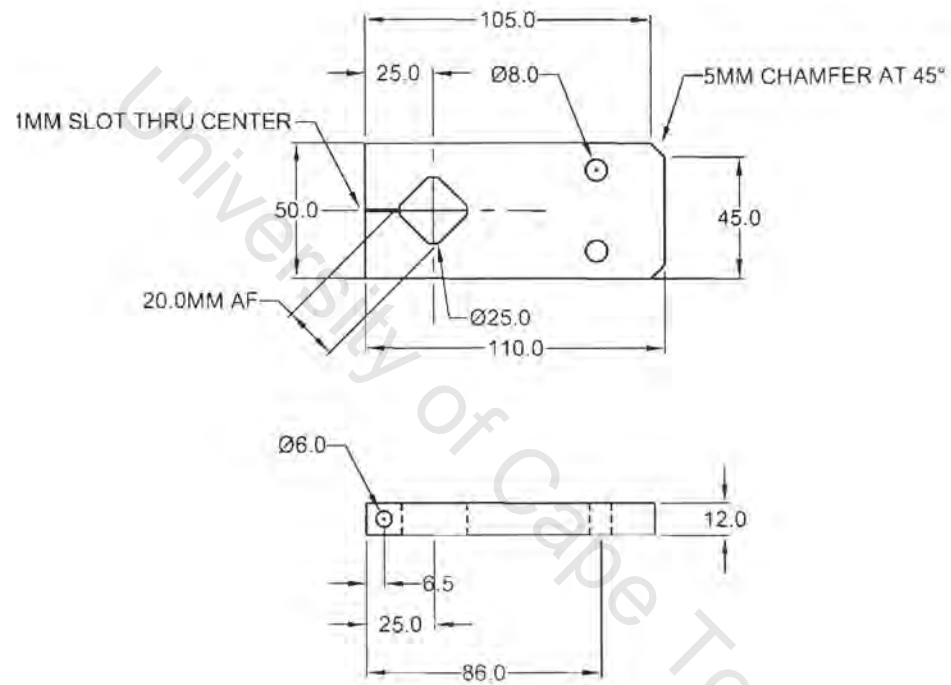
M8 THREAD THRU ALL



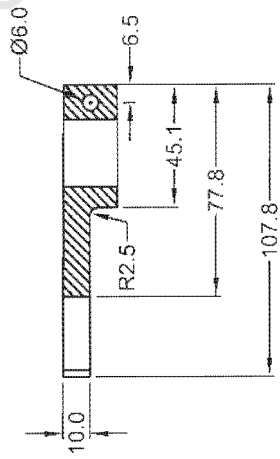
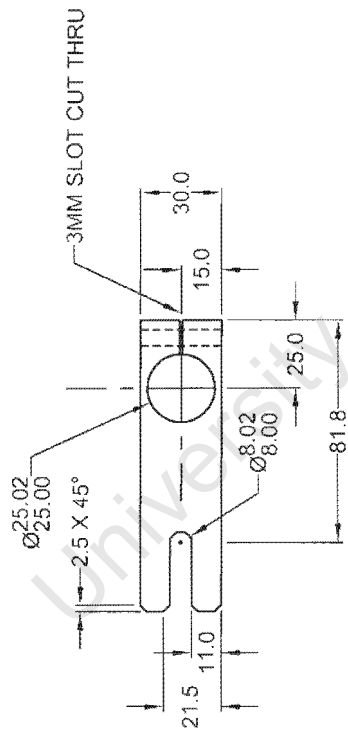
				PRESENTER MECH. BUSH			
	SIZE	FSCH NO.	DWG NO.		REV		
	SCALE				SHEET		



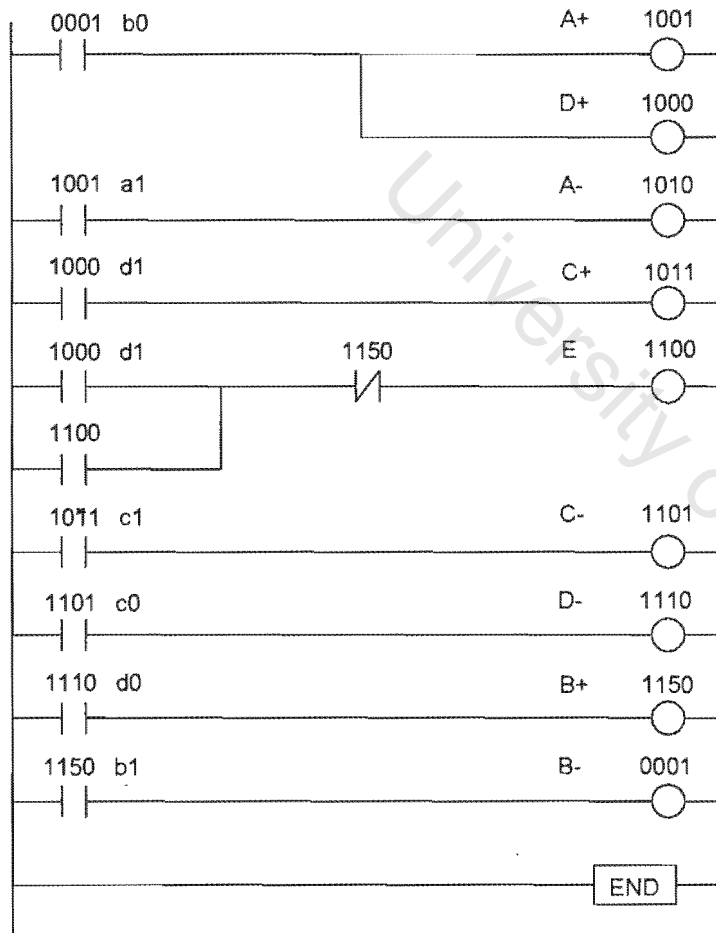
PRESENTER MECH. SHAFT			
SIZE	FSCH NO.	DWG NO.	REV
SCALE			SHEET



PRESENTER MECH. LOWER ARM			
SQC	FSCM NO.	DWG NO.	REV
SCALE			SHEET

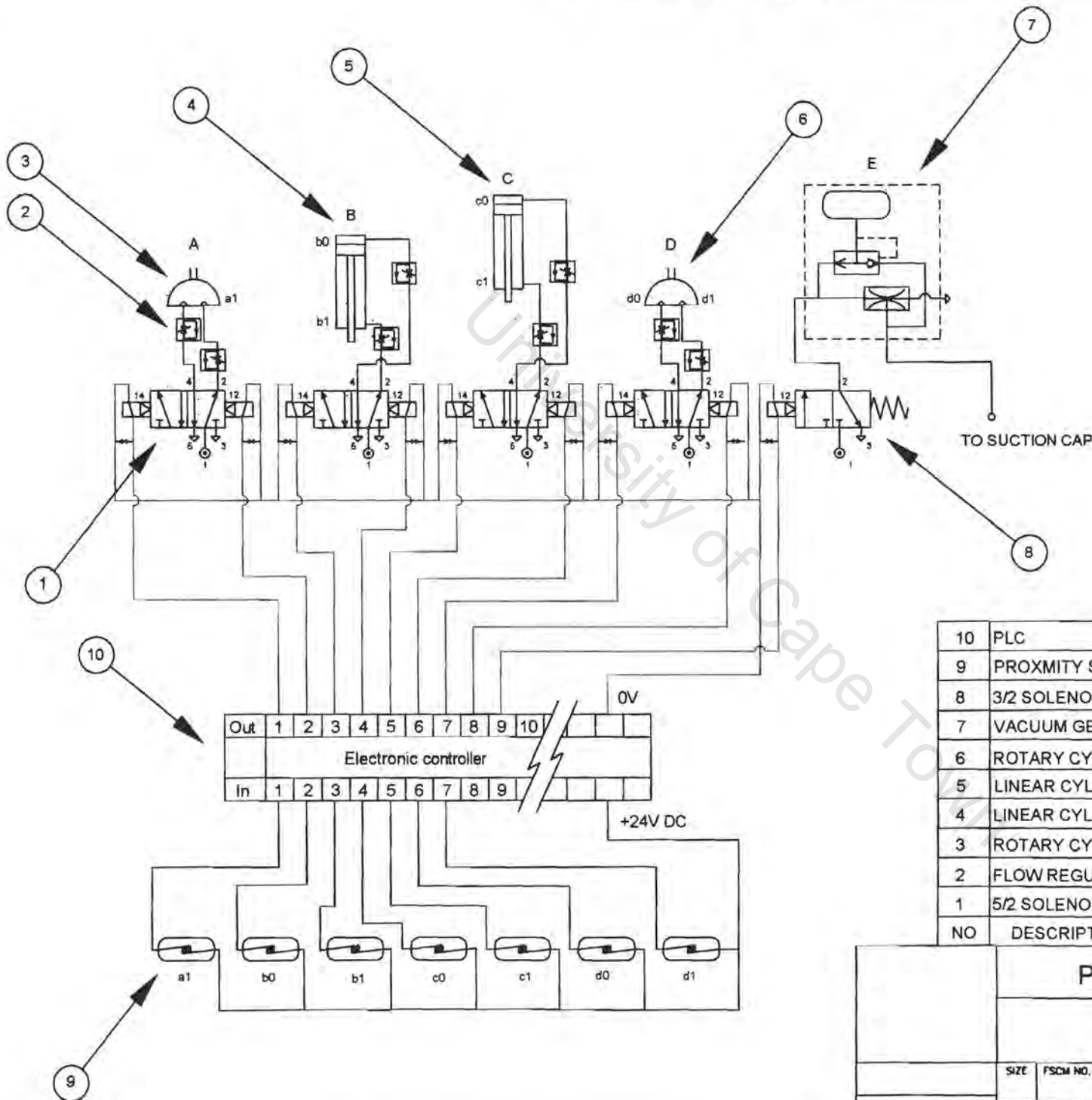


PRESENTER MECH. UPPER ARM			
DATE	FIG. NO.	DRG. NO.	REV.
SCALE		SHEET	



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	PLC LADDER DIAGRAM			
	SIZE	FSCM NO.	DWG NO.	REV
	SCALE			SHEET



10	PLC	?	1
9	PROXIMITY SENSOR	SEM-8-S-LED-24	7
8	3/2 SOLENOID VALVE	MYH-3-M5-L-LED	1
7	VACUUM GENERATOR	VAK-1/4	1
6	ROTARY CYLINDER	?	1
5	LINEAR CYLINDER	?	1
4	LINEAR CYLINDER	?	1
3	ROTARY CYLINDER	?	1
2	FLOW REGULATOR	GR-M5B	8
1	5/2 SOLENOID VALVE	JMYH-5/2-M5-L-LED	4
NO	DESCRIPTION	PART NO	REQ

PNEUMATIC CIRCUIT

SIZE	FSCM NO.	DWG NO.	REV
SCALE	SHEET		