The Design/Development of Automated Programmable Orientation Tools For Vibratory Bowl Feeders

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Declaration

The Design/Development of Automated Programmable Orientation Tooling for a
Vibratory Bowl Feeding System

Presented to: **Mr. Joe Phelan**

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This Thesis is presented in fulfilment of the requirements for the degree of Masters of Science. It is entirely of my own work and has not been submitted to any other college or higher Institution, or for any other academic award in this college. Where use has been made of the work of other people it has been acknowledged and fully referenced.

Signed: ____________________
Martin Maher

Date: ____________

Abstract

The success of Automated Assembly in Mass Production hinges on the effective performance of automated high speed part positioners. One such parts presenter is the conventional Vibratory Bowl Feeder (VBF). There is a need to extend this success of assembly automation in Mass Production into Batch Production. However, the lack of flexible part positioners to facilitate the handling of different batches of components is a major obstacle in this. A need for a flexible production feeder in batch production processes is therefore clear.

This project attempts to make progress in the development of a flexible VBF, the main problems being the inflexible nature of the orientation tools as currently employed. The project tackles the design, development and manufacture of a range of automated programmable orientation tools which, in combination, make up a typical orientation system for the VBF. Three prototype tools were developed: the Wiper Blade, Narrow Ledge and the Edge Riser Tools. These tools were focused for the purpose of the project on the feeding of a specific target component. Seven further orientation tools were designed with the intention of future development and implementation/inclusion into the feeding research process at a later stage.

As well as the tool automation programming, a programme was developed to drive the system automatically through a sequence of settings, whilst logging the data related to each. An algorithm was developed to establish the performance at each setting and establish the overall optimum. A design of experiment approach could be incorporated at a later stage to establish combined optimum settings (optimum taking into account the interdependencies). For the purpose of developing and demonstrating a prototype flexible VBF in the time scale available, the optimisation of each variable independently of the others only, was tackled in this project.

The outcome of this research was a prototype of a system of modular, programmable, interchangeable and self-optimisation orientation tools for the development of a fully flexible VBF system.

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1 Introduction

1.1 Background

To help maintain a competitive advantage in the global economy, manufacturing companies must continuously strive to increase productivity while reducing the manufacturing cost of their products. This can be tackled in various ways, e.g. reducing inventory cost, increasing machine utilisation (through flexibility) and/or reducing the direct labour cost. If productivity can be improved for instance by reducing the labour content of the process, this should help to reduce the manufacturing cost of their products.

Production assembly is generally the largest single cost element of product manufacturing. It has been estimated to account for 50 per cent of manufacturing cost and can employ more than 40 per cent of the workforce (Boothroyd, 1981). Consequently, attention to this aspect of production has the potential to yield great savings and should be a prime consideration when manufacturing cost savings are sought.

Automation is an obvious alternative solution to the high labour content of manual product assembly, but, it is important to remember that the initial capital invested is often very high. Moreover, one of the main disadvantages with automation is the difficulty of achieving flexibility within the process, in terms of shifting from one batch production process to another. However, if productivity can be improved through flexibility, then the initial cost of automation should be recouped through a reduction in the manufacturing cost of a product.

Conventional Vibratory Bowls Feeders (VBFs) employed to present parts to manufacturing machines in the correct orientations are used mainly in high volume production. The VBF is essentially a fixed-sequence feeding device, allowing a very limited range of parts to be accommodated for any given set-up and can therefore be considered unsuitable for batch manufacturing processes. This means that for batch production processes, work-piece orientation must be accomplished manually, unless alternative solutions can be found to the part orientation problems.

Conventional VBFs are considered as very versatile parts feeders but lack flexibility (they are configurable for many different components but they require huge set-up times). They have severe limitations even where families of parts, similar in shape but variable in weight and size are handled in the same system [Cokayne, 1991]. Their unpredictability occurs largely due to the vibrating nature of the machine. This is considered as a serious problem as it invariably affects overall performance. However, despite these problems they have become an integral part of the assembly process for the mass production system.

Modern manufacturing processes that utilize VBF technology require reliable production feeders (to reduce downtime and therefore cost) but ideally feeders that can be easily reconfigured for subsequent or future production runs. A flexible VBF might adapt readily to changes in part production mixes and levels of output, providing multiple components from the one bowl. This is valid to some extent in the mass production industry but is an imperative in Batch Production.

It is clear at this point that in order to make progress in the development of a flexible VBF (the focus of this project), that major consideration should be given to the design and development of programmable orientation tools. Automated orientation tools would certainly be useful in Mass Production as they would allow for slight variations in part design and geometry. Also these tools might be positionally adaptable, so that their position around the peripheral of the VBF would be interchangeable. These interchangeable features when incorporated might also allow more than one part family to be accommodated at different times within one VBF thus servicing the needs of Batch Production.

This thesis begins by examining the problems associated with current fixed-sequence VBFs. It discusses the different approaches taken by many researchers in the field in trying to solve the problem of inflexibility and represents how in the future, flexibility for VBFs may be attained [Maul & Goodrich, 1983; Lim, Ngoi, Lee et al, 1993; Jonega & Lee 1997; Maul & Jaksic, 1994; Tay et al, 2004). It then progresses to an innovative design solution towards making progress in the development of a flexible vibratory bowl feeder using “Automated Orientation Tools”. This challenges the standard VBF technology currently available. The current tool setting procedure throughout industry for the ubiquitous VBF is a lengthy, complex and totally manual interactive process demanding years of experience, specialisation, considerable skill, observational ability and intelligence. Because of this high cost set-up process and the consequent high volume nature of the applications, VBFs are seldom reconfigured for more than one component and are invariably retired at the end of the original component life.

The concept of developing modular tooling, adjustable tooling and indeed programmable tooling is not new. It was first proposed by Maul and Goodrich, 1983 (Fig. 1-1 below).

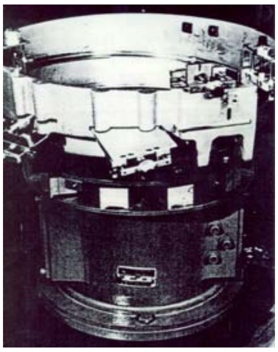


Fig. 1.1: Programmable Parts Feeder (Maul & Goodrich, 1983)

A logical extension to manual adjustable orientation tools (as developed by Maul & Goodrich), would be the design and development of a full range of tools with automated control features. These automated orientation tools should be designed with interchangeable features, which would allow the tools to be manually repositioned and sequenced as required in any order around the rim of the VBF: this would make the vibratory bowl feeding system more readily adaptable and flexible, by allowing the selection of the correct position of the tools for each part family. The most effective setting of each tool in relation to each part will be established automatically.

It is hoped that through this research that a fully functional and effective orientation system will be developed, using automated orientation tools. Its development should enable the deployment of this technology throughout industry. It would be ideally suited in batch production systems, where flexibility has been identified as a key requirement. It should also help in high volume industries by reducing, or eliminating, the time-consuming tool configuration process.

The work presented in this thesis was completed in the Advanced Manufacturing

Laboratory (AMTLAB) at Waterford Institute of Technology (WIT) and it addressed the design and development of automated orientation tooling as a partial contribution (stage one) towards the eventual development of a flexible VBF system. This thesis presents the outcome of a two year research project focused on the development of automated programmable orientation tooling for a VBF. It attempts to address the problem of inflexibility for VBFs. It describes the development of the WIT flexible VBF research cell. Three prototype flexible orientation tools (active and passive) were developed into a typical orientation system. A further seven orientation tools were designed with the intention of future development (see Appendix I). Extensive component feeding was carried out to confirm the design and functionality of the manufactured tools. This research and development should yield system level flexibility and finally help to solve the bottleneck in feeding for batch assembly.

Fig.1-2 below is a photograph of the Vibratory Bowl Feeding System, taken at the end of the project, showing the three prototype flexible orientation tools.

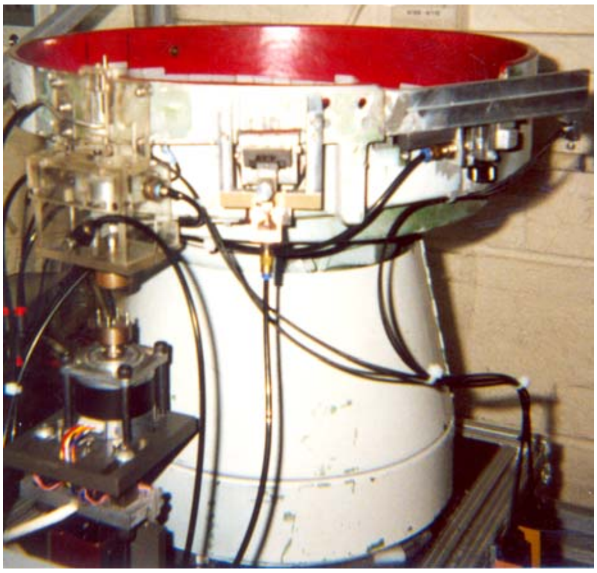


Fig. 1.2 The completed Vibratory Bowl Feeding System (AMTLAB)

The WIT VBF system developed consists of a standard 16” diameter AFAG Vibratory Bowl Feeder (mounted on a rigid frame), which has been modified to include the automated and flexible orientation tools. The system also contains the following elements:

- A standard AFAG VBF Controller.
- A Mitsubishi FX-48MR PLC for system control and data acquisition.

- An electrical circuit with associated power transformer and control switchgear.
- A Pneumatics Circuit for tool positioning, mechanical gear adjustment and air removal of jammed components.
- A Rotalink bi-polar Stepper Motor for tooling adjustment.
- A selection of reflective and through-beam optic sensors.

The Parameters of the Completed VBF System

A Typical Orientation System in automatic assembly has been described by Boothroyd [1981]. The VBF system developed here followed the same pattern. As in the system of tools selected by Boothroyd, those presented in Figure 1-2 (moving from left to right) consist of a family of orientation tools that included the Wiper Blade Tool (WBT), Narrow Track Tool (NTT) and the Edge Riser Tool (ERT).

Design guidelines and principles established by Boothroyd for the development of convention tools are also used in the design of automated orientation tools. Automated orientation tools are conventional orientation adapted for mechanisation. Mechanisation of conventional orientation tools, involved providing a means of tool adjustability or programmability through mechanical means.

The part selected for orientation in this project is a right rectangular prism. This part was originally identified by Boothroyd [1981] as a typical part for the purpose of experimentation on VBF performance. It was felt that selection of a similar part for use in this project would allow a comparison of the theoretical results provided by Boothroyd and the experiment results obtained in this research.

The overall dimensions of any orientation tool depends upon the parameters of the VBF selected. In industry the diameter and capacity of the VBF is selected based upon the size of the parts being conveyed and the required feed rate. The diameter of the bowl should ideally be at least ten times the length of the part it is to feed [www.autodev.com]. In this situation however the dimensions of the part depended on the size of the VBF already provided (donated from industry). The part selected for this project as mentioned above was a rectangular prism. The dimensions of this part was the only remaining component design feature to be considered for experimentation. Other parts could also be orientated in this system, for example washers, small cylinders, rectangular blocks with protrusions, nuts etc. If other parts are selected for future experimentation they should match the criteria mentioned above and satisfy the limiting factors of flexibility for these particular orientation tools.

1.2 Vibratory Bowl Feeders (VBFs)

Mechanical parts handling systems are used in a wide range of automated industrial processes. One of the main elements of assembly is the parts feeder and presenter (Fig. 1-3).

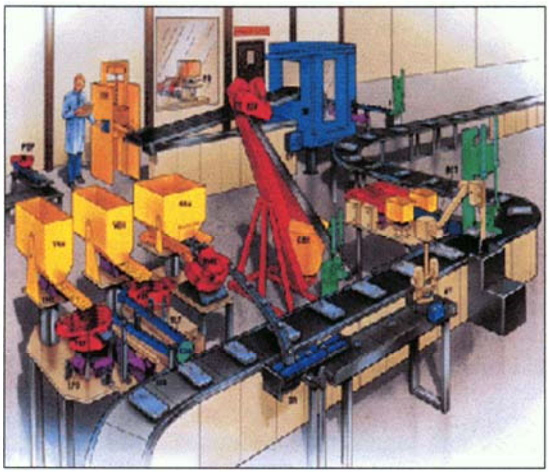


Fig. 1-3: The VBF Parts Feeder in Assembly (Cullinan, 2005)

VBFs are currently configured as special purpose parts feeders, and are usually dedicated to the feeding and orientating of one particular part or a small number of similar parts (family). However modern manufacturing processes, as stated earlier, require parts feeders that can feed and orientate more than one part. This is due to the demand for products in smaller quantities. The feeding and orientating of more than one part means that parts feeders should be adaptable or flexible (in terms of providing adjustability between different size and shape variations of parts, as well as being able to accommodate the inherent slight variation in part dimensions).

The main function of a conventional VBF is to supply a smooth continuous feed rate of orientated parts to the workstations of an automated assembly machine. The VBF orientates these parts using specially adapted tools (or traps) that are fitted to the VBF on the top row of its spiral track. The tools are initially placed in a specific order around the outer rim of the bowl (Fig. 1-4). They are then skilfully adjusted so the correct orientation is obtained at the required feed rate. The process requires great skill and experience. It is usually performed by an outside specialist (specialised tooling craftsmen) with vast experience in this area.

Fig. 1-4: Bowl Tooling on the VBF Track (www.autodev.com)

Disadvantages of Fixed-Sequence VBFs

1. There are persistent problems associated with obtaining constant feed rates from VBFs. Unpredictable feeding patterns associated with VBFs together with common problems of contiguous and overlapping parts, result in blockages (due to jamming) of the tools and a consequential loss in parts presenter efficiency.
2. Fixed-Sequence VBFs cannot accommodate a wide range of parts (different families) and are therefore considered inflexible for batch production processes.
3. In the initial set up process, the long lead times required in the development of specialised VBFs, which have been adapted with skilfully adjusted orientation tools for the feeding of a particular part, incur high cost

Flexible VBFs have not yet been developed, in terms of providing bowls that can be used economically for low and medium volume assembly (batch assembly). If a flexible bowl could be developed this should help to reduce the labour intensive nature of the batch production processes and hence utilize the full potential of the VBF. The ultimate goal in manufacturing terms would be to provide flexible VBFs that would contribute substantially to a flow-line (un-interrupted) batch production process, by reducing the set-up/downtime required for product changeover.

Advantages of a Flexible VBF

1. A programmable flexible VBF would reduce or eliminate the time and cost involved in re-tooling; this could help to shorten changeover down times even in

large volume production.

2. The development of VBFs in batch production should give greater control over the levels of output for batch production processes; this would help to improve productivity.
3. The possibility arises (with programmability) of improving the performance of the VBF in relation to varying part dimensions within production families. This could allow relaxed part tolerances to be accommodated which would lead to significant cost reductions.
4. The VBF is now a well-tried and tested technology. Migration from mass production to batch production has been a common development process for much of the current technology in batch production. This migration is long overdue in the case of the VBF. It could considerably reduce the part feeding element cost of batch manufacturing, thus helping the drive towards increased variety.
5. VBFs are currently retired at the end of product life due to the high cost of redemption. The flexible VBF may extend the life of the VBF across multiple product lifetimes thus leading to further cost reductions.

1.3 Previous Related Research at WIT

1.3.1 The WIT AMT Labatory

Postgraduate research commenced in the Advanced Manufacturing Labatory (AMTLAB) at WIT in 1995. This facility was established to study the application of advanced manufacturing theories and technologies in manufacturing facilities. Initial research centred on a number of stand-alone-machines, with the intention of developing a Flexible Manufacturing Cell (FMC). The first stage concentrated on the automatic manufacturing of Product 1 (Fig. 1-5) and was completed in 1997.

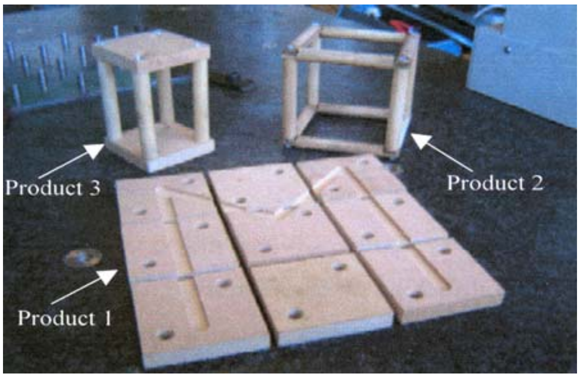


Fig. 1-5: WIT AMTLAB FMS Products (Alexander, 2005)

It resulted in the successful mechanical integration of these stand-alone machines by means of a Bosch conveyor system and the development of a master PLC/SCADA control and monitoring system, which is enabled by a series of network machine-PC interfaces. The development of this first stage is documented in the following MSc theses: [Cross, 1997], [Maher, 1997], [O’Connor, 1998], [Mitchell, 1998], [Mc Nelis, 2001] and a number of papers by Phelan et al [1999-2009].

The development of the FMC continued with single product focus switching to multiple product production in 2000, where products 1 & 2 could be produced simultaneously on separate designed machines [Barry, MSc Thesis pending]. More recent developments have seen the successful upgrade of the FMC into an FMS (Flexible Manufacturing System) where products 1 & 2 can be produced simultaneously on any available machine [Alexander, 2005]. Various other postgraduate projects have collaborated to improve the overall flexibility of the FMS (Fig. 1-6) and are documented in the following MSc theses: [Flanagan, 2004], [O`Mahoney, 2004], [Brennan, 2004], [Murphy, 2000].

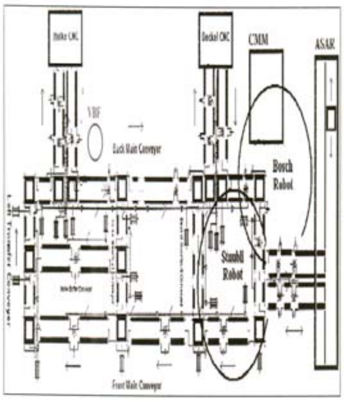


Fig. 1-6: Current Layout of the WIT AMTLAB FMS (Flanagan, 2004)

Currently, one VBF only is deployed in the cell (for the feeding of screws to the stabuli robot). Future products are being envisaged which will require the deployment of multiple VBFs as well as flexible VBFs [Alexander, 2005].

In 1997 post-graduate work began on the design/development of a high speed dedicated Automated Assembly System based on an earlier rotary indexing table. The objective of this project was the design, construction and commissioning of a fully functioning automated system, using a suitable product for assembly. The outcome was the development of a fully automated assembly of an audio cassette tape head cleaner (Fig. 1-7) with an output rate of one cassette every three seconds [Murphy, 2000].

Fig. 1-7: The WIT Automated Assembly System (AMTLAB)

1.3.2 Previous VBF Research at WIT

In the course of the development of workstations for the Automated Assembly System, it was deemed essential that parts be provided at certain stations in large volumes and in strict orientation. VBFs were integrated into the system for this purpose. Two separate undergraduate projects were undertaken with the objective of developing and commissioning these feeders. These projects examined the installation of VBFs and illustrated certain practical aspects of their performance [Brennan, 1999 and Nagle, 2000] and were based on Boothroyd's research in Automatic Assembly [Boothroyd, 1981].

Boothroyds analysis of conventional fixed sequence VBFs and a future requirement for flexible VBFs within the WIT FMS, inspired the ambitious project being presented here.

1.4 Project Objectives

This project was the starting stage (stage one) of a process concerned with the eventual development of a flexible VBF system. It consisted of the design, development and experimentation of a suite of prototype automated and flexible orientation tools that act in a unified VBF system. The design of seven orientation tools was proposed for future development (see Appendix I). These tools when fully developed as automated orientation tools (using the guidelines and principles developed for the prototype tools) should contribute to the eventual development of a the flexible VBF. The full benefits of a flexible VBF are yet to be realised.

The overall goal of the AMTLAB VBF is the eventual development of an automated flexible VBF. This VBF should help to solve the high cost involved in the tool setting process for high volume industry and deliver vibratory bowl flexibility for batch production set-ups. The tool setting factors where possible cost reductions have been identified are as follows:

- It will eliminate the need for specialised tooling craftsmen who are normally associated with the tool setting process.
- The need for retooling will be eliminated as slight changes in part geometry size/shape can be accommodated with automated (adjustable) tooling.
- The high cost associated with bowl tooling or reconfiguration leading to excessive lead-times will be dramatically reduced.

The specific objectives of the project were as follows:

1. To design and fully develop the first automated orientation tool (the wiper blade tool). This could be used as a prototype for future automated orientation tools. This tool should demonstrate the modularity/inter-changeability and re-programmability of prototype orientation tools for a VBF system.
2. To build a programmable system to control the automated orientation tools so that they could be adapted to new component features.
3. To design and develop further prototype mechanised and automated programmable orientation tools for VBFs.
4. To identify, study and design a wide range of future tools that would in future provide a platform for a flexible VBF system with large scale application in industry.
5. To build and test the new system by addressing the automated setting of these tools when feeding a specific targeted component.

The main objective of this project therefore was to develop prototype automated orientation tooling in the AMTLAB at WIT in terms of mechanical development, modularisation/inter-changeability and re-programmability using similar design principles as fixed sequence tooling. In striving towards these objectives the following intermediate objectives or milestones were identified:

- To investigate and gather information on VBFs that could be used along with current research to support decision-making in the project.

- To examine the operation of conventional VBFs identifying the critical aspects of its performance. The dynamics and mechanics of vibratory conveying would be addressed at this stage.
- To research various orientation tools developed for conventional fixed-sequence VBFs. This information would assist in the design process helping to contribute to the development of Prototyping Automated Orientation Tools such as the Wiper Blade, Narrow Track and Edge Riser Tools.
- To develop Prototype Automated Orientation Tool designs for seven future tools, the Step Module, Hold Down, Pressure Break (Wall Projection Module), Slotted Track, Sloping Track (Ledge Module), Cut-Out-Vee and Cut-Out-Notch (Scallop Module).
- To develop hardware and software for the first prototype automated orientation tool. This would be used to establish a common methodology for future orientation tools which would demonstrate the adaptability and re-programmability of automated orientation tool control using a PLC based control system.
- To evaluate the performance of the automated orientation tools using experimental data obtained from these tools, these experiments were conducted in the Advanced Manufacturing Technology Laboratory (AMTLAB).

It was anticipated that in the next stage, (Stage two), an automated adaptive feeder would be fully developed. This might involve the modularisation/inter-changeability, automation and computerisation across a wider range of tool types.

1.5 Summary of the Results

The detailed results of this project are presented in Chapter 7. Below is a brief summary of the achievements of the project at the time of writing:

- A suite of three functioning, automated prototype orientation tools (one programmable and two flexible) have been developed, these combine to provide a unified orientation system.
- Seven further orientation tools have been designed with the intention of future development and inclusion into the AMTLAB VBF (see Appendix I) at WIT at a later stage
- An Algorithm specifically developed to measure tool performance at each tool

setting, has been employed on all three orientation tools. A 'Design of Experiment' approach was considered at that point, but was postponed due to the time constraints of the project.

- An Automated Search Process has been developed whereby a suite of experiments is carried out on the prototype Wiper Blade Orientation Tool, this resulted in the automatic setting of the tool in its optimum position. It was then used on the remaining tools, the NTT and the ERT.
- A PLC program has been developed to control the tool operation and to monitor the unified orientation system.
- The design of the Wiper Blade tool is unique and identified the need for tool adjustability from a mechanical, electrical and programmability point of view. The design of this tool has been effectively standardised and implemented as a firm basis for future development.
- Experiment results have been achieved for the prototype tools developed in a unified VBF system. Tool setting for the Wiper Blade tool has been successfully optimised and automated.

2 A Review of Vibratory Bowl Feeding Technology

2.1 Introduction

The automated assembly process requires a constant supply of parts at the required feed-rate. Component feeding devices, such as the vibratory bowl feeder (VBF), form part of an integrated parts handling system and have therefore become an essential part of the automated process. This chapter provides a review of the conventional (generic) VBF.

The integrated parts handling system and the role of parts feeding in assembly is discussed. The various types of VBF are examined with regard to design, selection, construction and operation. The undesirable features of VBF conveying are discussed. Various groups and types of tooling devices are explained including their basic tooling principles. Consideration is given to the various aspects of parts positioning including part selection, orientation and presentation. The chapter concludes by describing the mechanics of VBF conveying and outlining the tuning procedures involved.

2.2 Manual Vs Automated Assembly

Assembly is a term used to explain the joining of two or more component parts. When all of the parts are assembled together they produce a sub-assembly or a final product. In the selection of assembly method there is a major strategic choice to be made between manual (operator) or automatic assembly. This discussion highlights an area of viability that exists between manual or automated assembly. It also defines the key technical requirements of VBF technology for use in automated assembly systems.

Before discussing automated assembly systems in some detail, it might be useful to compare operator assembly and automated assembly approaches. This would provide a clear understanding of the relative advantages and disadvantages of each type.

Manual assembly is extremely flexible in terms of accommodating variations in product design, whereas automated assembly will require a completely new machine or process. A manual operator is able to select, inspect, orient, transfer, place and assemble the most complicated parts easily, but many of these operations remain difficult if not impossible, to duplicate on a machine [Boothroyd, 1981]. In marked contrast, changes to the design of a product will generally require a greatly modified system. Manual assembly is therefore considered the most cost effective approach for small to medium sized quantities or where frequent design changes occur.

2.3 Automated Assembly

The term "automated assembly" refers to the use of mechanised and automated devices to perform various fixed sequence operations, in an assembly line or cell, combining multiple components into a single entity [Grover, 2007]. It is used to produce a wide variety of products or sub-assemblies in industry in high volume production processes. There has been significant progress made in the area of high volume assembly, (e.g. the automobile industry), in the last two decades. This has been attributed to advances in the field of robotics. Industrial robots are important components in manufacturing assembly systems because the are capable of consistently accurate and speedy operations. Modifications to existing assembly systems, or the incorporation of completely new systems, are easily performed through the reprogramming of robotic procedures.

The four basic design configurations for automated assembly systems have been classified by Grover [2007] as follows:

1. In-line assembly machine.
2. Dial-type assembly machine.
3. Carousel assembly machine.
4. Single action assembly machine.

Since the development of an automated assembly system involves high capital expenditure, certain conditions must be met to justify such expenditure. According to Boothroyd [1981], the following conditions must exist:

- A 'sufficient' demand for the product.
- A 'stable' product design.
- A 'limited number' of components for assembly (12 perhaps).
- Product is designed for automated assembly.

The fact that usually dedicated assembly systems become redundant at the end of their product life cycle or where minor design changes have to be implemented, must also be taken into account.

A Flexible Automated Assembly System

An assembly system that is automated yet flexible would be 'ideal' for industry. This ideal system would make the decision to automate more economically feasible for small products runs. It has been suggested that flexibility in automation would involve providing for frequent design changes involving many different models [Wolfson & Gordon, 1997]. A flexible automated system should also be capable of assembling multiple parts and models simultaneously with very quick response time provided for part design changes.

2.4 Component Feeding in Automated Assembly

One of the main problems in automated assembly that affects efficiency is the difficulty in providing a constant supply of correctly orientated parts to the work-head of the assembly machine. The objective is to present parts in strict orientation and at a constant feed rate to a specific location. The reality of normal supply is that parts are stored loosely in bulk containers. Separating and orientating these parts for assembly remains a difficult task. The difficulty will be exaggerated when considering the feeding of different kinds of parts (or even different sizes of the same part) using the same parts feeders.

Performance Requirements of a Parts Feeder

Boothroyd defines the performance requirements of parts feeders as follows:

- The parts presented by the feeder must be in the same correct orientation.
- The restricted feed-rate should not vary widely.
- The mean unrestricted feed-rate must not fall below the output rate of the machine being fed.
- The parts feeder should be designed so that the possibility of parts jamming in the feeder, or in its orienting devices, is minimized or eliminated.
- The parts feeder device must ensure rejection of any foreign matter from the feed track/line.
- The parts feeder must ensure minimal damage to the parts being fed.
- The parts feeder should be designed to operate as quietly as possible.

2.5 The Conventional Vibratory Bowl Feeder

The three main categories of parts feeders have been classified by Boothroyd as follows:

- Non-Generic Special Feeders.
- Generic Non-Vibratory Feeders.
- Generic Vibratory Bowl Feeders.

Non-generic parts feeders are ‘special solution’ parts feeders and are usually developed for specific parts. The Generic Non-vibratory feeders are classified into three main categories; Rotary feeders, Reciprocating feeders and Belt type feeders. The generic vibratory bowl feeder is the most common and versatile of all hopper feeding devices for small engineering parts [Tay et al, 2004]. It was first introduced back in the late 30’s and early 40’s. The first patented electromagnetic drive system is associated with Carl Weyandt of Syntron/FMC Technologies, Pennsylvania, US, but it is still not clear who invented the first VBF. This following section presents the Generic Vibratory Bowl Feeder as a essential component of modern assembly processes.

2.5.1 The Integrated Parts Handling Systems:

The requirement of a steady feed rate of parts is common in manufacturing and assembly. Work-piece (part) orientation is usually accomplished via parts feeders or by transfer devices that can maintain orientation. The conventional VBF is a self-contained unit that utilizes vibration motion to feed and manipulate parts in a consistent repeatable position. Feeder bowls select, orientate and sort parts in the most cost effective manner therefore eliminating the hand selection, inspection and assembly process. These bowls have become an essential part of a parts handling system, designed for feeding one particular part or a selected number of similar parts (family).

The VBF is therefore the heart of many parts handling systems (Fig. 2-1). It performs the three main functions of Singulation, Orientation and Presentation of parts for automatic assembly.

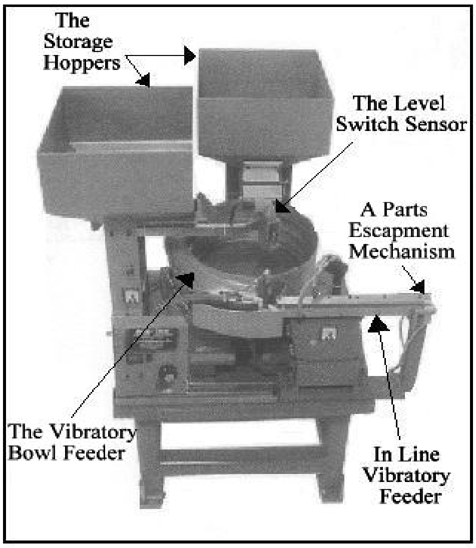


Fig. 2-1: The Integrated Parts Handling System [www.autodev.com]

The parts handling system may also contain some or all of the following elements:

- A storage hopper.
- A level switch sensor.
- An inline vibratory feeder.
- A parts escapement mechanism.

The storage hopper is essentially a 'bin' that stores parts in mass quantity. Its main function is to deliver a regulated flow of parts to the VBF. This helps to maintain a constant level of parts in the bottom of the bowl. This is important because the volume of parts in the bowl must be controlled at approximately 25% (often one layer deep) of the bowls capacity in order to maintain a maximum feed-rate from the VBF [Boothroyd, 1981]. A regulated level of parts helps to reduce the risk of jamming under the orientation tools and in the return pan when the bowl is being operated [www.autofeed.com].

The purpose of the level switch sensor is to detect when the level of the parts in the bowl falls below the required level: the switch will then activate the storage hopper and refill the bowl to the predetermined level. This ensures that the VBF is never overloaded or under-loaded when operating condition.

As the components are singulated and orientated from the vibratory bowl they are then supplied to the tracking system. This tracking system will provide a buffer of orientated parts to the assembly process. A tracking system consists of a linear-horizontal or sloping track that uses gravity feed, vibration or conveying motion to transport parts upstream to the parts escapement mechanism.

The parts escapement mechanism allows for the effective release of the correctly orientated parts at the correct location. When all of the components of a parts handling system are integrated as a unified system it produces a steady flow (constant feed rate) of orientated parts for the associated assembly operation.

2.5.2 VBF Construction and Operation

A VBF is a dynamically balanced vibratory system made up of two essential ‘parts’ or sections connected by springs (Fig. 2-2). The top part consists of a part orientation bowl that is either made of cast aluminium/synthetic or fabricated stainless steel. An electromagnet striking plate is attached underneath; this is part of the vibratory drive unit. The second part is an electromagnetic coil that is connected directly to the base. Between the bowl and the base a series of leaf springs (commonly three blocks of springs, but occasionally four) are connected or arranged at regular intervals along the circumference of a circle in the plane of the bowl. These springs are used to constrain the vibrating system as well as supporting the structure of the VBF system.

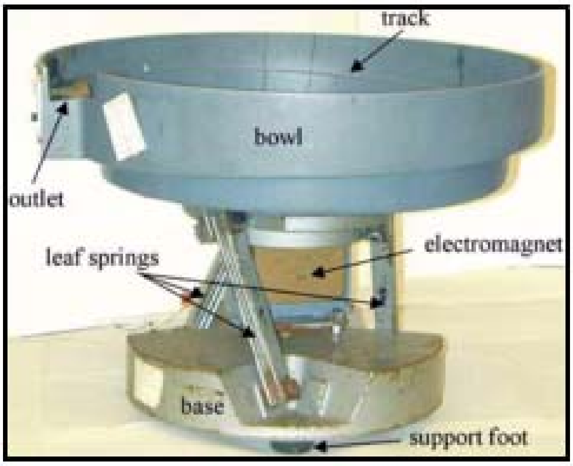


Fig 2-2: A Typical Vibratory Bowl Feeder (Maul & Jaskic, 2002)

In this case the bowl and the volume of parts placed within it will be considered as a single mass that is vibrating through the action of a vertical forcing function provided by the electromagnet. The electromagnet used to vibrate the system has a natural frequency of 50Hz to 100Hz. Normally a 50Hz mains supply produces 100 magnetic cycles per second and transmits 100 magnetic cycles (or strokes) to the vibratory bowl. The number of strokes produced by the electromagnet therefore relative to the frequency of the power supply. A variable amplitude controller adapted with a bowl potentiometer is used to control the length of bowl stroke. Controlling the length of bowl stroke ensures the normal amplitude of vibration ($\mathbf{a_n}$).

As the electromagnet forces the striking plate towards itself, during each pull of the magnetic cycle, it also pulls the bowl vertically (linearly) downwards . The inclined springs acting under a compressive load will cause the bowl to move torsionally about its vertical axis [Boothroyd, 1981]. Under the action of this vibration, parts within the vibratory bowl will move in a cylindrical format about the base of the bowl. The parts in the cylindrical base or bottom of the bowl tend to circulate at a greater speed than the parts on the inclined track [Boothroyd, 1981].

This movement in the bottom of the bowl results in parts separating and working towards the outer wall of the inclined track. Climbing between the part and the inclined track occurs due to the mass of parts in the bowl and the track vibration. Each part seems to be sliding or hopping along a straight path towards the upper level of the bowl. It appears that each part has a smooth translation that should have an almost constant conveying velocity. However the motion of each part (Fig. 2-3) is a combination of a variety of dissimilar/similar motions.

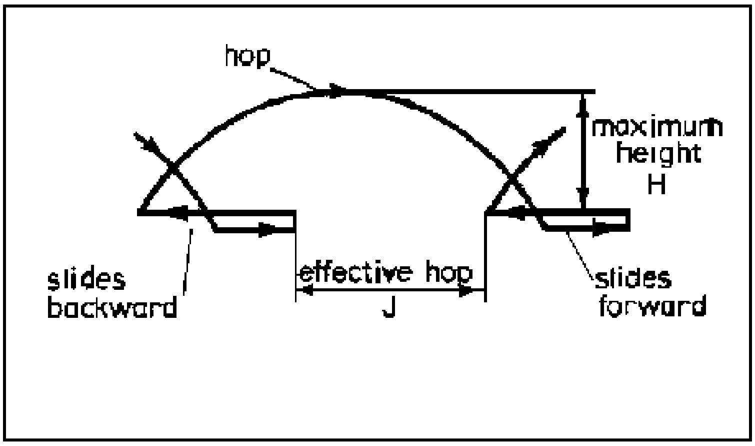


Fig. 2-3: Typical Part Motions Including the Hop (Boothroyd, 1981)

At first the part appears to slide forward then backwards and eventually hops over an effective hop distance (J). The parts are now moving up the incline at a velocity depending upon the effective hop. As the part approaches the upper level of the bowl it must pass through a series of engineering obstructions or guides in the bowl track commonly referred to as tools or traps. These tools are usually custom designed and placed in a specific order around the upper rim of the bowl. Their main function is to separate parts, select orientations or relieve pressure build up on orientated parts. The tools consist of selectors, sweeps and turning mechanisms that depend on the configuration of the part and its natural feeding characteristics to obtain the desired attitude.

2.5.3 Types of Vibratory Bowl Feeders

There are three basic styles of VBF; Straight Wall, Cascade and Conical or Wok style bowls (Fig. 2-4).

Straight Wall

Conical

Cascade

Fig. 2-4: The Three Basic Styles of VBF [www.autodev.com]

The straight wall type is basically cylindrical in shape and has an inclined spiral step running along the inside of the bowl ledge. This ledge carries components to the outlet at the top of the bowl. It is generally easier to tool and modify for various applications than that of the outward spiralling cascade bowl and for this reason it is used a lot in VBF applications.

Conical or Wok style bowls are as the name suggests shaped externally like a wok, having tapered sides slopping inwards towards the centre of the bowl in contrast to a cascade style VBF that is shaped with various helical steps. Its internal surface area is similar to that of a cascade style VBF. The conical style VBF provides an economical solution for applications requiring moderate feed rates that do not require the intricate tooling associated with the other two types. They do not require extensive retrofitting of the orientation tools because they are used to feed parts with basic geometric features

A cascade style VBF has an inclined helical step running centrifugally around the interior of the bowl. The orientation tools required are usually placed on the rim of the upper step of the bowl just before the delivery chute. This means that it has a limited tooling area and is often used to feed simple to moderately complex parts.

A cascade style vibratory bowl feeder was used in this project for two main reasons as follows:

1. It was considered that a sufficient manipulation area around the upper step of the bowl was available to allow the orientation tools to be adjusted mechanically.
2. Some identical bowls of this type became available (donated by industry from redundant stock) (Fig. 2-5). Separate bowls would allow for the considerable experimentation that was envisaged in the project in terms of optimisation of tooling inter-changeability.

Figure 2-5: The VBF used in the Project (AMT LAB)

2.5.4. Vibratory Bowl Feeder Selection

These bowls are therefore relatively simple and very effective when considered for most small part applications. They must be provided with effective orientation tooling specifically designed for a particular part. These tools must function effectively with the natural feeding characteristics of the bowl and are selected based upon the geometric features of the part being conveyed.

VBFs have a potential for feeding a wide range of parts. They are therefore very versatile and there is an amount of proven technology available for such a feeder.

There are however key factors that must be considered in their selection.

1. The bowl size. As a rule of thumb a bowl size is selected to be ten to fifteen times the largest dimension of the part.
2. The choice of the most suitable vibration bowl, with an adequate base drive unit and amplitude controller, is important.
3. The selection and sequencing of effective orientation tooling is also an important factor.
4. The correct spring angle of the bowl must be determined in order to provide an effective throw angle in relation to the track, for a specific component.
5. It is important to consider any internal surface coatings that may be required, to improve the coefficient of friction between the parts and the track.
6. The hardware costs associated with VBF projects.

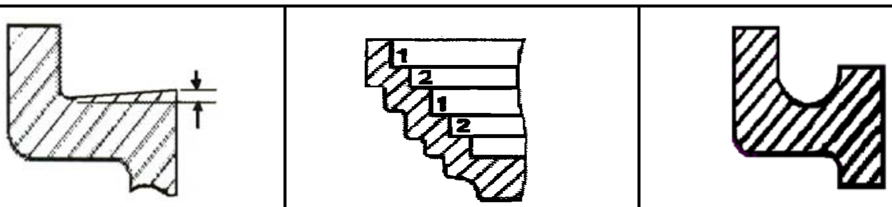
[www.esclintatomation.com]

Track Coatings

In some cases and depending upon the material of the part being conveyed, the interior surface of the bowl may have to be coated with a soft pliable material. This helps to increase friction, reduce noise, improve chemical resistance and reduce surface abrasions. In some cases, where noise levels are a serious problem, a sound enclosure may be required, this is placed outside the feeding system. There are many different coating materials available but the most common types are Teflon, Brushlon, Suryln and Urethane coatings. One of the main disadvantages of coating materials is that soft surfaces tend to grip parts at tool locations and this may contribute to blockages. However not all coating materials are soft.

VBF Tracks

VBFs can be manufactured in various shapes and sizes. One important point to consider in the selection of a bowl for a particular part will be the shape of its inclined track (Fig. 2-6). The shape of a track is usually selected based upon the geometry of the part being conveyed. Most parts feeders will accommodate one of two types of parts, either rotational or non-rotational in shape.


(a) Positive Type Track
(b) Multiple Form Track
(c) Radius Form Track

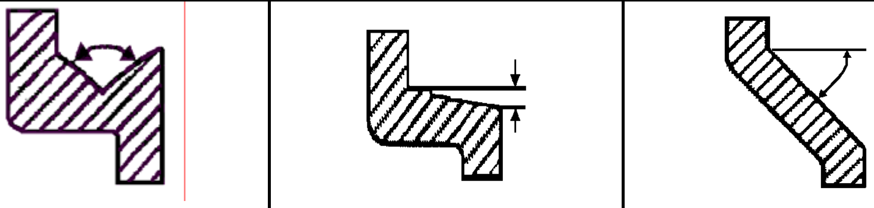

(d) V-Form Track
(e) Negative Track
(f) Hi-Form Track

Fig. 2-6: Cross Section of VBF Track (www.autodev.com)

- A Positive type track bowl, will have a less than 90^{O} included angle between the track and the sidewall of the bowl (Fig. 2-6a & 2-7b). The track angle is expressed in degrees of slope above the horizontal plane; usually 7^{O}, 8^{O}, 15^{O} or 60^{O}. The VBF used in this project has a positive track angle of approximately 7^{O} (Fig. 2-7a).

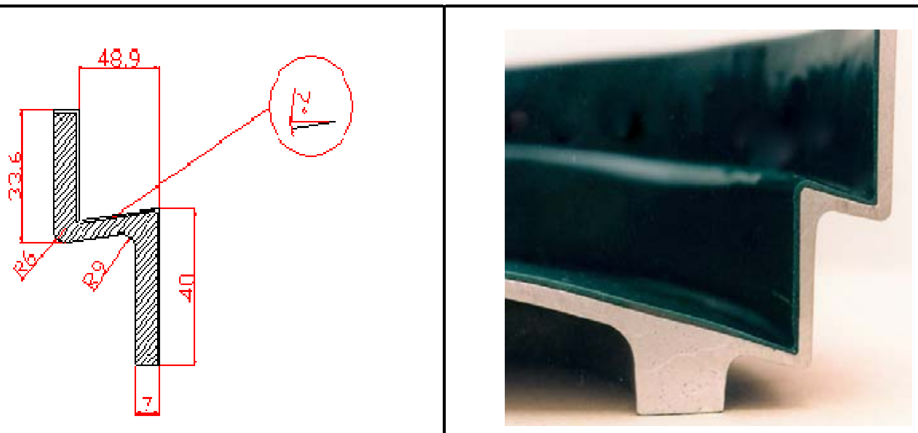

(a)
(b)

Fig. 2-7: Cross-section through a VBF ledge similar to that used in the Project

- A Multiple Form track, will have two or more tracks (Fig. 2-6b). Each track carries parts from the bottom of the bowl to its own discharge chute. The discharge of such bowls may have up to ten tracks depending on its requirements. Advantages of this type of bowl may include higher production rates and the simultaneous delivery of fixed numbers of parts to the bowl's discharge.

- A Radius Form track will generally have a groove formed along the entire length of track, but in some cases just for the last quadrant (Fig. 2-6c). Radius form tracks are designed to feed cylindrical parts whose length is equal to or greater than its diameter. In most cases the track profile matches the profile of the part being fed.
- A V-Form track will contain grooves of 60^o,90^o, 120^o or 150^o as the included angle (Fig. 2-6d). Some may run the entire track length, but others only the latter part of the track. These tracks are designed to feed cylindrical parts.
- A Negative track, will have an included angle greater than 90^o between the track and the sidewall (Fig. 2-6e). It is also expressed as degrees of slope above the horizontal plane usually as 15^o, 30^o or 60^o. Typical parts orientated include thin rectangular stampings and shallow pan or cup typed parts.
- A Hi-Negative track, will have a 60^o negative angle in the last quadrant of the bowl (Fig. 2-6f). Some may follow a transition from a positive to a negative angle. Typical parts orientated in these bowls are flat irregular parts or parts with a projection on one side.
  [www.vibratoryfeeders.com]

2.6 Types of Orientation Tooling for a VBF

Orientation tools are devices employed to ensure that only correctly orientated parts are fed to the assembly machines. These tools have been categorised by Boothroyd. In his analysis he explains that there are two main groups of tools: those tools that are placed in the parts feeder that are referred to as “In-bowl” tooling (Fig. 2-8) and those fitted to the delivery chute referred to as “Out of bowl” tooling (Fig. 2-9). In the case of in-bowl tooling the components that are rejected are components in an undesired attitude (do not obtain a specific attitude).

Fig. 2-8: In-Bowl Tooling [www.autodev.com]

In-bowl tooling consists of two groups of tools known as passive or active orientation tools.

- Passive orientation devices are orientation tools specifically designed to work as rejection devices in order to obtain the required orientation of the part. The rejected components are returned to the bottom of the bowl where they begin another attempt at passing through the orientation devices. Examples of passive orientation devices are: the wiper blade, the narrow ledge, the pressure break and the v-cut out tool.
- Active orientation devices are a second group of tools that are not as widely applicable as the passive orientation devices. These orientation tools change the orientation of the part so that it will be accepted by the assembly machine in a desired attitude. Active orientation devices are more efficient than passive orientation devices in respect to feed rates, as these tools present no reduction in the feed rate due to rejected parts, as no parts are rejected. Examples of active orientation devices are: raised ledge, slotted track, sloping track, hold down and active step orientating tool.

In-bowl tools are fitted to the track or on the rim of the upper ledge of the bowl just before the delivery chute (Fig. 2-8). This type of tooling is usually associated with cascade or conical type bowls. The tools can be easily developed, observed and tested inside the bowl. In the case of straight wall bowls visibility underneath the upper ledge may prove more difficult. Straight wall bowls are therefore sometimes fitted with external tooling when intricate parts are involved requiring clear visibility for set-up and management. Outside track tooling is often referred to as ‘external tooling’ (Fig. 2-9).

Fig. 2-9: Outside Track Tooling [www.autodev.com]

Outside tooled straight wall bowls allow for more complex tooling where required for intricate parts, higher feed-rates and multiple discharge (www.autofeed.com).

As the parts leave the base of the vibratory bowl, therefore, they are carried in the track that follows the bowl perimeter (inside and outside as described above). This track contains the tools that regulate the parts as they move up towards the outlet. At the desired height they are moved into the delivery chutes. These delivery chutes can have either single or multiple tracks for feeding one or more assembly station, or perhaps, for feeding just one station with simultaneously placed multiple components. In some cases both internal and external tooling are used in one feeder bowl. In this case one type of tooling is predominant over the other. The internal (primary) tooling in this case, serves to minimise the number of orientations a part may have up to the point of the outside track chute. The outside (secondary) track tooling will then re-orientate any part that enters the outside track chute and maximise the number of Parts Per Minute (PPM) delivered to the delivery chute.

2.6.1 Basic Tooling Principles

When the VBF drive is energised, the parts in the bottom of the bowl separate and move towards the outer wall of the bowl in their natural feeding orientations. The parts are continuously conveyed up the inside track of the vibratory bowl through a ‘hopping’ action (Fig. 2.4 previously) that has been induced to the parts by the operation of the VBF. As the parts climb the inside track, they must maintain contact with the track ledge, in order to maintain a constant feeding pattern at an almost constant feed rate. When the parts reach the upper level of the bowl they encounter the orientation tools. At this stage they are acted upon by the orientation tools and either pass-by, fall-off or are rearranged into other orientations depending upon their specific orientation at this time and the type of orientation tool encountered. The configuration of the part, along with its natural feeding characteristics, determine which tool is used to successfully negotiate the parts. The features of a part that must be considered to determine its natural feeding characteristics are its length, width, thickness, weight and shape. When considering the natural feeding patterns of a part, it is important to consider its particular design features. If a part has already an existing outstanding feature this may serve to act as a guide for orientation. An outstanding feature may be angles, grooves, flanges, bosses, projection pins and concave or convex surfaces. Where no natural outstanding feature exists it may be possible to design a part with one; this should help to determine the required tooling.

An inexpensive tooled VBF is one that follows a basic plan regarding the selection of correct tooling. The tools should be selected so that they can be used to feed one particular part or a small number of similar parts. The basic plan used according to Automation Devices Inc. [www.autodev.com] to obtain the final orientation of the part is as follow :

1. Size the bowl for the specific part or a small number of similar parts.
2. Begin selecting tools by first reducing the parts to a single line of feeding.
3. Select and sequence the tools using the parts natural feeding characteristics.
4. As the parts pass by the orientation tools, the number of possible orientations will also reduce, therefore specific tools can be selected until the final orientation is obtained.
5. Maintain orientation of the part as it leaves the bowl.

With reference to the automated orientation tooling in this project, certain basic design guidelines were developed to assist in the development of the new tools. These guidelines together with the ‘basic plan’ mentioned above helped to guide the development of the new tooling. The basic guidelines followed were as follows:

1. All orientation tooling fitted to the VBF should be of light but rigid construction. According to Boothroyd [1981], the VBF is a dynamically balanced system (see section 2-10) that depends on the natural frequency of the feeder mass (the vibratory bowl and its associated tooling). An increase in feeder mass might restrict the bowls natural frequency. Restricting the bowl’s natural frequency of vibration (see section 2.9) might effect its conveying velocity and hence the performance of the bowl.
2. The tooling assembly must be securely fixed to the bowl so that the tool performs adequately and maintains the functional characteristics of the original tool.
3. Discharge tooling beyond the normal bowl outlet position should be kept to a minimum. According to Boothroyd [1981], VBFs are load sensitive (see section 2.8.1), therefore tooling assemblies that project out beyond the rim of the bowl might have an adverse affect on the bowl’s amplitude of vibration and this might contribute to unpredictable feeding.

4. The orientation tools must not be rigidly attached to any surface outside the bowl’s perimeter as such connections will create malfunctions with feeding [Morrey, 1990]. This might restrict the conveying velocity and therefore the performance of the VBF.

2.7 Selection, Orientation and Presentation of Parts

Obtaining the final orientation and presenting this orientation in the correct location (position) is essential to the assembly process. Incorrectly positioned parts damage equipment and upset production schedules. When the parts are correctly positioned and adequate numbers of these parts are provided at the required time, this should help to maintain an efficient assembly process. Parts positioning is a combination of singulation, orientation and presentation.

- Singulation is a process where individual parts are separated into a single line from the mass of parts in the bowl.
- Orientation is the process of arranging the part in a predetermined position for assembly.
- Presentation is a positioning process where correctly orientated parts are actually moved into location for the assembly cell.

An efficient VBF will perform all of the above functions at the correct feed rate. Part feeding and part positioning are also considered as separate processes but to obtain an effective feeder these processes are closely connected and must work in conjunction to be effective [Weber, 2001]. The feeding process is concerned with conveying the parts to a specific location whereas parts positioning is considered as a combination of singulation, orientation and presentation as mentioned above.

2.7.1 Part Selection and Design:

There are two main categories of parts used in VBFs namely, are rotational parts and non-rotational parts. Rotational parts appear to be predominant as approximately two-thirds of all mechanical parts are rotational [Maul & Goodrich, 1981]. Rotational parts consist of parts such as Long Screws, Rivets, Short Screws, Rivet Pins, Tapered Cylinders, Short Protrusions, Grooved Cylinders, Blind Hole Cylinders and Cylinders with Protrusions, almost any part with its longest dimension rotational. Non-rotational parts consist of parts such as Rectangular Blocks, L-Shaped Rectangles, Long-U Shaped Channels and Short-U Channels. To obtain an effective VBF it is essential that the supply of parts be quickly and accurately orientated. Designers of small parts very often give little thought to designing parts that will facilitate feeding and orientation. It is necessary that parts be designed for ease of assembly, but parts must also be designed or redesigned for feeding and orienting. For the purpose of this research, the latter will be discussed to assist in the selection of a part to be orientated in a VBF.

2.7.2 Part Design for Feeding and Orienting in a VBF:

The main objective of part design for feeding and orientating is to determine how easily a part can be orientated using machines with limited tooling capabilities. This should also determine how difficult it is to feed a particular part. There has been a lot of work carried out on the design of small parts for automatic assembly by Boothroyd, Poli & Murch, [1978]. This latter work resulted in the development of a coding system, the University of Massachusetts (U-Mass) coding system. This coding system essentially asks questions concerning symmetry and geometric or non-geometric features of parts in an effort to determine the ease or difficulty with which a part may feed. A coded number is given to a particular part and this should be used to indicate what design changes can be made to simplify the handling problems. It is important to specify the basic design principles that should be consider regarding symmetry and geometry for the selection of component parts for a VBF.

1. Care must be taken to avoid parts that might tangle or nest during feeding.
2. The parts should be as symmetrical as possible.
3. If parts cannot be made symmetrical, avoid slight asymmetry or asymmetry resulting from small or non-geometrical features.

[Boothroyd, 1978]

Consideration must be given to these design principles when focusing on the development of automated orientation tools later in this project. In all situations attempts should be made to design parts that are symmetrical to avoid the need for extra orientation devices and possibly a loss in feeder efficiency.

2.8 Problems on Conventional VBFs

In the past VBFs were used to provide orientated parts to assembly operations at moderately slow feed rates. In recent years with advanced technology, these feeders are required to run at very high feed rates. These high feed rates very often result in feeding and orientation problems occurring between the parts and the tools. There is also the problem of excessive lead times associated with the fabrication of vibratory bowls as dedicated parts feeder; this often results in high capital cost.

Undesirable Features of Conventional VBFs

A lot of problems associated with VBFs affect both manufacturers and users. The main problems at present are:

1. Vibratory feeders can be considered very noisy especially when they are operated at very high frequencies.
2. The very high resonant vibrations produced by the electromagnets may cause fatigue failure resulting in unstable leaf springs and poor operating frequencies.
3. Smooth continuous feed rates are difficult to achieve and are very often attributed to inadequate tuning procedures as reviewed in Appendix G.
4. High feed rates can result in blockages at tool locations and these have to be cleared manually.
5. Poor unpredictable feeding patterns can occur due to behavioural changes in response to bowl loading especially for under-loaded conditions.

2.8.1 Load Sensitivity

Under normal conditions of operation where a vibratory bowl load is gradually decreased, its forced excitation frequency increases. This results in an increase in the amplitude of vibration of the bowl and hence the maximum bowl acceleration. These factors can cause poor feeding patterns to occur, resulting in unpredictable feeding, which is an undesired feature of VBF technology. This change in VBF performance is referred to as the bowl’s load sensitivity. Figure 2-10 overleaf shows how the unrestricted feed rate of a VBF varies as the bowl gradually emptied, with the maximum feed rate achieved when the bowl load was approximately 10lb (which is approximately 25% full). As the bowl gradually empties the feed rate is seen to reduce steadily to zero. This is due to the greater velocity of parts in the flat bowl bottom than that on the track; when the bowl is full, the feed rate depends on the feeding characteristics in the bottom of the bowl, where the circulation of parts pushes those that are on the track. This pushing action ceases as the bowl gradually empties below a certain level and the parts on the track are then conveyed at the velocity of the inclined track.

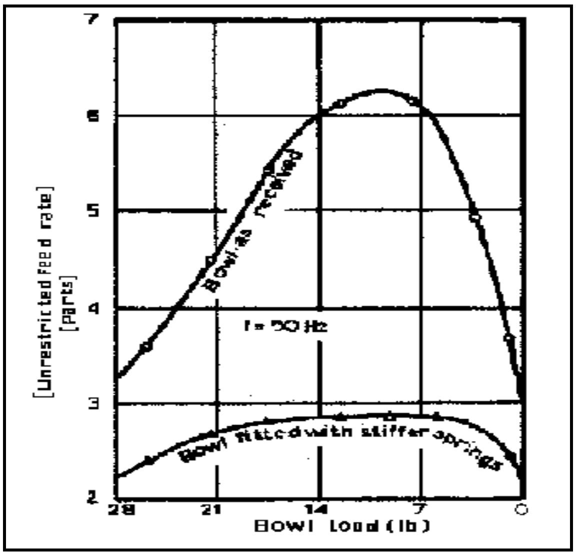


Fig. 2-10: Experimentally Determined Load Sensitivity of a VBF (Boothroyd, 1981)

Solutions to load sensitivity:

- VBFs are mechanically adjusted (tuned) to have a natural frequency (Bowl and leaf springs) slightly higher than that of the forced frequency (electromagnet frequency). Lowering the forced frequency or alternatively increasing the natural frequency (by increasing the stiffness of the leaf spring) will cause the bowl acceleration to appear approximately constant. This will have the effect of reducing load sensitivity. This is shown in the lower part of the graph (Fig. 2-10).
- The VBF should be adjusted slightly to overfeed under all conditions of loading. The effect of overfeeding is to counteract the variations in part acceleration. This will provide a constant feed rate of parts from the VBF.
- Maintain a constant level of parts in the VBF at 25% of the bowl’s capacity as the bowl is continually emptying. This can be achieved by mounting a load-level limit switch at a specified height in the VBF. The switch activates a secondary feeder that supplies parts to the bowl as required, thus increasing the frequency of refills. This will have the effect of reducing feed rate variation.
- Maintain a constant vibration amplitude, which is achieved by using an accelerometer coupled with a drive system (rectifiers) that provides feedback to the control system. The control system then switches the VBF on/off as required and prevents the mean conveying velocity of the parts from increasing as the bowl gradually empties.

2.9 Mechanics of a Vibratory Bowl Feeders

A theoretical analysis of the mechanics of vibratory conveying has been presented by Boothroyd and can be reviewed in Appendix D. In this analysis he explains that vibratory conveying is the result of a phase difference between the parallel and normal components of track vibration, produced by a forced oscillating frequency of an electromagnet counteracted by the support system. He identified the factors which affect the conveying velocity as follows:

1. Track Angle (Angle of inclination of the feeder track) - θ
2. Vibration Angle (Angle between the track and its line of vibration) - Ψ
3. Track Amplitude - A_0, both parallel and normal to the track, - A_p and A_n (m/s^2)
4. Frequency of vibration of the track, *f*, expressed as Angular Frequency, -ω (rad/s)
5. Mass of the parts, - M_p
6. The coefficient of static friction between the track and the parts, - μ_s
7. Gravity, - g (m/s^2)
8. Friction Force, acting between the part and the bowl coating, - F (N)

It is necessary to resolve the forces acting on a part in order to understand the behaviour of a part that is placed on a track, whose amplitude of vibration is increased gradually from zero.

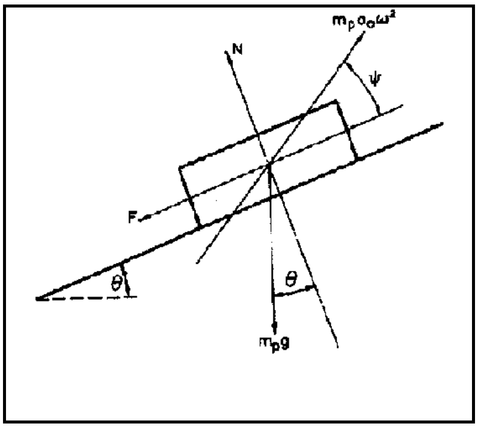


Fig. 2-11 Parallel and Normal Forces acting on a Part in a VBF (Boothroyd, 1981)

Fig. 2-11 shows the forces acting at zero. Movement will occur when the parallel inertia force ($m_p a_0 \omega^2 \cos\psi$) acting up the incline overcomes the normal force and friction force ($m_p g \cos\psi + F$) acting downwards, hence:

$$m_p a_0 \omega^2 \cos\psi > m_p g \sin\psi + F$$

The relevance of each topic mentioned above has been discussed regarding the conveying velocity, along with the limiting conditions for the various modes of vibratory conveying

(Fig. 2-12). Boothroyd explains clearly how the mean conveying velocity of a part can be calculated and shows, that the motion of a part is actually a combination of a variety of dissimilar smaller motions giving the total effect of a smooth translation.

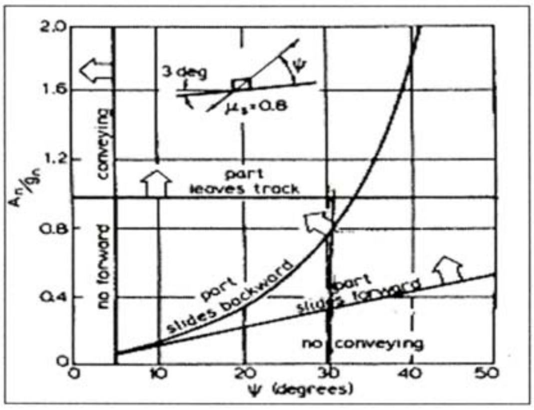


Fig. 2-12 Limiting Conditions for Various Modes of Vibration (Boothroyd, 1981)

He concludes his research by summarising the results on the mechanics of vibratory conveying by providing useful advice in the design of vibratory bowl feeders. The important points to consider here are:

1. The higher the coefficient of friction between the track and the parts being conveyed the higher the conveying velocity.
2. The conveying velocity is inversely proportional to the operating frequency.
3. An increase in conveying amplitude will increase the conveying velocity.
4. The parts that are conveyed on the feeder track will be slower than that of the parts moving in the bottom of the bowl.
5. An optimum vibration angle will exist for any given condition.

The last point should be considered significantly important when designing orientation tools. It means that the mass of parts stored in the bottom of the bowl acting under the action of forced vibration frequency are pushing the parts at the base perimeter up the inclined track. This pushing action results in unpredictable feeding that can often lead to blockages at orientation tool locations.

2.10 Tuning

Proper tuning is an important factor in achieving maximum spring energy and constant feeding efficiency. Tuning is defined as the adjustment of spring values (thickness and quantity) to achieve a balanced oscillation between the natural (resonant) frequency and the electrical frequency as reviewed in Appendix G. In order to attain the optimum performance from the equipment correct spring thickness and quantity compensation must be achieved. If a drive unit is improperly tuned (over or under-sprung) the spring tension will not correspond to the natural frequency of the feeder mass. Either of these conditions will prevent the mass from returning to its natural position before the next magnetic pulse takes over, thus restricting or restraining its full motion. The unit must therefore be tuned to its mains frequency of either 50Hz (Half wave, DC, uni-directional) to 100Hz (Full wave, bi-directional) for proper balance between the coil assembly energy development and spring tension (in some countries this may be 60Hz to 120Hz). This is significantly important to a smooth and efficient feed system. At this balance point, parts will feed at a maximum efficiency with the maximum current drawn from the supply for that particular bowl. The addition or removal of springs may be necessary to obtain the balance needed. Maintaining the air gap between the coil assembly and the armature plate is important. If it needs to be reset, it must be adjusted so the pole faces are as close as possible to each other without striking under normal conditions of loading. When the air gap is set properly it will not exceed its current limitations, as excess air gaps draw more current and this will reduce the power to the electromagnet resulting in a poor performance. If the air gap is too small, the coil will clatter; if too large, the excess current will cause the coil to overheat.

Installation and Troubleshooting

Because the VBF used in the project was provided by industry from redundant stock, considerable troubleshooting had to be carried out to get it to work efficiently. Proper tuning is a step-by-step process. Incorrect tuning may be the result of factors such as broken springs, air gaps set at incorrect distances etc, as reviewed in Appendix F. This step-by-step process was followed successfully in this project in getting the VBF operating efficiently.

3 A Review of Component Feeding

3.1 Introduction

The search for flexibility in the manufacturing process remains elusive in the area of automated assembly. One of the key difficulties is in the provision of adaptable and cost effective parts feeders. The inflexibility associated with the conventional VBF has proven exceptionally difficult to solve. As a result researchers from a wide range of backgrounds have generated significant volumes of literature on this topic over the past few decades. Particular emphasis is targeted at developing new or alternative approaches to that of the VBF technology, as well as the combination of new or recently developed technologies with existing hardware.

If flexibility can be achieved, the benefits for the manufacturing process, apart from dramatically reducing cost, are yet to be fully revealed, but should prove significant for both Batch and Mass production processes. This chapter seeks to provide a comprehensive literature review and analysis of the various techniques used and/or developed to challenge and possibly break the bottleneck associated with inflexibility of the parts feeding mechanisms and in particular the VBF.

3.2 The Fixed-Sequence VBF

The fixed-sequence vibratory bowl feeder (VBF) is a well tried and proven technology, widely accepted in industry especially in the area of high volume assembly. These VBFs are dedicated parts feeders tailored for a specific part or a limited range of parts for the same family. As outlined earlier the parts are orientated using fixed orientation tooling attached to the bowl near the bowl’s outlet. The tools are arranged in a specific sequence. This sequence ensures that only one orientation of the part, the required orientation, can be obtained from the VBF. This means that fixed-sequence VBFs have a limited range of flexibility, in terms of part variability and part changeover. Inevitably fixed-sequence VBFs are retired at the end of the component life cycle.

Limitations of Fixed-Sequence VBFs

The main limitations of the VBFs are as follows:

- The long-lead time required to tool a VBF, together with market requirements of fast production turnaround, leaves an implicit risk of obsolescence for dedicated bowls.

- Orientation tools are designed to orientate parts by rejecting or accepting specific orientations of that part. In situations where parts tend to tangle or nestle, feeding problems may occur. This restricts the orientation tooling to basic geometric shaped parts only.
- VBFs are prone to unpredictable feeding patterns due to the nature of their operation as vibration machines. This can cause unexpected blockages at orientation tool locations and therefore result in feed rate restrictions. This is a common problem, even for high volume industry, where the feeder may be dedicated to feeding of a single component.
- Fixed-sequence VBFs are severely limited by the range of parts that can be accommodated from one VBF. They are therefore very limited in terms of versatility.

3.3 The Flexible Parts Feeder

Various methods have been used for feeding parts for assembly machines. These include VBFs, centrifugal feeders, rotary feeders and belt feeders. Each type has specific advantages and disadvantages for feeding particular parts. However one could not definitively assert that any parts feeder is totally flexible in terms of accommodating a wide range of different parts. To make such an assertion is really a matter of personal opinion only. However, a parts feeder that can accommodate variations in part dimensions and geometry, might be considered flexible.

The time and expense involved in tooling a VBF can frequently only be justified by the achievement of versatility in handling different parts at various feed rates. Such an achievement, if it were feasible, should make the VBF available to medium and low volume assembly industries. The need for such flexible parts feeders in batch production setups has been identified. This has inspired a lot of research and development in recent years. There have been significant advances made in the area of flexible feeding but the search for true flexibility, in terms of feeding different parts with different sizes, shapes, density, concentricity and material, remains elusive.

Advantages of a Flexible VBF

The VBF is an accepted technology in industry and an improvement in its flexibility, if achievable, could result in significant advantages for low and high volume assembly.

The main advantages would be as follows:

- A flexible VBF should be more economical for medium to low volume assembly. This could reduce the cost of labour and provide a competitive edge in production especially in those countries with high labour cost economies. One of the key bottlenecks in automation assembly would therefore be solved.
- Reliance on specialised tooling craftsmen would be less necessary, as flexible VBFs could be mass produced for the global market.
- A flexible VBF would be integrated into the parts handling system making the system more versatile and possible more productive. Completely different parts could then be conveyed to separate assembly machines using a single VBF.
- The lead-time required for production changeover could be reduced considerably. A non-production feeder, for instance, used strictly to determine programs for specific parts could be used to pre-program the orientation tools.
- The efficiency of the VBF could perhaps be improved. This could be accomplished by automating the optimisation of the tool setting process for the parts to be fed prior to and during production. This optimisation process will be seen later as an inherent part of the flexible VBF.

3.4 Research into Flexible VBF Technology

> *The AMT group at WIT identified vibratory bowl lack of flexibility as a major problem in the ongoing automation of assembly in 2000. This arose as a result of experience with a high-speed dedicated assembly system [Murphy, 2000]. The idea of an inflexibility VBF was developed independently by that group who were unaware of earlier work by Maul & Goodrich [1983], Tay et al [2004] and others at that time.*

Obtaining flexibility in VBF technology is proving problematic and remains an ongoing research problem. There has been a wide range of research approaches considered all of which have had limited success. Some of these developments will now be discussed.

The Programmable Parts Feeder (PPF)

An approach to flexible feeding by Maul and Goodrich [1983], proposed modifications to a fixed-sequence VBF through the development of manually programmable tooling. The orientation tools were mechanically modified so that they could be adjusted or programmed manually into a new position. The PPF attempted to orientate the parts using the general characteristics of the parts in conjunction with the programmable tooling to determine the general characteristics to be employed.

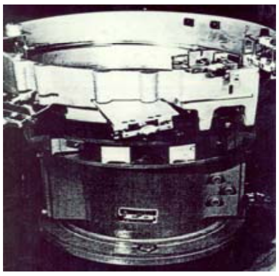


Fig. 3-1: The Programmable Parts Feeder (Maul & Goodrich, 1983)

The researchers developed a purely manual prototype to demonstrate, through a trial-and-error process, the benefits and feasibility of using manually programmable tooling. The tools developed could accommodate a wide range of parts. Obtaining the exact location of the tool in relation to the parts would be done, prior to production, in an off-line non-production feeder. The tool setting obtained could be stored in advance and then later retrieved to reproduce the tool settings during product changeover. This would help to minimise feeder downtime and reduce lead-time in assembly systems.

Further to this development it was suggested that an adaptive controlled feeder system could eventually be developed. Such a system could record tool setting information by work piece part number and retrieve this information so that the tools could be automatically programmed prior to on-line production. An adaptive control feeding system would provide an record (index) of performance; this would help to ensure that programming would meet certain minimum performance criteria. One of these criteria could be as simple as meeting a minimum feed rate. The objective could be accomplished by locating sensors in the feeder to monitor feeder performance. The information obtained would serve as input to a microprocessor programmed with a search strategy. The search strategy would enable the system to act on information supplied by the sensors to control the position of the tools in accordance with the index of performance.

It was also suggested, in order to implement the above adaptive control concept successfully, that part families for which certain groups of tools are required, would have to be established. This would mean that a certain group of parts would be orientated by a certain group of tools that could be fitted to the VBF for that specific purpose. Similar parts feeders could then be fitted with similar orientation tools to pursue this process. A final suggestion on the concept of flexibility was that, by increasing the bowl's versatility this might help to increase their use in batch production assembly and hence prolong their useful life cycle in the event of changes in work piece design.

Programmable Silhouette Recogniser (PSR)

To advance the PPFs (previous section) still further, a VBF which was incorporated manual programmable tooling in combination with a vision system, referred to as a Programmable Silhouette Recogniser was considered. This was developed by Goodrich & Delvin [1985], at Pennsylvanian state University (Fig. 3-2). The PSR system uses a sensor package, consisting of 16 fibre optic light sensors, overhead lighting and a single air jet tool. The light sensors form a grid in a planer configuration on the bowl track. Sixteen phototransistors convert analogue-to-digital signals forming a sensor array interface to a personal computer. The image collected consists of light and dark silhouette patterns. As components travel over the grid, patterns are collected and compared with stored patterns of correctly orientated components. If the component image matches the stored image the component is passed and goes through to the outlet of the VBF. If it does not find a match with a stored image it will be rejected back into the bowl by a blast of air from the air jet tool. The air jet tool is a passive orientation device, as it performs a function of rejecting parts only. The air jet tool is placed just before the outlet of the bowl and after the grid; it essentially provides an alternative to fixed sequence orientation tooling. The main advantages of this system, were as follows:

- Air jet tooling is relatively inexpensive with quick response time.
- The air jet tooling is a none-contact passive tool that could be used on fragile parts.
- There was no need for lengthy or complex algorithms.
- This system proved suitable for parts with simple part orientations.

The disadvantages of the system were as follows:

- There were problems with overlapping and contiguous parts as these produced distorted images. This meant that correctly orientated parts could be rejected by the system.

- Because of the low resolution detection system, only parts with basic geometry are recognisable.
- A passive air jet tool was used to reject components. This resulted in a poor throughput rate.

Fig. 3-2: The PSR system [www.posifeeders.com]

Further research by Goodrich at a later date considered an improvement to the PSR system. The improved system could be used to distinguish between parts with different geometries. This would enable the parts feeder to orientate parts with features such as through holes and slots. A Personnel Computer system was used to store many more images. A comparative analysis was performed between the conveyed parts and the stored images as before. A decision was made and parts were either accepted or rejected using the passive air jet tool. This improved version of the PSR system demonstrated a higher level of flexibility in part variability, as parts with through holes and slots could be recognised and orientated from a single VBF. The main problem with this system was that it still provided a single silhouette image that resulted in similar problems as before.

Sensor Based Programmable Silhouette Recogniser

The sensor based system was an advancement on the earlier PSR system [Goodrich, 1985]. Maul & Jaksic [1994] collaborated in the development of a new computer based 3-D sensing strategy and a 16-bit single board computer system. The objective was to develop a system to cope with contiguous and overlapping parts, the computational resolution of parts in discrete units and the speed of recognition and decision making. This involved the development of a standardised sensor grid and software. The grid consisted of 16 fibre optic cables as before, 8 were mounted horizontally on the side wall of the bowl and 8 were mounted vertically on the planer track.

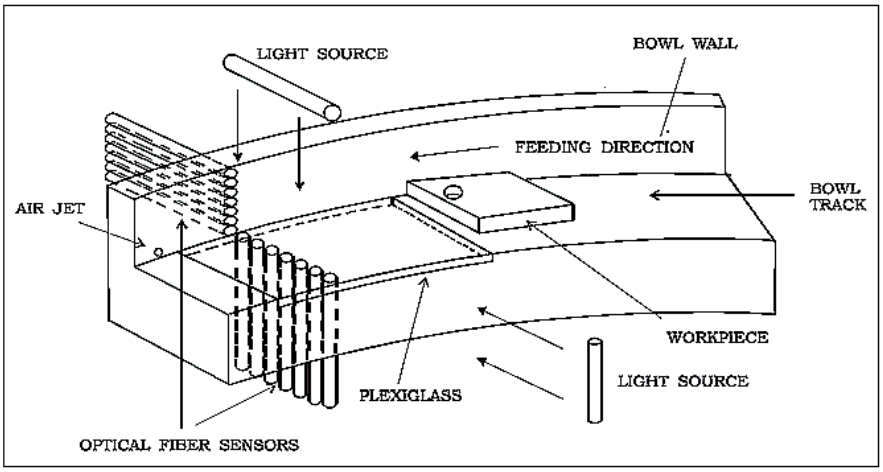


Fig. 3-3: Sensor Based PSR system (Maul & Jaksic, 1994)

A light source was used as before. As the part passed the fibre optic sensors grid a 3-D view was constructed using 2 silhouette images. These images were compared with stored images. If a matching image was identified the part would be accepted and if not it would be rejected by the air jet tool. The vertical set of optical fibres was used to detect overlapping parts; while contiguous parts are detected algorithmically [Negad, 2003].

The main disadvantages of this system were as follows:

- The planer set of optical fibres could not distinguish between parts that were touching i.e. where one part began and another one ended.
- Variations in part velocity occasionally confused the algorithm.
- It had limited sensor precision which resulted in increased computation problems.
- The throughput obtained from the VBF was regarded as poor.

The most important development for this system was that the algorithm dealt successfully with most part geometries. The researchers concluded that the 3-D sensor strategy worked efficiently as it could distinguish clearly between overlapping and contiguous parts. The computer processed the results and parts were accepted or rejected as required.

Modular Orientation Devices (MODs)

Continuing research into increased flexibility for VBFs led to the development of Modular Orientation Devices by Lim et al [1993] based in Singapore. It was assumed that by using MODs that the functions of the VBF could be rendered flexible, as MODs were interchangeable and reusable, giving rise to the use of one bowl for many parts. An MOD was not a fixed part of the VBF. It differed from that of conventional tooling which was permanently tooled or fixed in one position on the VBF.

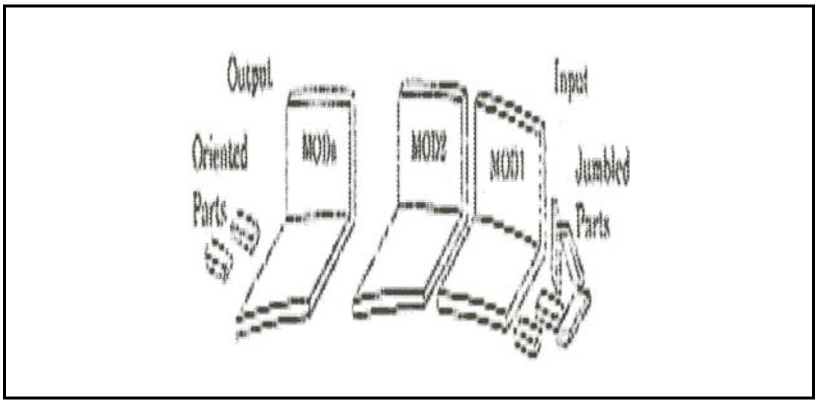


Fig. 3-4: A Sequence of MODs (Lim, Ngoi, Lee et al 1993)

The tools were designed to be manually adjustable forming segments that could be attached to the VBF outlet. Each tool had a specific orientation objective and its unique design features depended on that objective. The MODs were designed and named according to the UMASS classification system developed by Boothroyd [1981]. The tools proved very flexible as they could be manually adjusted to allow for variations in part geometry (Fig. 3-5). They could also be relocated and placed in the desired sequence for use with different part families. This meant that parts with totally different geometries could be accommodated within a single VBF.

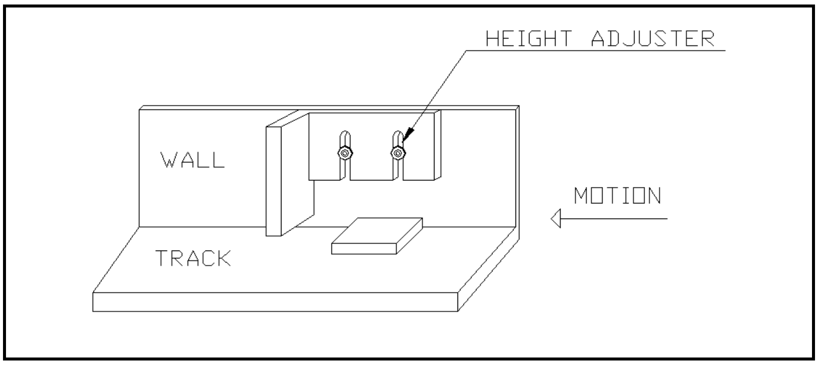


Fig. 3-5: A Wiper Blade MOD (adapted from Lim et al, 1993)

The prototype system developed used 12 various MODs and investigated a series of 13 different parts, 9 rotational and 4 prismatic to test for overall efficiencies. An MOD sequence design methodology was not provided. The researchers used a trial-and-error process to determine the proper sequencing for the test parameters. The important concept of tool relocation had the added advantage of allowing quick response times to occur between part changeovers. This helped to improve the viability of VBFs as adaptable commodities. This versatility and inter-changeability associated with MODs clearly demonstrated that a certain degree of flexibility is possible with VBFs.

Modular Parametric Assembly Tool Sets (MPATS)

A couple of years after Lim et al developed the MOD prototype feeder, a similar approach was developed in Hong Kong, called MPATS by Jonega and Lee [1997]. This latter approach was developed based around the idea that the majority of small components used in assembly obtained basic geometric shapes. The tools used to orientate these parts should comprise of simply shaped features, but they must be easily reconfigurable to handle several variants of that shape. A standard VBF was modified by removing a section of track just before the outlet (Fig. 3-6a).

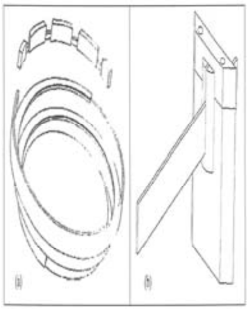


Fig. 3-6: MPATS Track Profile & Tooling Modules (Joneja & Lee, 1997)

The cut-out section was replaced by a single modular section of track that consisted of various slots machined into it and reattached using screws. These slots were asymmetrically designed with a bevelled edge and standardised with mating surfaces for the various tooling modules (Fig. 3-6b). The modules slotted into position from above and were clamped firmly in place using clamping plates and screws. The tooling modules were reconfigured according to tool parameters set down by Boothroyd [1981]. The sequencing was achieved by a trial-and-error process that initially depended on the final orientation of the part. If a part required limited tooling the remaining slots were filled with spacer blocks.

The possible advantages of using MPATS were as follows:

- Variation in tooling parameters allowed for fine tuning and therefore optimal feeding.
- Modular tooling assemblies were reusable reducing tooling cost.
- The tools could be reconfigured and this provided a level of system flexibility in terms of production line modifications and variant changes.
- Rapid retooling reduced lead time in production setups.
- VBFs fitted with MPATS might be retooled, it was claimed, by even unskilled operators without the need for reprogramming.

Programmable Active Air Jet Tooling

Having demonstrated passive air jet tooling in combination with the 3D sensing strategy for the PSR system, Maul & Jaksic [2001] developed passive active air jet tooling devices (Fig. 3-7) in an attempt to eliminate part blockages, by replacing mechanical orientation tooling on a VBF. If this proved successful, then the possibility of improved throughput from a VBF would be increased.

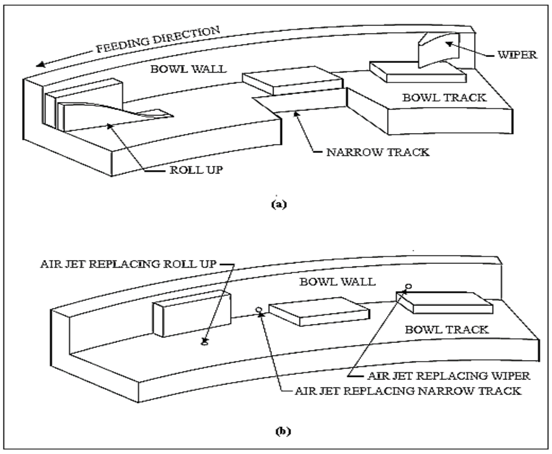


Fig. 3-7: (a) Mechanical Tooling, (b) Air Jet Tooling (Maul & Jaksic, 2001)

A mathematical model of part behaviour was developed initially and the air jet tools were placed in discrete positions. A computer aided algorithm of the model was incorporated into the control system and an air jet pulse was used to re-orientate the part. The model was validated using three rectangular prismatic parts, including prisms, connecting housings and electrical push buttons. A typical orientation system shows prismatic parts being orientated by the mechanical tools that included a wiper blade, narrow track and roll up (raised ledge) tools (Fig. 3-7a). Fig. 3-7(b) demonstrates reorientation of the same parts using active air jet tooling. Sensors were used to aid in the reorientation process by providing feedback to the computer programme. This system in theory seemed simple and effective but proved problematic. Fig. 3-8 shows the reorientation of a part at the narrow track tool location.

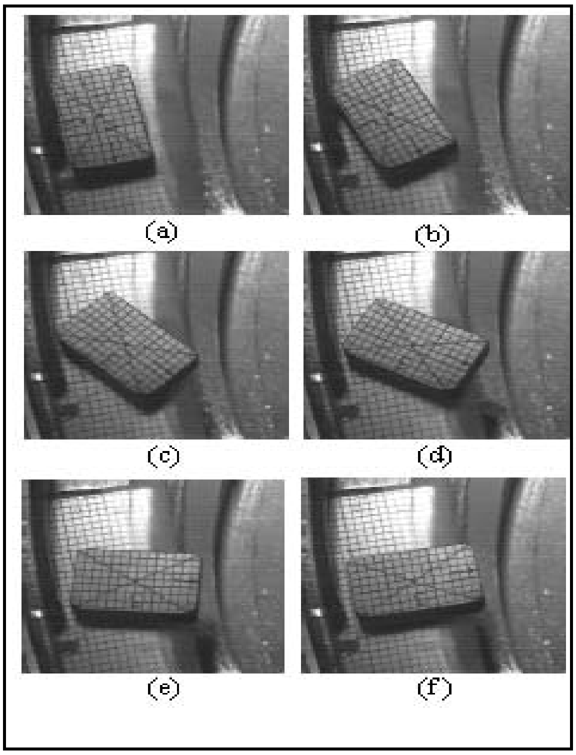


Fig. 3-8: Stages of Part Reorientation Using Air Jet Tooling (Maul & Jaksic, 2001)

One possible advantage of using air jet tooling is that it could be use on delicate parts where mechanical tooling would prove ineffective. Blockages caused by *'jamming'* at mechanical tool locations will not affect active air jet tooling devices. Where a part needs to be reoriented as in example Fig. 3-8, a continuous stream of air jet pulses would be required to reorient the part completely. Essentially the air jet tools must be accurately positioned and the air jet pulses must be timed precisely in order to achieve reorientation. Contiguous or overlapping parts complicated the part reorientation process even further.

Decoupled Vibratory Bowl Feeder

A theoretical analysis which allowed predictions to be made of the motion of a part on a VBF track that is vibrating with simple harmonic motion, with or without a phase difference between the normal and parallel motions, (see section 2.10), was presented by Redford & Boothroyd [1968]. Empirical experimentation confirmed the theoretical analysis (Negad, 2003). A VBF works on the principle that the normal and parallel components of vibration are in phase. An experimental apparatus was developed to demonstrate that the normal and parallel components of vibration could be altered independently. The normal component was set at a stable fixed level and the parallel component adjusted accordingly. The results demonstrated an increase in feed rate which was attributed to a reduction in the effective hop (section 2.5.2). This indicated that by decoupling and controlling the phase difference between the normal and parallel components of vibration, a level of flexibility could be achieved that would compensate for the coefficient of friction and the pushing action associated with part motion in a VBF.

<u>SBFVFS Feeding System</u>

The theoretical analysis presented by Redford & Boothroyd [1968] and research into flexible feeding by Maul & Jaksic [1994], encouraged the development of a combined system by Han & Tso [2003] in China. The system consisted of a decoupled VBF (Fig. 3-9), a vision system, displacement sensors, power amplifiers and computer.

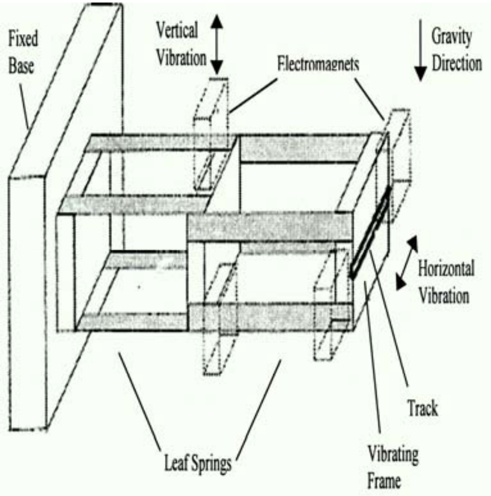


Fig. 3-9: Mechanical Structure of a Decoupled VBF (Han & Tso, 2003)

Computer software was used to control the out of phase difference between the normal and parallel components of vibration for the decoupled VBF. A machine vision system determined the orientation of the parts using a sensor optical grid or a camera. Correctly orientated parts were accepted and incorrectly orientated parts were rejected using an air jet tool. Displacement sensors measured horizontal and vertical vibrations of the VBF track. This provided feedback and with the aid of some inbuilt intelligence the computer could determine the natural frequencies of the feeder by means of a frequency response analysis. It generated optical control signals from the displacement sensor, and the machine vision then amplified these signals using the power amplifiers. The amplified signals wee used to operate the decoupled feeder and obtain the required feed rate. The decoupled feeder used a drive unit that was not dedicated to any particular bowl. The driver permitted the interchanging of bowls on standard drive units; hence, eliminating the requirement of bowl tuning (Negad, 2003). The driver also permitted a change of phase that converted the drive unit from a left hand feed to right hand feed. This meant that the feeding direction could be reversed, and when integrated into the computer system, would help to clear blockages. To reduce noise and maximise power consumption the feeder should be operated at the natural frequency of the system.

The Replacement Bowl Approach

Obtaining flexibility by replacing the bowl section of the VBF is common practice in industry nowadays. This is achieved via quick release system (bolt in the base of the bowl). The bowl is completely detached from its base and a second identical feeder bowl is reattached. The second bowl has been retooled using an offline VBF. This effectively eliminates the lead time involved in retooling and re-sequencing for a second part. The orientation tools are fixed in position and set to determine a maximum feed rate from the VBF. The new part can now be conveyed to the same takeaway point. The quick release system improves down-time as part changeover and setup-time is reduced. This approach to flexible feeding may be limited to assembly stations that use dedicated parts feeders. A pre-tooled vibratory bowl allows for variations between different parts, but does not accommodate variations in part parameters, or unexpected changes in product design, effectively eliminating its overall objective and effectiveness in medium to low volume assembly. The high cost involved in providing an off-line VBF for experimentation and analysis, together with the requirements of a number of replicable bowl’s, could restrict its deployment in industry to high volume production.

The Multiple Bowl Approach

An alternative to flexible tooling for VBF is an approach that requires the use of multiple VBFs equipped with standardised tooling to supply different parts at the same pick up point. In this case a number of similar bowls are used in close proximity helping to feed the same assembly machine (Fig. 3-10).

Fig. 3-10: Multiple Bowl Feeders [www.afag.com]

These bowls might be used to provide completely different parts or even similar parts with slight variations. This approach to flexible feeding does not solve the problems associated with fixed sequence tooling. Its objective is to provide for a selected number of parts at a fixed location. This demonstrates flexibility for the assembly machine through multiple component pickup but does not enhance flexible VBF methodology The cost and utilization factors involved to provide this level of flexibility are significant factors to consider for small and medium sized production setups.

Programmable Feeder

This proposal by Tay [2004], involved the adaptation of a conventional VBF to include programmable tooling, a recognition system and passive air jet tooling that were used in a combined system to feed and identify orientations of non-rotational parts (Fig. 3-11). This proposal was similar to the programmable feeder developed by Maul & Goodrich [1983].

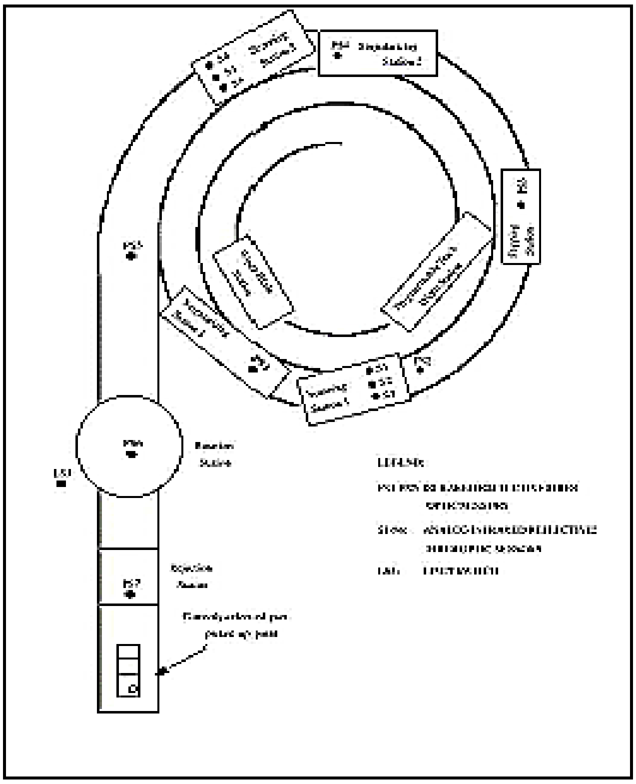


Fig. 3-11: Programmable Feeder (Tay et al, 2004)

There were 7 orientation tools used in total, 5 passive tools, and 2 active. The passive tools consisted of a wiper blade, track width, air jets and 2 singulisation stations. The 2 active tools used consisted of a flipping station and a rotary station: these tools are operator programmable using electro-pneumatic cylinders or motors. There were 2 scanning stations, that used fibre optic sensors as part of the recognition system to identify parts with internal features only. The system was tested using three different neural network modules for part recognition suitability; namely, ARTMAP, ART2 and Back-propagation, with ARTMAP yielding the best results. The network obtained scanned images of the surface of the part and compared them to learned patterns similar to the PSR system presented by Maul & Jaksic [1994]. This system claimed to extend the capability of conventional VBF technology to include feeding parts with internal features only. The recognition system required manual programming during the setup process. A number of passive orientation tools were used before and after the scanning stations. Previous research by Maul & Jaksic [2001] indicated a reduction in the throughput where passive orientation devices were used. A combination of these tools together with rotation and singularisation stations; would appeared to limit feed rate potentially from the VBF system.

3.5 The Approach at WIT in the development of a Flexible VBF

The concept of making progress in the development of a flexible VBF through automated tool prototyping was developed independently at Waterford Institute of Technology. This eventually was recognised as being built on an approach by Maul & Goodrich [1983] in the development of a Programmable Parts Feeder as mentioned in section 3.4, previously. Maul and Goodrich's original idea of manually programming the normally fixed tooling was an attempt to render the functions of the VBF flexible. The manually programmed tools permitted a wide range of dimensional changes between tool settings, thereby permitting a wide range of parts to be fed from a single VBF. Maul & Goodrich envisioned an adaptive programmable VBF through the automation of the programmable tools (which they believed was highly feasible) as a later stage development in the research process. The approach taken by WIT in the AMTLAB was the design and development of prototype automated orientation tooling which was considered to be the next stage step in the process of the development of a fully flexible VBF.

The stages that might be followed in the development of automated orientation tools are as follows:

1. At the initial stage a methodology for the design of automated orientation tools might be established.
2. The first automated orientation tool would be designed and developed and then used as a prototype for future orientation tools.
3. A drive system could then be developed to control the position of the orientation tools. This drive system might become standardised for the range of tools developed.
4. Continuing on that success the design and development of a range of automated orientated tools would be completed.
5. A programmable system might then be developed to demonstrate automatic control of the orientation tools.
6. Experiments specifically developed to measure tool performance over a relevant range of tool settings might be completed through this programmable system.
7. The optimum performance of the individual orientation tools might then be determined using the optimum tool setting.
8. The optimum system performance should then be determined using the individual optimum performance calculations.

The objective in this case was to contribute to the eventual development of a fully flexible VBF. The approach was therefore to adapt the fixed sequence, but highly successful VBF, through automation, instead of developing completely new and unproven approaches to feeding as demonstrated in most of the foregoing studies. The intention was to build on the success of the VBF, by making it more versatile and adaptable for today's ever increasingly demanding and competitive markets.

It was expected that the development of automated orientation tools would eventually lead to the development of a fully functioning and effective flexible VBF that could be used in industry. If and when that happened the following results were expected:

- The need to retool a VBF for slight changes in part tolerance or part change-over would be eliminated.
- The development of an automated VBF would reduce the high cost of the tool setting process and prolong the applied usefulness of the VBF, thereby extending its life cycle.
- The high costs associated with sub-assembly part change in automated assembly would be avoided as the system could readily adapt to new parts.
- The need for specialised tooling craftsmen, required for the tool setting process would be eliminated.
- The initial lead-time required to tool a VBF would be dramatically reduced.
- The sequencing of the tools and the optimum tooling position for the parts would be determined and set prior to production processes on an off-line VBF.
- A flexible VBF would be beneficial to both medium and low volume industry, through is adaptability and flexibility and might help to reduce the impact of continual production variations.

4.0 Design/Development of Automated Programmable Orientation Tools

4.1 Introduction

As production feed-rates continually increase on modern assembly machines, leading to reduced batch cycle times, the demand for a more flexible VBF has become increasingly important. In recent years there has been a lot of research on the development of flexible parts feeders, in particular modular orientation devices and programmable parts feeders (see Section 3.4). The mechanical design and development of Automated and Programmable Orientation Tools (APOTs) became the prime focus of this chapter. The research literature most relevant in the design of orientation tools is provided by Boothroyd [1981]. This literature was referred to continually to verify design decisions made in the development of the orientation tools.

This chapter begins with the specification and selection of the AMTLAB vibratory bowl feeder and controller used in the project. Certain tools were specifically selected for development as a family of orientation tools making up a typical orientation system. The typical orientation system consisted of three automated/programmable orientation tools, the Wiper Blade Tool (WBT), the Narrow Track Tool (NTT) and the Edge Riser Tool (ERT). The first tool the wiper blade tool (Prototype #1), was completely automated; this established a methodology for the development of future automated orientation tools on the AMTLAB vibratory bowl feeder system. The other orientation tools were developed as manually programmable tools to complete the orientation system, they are the Narrow Track Tool (Prototype #1) and the Edge Riser Tool (Prototype #1).

The design and development of the three automated/programmable orientation tools followed a basic plan. This plan included the following: descriptions of the conventional tool; development of a concept model and the production of scaled drawings (Appendix A) to graphically demonstrate the principle movements of each tool; the development of the prototype tool in each case; the operation procedure; the operating range and the component range of the finished tool. The chapter concludes with the development of a sound enclosure system that encompassed the AMTLAB vibratory bowl feeder system.

4.2 A Typical Orientation System of Conventional Tools

The orientation tools considered for redesign and development as automated prototypes make up a typical orientation system (Fig. 4-1). This system was used to orientate a rectangular prism component, that was extensively experimented with and documented by Boothroyd [1981]. The automated tooling concept was therefore developed around this system.

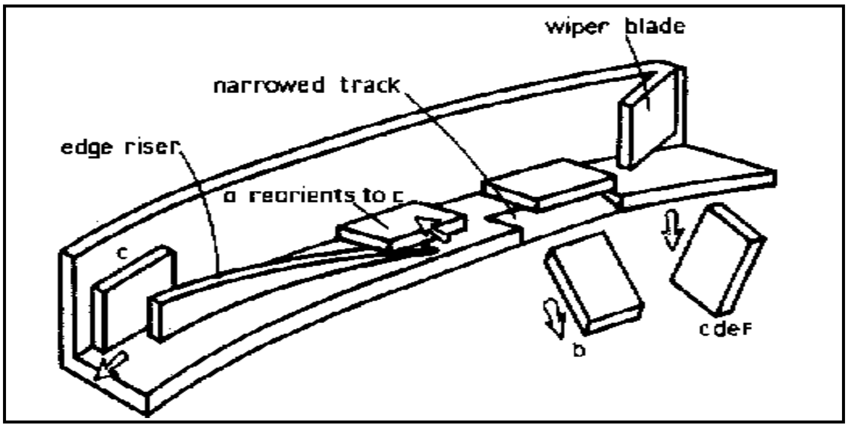


Fig.4-1: A Typical Orientation System for Orienting Rectangular Prism Components (Boothroyd, 1981)

Moving from left to right in the orientation system, the first tool encountered by the components is the Wiper Blade Tool (WBT), the second is the Narrow Track Tool (NTT) and the third is the Edge Riser Tool (ERT). The wiper blade tool rejects all orientations of the part back into the VBF that are not lying flat on the bowl track, in this case orientations ‘c’, ‘d’, ‘e’ and ‘f’. It also rejects parts travelling on top of one another (as a second layer of components) and is referred to as ‘layering’. The second tool the Narrow Track Tool is used to distinguish between the two remaining orientations of that part, orientations ‘a’ and ‘b’. It achieves this by rejecting the undesired orientation, orientation ‘b’. As the components pass by the narrow track tool location, components in orientation ‘b’ become unstable, as their centre of gravity lies outside the tool track and they fall back into the VBF. Orientation ‘a’ is the only orientation of the components that travel through to the final orientation tool (The Edge Riser Tool). The Edge Riser Tool is employed to re-orientate parts into a vertical upright position. In this case it re-orientates orientation ‘a’ to orientation ‘c’ (the desired orientation). This research was based on the analysis of a typical orientation system described above and on experimental data on rectangular prism parts available in research literature. The basic design and development of this system of orientation tools for redesign into automated/programmable tools was used as the starting point for this research.

4.3 The AMTLAB Vibratory Bowl Feeder

The AMTLAB vibratory bowl feeder is a standard cascade type AFAG feeder bowl. It is manufactured from cast aluminium and is spray coated with a red polyurethane to provide an internal lining. The bowl measures 430mm in diameter and has a track width of 24mm. The track forms a centrifugal counter clockwise step up to the bowl outlet and has a positive helical angle of 7^{o}. The bowl was selected because of its external shape which extends outwards and upwards following the path of the helical step. This shape provided a sufficient area for manipulation and placement of the externally mounted orientation tools and their associated mechanical assemblies. The vibratory bowl feeder consists of four primary components; the bowl, sets of leaf springs, an electromagnet and a heavy bowl base (Fig. 4-2). Three sets of leaf springs firmly attached to the base form a triangular support system, on which the bowl is mounted. The electromagnet is centre-mounted between the bowl and the base.

Fig 4-2: The Vibratory Bowl Feeder used in the Project

The electromagnet drive unit is controlled by a compatible AFAG variable amplitude controller. This was employed to control the length of bowl stroke. Controlling the length of bowl stroke controls the normal amplitude of vibration (a_n). The electromagnet is energised by the mains supply with an alternating current (AC) of 50Hz. This produces 100 magnetic cycles per second (or strokes) to the vibratory bowl. The number of strokes will therefore remain constant to the power supply. The AFAG variable amplitude controller is adapted with a bowl potentiometer, which controlles the amplitude of vibration and thereby the feed rate of components from the VBF.

4.3.1 Component Selection

The part (component) selected for orientation in this case is a rectangular prism and remains consistent with Boothroyds research in the analysis of a typical orientation system. A comparison of the experimental results (Chapter 7 later) could then be made using a similar component. The rectangular prism component had six possible orientations (Fig. 4-3).

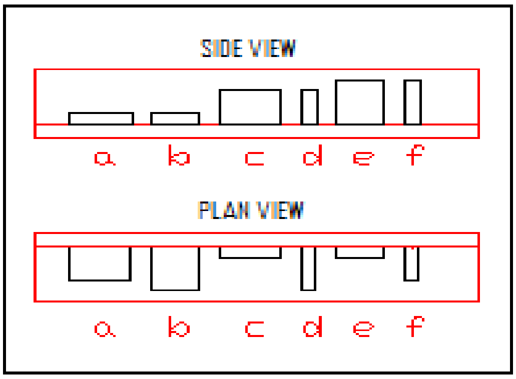


Fig. 4-3: Possible Orientations for a Rectangular Prism Component

Of the six possible orientations that can be obtained orientation ‘c’ is the desired orientation. This means that the orientation tools employed to orientate the component had to be arranged in a specific order so that orientation ‘c’ is the only orientation that is presented at the delivery chute. Presenting orientation ‘c’ at the delivery chute requires careful consideration of the positioning of the orientation tools (Fig. 4-1). Specific orientation tools perform specific orientation objectives. They are used in this situation, as is usual, to reduce continually the number of miss-orientations of the component until the final orientation is obtained.

The dimensions of the rectangular prism component (Fig. 4-4) are shown here as Dimensions **A**, **B** and **C** in millimetres. Where A is the length, B is the width and C is the thickness of the component.

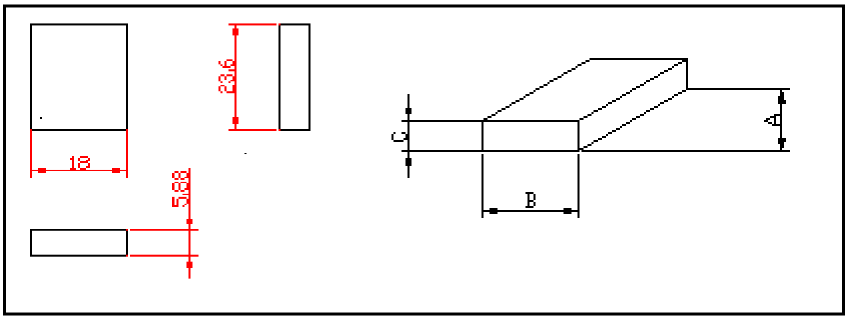


Fig. 4-4: The Dimensions of the Rectangular Prism Component

The dimensions of the component were calculated using the dimensions of the VBF.

This decision was based on the AMTLAB vibratory bowl feeder being made available from industry as redundant stock. In practice, in a commercial situation the procedure is reversed and the VBF is selected based upon the dimensions of the component.

The width of the component is based on the width of the bowl track (i.e. track width is 24mm). Components travelling in single file permit a minimum width of between say 16.5mm and 24mm for stability. This ensures that a single component with a width 16.5mm or greater is stable on the bowl track, because it maintains full surface contact with the bowl track in orientation ‘a’. It will not be possible for two components to travel on the bowl track side by side in orientation ‘a’; as the outside component will be unstable and will inevitably fall back into the VBF. The width of the component had also been calculated to provide a “safe distance” between the centres of mass of the component in either orientation ‘a’ or orientation ‘b’ (Fig.4-5). This safe distance would be required when working on the narrow track tool later. The narrow track tool is used to distinguish between these two orientations of the component by rejecting orientation ‘b’ and accepting orientation ‘a’ only.

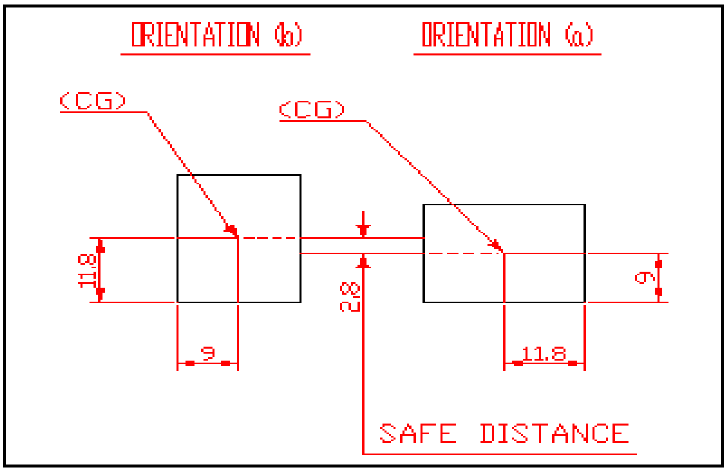


Fig. 4-5: Providing a Safe Distance between the Centres of Mass of the Components

The width of the rectangular prism component has been calculated at 18mm. The length of the component is set by the diameter of the VBF (see Chapter 1) and had to be greater than the width of the component. It was set at 23.6mm. The wiper blade tool imposes limits on the thickness of the components used in the vibratory bowl. There is a small region of error that occurs between components that can be safely conveyed in the correct orientation and components that are continuously ‘jamming’ under the wiper blade tool. If a component is selected that is too thin, this region of error decreases and that will inevitably increase the possibility of jamming. This means that the thickness of a component should be selected so as to minimise this region of error. The function of the wiper blade tool is to reject components that are lying on top of one another (Layering) as they encounter the tool. The thickness of the right rectangular prism components was therefore based on the possibility of conveying a single component in orientation 'a' or orientation 'b' only. The thickness was selected at 5.88mm. The material selected for the components had to provide a good coefficient of friction between the bowl coating and the components, accordingly Nylon was selected as the component material.

4.3.2 Automated Tooling Design Constraints

A design investigation into the requirements of automated tooling highlighted the following constraints/issues that needed to be addressed before their development:

1. Automated tools must be designed to function exactly like conventional tools without affecting the tools natural characteristics.
2. The combined weight of a tool and its mechanical assembly should be minimised to reduce its affect on the natural frequency response of the vibratory bowl.
3. The tools should be designed to accommodate dimensional variability in component size and shape. This should support larges batches of components with at least normal variability.
4. The tools should be as repeatable and accurate as possible. This would allow experiments to be conducted on reliable orientation tools.
5. A full range of active and passive orientation tools should be designed using the appropriate design data. This data has been conveniently provided by Boothroyd.
6. The tools when developed should vibrate as a single unit with the bowl.
7. The tool and its mechanics must be as robust as possible to withstand the hazardous vibration conditions associated with vibratory feeding.
8. A standardised/universal drive system should be developed that would provide continuous control of the tool. This drive system should not interfere with the operational characteristics of the VBF.
9. The tools should be designed to be as small as possible because there is a limited tooling area available on the VBF rim.
10. The tools should be designed to be as modular as possible to incorporate inter-changeability. Inter-changeability would provide greater variability between components with the possibility of creating families of different tool components.

11. The tools should be designed so that their position in relation to fixed datum points is repeatable to assist in programmability and re-programmability.

The design constraints mentioned above are addressed in the mechanical design and development of three prototype tools as described later in this chapter.

4.4 Part Orientation

In previous years maintaining orientation (i.e. providing oriented components to the user) at the manufacturing stage and/or supply stage seemed to be the only logical conclusion to the component orientation problems associated with assembly machines. In recent years there has been a lot of interest in the design of conventional parts feeders and presenters with the aim of producing more flexible feeding devices. The conventional VBF receives particular attention because of its success in mass assembly. However it proved particularly inflexible in terms of providing a wide range of components and/or providing for dimensional variability between similar components. It is believed by the author, that flexibility could be obtained through the mechanical adaptation and automation of the conventional orientation tools. This means designing orientation tools with automated/programmable control features. Automated orientation tools adapted with a wide operating range would help to accommodate component dimensional variability. In addition, if the orientation tools are designed to be as interchangeable as possible so that they could be repositioned around the peripheral of the VBF this would provide a level of system flexibility. This would possibly result in the development of a VBF that could accommodate different size and shape variations between components.

4.5 The Design and Development of a Standardised Tooling Drive System

Automated/programmable orientation tools should demonstrate the advanced features of interchange-ability, programmability and re-programmability as previously described. These tools should be useful in determining certain groups of tools for specific component families, even if those component families consisted of completely different components. When establishing component families, it should be remember that each tool performs a specific function of orientation and that each family of components selected should be associated with a specific set of orientation tools. The development objective of modularised/interchangeable automated orientation tools stimulated the development of a standardised drive system for independent positioning of the orientation tools. Independent positioning involves incremental adjustment of the tools through electromechanical means, involving ideally an open loop control system. Stepper motors were selected as the tool driving system for this reason. Also, stepper motors are small (an advantage in the restricted space around the VBF) and accurate. Using a motor of adequate torque it is possible to program and keep track of the input step pulses using a programmable logic controller (PLC). This might eliminate the need for expensive sensing and feedback devices such as optical encoders. A Rotolink uni-polar hybrid stepping motor model number M234118C632 was selected that has the following characteristics:

- Step Angle of 1.8^o (Provides 200 step/rev).
- 360g (Minimum weight restrictions).
- Holding Torque of 360mNm (Adequate to move the tool mechanically).
- Detent Torque of 30.0mNm (Adequate to locking the motors position in standby).

The drive system, a stepper motor in this case, must survive the hazardous conditions involved in vibratory bowl feeding if directly attached to the tool. Also at a weight of 360g per stepper motor, direct attachment could prove detrimental to the VBF system, due to the latter's high load sensitivity. It was decided therefore to mount the motor on a separate support to the VBF. Gaining control of the tool indirectly by means of engaging and disengaging from the tool at the required time therefore became a requirement of the system. This involved using a stand-alone stepper motor drive clutch system (Fig. 4-6).

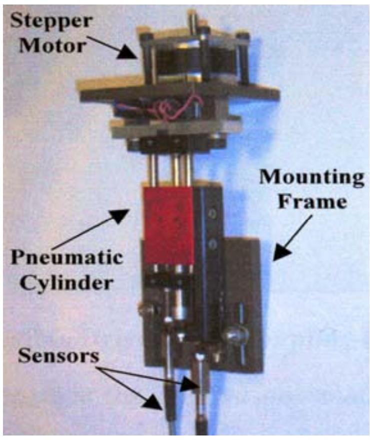
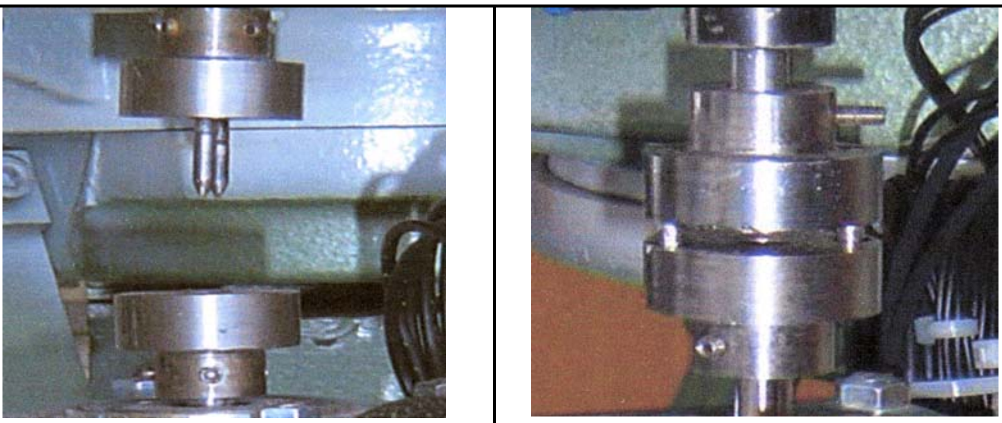


Fig. 4-6: The Stand-Alone Stepper Motor Drive Clutch System

The stepper motor attached to a double-acting pneumatic cylinder is employed to operate the clutch system with the aid of positional sensors. The cylinder when extended engages the tooling assembly via the clutch system (Fig. 4-7b). When the cylinder is retracted it disengages from the tool assembly and allows the vibratory bowl to vibrate normally (Fig. 4-7a).



(a) Disengaged (b) Engaged

Fig. 4-7: The Clutch Coupling

The operation of the stepper motor drive clutch system and the movement of the tool is performed when the VBF is in stand-down mode.

4.6 The Design of Automated Orientation Tools for VBFs

The three tools listed below were designed as automated orientation tools but due to the time involved in the manufacture and experimentation of such tools it was not possible to implement fully all of them within this project. The tools selected for development were the wiper blade, narrow track and edge riser tools. Seven other orientation tools were redesigned as programmable tools with the intention of automation and inclusion into the AMTLAB vibratory bowl feeder system, at a later stage. These tools may be viewed in full, in Appendix A. All of the tools mentioned have been classified into specific groups (active or passive) depending on their specific functions. The three developed tools were as follows:

1. The Wiper Blade Tool
2. Narrow Track Tool
3. Edge Riser Tool

4.6.1 The Wiper Blade Tool

The wiper blade tool was the first orientation device to be encountered by the rectangular prism component in the orientation system (Fig. 4-1 previously). The conventional tool consists of a piece of flat material (usually steel) that is rigidly attached to the VBF at various angles. This tool is classed as a passive orienting device as its main function is to reject components in an undesired orientation, back into the VBF (Fig. 4-8). Undesired orientations in this case are components that are standing in an upright position on their sides or components that are not lying on end, components lying on their base or top will pass through to the delivery chute [Boothroyd, 1981].

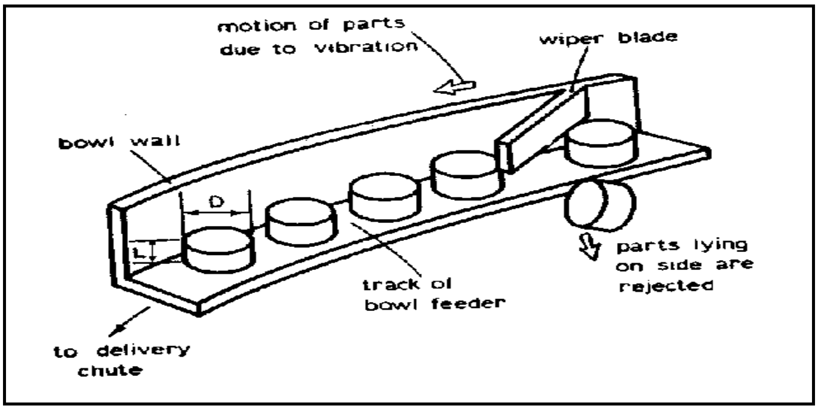


Fig. 4-8: Simple Orientation System for a VBF (Boothroyd, 1981)

The height of the wiper blade is set to allow one component through at a time. This means that components resting on top of others will also be rejected back into the VBF. Only components that are in the correct orientation will be accepted. This allows the remaining tools to act on them in an attempt to obtain the final orientation. The feed rate of correctly orientated components that successfully pass by the wiper blade tool in the correct orientation (the desired orientation), will depend on the number of components that are lying on their ends (standing on its side) and the rate of components that encounter the wiper blade tool. An efficient wiper blade tool should if it were possible help to increase the rate of components travelling onto the remaining orientation tools. The remaining tools will then continually reduce the number of miss-orientated components until the desired orientation is obtained. The wiper blade tool had been selected for development as a prototype tool (Prototype #1) for two main reasons.

1. Firstly, there was sufficient literature that provided essential design data, documented by Boothroyd [1981] for the development of such a tool.
2. Secondly, this tool is a very common type of orientation tool. It is commonly used with different families of orientation tools that orientate completely different components.

<u>Design Data to Consider in the Development of an Automated WBT</u>

In designing a prototype wiper blade tool it is important to remembered that the new tool should retain the system characteristics (functions) for which it was initially designed. This means that it will act in a similar fashion to the conventional tool and present no unnecessary problems with the parts. The two most important pieces of design data to be consider are the angle (θ_w) and the angle (β_w) (Fig. 4-9).

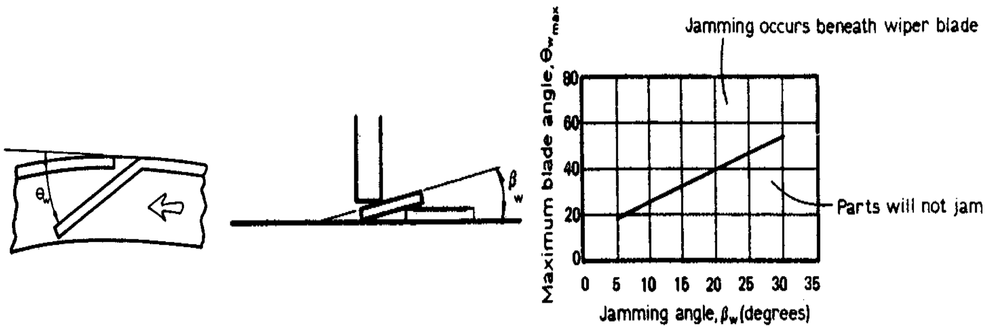


Fig. 4-9: Design Data to be Consider in the Development of the Automated Wiper Blade Tool (Boothroyd, 1981)

θ_w degrees is the angle made between the wiper blade and the side of the bowl, while β_w degrees is the jamming angle that should be avoided and is easily set by adjusting the height (**h_w**) of the wiper blade above the track. The height should be adjustable for two reasons, the first is that different components will be of different thickness and an automated tool should be capable of accommodating various components. The second is that there must be a clearance height provided between the component and the wiper blade, due to nature of vibratory conveying (hopping). This clearance height should be determined through experimentation. The blade angle θ_w is set so that the blade will assist in rejecting components in an undesired attitude, this should help to prevent jamming under the wiper blade tool. This means that the wiper blade will have the capability of rotating through an included angle of up to 90^o. At 0^o the wiper blade is acting perpendicular to the vibrating plane and at an angle of 90^o to the bowl wall. The range of angles selected should be sufficient to determine the most efficient angular position of the tool in relation to the components.

Factors to consider in the Design of an Automated Wiper Blade Tool

1. The only part of the wiper blade assembly that should come in contact with the components is the blade of the wiper blade tool.
2. It is important that the motion of the tool, for either an increment angle (θ_w) change or a increment height (h_w) change, be independent and intermittently controlled.

3. The wiper blade tool should be automatically controlled using the standardised stepping motor drive system developed.
4. The tool should be locked in position during the operation of the VBF. This could be achieved using carefully positioned pin cylinders.

The Automated Wiper Blade Tool Concept Model

A WBT concept model was developed. This was based on numerous designs (sketches). The final concept model (Fig. 4-10) was developed by the author as a specially constructed 3D cardboard model. The purpose of the 3D model was to demonstrate and evaluate the prototype design.

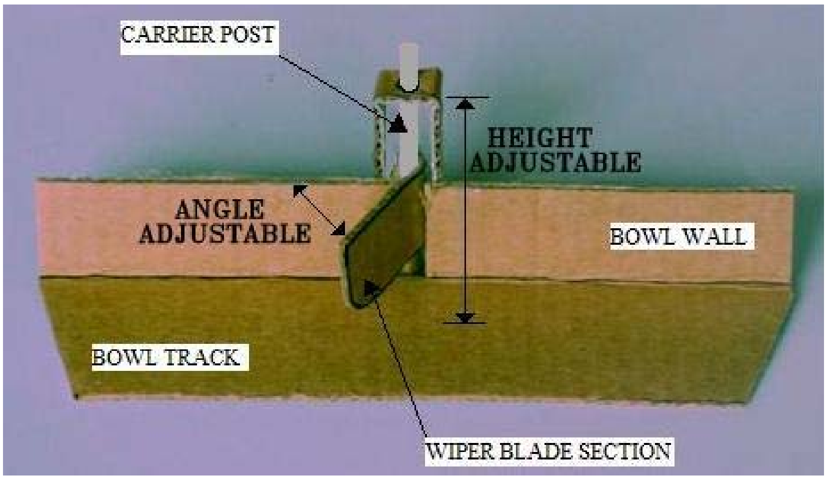


Fig. 4-10: The Wiper Blade Tool Concept Model

The concept model consisted of a wiper blade section that is attached to a carrier post. The blade protrudes through a slot in the wall and hangs directly over the bowl track. The wiper blade angle is adjusted accordingly by rotating the carrier post, clockwise rotation will reduce the included angle θ_w whereas anti-clockwise rotation will increase the included angle θ_w. The wiper blade tool will move linearly (up and down) on the carrier post when the blade angle is locked in position. The concept model demonstrated the two important functions of height and angular adjustment of the wiper blade tool.

Design Functionality - The components must negotiate the slot in the wall of the bowl. This might cause unsteady transfer movement, which could possibly result in unintentional reorientation. The wiper blade will have a certain amount of vibration transmitted to it though it no longer vibrates as a fixed part of the VBF. This might affect component feed rate.

Technical Feasibility - The development of an automated prototype involved the incremental adjustment of the wiper blade tool in two completely different directions. This could prove problematic, as it was considered that a single stepper motor drive system should be employed to drive the wiper blade mechanism for both angle and height configurations. This latter was in order to reduce both angle and space requirement for the tools.

Operation of the Prototype Wiper Blade Tool

Drawings of the prototype wiper blade tool were developed (Fig. 4-11). These drawings incorporate all the requirements of the original tool, but are adapted with automated programmable features.

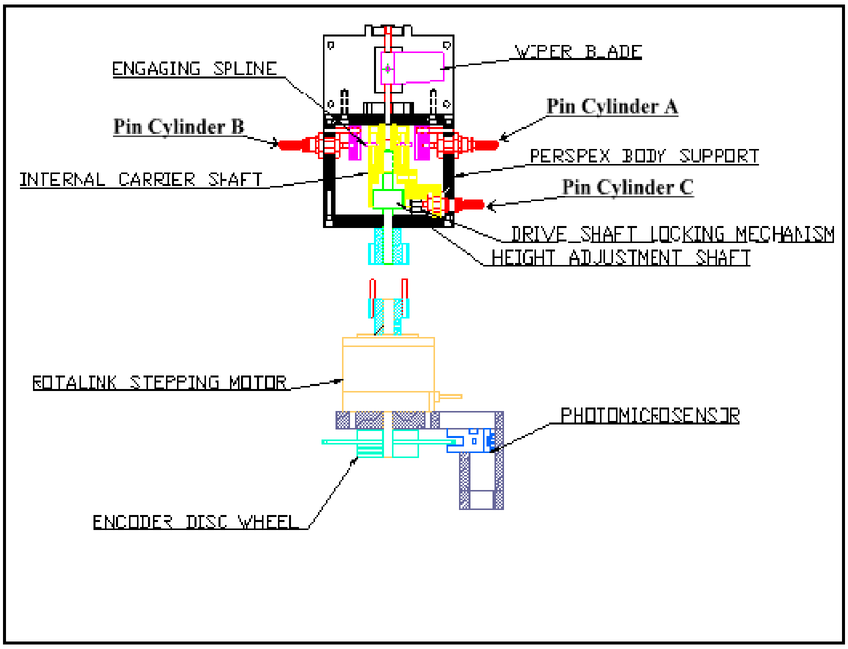


Fig. 4-11: Section View Showing the Parts of the Wiper Blade Tool

The tool was constructed to fit onto the VBF wall. The dimensions of the components that made up this design were based on the dimensions of the profile of the VBF. Fig. 4-12, shows the overall dimensions of the wiper blade tool assembly. Detailed views of the component parts that make up the automated wiper blade tool assembly can be viewed in Appendix A.

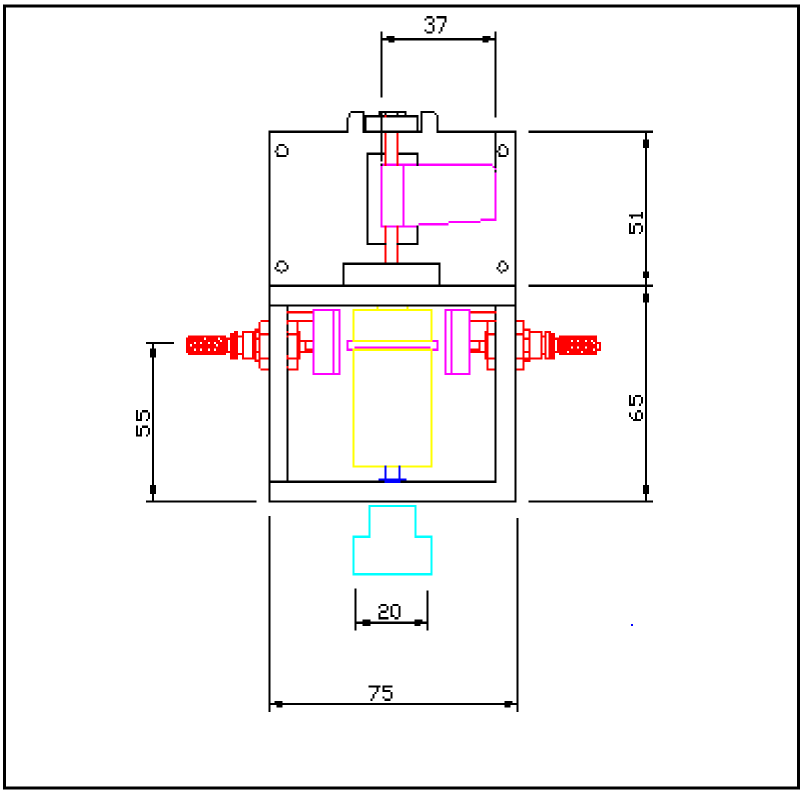


Fig. 4-12: Dimensioned View of the Wiper Blade Tool

The component materials used in the construction of the wiper blade tool(e.g. Perspex ^{TM}) were selected based on the weight (to prevent damping) and size of the finished tool. The objective was to make the final assembly reasonably light but rigid.

Operation of the Wiper Blade Tool

Initially the two drive pulleys (clutch) are disengaged while the VBF is in operation mode. The pin cylinders are extended locking the tool in position.

Changing the Angle (θ_w) of the Wiper Blade Tool

When the VBF is switched off the guided cylinder (not shown) that supports the stepping motor and encoder disc wheel is extended; this connects the drive pulley (male side) with the driven pulley (female side). Pin Cylinder A remains in the extended position (locking the height) while pin Cylinders B and C are retracted (see Fig. 3-11 previously). This allows the following components to move as a combined unit; the height adjustment shaft, pin Cylinder A, internal carrier shaft and the wiper blade tool post with the wiper blade attached.

As the stepper motor is pulsed the combined unit, including pin Cylinder A, will move to a new angular position. When this is located, pin Cylinders B and C are extended into the angle locking gear. These along with pin Cylinder A will lock the assembly in position. The photo-microsensor is used to count the number of steps made by the stepping motor. It achieves this by registering the number of holes that pass by on the encoder wheel. The stepping motor can now be disengaged from the assembly as the guided cylinder is retracted and the VBF is switched back on.

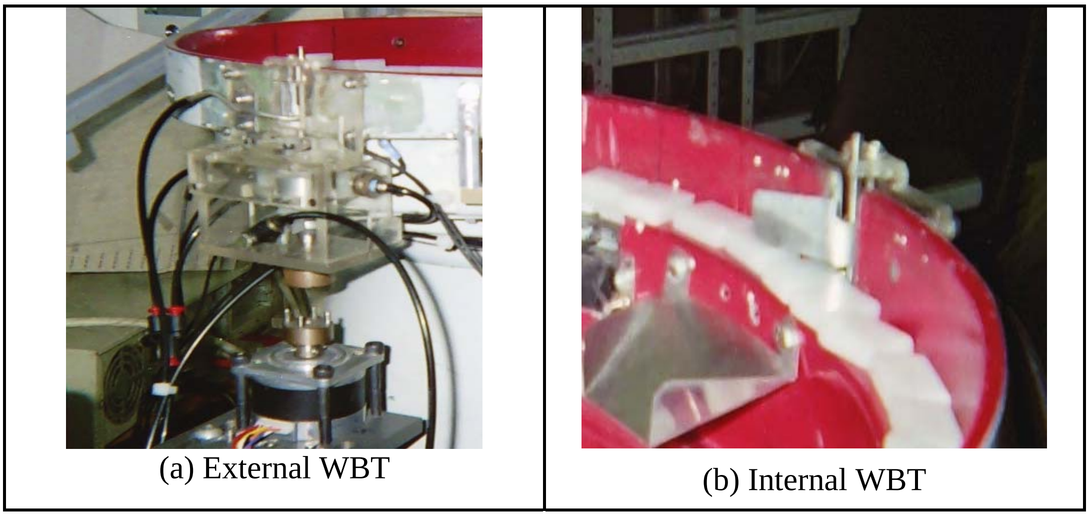
Change the Height (h_w) of the Wiper Blade

The VBF is switched off. The guided cylinder will be extended and the pulleys engage as before. Pin Cylinder A will be retracted as pin Cylinders B and C remain in the extended position (locking the angle). This allows the height adjustment shaft to act independently of the carrier shaft through the clutch mechanism.

As the stepping motor rotates the height adjustment shaft rotates through the internal thread in the carrier shaft. The carrier shaft will now move up or down (linearly) depending on the rotation of the stepping motor. This is assisted by the engaging slides mounted on pin Cylinders B and C. When a new height has been obtained pin Cylinder A will be extended, this locks the wiper blade in the new position. The stepping motor will now be disengaged from the assembly and the VBF will be turned back on.

Design Discussion

The design of the automated wiper blade tool was difficult to visualise at first. The tool was designed around the dimensions of the VBF and has been restricted to the functions of the original tool (i.e. θ_w and h_w). The final design provided a working range of between $\theta_w = 0^o$ to $\theta_w = 90^o$ (at 3.6^o, 1.8^o or 0.9^o increment steps as provided by the stepper motor) and h_w = 0mm to h_w = 10mm (at 0.24mm increment steps). The mechanical parts that made up the assembly were developed in the AMTLAB. The wiper blade was made of stainless steel. This meant it had a hardwearing surface and a low coefficient of friction that would assist the sliding of components as they were rejected back into the VBF (Fig. 4-13).



(a) External WBT

(b) Internal WBT

Fig. 4-13: The Automated Wiper Blade Tool

The pin cylinders used on the prototype tool were large in comparison to the manufactured parts. This was due to availability at that time. They were also fairly heavy and did not suit the weight restriction applied to the tool. Miniaturised pin cylinders should be considered for future tool development. Overall the tool worked correctly for both a height and angle change as required during the experiments (seen later in Chapter 6). The tool was light but rigid and vibrated as a single unit with the bowl when the VBF was operating. It did however have a slight inherent vibration as opposed to the bowls vibration; this was probably due to a tolerance difference between mating or moving parts within the mechanical structure of the tool. This vibration did not present any unnecessary problems to the components as they were conveyed. To a certain extent the design development and manufacture of this tool could be considered reasonably successful because it demonstrated in detail the design requirements, functions and operation of an automated orientation tool.

Operating Range of the Tools

The operating range of the wiper blade height is set by the blade characteristics and the bowl chosen. The blade was fixed on a carrier shaft that is driven by the drive mechanism. This could be replace by blades with different dimensions. This would provide a wider wiper blade operating range if required, alternatively a new carrier shaft could be designed with an increased length. Component width and length is limited by the characteristics of the VBF. In a commercial situation different sized bowls should be supplied for various sized components.

<u>*Component Ranges*</u>

The AMTLAB wiper blade tool (Prototype #1) has a specific component operating range for which the tool is capable of orienting:

- Component ***width*** and ***length*** is limited by the bowl:
    - A maximum of 24mm applies (i.e. the vibratory bowl track width)
- Component **height** is limited as follows:
    - A maximum of 10mm applies (i.e. < The max blade height).
    - A minimum of 0mm applies (i.e.> The min blade height).

4.6.2 The Narrow Track Tool

The Narrow Track Tool (NTT) is a section of the VBF track that has been cut out, modified (narrowed down) and/or replaced in the cut-out section to function as an orientation device (Fig. 4-14). It can be classed as a passive orienting tool, as it rejects components that are incorrectly orientated (one of only two possible orientations) back into the VBF.

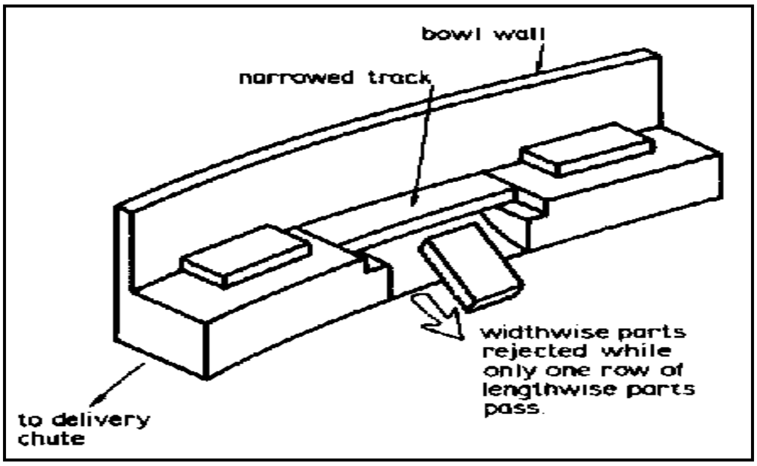


Fig. 4-14: The Narrow Track Orienting Tool (Boothroyd, 1981)

A narrow track orientation device is generally employed to orientate components lengthwise end to end, while permitting only one row to pass. This means that components (rectangular or otherwise in shape) with their longest dimension running at 90^o to the bowl wall will be rejected while only those components with their longest dimension running parallel to the bowl wall will be accepted.

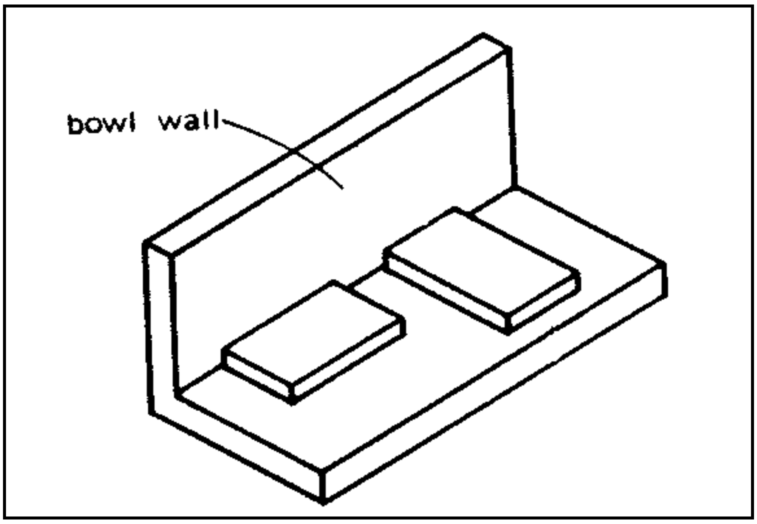


Fig. 4-15: Rectangular Prism Components on a Track (Boothroyd, 1981)

The main function of the narrow track tool is to reject the undesired orientations leaving only a continual supply of correctly orientated components through to the final orientation tool, in this case the Edge Riser Tool (ERT). The function of the narrow track tool is achieved by controlling the width of the replacement section of the bowl track to the bowl wall. The feed rate of correctly orientated (the required orientation) components that successfully pass by the narrow track tool would depend on the number of components that have there full length parallel to the bowl wall and the rate of components that encounter the narrow track tool. An efficient narrow track tool should help to increase the rate of components travelling on to the remaining orientation tools. The narrow track tool will be positioned on the VBF where only two possible orientations can occur. This is located between the wiper blade tool and the edge riser tool. The NTT has been selected for development as a prototype tool (prototype #1) for two reasons.

1. The first is that there is sufficient literature that provides essential design data, documented by Boothroyd [1981] for the development of such a tool.
2. The second, is that it is part of a typical orientation system, that in this situation is used to demonstrates the orientation of the rectangular prism components for the purpose of automation.

Design Data to Consider in the Development of a Programmable Narrow Track Tool

In designing the prototype NTT tool the system characteristics (functions) for which it was first developed were initially considered. The tool could, therefore, act in a manner similar to that of the conventional tool, without presenting any additional problems to component feeding.

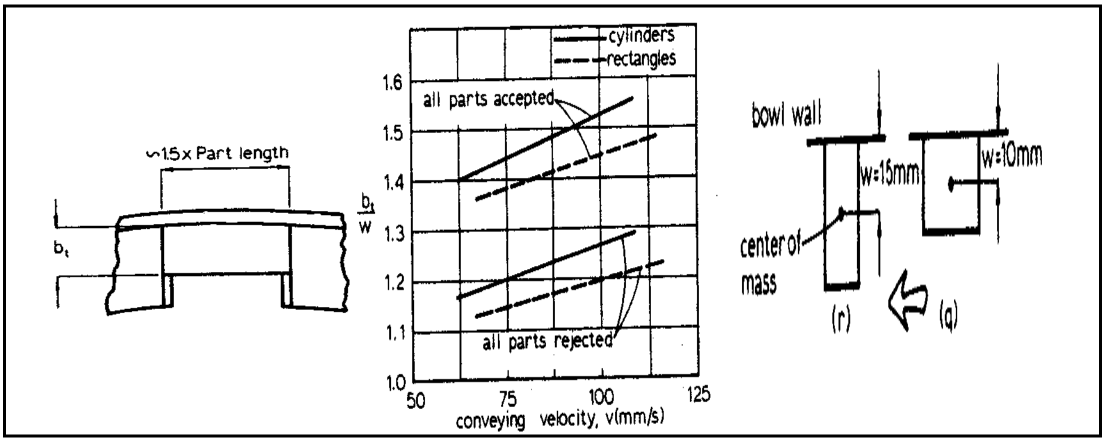


Fig. 4-16: Design Data for the Narrow Track Tool (Boothroyd, 1981)

The important design data (Fig. 4-16) to consider here in accordance with Boothroyd, will be the length of track (1.5 x component length) and the width (**b_t**). The AMTLAB rectangular prism component used in the WIT experiments has a length of 23.6mm and a width of 18mm. Using a conveying velocity of 100mm/s (as chosen by Boothroyd), the corresponding values of the dimensionless track width (**b_t/w**) were 1.2 and 1.45 respectively. A tool that supplies components with these dimensions will be calculated as follows.

Thus in millimetres: $(1.2)\ (\text{Part}_{(\text{length})}/2\ ) > \mathbf{b_t} > (1.45)\ (\text{Part}_{(\text{width})}/2)$

$$(1.2)\ (23.6/2) > \mathbf{b_t} > (1.45)\ (18/2)$$

$$(1.2)\ (11.8) > \mathbf{b_t} > (1.45)\ (9)$$

$$(14.16) > \mathbf{b_t} > (13.05)$$

Therefore, the AMTLAB narrow track width (b_t) should be at least 13.05mm wide and not greater than 14.16 mm for the rectangular prism components. The tool has the capability of handling a full range (0mm to 24mm) of different components. The length of the track section is based on the length of the component and is therefore 35.4mm (23.6 x 1.5) long in accordance with Boothroyd's guidelines. The length of the track section will ensure that a component can sit comfortably with its longest dimension parallel to the bowl wall. The width (b_t) ensured that components travelling at 90 degrees to the bowl wall would fall back into the VBF.

Factors to Consider in the Design of a Programmable Narrow Track Tool

Other important factors considered in the design of an automated narrow track tool were as follows:

1. The tool will be designed so that automatic control of the width (b_t) is variable. This will help to accommodate components with different dimensions and allow various experiments to be conducted at a later stage.
2. The only part of the tool that should come in contact with the conveying components is the narrow track ledge. This will ensure that the tool retains its original design features.
3. The tool will be designed and manufactured to accommodate stepper motor control. For the purpose of experiments (conducted at a later stage) the tool is manually programmable at present.
4. The tool must be locked in position (using a pin cylinder) while the VBF is operating.

The Programmable Narrow Track Tool Concept Model

A prototype design was developed. This was based on numerous designs (sketches). The final design was developed by the author with the aid of a specially constructed 3D cardboard model (Fig.4-17) as before.

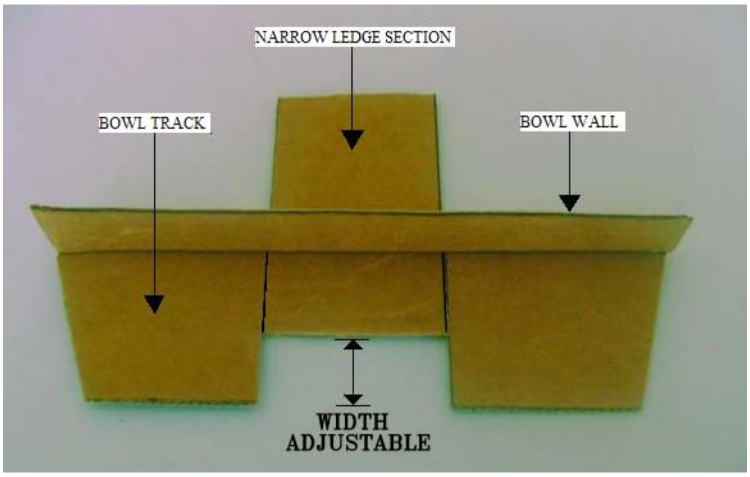


Fig. 4-17: The Narrow Track Tool Concept Model

This design consisted of a narrow track ledge section that protrudes through a horizontal slot in the bowl wall of the VBF. This ledge section will be connected to a shaft from outside the bowl wall, which could be driven by the standardised stepper motor drive system. The design demonstrated the important function of width-wide ledge adjustment for the NTT.

Design Functionality - The NTT will have a certain amount of induced (linear) vibration transmitted to it as it no longer vibrates as a completely fixed orientation tool. The induced vibrations might affect component feed rate. As the components enter the NTT location and as they leave it they have to negotiate a slight step change down (of approximately 0.01mm) from the bowl track to the narrow ledge section and again from the narrow ledge section to the bowl track without resulting in reorientation problems. These steps were considered necessary to facilitate component transfer across the narrow track ledge by counteracting the linear vibration in the narrow ledge section.

Technical Feasibility - The development of an automated prototyping tool would involve the incremental movement of the cut-out section for automated control of the width (b_t). These incremental movements should be obtained using the stepper motor drive system.

The Operation of the Programmable Narrow Track Tool

Drawings were developed of the prototype NTT (Fig. 4-18). These drawings incorporated all of the requirements of the original tool but were adapted with automated programmable features. The design of this tool proved relatively simple in comparison to the design of the wiper blade tool, because the narrow track tool had to accommodate various changes in the width (b_t) of the track only. This meant that there was only one adaptable feature to consider in the new design.

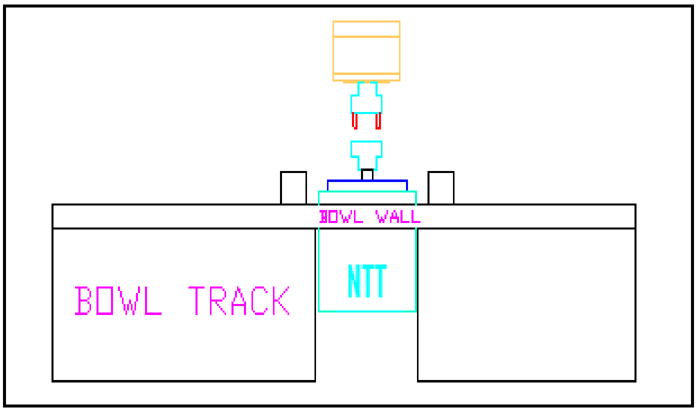


Fig. 4-18: Plan View of the Automated Narrow Track Tool

The new design proposal was based on the initial research and satisfied the basic functions of the original tool while making automation possible. The side view of the NTT (Fig 4-19) shows how the tool will be operated through the rotation of a threaded shaft. This shaft is attached to a cross roller slide that assists in the movement of the NTT replacement ledge.

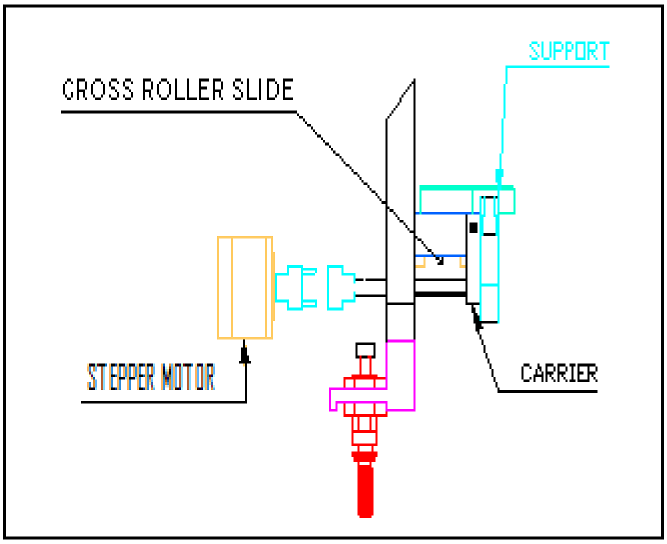


Fig. 4-19: Side View of the Programmable Narrow Track Tool

The dimensions of the narrow track tool depends on the dimensions of the profile of the VBF track (Fig.4-20).

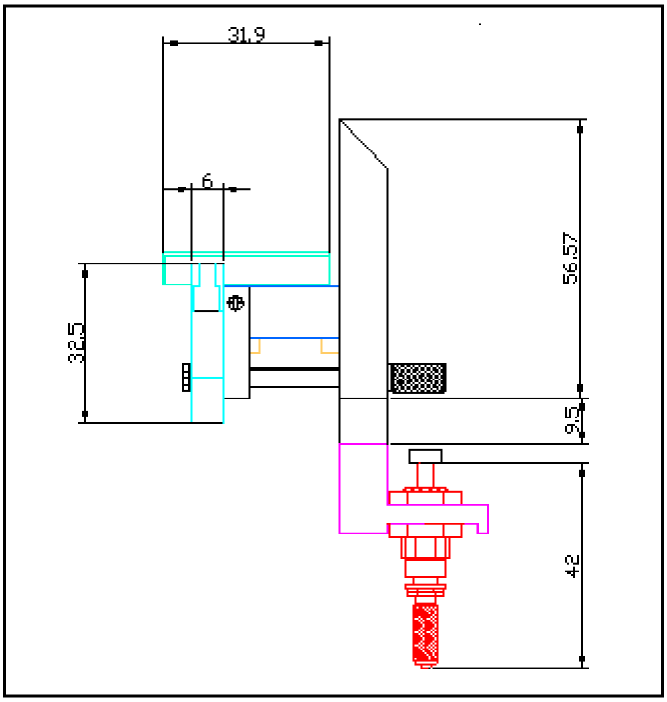


Fig. 4-20: Dimensioned View of the Programmable NTT

The main components that make up the narrow track tool can be seen in Fig. 4-21.

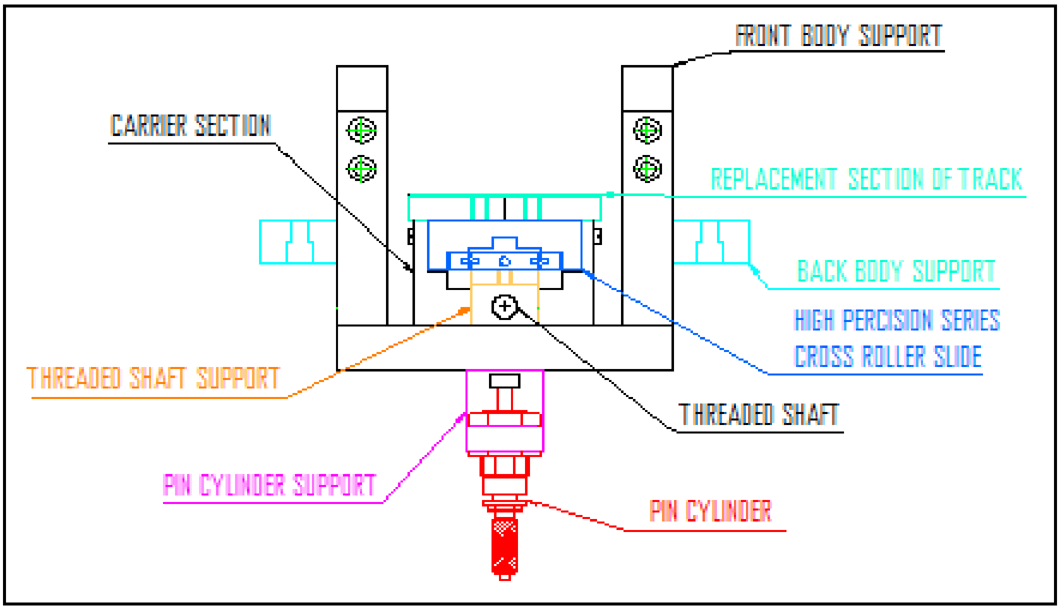


Fig. 4-21: The Narrow Track Tool Assembly

This tool could be operated either manually (knurled screw) or automatically using a stepping motor as before. The design of the tool clearly demonstrates how the movement of the narrow track tool replacement ledge section of track is achieved.

*<u>Increasing the Width (**b_t**) of the Narrow Track Ledge</u>*

Initially the VBF is switched off and the pin cylinder that locks the threaded shaft in position is retracted. As the threaded shaft is rotated clockwise the carrier section will move through a certain Distance “L” assisted by the high precision linear cross roller slide. The carrier is attached firmly to the upper part of the cross roller slide and the replacement section of track (narrow ledge section) is attached to this. As rotation occurs the carrier moves linearly carrying the narrow track section. The width (b_t) of the narrow track is increasing with every movement (in degrees) of the threaded shaft. When the new position of the narrow track ledge has been located the pin cylinder is extended locking the tool in position and the VBF is switched back on.

Reducing the Width (b_t) of the Narrow Track Ledge

Initially the VBF is switched off and the pin cylinder that locks the threaded shaft in position is retracted. As the threaded shaft is rotated anti-clockwise the carrier section will move through a certain distance “L” assisted by the high precision linear cross roller slide. As rotation occurs the carrier moves linearly carrying the narrow track section. The width (b_t) of the narrow track section will decrease with every movement (in degrees) of the threaded shaft. When the new position of the narrow track section has been located the pin cylinder is extended locking the tool in position and the VBF is switched back on.

Design Discussion

The dimensions of the narrow track ledge have been previously described and the remaining parts that made up the assembly have been designed around these dimensions taking into consideration the VBF profile. The assembled parts have been attached to the VBF via an external support structure (Front and back supports). An important point to consider is that the replicable narrow track ledge must operate efficiently at an angle of 7^0 to the horizontal. This leaves an included angle of 83^0 between the inclined track and the bowl wall.

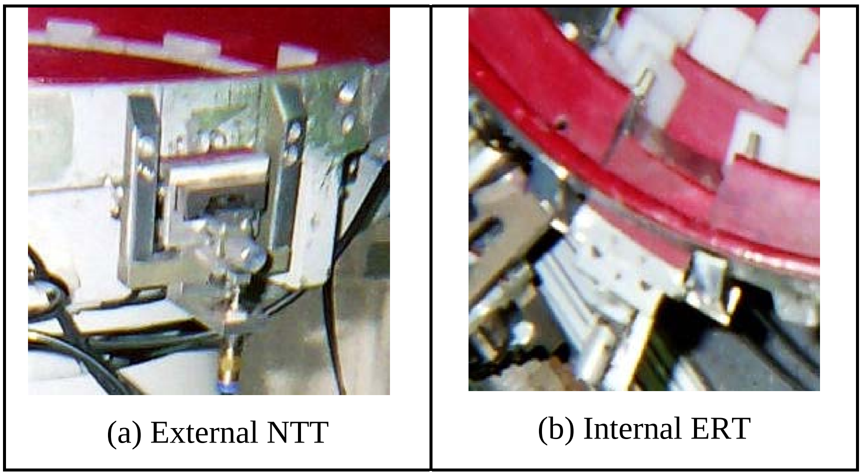

(a) External NTT
(b) Internal ERT

Fig. 4-22: The Programmable Narrow Track Tool

As mentioned earlier the design of this tool was relatively simple as the only variable to consider was the movement of the narrow track section. If possible, future orientation tools should be designed as completed assemblies with common/standardised attachment arrangements leaving attachment to the VBF relatively simple and convenient. The dimensional accuracy of the bowl profile would be essential in either case. The end result (Fig. 4-22) demonstrated a narrow track orientation tool that was manually programmable but which might be automated if required. This tool was light but rigid and vibrated as a single unit with the VBF. To a certain extent the design and development of this tool could be considered reasonably successful as it demonstrated in detail the design requirements, functions and operation of a prototype programmable narrow track tool.

<u>Component Ranges</u>

The AMTLAB narrow track tool (Prototype #1) has an operating range as follows:

- Component ***width*** is limited as follows:

  The width of 19mm (i.e. 80% of the maximum track width applies of 24mm). The 80% maximum is applied to ensure that components travel in a single file in either orientation ‘a’ or orientation ‘b’.

- Component ***height*** is limited as follows:

  Maximum component height is limited by the height of the bowl wall.

  Minimum component height of 1.5mm applies (this limit is set by the jamming angle at the ledge/track transfer).

- Component ***length*** is limited as follows:

  The Length of the component is limited by the diameter of the bowl (as suggested by Boothroyd).

4.6.3 The Edge Riser Tool

This device is attached near the outlet of the VBF and it is the third and final orientation tool to be developed in the AMTLAB orientation system. The edge riser tool is a piece of material that has been machined out and forms a curved angle with the bowl track. The tool is usually made from the same material as the bowl. Its function is to re-orientate the rectangular prism components (while maintaining certain orientations) from a position lying flat on the bowl track up into a vertical upright position (Fig. 4-23).

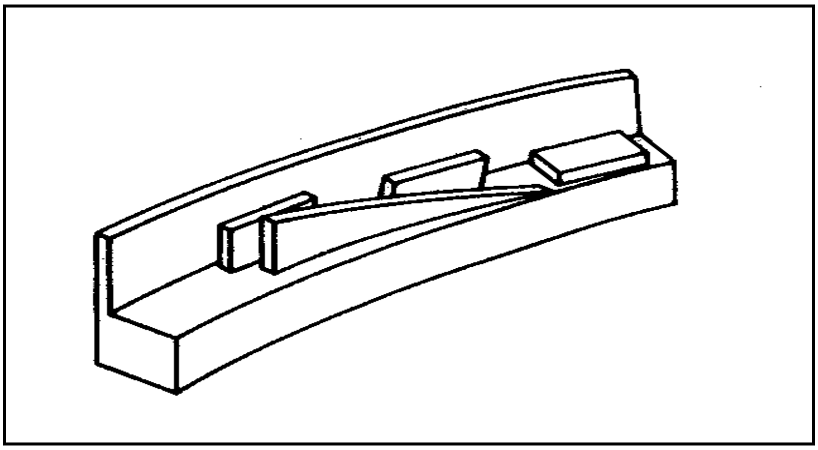


Fig. 4-23: Orientation System for the Rectangular Prism Component (Boothroyd, 1981)

The edge riser tool is classed as an active orientation device as it does not reject parts back into the VBF. The upright position of the rectangular prism components is the final (desired) orientation required from this system of orientation tools. The edge riser tool forms an angle with the bowl track, that is fixed in position, to assist in the smooth translation and reorientation of the components. The distance between the tool and the bowl wall is set to allow one component through at a time. The feed rate of components that pass by the ERT tool will depend on the angle of the rail set relative to the bowl track and the number of components that encounter the tool. An efficient edge riser tool should facilitate the reorientation process and the probability of demonstrating a 100% efficiency is considered highly feasible in this case.

Reasons for the Development of the Programmable Edge Riser Tool

The edge riser tool has been selected for development as a prototype tool (prototype #1) for two reasons as follows:

- The first is that there is sufficient literature that provides essential design data, documented by Boothroyd [1981] for the development of such a tool.
- The second is that this tool is a very common type of orientation tool and it is part of the orientation system of tools required to orientate the rectangular prism components. The redesign of the edge riser tool as a programmable orientation tool completes the design/development of a typical orientation system.

Design Data to Consider in the Development of a Programmable Edge Riser Tool

The design data used in the development of the automated edge riser tool is provided in Fig. 4-24. One of the most important piece of design data to considered is the Angle (γ), made between the bowl track and the tool rail edge. This angle is used to re-orientate the components, by turning the components as they are conveyed into orientation ‘c’ an upright position. A rectangular prism component of dimension length (**A**), width (**B**) and thickness (**C**), where **B>4C** the distance “**d**” made between the side of the edge riser tool and the bowl wall was calculated and applied as follows; **1.5C** and **0.9B** from the bowl wall (**C** = 5.8 the mean thickness of the components, **B** = 18 the mean width of the components).

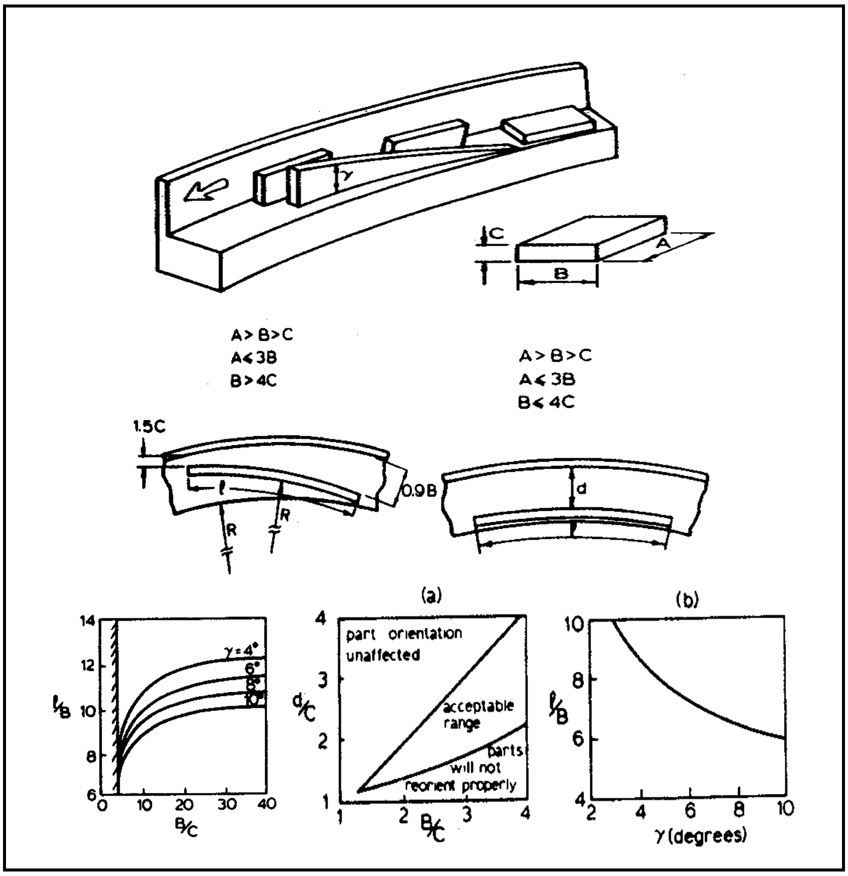


Fig. 4-24: Design Data for the Edge-Riser Tool (Boothroyd, 1981)

Hence

$$1.5C = 1.5(5.8) \text{ or } 1.5C = 8.7\text{mm}$$

and

$$0.9B = 0.9(18.0) \text{ or } 0.9B = 16.2\text{mm}$$

The length of the edge riser tool (rail length) "**L**" should be sufficient to allow components to travel up the incline smoothly without restricting or increasing the pressure on the remaining components. In this situation the angle (γ) is made adjustable through automation. Experiments can then be preformed at various angles from between 0^{o} lying flat on the track to 10.5^{o} vertically up, until the optimum angle has been obtained. The optimum position for the values of **1.5C** and **0.9B** are calculated and set stationary in this instance, but for future tool development (Prototype #2) and to accommodate a wide range of components both these values along with the Angle (γ) should be automated as independent variables. The other factors to consider in the design of the edge riser tool are as follows:

1. The tool will be attached to the VBF as a combined assembly manufactured independent of the VBF.
2. The tool will be designed as a manually programmable tool (prototype #1) at first,

but when adapted with a clutch coupling and stepper motor drive system will become automated.

The Programmable Edge Riser Tool Concept Model

An edge riser tool concept model was developed that was based on numerous designs (sketches). A prototype design was developed by the author with the aid of specially constructed 3D cardboard model as before. The purpose of the 3D model was to demonstrate and evaluate this design as a feasible concept towards programmability of the conventional tool (Fig. 4-25).

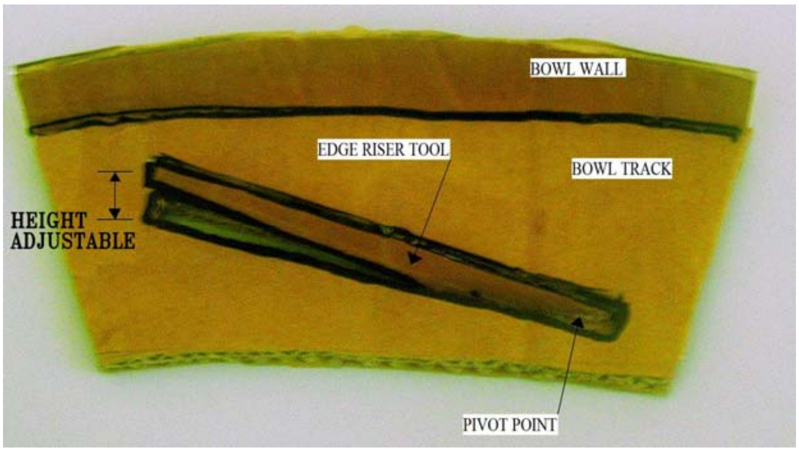


Fig. 4-25: The Edge Riser Tool Concept Model

This design consists of a section of track with a recess slot machined down into the track. The slot is set at a angle to the bowl wall and is used to accommodate the angular movement of the raised ledge section as it pivots about a point in the slot. The raised ledge section protrudes up through the slot and makes a vertically raised angle with the bowl track.

Design Functionality - As components are conveyed on the bowl track they begin to climb up the raised ledge section. The point at which the components touch the raised ledge section is considered significant; at this point the components might change orientation, so a smooth transition from the bowl track onto the raised ledge section is vital for the reorientation process. Excessive vibration in the raised ledge section would cause problems to components travel up the incline. A locking mechanism (pin cylinder) should be used to restrict vibration in this case.

Technical Functionality - The development of a programmable raised ledge tool would prove difficult, as it would involve machining into the surface of the VBF. If possible a section of track should be removed from the VBF to assist in the manufacture and assembled of the tool. This section could be reattached at a later stage. The attachment and reattachment of the orientation tool as in this situation demonstrates a level of modularity in the orientation tool design.

The Programmable Edge Riser Tool

The programmable edge riser tool (Fig.4-26) is designed to accommodate various changes in the angle (γ). The components are conveyed to the outlet of the VBF in one orientation only, orientation ‘c’.

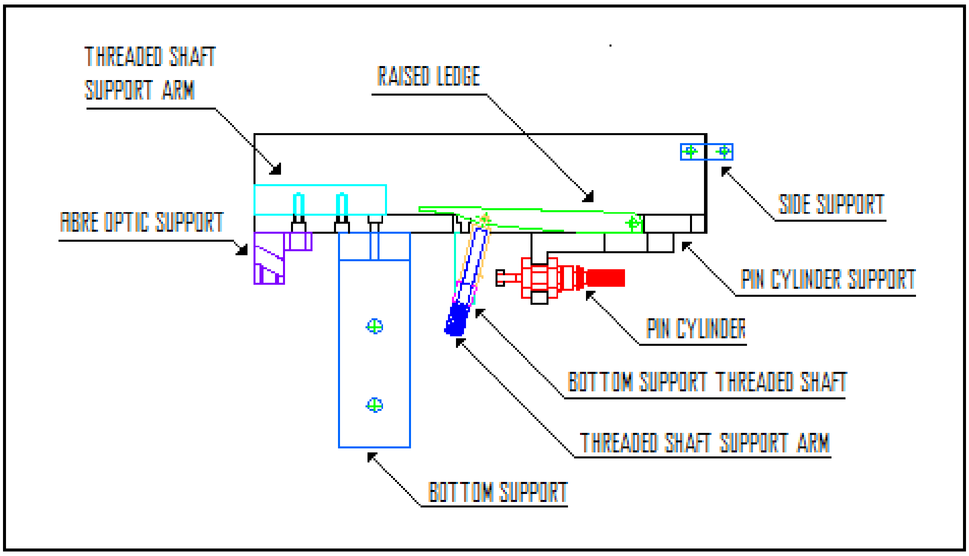


Fig. 4-26: Front View of the Programmable Edge Riser Tool

This tool was the final orientation tool developed in the orientation system and demonstrates the design process involved in programmability of the convention tool.

Operation of the Edge Riser Tool

The tool is mounted as a complete assembly on the VBF using the bottom and side supports. The narrow track ledge section can be adjusted by means of a threaded shaft from beneath the track. The threaded shaft is accommodated mechanically to pivot slightly as the edge riser tool is raised. The pin cylinder is used to the lock the tool in position when the VBF is in operation mode. The tool has also been adapted with a “hold in” section that is used to maintain the final orientation of the components over the remaining section of track. A plan view of the automated edge riser (Fig. 4-27) shows the position of the raised ledge section in proximity to the bowl wall.

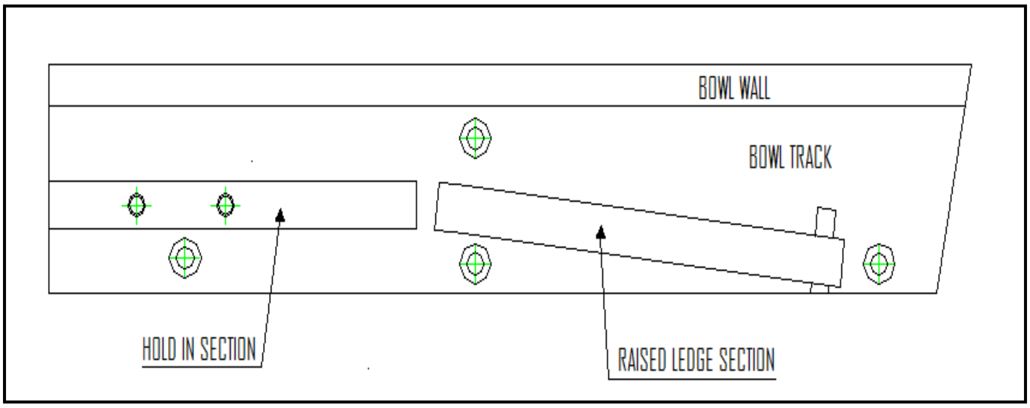


Fig. 4-27: Plan View of the Automated Edge Riser Tool

The dimensions of the edge riser tool depend on the dimensions of the VBF (Fig. 4-28).

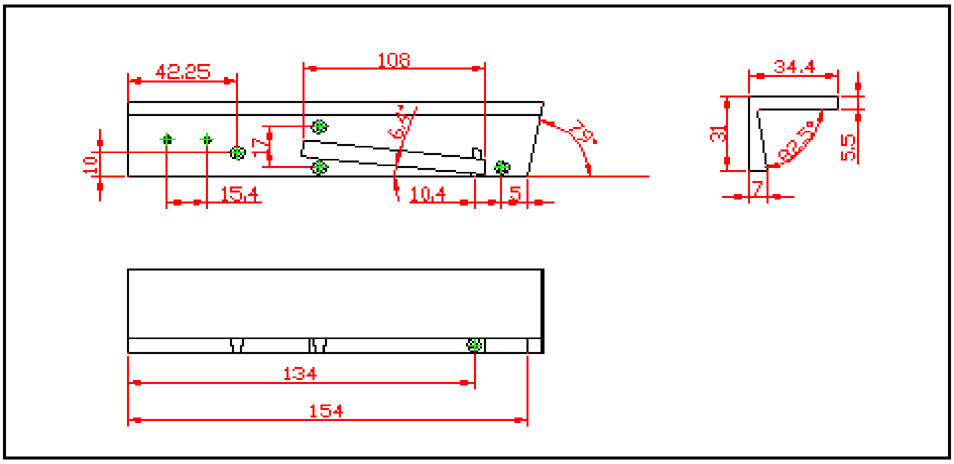


Fig. 4-28: Dimensioned View of the Edge Riser Tool

The operation of this tool is relatively simple. The tool's operating range begins at 0^o (lying flat on the bowl track) but for the purpose of reducing a range of negligible experiments resulting in insignificant data, an operating range of between 4^0 to 10.5^0 at increments of 0.138^0 angular steps was considered sufficient.

<u>Adjusting the Edge Riser Angle (γ) during the Experiments</u>

The VBF is switched off and the pin cylinder is retracted. This allows the screw thread to be adjusted. A clockwise rotation of the screw thread raises the edge riser ledge to the next experiment position. The pin cylinder is now extended and locks the tool in the new position. The VBF can now be switched back on.

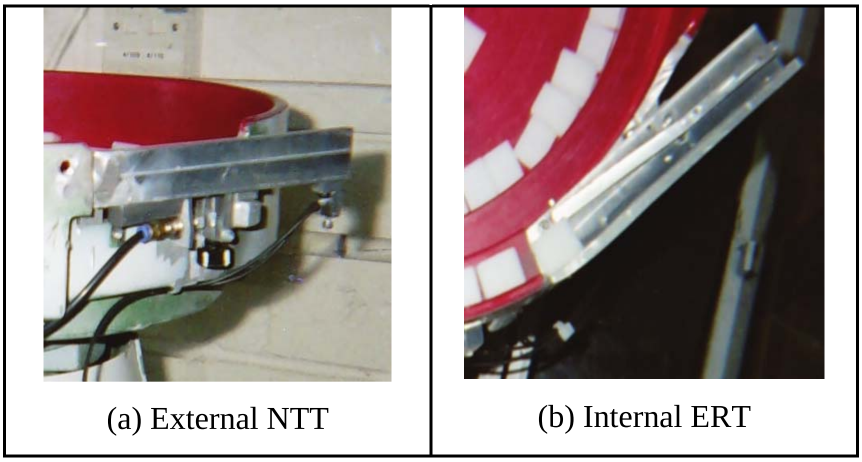
Adjusting the Edge Riser Angle (γ) as the Experiments are Complete

The VBF is switched off and the pin cylinder is retracted. An anticlockwise rotation of the screw thread will lower the edge riser ledge after all of the experiments are completed. When the ledge is at 4 degrees (the start position) the pin cylinder is extended and the tool is locked in the new position. The VBF can now be switched back on.

Design Discussion

The design of the tool was considered acceptable. Its development as a complete assembly manufactured independently of the VBF demonstrated its inter-changeability and modularity. The tool was made entirely of aluminium with the exception of the screws and pin cylinder mechanisms. The tool was assembled and then attached to the VBF using support brackets. The edge riser orientation tool had a positive track angle of 7^{o} similar to that of the VBF. This helps to orientate the components as they are conveyed to the delivery chute. The edge riser tool is manually programmable at present but could be adapted for automation using the standardised clutch type mechanism and stepping motor drive system as before.

This tool worked well in practice and demonstrated an effective programmable edge riser orientation tool (Fig. 4-29). The tool was designed around the profile of the AMTLAB VBF and was used to accommodate various changes in the edge riser angle (γ).



(a) External NTT

(b) Internal ERT

Fig. 4-29: Photograph of the Automated Edge Riser Tool

If possible a new design should be considered for this tool that could provide axial movement for the raised ledge section about the distances **1.5C** and **0.9B** that are completely independently of the angle (γ). With these design developments the prototype tool (Prototype #2) should accommodate a wide range of components with different dimensions and shapes. This tool helps to demonstrates in detail the design requirements, functions and operation of an automated/programmable edge riser orientation tool.

Operating Ranges

The operating range of the tool is set at distances **0.9B** and **1.5C** by the edge riser section fixed location. This restricts the dimension and shape of the components used in the experiments. A wider operating range could be achieved with a higher degree of automation about these variables. The possible operating range for the angle (γ) is from 0^o to 25^o but the working range used in the experiments (Chapter 6) by the author is 4^o to 10.5^o for a rectangular prism component of these dimensions.

Component Ranges

The AMTLAB edge riser tool (Prototype #1) has a component operating range as follows:

- Component ***width*** and ***height*** (thickness) is limited by the bowl:
  - A maximum of 24mm applies (i.e. the vibratory bowl track width).
  - A maximum of **1.5C** applies =1.5(5.8) = 8.7mm (Boothroyds recommendation). The minimum thickness of a component at this location is set by the practicalities of feeding narrow components but could be as little as 1.5mm.
  - A minimum of **0.9B** applies =0.9(18) = 16.2mm. (Boothroyds recommendation).

4.7 The Sound Enclosure

Where excessive noise or vibration levels are produced by operating machinery a means of reducing both levels should be provided and was deemed necessary to comply with regulatory noise levels. Noise levels are measured in decibels (dB). In compliance with law requirements the working environment 'exposure limit values' set to reduce noise to a minimum are as follows:

- Lower Exposure Action Levels (EAV_{LWR}): Daily exposure 80(dB) not to exceed a peak sound pressure of 135(dB);
- Upper Exposure Action Levels (EAV_{UPR}): Daily exposure 85(dB) not to exceed a peak sound pressure of 137(dB):

[www.uk-legislation.hmso.gov.uk]

A special purpose acoustic sound enclosure was built for this purpose. Sound enclosures are widely used in industry especially where upper exposure limit values are expected. The sound enclosure developed for this project is based on the following requirements:

- Noise levels in the AMTLAB research environment should be at a minimum.
- It is necessary to inspect the vibratory bowl feeder, its tooling and the associated equipment in its operating condition.
- Ease of access for tooling modification and inspection.
- Vibration levels should be kept to a minimum.
- Operator safety (when the vibratory bowl feeder is in operating mode).

The sound enclosure is made up of two sections, a hinged lower section and a raised upper section. The lower section surrounds the VBF and its associated equipment. A box iron frame is attached firmly to a solid base (table) on which the bowl is mounted. The upper section was attached to the lower section by hinges and two hydraulic shock absorb cylinders. These cylinders keep the enclosure in the open position dividing the upper and lower sections. The open front and side sections of the enclosure allowed access to the VBF and the associated equipment as required. The upper and lower sections are covered with Perspex panels to allow visibility (Fig. 4.30).

(a) Open Position **(b) Closed Position**

Fig. 4-30: The VBF Acoustic Sound Enclosure System (AMTLAB)

When the enclosure is closed and the VBF is operated the ambient noise levels are below 85(dB) but in the open position it would be above 90(dB). Elastic synthetic rubber pads were placed between the solid base legs of the table and the floor to prevent vibration transmission, this also helped to reduce the ambient sound level.

5 The Automatic VBF Tool Setting Software System

5.1 Introduction

As the mechanical problems of tool vibrations and motion control were solved, the development of a tool automation and optimisation system for the AMTLAB VBF Wiper Blade tool became central to the project. This involved the introduction of a PLC into the VBF system with its ancillary wiring and sensing hardware and gave rise to an extensive PLC program development stage in the project.

The VBF PLC program developed consisted of a number of part programmes. These were produced independently and then integrated to control the VBF system. Central to the PLC control structure was the development of a stepping motor program. This stepping motor program was developed by building on a smaller stepping motor program using switch sequence control (Rota link catalogue, Appendix H). Having commissioned the main stepping motor programmes (see Appendix B), the Wiper Blade PLC sequence program could then be developed.

The overall WBT PLC program contained a “Management Program” for running automatic experiment programmes for the tool. The management program ran the experiments obtaining feedback from the sensors and then used this data to determine the performance at each specific tool setting. An index of performance was created by the program and the optimum performance was established from this index. The optimum performance point of the tool would be a basis for the final tool setting for that specific component.

As each part program was developed it was linked into a unified PLC control structure establishing a completely automated orientation tool on the VBF. Having successfully completed and commissioned the Wiper Blade PLC program, two further equivalent management programmes were implemented, one for the Narrow Track Tool and the other for the Raised Ledge Tool. As these tools were not yet automated these programmes did not include stepping motor programmes in their ladder logic specifications. The programmes were developed to enable experiments to be conducted across the 3 tools as a ‘tool set’ for a typical orientation system.

5.2 The Automatic VBF Tool Setting System

The ultimate aim of the AMTLAB PLC control system was to determine the optimum setting for each of the orientation tools for the feeding of the specific component. This was achieved through automatic experimentation (see Chapter 6). The optimum performance of each orientation tool was obtained by driving the programmable bowl through a suite of automated performances. This entailed the automatic control of the following key areas:

1. The VBF electro-mechanical systems itself (start, stop etc.).
2. The management search process.
3. Data acquisition, calculations and storage.
4. Selection of the optimum performance and generation of the associated settings.
5. Possible graph generation for manual monitoring of progress.

This chapter deals with the above, as well as storage and retrieval. Graph generation is discussed in detail in Chapter 6.

The VBF Electro-Mechanical Systems

The AMTLAB VBF programmable orientation tooling modules were individually designed to meet conventional tooling requirements. The development of the WBT electro-mechanical system was focused on the creation of a generic PLC control system architecture that could be used for future tool development. The WBT tool electro-mechanical system included:

1. The stepping motor drive system.
2. A component blockage management system.
3. A fibre optic component counting sensor system.
4. The VBF electromagnet drive system.
5. The pneumatic drive engaging/disengaging system.
6. The orientation tooling pneumatic locking system.

These systems were integrated to create the automatic VBF tool setting system.

The Automated Experimentation Process

The main PLC programmes developed for the current range of tools contained an experimentation management program; this program performed the automated search.

Tool Setting Programme

This involved automatically setting the programmable tool at a range of predetermined settings on batches of components in order to determine the optimum position. The number of experiments for example, conducted to establish an optimum angular position of the wiper blade tool covered 31 angles and 26 heights, so the total number of experiments, for the wiper blade tool totalled 806 i.e. (31x26). The experimental quantity (number of components tested per experiment) was set at 1000 components. The process was fully automated from the point where the user inputs the maximum and minimum tool setting parameters (height & angle) to the system. The performance search process is explained in the operating sequence for the WBT later in this chapter, in conjunction with the WBT ladder logic programme (Appendix B).

Optimum Performance Process Data Acquisition, Calculations and Storage

The optimum performance of each experiment was calculated using a specially developed algorithm (see Chapter 6). The algorithm used component count data obtained from carefully positioned fibre optic sensors in the orientation tool. The resulting performance calculation (*current performance*) was then compared with the *previous maximum.* If it was higher, then the *current performance* calculation became the optimum performance and the current tooling setting position was stored for retrieval at the end of the experiment process. The optimum performance process is explained under the operating sequence for the WBT later in this Chapter. At the end of the experimentation the system automatically sets the tools to the optimum position as identified.

5.3 Outline Specification for the VBF system of Automated/Programmable Tooling

1. The automated orientation tool would be used on a manually selected sequence of orientation tools.
2. The power to the vibratory bowl feeder should be intermittently controlled for continuous engaging and disengaging of the stepper motor during the experiments.
3. The stepping motor must be programmable allowing clockwise and anticlockwise rotation of the tool when required (i.e. the tool’s position in relation to the VBF will be constantly changing during the experiments).

4. The PLC program should obtain, monitor and analyse data pertaining to the experiments in an effort to establish performance numbers for the orientation tool.
5. Any blockages caused by jamming or otherwise must be cleared (using air-jets) by the PLC program without human intervention and without affecting the performance of the Vibratory Bowl Feeder
6. The PLC program should select an optimum performance from the index of performance obtained at the end of the experimentation process and should proceed to set the orientation tool to its optimum position (This optimum position of the tool for a specific component will of course be its re-programmable position for that specific component at any future date).

5.4 Programmable Logic Controller (PLC)

The decision to use a Programmable Logic Controller (PLC) to control the VBF system was made during the automation stage of the project. An alternative could have been to use a personal computer (PC) with an in/out interface (such as Lab VIEW), but the reliability aspect of the PLC was a significant factor to consider in this decision (since the unattended experimentation process took perhaps twelve hours to complete).

A PLC is an industrial computer control system that continually monitors the state of the input devices and makes decisions based upon a custom program stored in a Central Processing Unit (CPU) to control the state of output devices. The functions of the CPU were as follows:

- To execute the control instructions contained in the user’s program.
- To communicate with other devices that would include input/output (I/O) devices, programming devices, networks and even other PLC’s.
- To perform housekeeping activities such as communications, internal diagnostics.

The PLC operated by performing a continual ‘loop’ through its internal user program as follows:

- Input Scan to detect the state of all input devices.
- Program Scan to execute the user created program logic.

- Output Scan to energise/de-energise all output devices.
- Housekeeping to communicate with program terminals.

The PLC used to control the VBF and its orientation tools was a Mitsubishi FX-48MR programmer (Fig. 5-1); that used a MELSEC-MEDOC (MS-DOS BASED) software package. An SC-09 programming cable was used to communicate from the serial port of the VBF PC to the programming port (RS232) of the PLC.

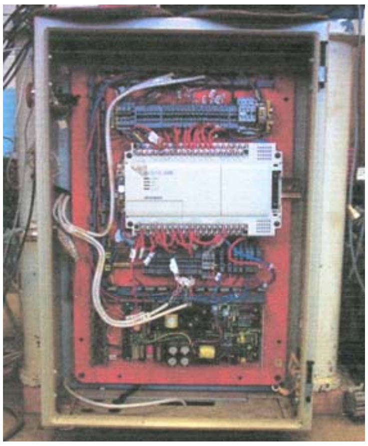


Fig. 5-1: Mitsubishi FX-48MR PLC (AMTLAB)

The PLC had 24 inputs and 24 outputs, this could be combined with digital input/output add-on units if required. This was considered adequate at the time to program the wiper blade tool. The programs, developed by the author, used a graphical programming language referred to as ‘Ladder Logic’ programming. All the ladder logic programs developed (described later) are provided in Appendix B, and are fully commented and accompanied by the associated I/O lists.

Stepper Motor Control

The decision to use stepping motors for precision control of the orientation tools (decided during the design stage of the project) was made for the following reasons:

- The reprogramming (setting and resetting) of the tools location involves clockwise and anticlockwise rotation through its mechanical assembly. Stepper motors feature bi-directional control.
- The engaging and disengaging of the drive system via clutch coupling involves the stationary positioning of the motor assembly in standby. The ability to keep the power on and hold (to stall indefinitely) the rotor of the stepper motor in

position (without damaging it) is a unique feature associated with stepper motor design.

- Precise positioning of the drive system is required to continually reposition the orientation tools. Stepper motors exhibit precise positioning, especially in low acceleration applications. A very low acceleration is expected in orientation tool repositioning applications.
- Stepper motors are electro-mechanical rotary actuators that convert electrical pulses (from a DC supply) into discrete shaft rotations. The output current from a PLC is also DC. This means that stepper motor could be directly connected to the output side of a PLC programmer.
- Stepper motors are small and are particularly suited to this application as space in or around the VBF is limited.

Stepper motors exhibit, an excellent power to weight ratio and (if not overloaded) have no cumulative errors. [www.motiongroup.com]

It is important in terms of the vibration dynamics of the feeding system that the stepper motor is not rigidly attached to the orientation tool, but instead engages and disengages from the orientation tool when required and so a clutch coupling transmission system was envisaged for all the tools. For precision control of the orientation tool, each individual step of the stepper motor would have to be directly controlled by the PLC program. It was considered essential to acquire knowledge and gain experience in controlling the stepper motors directly using PLC programs. If a stepper motor could be controlled directly by the PLC program, then there would be no need for stepper motor controllers/drivers. This should reduce cost and might give the programmer more control over the positioning: use of associated encoders, might allow a wider choice of motor suppliers on which to develop a standardised system approach.

The switching sequence (Rotalink catalogue Appendix H) of the stepper motor defines the energisation patterns necessary on the windings to achieve controlled rotational movement. This must be addressed as a switching sequence in the PLC program. For this the windings (or phases) of the stepping motor must be connected directly to the outputs of the PLC programmer. If the outputs are pulsed in the correct sequence the energisation patterns on the windings are obtained and this will result in rotational motion of the stepper motor.

The energisation patterns in steppers can be single phase, two-phase (full step), one/two phase (half stepping) or micro stepping. Only one winding will be excited for single-phase motion and two windings are simultaneously excited for two-phase motion and for one/two phase excitation there is a cross between the two mentioned above. In micro stepping the rotor can be made to rotate in much smaller increments; this is achieved by progressively increasing or decreasing the currents in the windings electronically.

The first PLC program that was undertaken was developed using the switching sequence for single-phase motion and resulted in a clockwise rotation of the stepping motor (see Appendix B). At this stage it was discovered that, by simply reversing this switching sequence, that the rotation of the stepper motor could also be reversed, providing anticlockwise rotation. Considerable progress had therefore been made at this stage as control of a stepping motor could now be demonstrated. Five PLC programs were subsequently developed as follows:

1. One phase excitation, clockwise rotation, step angle 1.8^{o}.
2. One phase excitation, anticlockwise rotation, step angle 1.8^{o}.
3. Two-phase excitation, clockwise rotation, step angle 1.8^{o}.
4. Two-phase excitation, anticlockwise rotation, step angle 1.8^{o}.
5. One/Two phase excitation, clockwise rotation, step angle $.9^{o}$.

The Logic specifications for the above programs are described in Appendix B along with the associated PLC programs and explanatory comments.

The success in developing these programs supported the decision to use stepper motors for rotary motion of the orientation tools. It had now been proven that an orientation tool designed mechanically for controlled rotary motion could be effectively programmed directly using a PLC programmer.

The wiper blade tool had been previously designed, based on the use of a stepper motor, but a problem still remained in terms of verifying the exact number of steps that the stepper motor was taking in relation to the actual number set in the PLC programme. An optical encoder was designed and manufactured in-house using a fibre optic sensor as a location sensor (start position) and a photo-micro sensor as a counting sensor to provide feedback to the PLC program. The encoder was attached (installed) in a convenient location on the underside of the stepper motor.

The stepper motor (Fig. 5-2) with the optical encoder attached was located on top of a guided cylinder. This guided cylinder could be programmed to extend and retract allowing engagement and disengagement of the stepping motor with the orientation tool, at the required time.

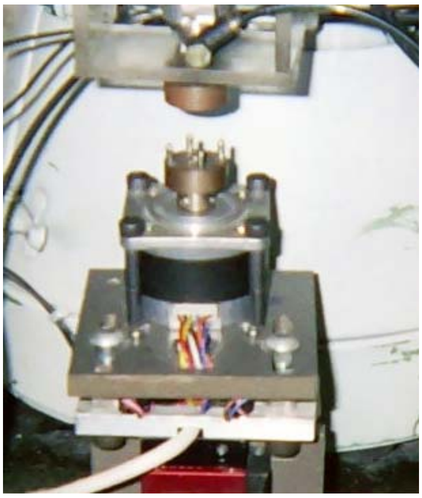


Fig. 5-2: The Stepper Motor Drive System Mounted on a Guided Cylinder

The number of steps moved through by a stepper motor in the case of the WBT angle function defined the overall angle taken. Controlling this angle was essential to the control of the orientation tool. Through experimentation it was then possible to demonstrate the consistency of the system in obtaining any required angle. The stepper subsequently was linked to the wiper blade tool to demonstrate a wiper blade tool with full step switching sequence producing a step angle of 1.8^o, one phase excitation and with clockwise or anticlockwise rotation.

The WBT ladder logic program (Appendix B) was then developed. It consisted of a number of part programmes, each part program being developed independently and then integrated into a unified program. This demonstrated control of the wiper blade orientation tool in the VBF system. The part programs developed were as follows:

1. The vibratory bowl feeder control program.
2. The experiment management program.

3. Blockage management program.
4. Tool performance calculations (Maths calculations) management program.
5. The automated stepper motor control program.

The logic specifications for the WBT program will be described at a later stage. This program is the most important program in this chapter as it clearly defines how the program performed the automated search process during the experiments. The program operated the automated orientation tool (the wiper blade tool) by experimenting with various positions of the tool relative to the VBF. It determined its optimum position by identifying its maximum performance and proceeded to locate this position having completed the experiments.

Having successfully developed the wiper blade PLC program, two further orientation tools were developed and programmed to complete a family of orientation tools, they are the Narrow Track Tool and the Raised Ledge Tool. These programs were interfaced manually during the experiments, as stepper motors were not incorporated. The programs developed for these tools were titled as follows:

- Narrow Track Tool PLC program.
- Raised Ledge Tool PLC program.

The logic specifications for the above programs will be described at a later stage.

5.5 PLC Program Operating Sequence for the Wiper Blade Tool Experiments

As mentioned before, the number of experiments conducted to establish an optimum angular position of the wiper blade tool covered 26 height settings and 31angle settings, so the total number of experiments for the wiper blade tool totalled 806 i.e. (31x26). The experiment quantity (number of components tested) was set at 1000 components. To simplify the explanation of the operating sequence (for the reader) the experiment parameter numbers will be changed, thereby, describing in total 8 experiments of 1000 components each for 4 different height settings at 2 different angles settings i.e. (8=4x2) The associated operating sequence cycle drawings shown (Fig. 5-3a & 5-3b) will help to explain the automated search process procedure. The Input/Output conditions for the experiments are displayed in Appendix B.

Start Sequence

Initially the PLC will be switched to run mode by operating the toggle switch (X27). This resets all the markers, counters and data registers in the program. At start up the guided cylinder is in the retracted position and (X1) is on. The photo-micro sensors and the fibre optic LED sensor mounted on the optical encoder are in home position (X6 & X10 are on). The fibre optic sensors monitoring the component “fall-off” rate at the wiper blade tool location are on, switching on (X3), (X4) and (X5). The fibre optic sensor monitoring the “pass-by” rate is also on, switching on (X11). The pin cylinders are in the extended position (Y12 & Y14 are on). The vibration bowl controller is switched on manually and the vibration bowl feeder begins vibrating. At this stage a vibration sensor mounted on the vibration bowl detects this vibration and switches on (X0). This causes the components within the bowl to vibrate towards the upper level of the bowl.

Management Automated Performance Search Logic Sequence

The initial starting position of the wiper blade is “Height Zero” and “Angle Zero”. Prior to run mode the following counter values are set in the PLC program, (C10) =1000, (C4) = 2 and (C5) = 4. (C10) corresponds to the experiment quantity, (C4) corresponds to the number of angles and (C5) corresponds to the number of heights. The number of components that are rejected will be added to the number of components that successfully pass-by the wiper blade tool, until the experiment quantity of 1000 components is reached. At this point the information is stored and a new experiment begins at “Angle Zero” and “Height One”. Any blockages that might have occurred during the experiments are recorded and will affect the performance of the tool for that specific set of settings.

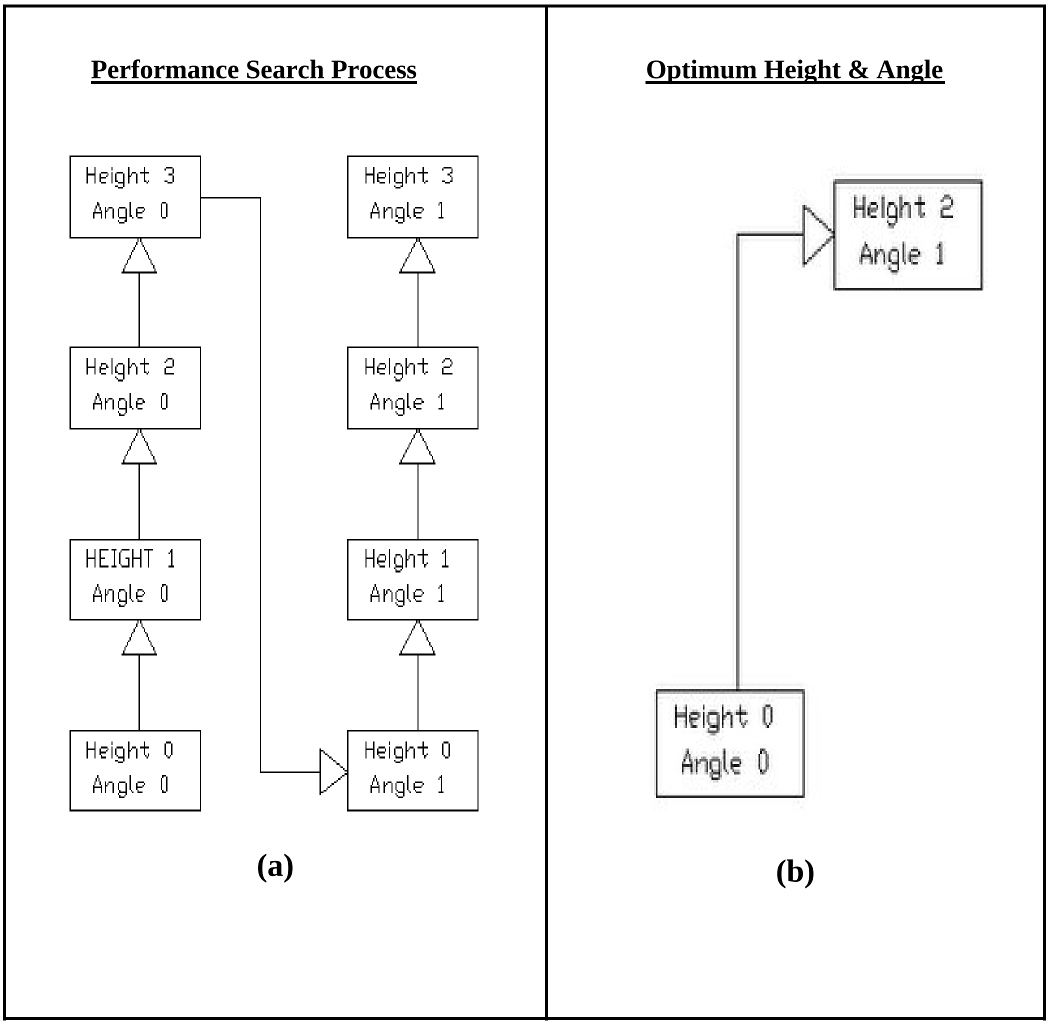


Fig. 5-3: Sequence Control Cycle Diagram for the 4 x 2 experiments

Blockage Management Procedure Logic Specification

If a blockage occurs during an experiment, there is no input from the counting sensors (X3), (X4), (X5) and (X11) because there are no components falling-off or passing-by the wiper blade tool. When this happens the timer (T30) begins timing out. When it has fully timed out the PLC program begins a procedure that attempts to clear a blockage at the wiper blade tool location. Initially a warning light will be activated switching on the output (Y17). This produces a cycle of five continuous flashes at 0.2-second intervals. When the final flash has occurred a blast of air attempts to clear the blockage by operating the air blast control valve (Y10). The air blast will stay on for 0.3 seconds, long enough to clear the blast (determined through experimentation). The vibratory bowl feeder remains on during this procedure and continues with the experiments once the blockage is cleared. The number of blockages (C8) that occur during the experiments are recorded and will be used by the management program (part program) to determine the performance of the wiper blade tool for that specific location.

Clockwise Rotation Logic Sequence (Height Change)

When the first experiment has been completed the stepping motor must be activated to move the wiper blade tool to a new height “Height One” but the angle of the wiper blade remains the same at “Zero Angle”. To complete this move the following steps are undertaken by the PLC program. The vibration bowl relay (Y7) is turned on stopping the VBF from vibrating. The guided cylinder (Y13) is turned on extending the stepping motor into is operating position. Time allowed is 0.2 seconds. When the guided cylinder has fully extended it activates the reed switch (X2). This turns off the pin cylinder (Y14). The stepper is now activated to move to the next wiper blade height as follows: as soon as the pin cylinder (Y14) has been retracted from the tool, a marker is set in the PLC program forcing on the outputs to the stepping motor (Y0), (Y1), (Y2), and (Y3) in the correct switching sequence; this produces a clockwise rotation of the stepping motor for a specific number of pulses controlled by a counter in the PLC program; the photo-micro sensor (X6) placed on the optical encoder counts the number of steps taken by the stepping motor. When the new height is obtained the pin cylinder (Y14) is turned on locking the tool in position. The guided cylinder (Y13) will be retracted removing the stepping motor from its operating position. The vibration bowl relay (Y7) is turned off and the VBF begins vibrating again and the next experiment can now begin. This cycle is repeated continuously after each experiment until the maximum height “height three” is obtained for that specific angle “angle zero”.

Anticlockwise Rotation Logic Sequence (Height Change)

When four experiments are completed and the maximum height has been obtained the wiper blade will be returned to its starting position “height zero”. The stepping motor must be activated to move the wiper blade tool to a new height, however the angle of the wiper blade remains the same at “zero angle”. To complete this move the following steps are taken by the PLC program.

The vibration bowl relay (Y7) is turned on stopping the VBF. The guided cylinder

(Y13) is turned on extending the stepping motor into the operating position. Time allowed is 0.2 seconds. When the guided cylinder has fully extended, it activates the reed switch (X2) this will now turn off the pin cylinder (Y14) allowing a height change to occur. As soon as this is complete a marker is set in the PLC program forcing the outputs of the stepping motor (Y3), (Y2), (Y1), and (Y0) on, in the correct switching sequence. This produces an anticlockwise rotation of the stepping motor for a specific number of pulses controlled by a counter, set in the PLC program. The photo-microsensor sensor (X6) placed on the optical encoder counts the number of steps taken by the stepper motor. When the new height has been obtained the pin cylinder (Y14) is turned on locking the tool in the new position. Retracting the guided cylinder (Y13) removes the stepping motor from its operating position.

Clockwise Rotation Logic Sequence (Angle Change)

The angle of the wiper blade will now be changed to “angle one”. The guided cylinder (Y13) is turned on extending the stepping motor into is operating position. Time allowed is 0.2 seconds. When the guided cylinder has fully extended it activates the reed switch (X2) and turns off the pin cylinders (Y12). As soon as the pin cylinders (Y12) have been retracted from the tool, a marker is set in the PLC program forcing on the outputs to the stepping motor (Y0), (Y1), (Y2), and (Y3) in the correct switching sequence. This produces a clockwise rotation of the stepping motor and moves the wiper blade into a new angular position (angle one). When the new angle has been obtained the pin cylinders (Y12) are turned on locking the tool in this position. The guided cylinder (Y13) is now retracted removing the stepping motor from its operating position. A new set of experiments will now be conducted at “height zero” and “angle one”. As each experiment is completed the height of the wiper blade will be continually adjusted as before. When the maximum height is obtained “height four” and “angle one” the experiments are completed and the wiper blade will be returned to its original height “height zero”. The angle of the wiper blade will now be adjusted and returned to its original position “angle zero”.

Anticlockwise Rotation Logic Sequence (Angle Change)

The guided cylinder (Y13) is turned on extending the stepping motor into is operating position. When the guided cylinder has fully extended it activates the reed switch (X2) and turns off the pin cylinders (Y12). As soon as the pin cylinders (Y12) have been retracted from the tool, a marker is set in the PLC program forcing on the outputs to the stepping motor (Y3), (Y2), (Y1), and (Y0) in the correct switching sequence. This produces an anticlockwise rotation of the stepping motor and moves the wiper blade back to its starting position “angle zero”. When this angular position has been obtained the pin cylinders (Y12) are turned on locking the tool in this position. The guided cylinder (Y13) is retracted removing the stepping motor from its operating position.

Optimum Performance Data Acquisition, Calculations and Storage Logic Sequence

As each experiment is completed using the appropriate data (acquired from the fibre optic monitoring sensors) the *current performance* is calculated using the algorithm (see Chapter 6) and compared with the *previous maximum.* The highest result is then stored in the appropriate data register. The optimum performance will thereby be identified automatically and carried forward and can be used to reposition the wiper blade tool to its optimum position. For the purpose of explanation, the maximum performance in this case will be taken as “height two” and “angle one” (see Fig. 5-3b). The logic sequence involves a clockwise rotation of the stepping motor to obtain the exact height No2 followed by a clockwise rotation to obtain the required angle No1. This is achieved by changing the counter values on the stepper motor within the PLC program.

5.6 PLC Program Operating Sequence for the Narrow Track Tool Experiments

Start Sequence

Initially the PLC program is switched to run mode by operating the toggle switch (X27). This toggle switch is switched on and then off again, this will reset the data registers in the programme to a value of zero. When toggle switch (X21) is switched on, the pin cylinders (Y12) and (Y14) will extend locking the wiper blade tool in its optimum position. The narrow ledge tool experiments can begin when the narrow ledge section has been fully extended to its starting position. This situation will occur when the toggle switch (X23) is switched on and the pin cylinder (Y6) is extended locking the narrow track tool in position.

Experiment Mode Logic Specification

The fibre optic sensor (X14) registers the number of components that fall-off at the narrow ledge tool location, while the fibre optic sensor (X11) registers the number of components (that successfully pass-by the wiper blade tool) that enter at the narrow track tool location. The experiment quantity (a maximum number of 500 components were used in this case) will be determined by adding the number of components that fall-off to the number of components that pass-by at the narrow ledge tool location. When the full experiment quantity is reached the warning light (Y17) comes on. The operator turns off the toggle switch (X24). This switches on the vibratory bowl relay and that in turn switches off the vibratory bowl feeder. At this stage the experiment results are recorded. The toggle switch (X23) is turned off retracting the narrow ledge pin cylinder (Y6). This allows the narrow track tool setting to be moved into a new position for the second experiment. The toggle switch (X23) is turned back on locking the narrow ledge pin cylinder (Y6) in the new position. The toggle switch (X24) is turned back on switching the vibratory bowl relay off and this turns on the vibratory bowl feeder. This process will be continuously repeated until all of the experiments are fully complete.

Stopping the Experiments Logic Specification

When the experiments are complete the toggle switch (X24) will be turned off switching on the vibration bowl relay (Y7) and turning off the vibratory bowl feeder. The toggle switch (X24) is turned off switching off the pin cylinder outputs (Y6) on the narrow track tool. The toggle switch (X21) can now be turned off switching off the pin cylinder output (Y12) and (Y14) on the wiper blade tool. To take the PLC out off “run mode” the toggle switch (X27) is turned off.

The Narrow Track Tool (Experiment Operating Procedure)

Here is a summary of the operating sequence of the Narrow Track Tool:
Reset the tool to starting position (manual).
Lock Pin Cylinders on the WBT in optimum position (manual).
Activate Start Sequence (manual).
Lock Pin Cylinder on NTT into starting position (manually).
Turn on the VBF (manual).
Count Rejection-Rate of components (automated).
Count Pass-By-Rate of components (automated).
Execute Math Calculations to determine the Experiment Quantity (automated).

Turn on Warning Light when the experiment quantity is reached (automated).
Turn off the VBF (manual).
Shift and Store Data Register values (automated).
Reset Counters, Markers, Timers and Data Registers values.(automated).
End Program (manual).

5.7 PLC Program Operating Sequence for the Raised Ledge Tool Experiments

Start Sequence

Initially the PLC program is switched to “run mode” by operating the toggle switch (X27). This toggle switch is switched on and then off again. This resets any data registers in the program to a value of zero. The raised ledge tool experiments will begin when the raised ledge track has been retracted to its starting position. When toggle switch (X21) is switched on, the pin cylinders (Y12) and (Y14) extend on the wiper blade tool (Locking this tool in its optimum position). Operating the toggle switch (X21) turns on the pin cylinder (Y6) effectively locking the narrow ledge tool track in its optimum position (determined by the experiments). When the toggle switch (X24) is turned on, the vibration bowl relay (Y7) is switched off and the vibration bowl begins vibrating.

Experiment Mode Logic Specification

The fibre-optic sensor (X11) registers the number of components that successfully pass-by the tool in the correct orientation. The experiment quantity will be reached when 500 components have been tested. When the experiment quantity is reached the flashing light (Y17) is switched on. The operator reacts by switching off the toggle switch (X24). This switches on the vibration bowl relay (Y7) and the vibration bowl stops vibrating. At this point the experiment values are recorded.

To begin a second experiment the toggle switch (X23) is switched on retracting the raised ledge pin cylinder (Y11). This allows the raised ledge section to be moved into a new position. When the toggle switch (X23) is switched off, the pin cylinder (Y11) is extended locking the raised ledge tool in position again. At this stage the toggle switch (X24) is turned on, switching the vibration bowl relay (Y7) off. When this happens the vibration bowl feeder begins vibrating again for the second experiment. This process will be continued until all of the experiments are completed.

Stopping the Experiments Logic Specification

When the experiments are complete the toggle switch (X24) is turned off switching on the vibration bowl relay (Y7) and turning off the vibratory bowl feeder. The toggle switch (X23) is turned off, switching off the pin cylinder output (Y11) on the raised ledge tool. The toggle switch (X21) can now be turned off, switching off the pin cylinder outputs (Y12), (Y14) and (Y6) on the other orientation tools. To take the PLC out of "run mode" the toggle switch (X27) is turned off.

The Edge Riser Tool PLC Program (Experiment Operating Procedure)

Here is a summarising of the operating sequence of the Edge Riser Tool:
Reset the ERT to the starting position (manual).
Lock Pin Cylinders on the WBT and NTT in optimum position (manual).
Lock Pin Cylinder on ERT into starting position (manual).
Turn on the VBF (manual).
Activate Start Sequence (manual).
Count Pass-By-Rate of components (automated).
Do Math Calculations to determine the Experiment Quantity (automated).
Turn on Warning Light when experiment quantity is reached (automated).
Turn off the VBF (manual).
Shift and Store Data Register values (automated).
Reset Counters, Markers, Timers and Data Registers values (automated).
End Program (manual).

5.8 Component Sensing

The conventional VBF uses fixed sequence orientation tooling to provide a fixed rate of orientated components to an assembly machine. VBF applications of this type require no sensors. It became clear during the automation stage of this project that component sensing would be required to oversee the entire automated programmable-tool configuration process, in terms of component counting. The algorithm, presented in Chapter 6, is dependent on the data from counting sensors

Sensor Selection

In the situation here sensors were used for simply counting components: no component recognition or component orientation sensing was used. Sensors for the AMTLAB VBF application were selected based on the following criteria:

- Distance sensitivity.
- Accuracy & Reliability.
- High resolution.
- High speed.
- Inherent vibration resistance.
- Low Cost.

A range of sensor types were considered for use in a vibratory application such as photo electric sensors, fibre-optic sensors, lasers and infrared sensors. Fibre optic type LED sensors adapted with amplifiers were eventually selected. These used fibre optic light tubes to transmit light to the sensing area, thereby enabling the remote location of the light source away from the sensing area, reducing the danger of amplifier damage.

Following a comprehensive review of the key reputable sensor manufacturers (including Keyence, Omron and Siemens) Keyence manual type fibre optic sensors and amplifiers were selected (model no FS2-80). These had a wide range of sensor heads that were compatible with the selected amplifiers. These included:

1. <u>Reflective</u> - Keyence FU35FZ
2. <u>Through beam</u> - Keyence FU77V

Sensor positioning (Chapter 6) presented a very significant challenge with each tooling module introducing its own complications. This will be dealt with at a later stage.

5.9 Wiring of the PLC

As mentioned previously the wiper blade program was developed, based upon the development of the stepping motor programs. In this case the stepping motor was initially wired up to a Mitsubishi FX-48MR programmer. Programs were then developed using the appropriate switching sequence. Having obtained sufficient knowledge and experience through experimentation it was time to develop the first programmable tool i.e. wiper blade tool. When the wiper blade tool was eventually developed it was attached to the vibratory bowl and its stepping motor was wired up to the Mitsubishi FX-48MR programmer that had previously been place in an appropriate control cabinet (Fig. 5-1 previously).

In this situation any mechanical debugging could be done by operating the solenoids manually and only completed when the PLC program was fully in place. The PLC wiring diagrams were drawn prior to any wiring. This is equivalent to the “as-built” arrangement shown in Appendix B and a logic specification (Section 5-5). The PLC wiring diagrams were as follows:

1. The Basic Stepper Motor programs.
2. The Wiper Blade Tool program.
3. The Narrow Track Tool program.
4. The Edge Riser Tool program.

Having completed the experiments on the wiper blade tool the two remaining tools, the NTT and the ERT tool were similarly developed and wired into an electric cabinet (Fig. 6-4) that was placed at the base of the VBF system. The electrical system developed consisted of the follow components: terminal connection blocks; emergency stop and isolator switches; digital output optic devices; various relays; circuit breakers. As a safety precaution a mains isolator switch and emergency stop relay switch were incorporated into the VBF system and mounted externally on the PLC control cabinet (5-1 previously).

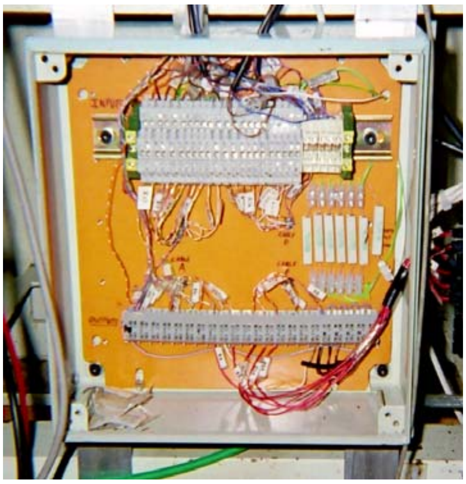


Fig. 5-4: Sets of Electrical Connectors for the VBF System (AMTLAB)

5.10 The Vibratory Bowl Feeder Controller

The AMTLAB vibratory bowl was driven by an electromagnet. This was controlled using an AFAG variable control unit (Fig. 5-5). The controller manipulates the electromagnet by varying the voltage sine wave (twice every mains cycle): the number of strokes per second remained constant, relative to the frequency of the AC power supply. Varying the amplitude of the voltage sine wave varies the length of bowl stroke. An increase in the length of bowl stroke will increase the conveying amplitude (see Section 2-9) and therefore the conveying velocity.

Fig. 5-5: AFAG Variable Controller for the VBF (AMTLAB)

A need for intermittent (on/off) control of the VBF was identified earlier in the project. This enabled intermittent control of the stepper motor drive system for automated control of the orientation tools. This was achieved by incorporating a relay system between the VBF controller and the AC mains supply. The relay was activated using a 24vdc current from the PLC system.

5.11 The Pneumatic System

A pneumatic system was developed and incorporated into the VBF system for use with the orientation tools. The pneumatic system performed three main functions, as follows:

1. It maintained the tools position when the VBF was operating. The orientation tools were locked in position during the experiment process; this was achieved using carefully positioned pneumatic pin cylinders.
2. It positioned the drive system by providing a means of engagement and disengagement from the VBF system. The drive positioning system therefore consisted of a stepper motor with its drive clutch coupling mounted on a double acting pneumatic cylinder (Fig. 4-6 previously).
3. It cleared blockages using an air jet tool at the WBT location.

The pneumatic system was operated using solenoid operated valves which were wired up to the Mitsubishi FX-48MR programmer (Fig. 5-6).

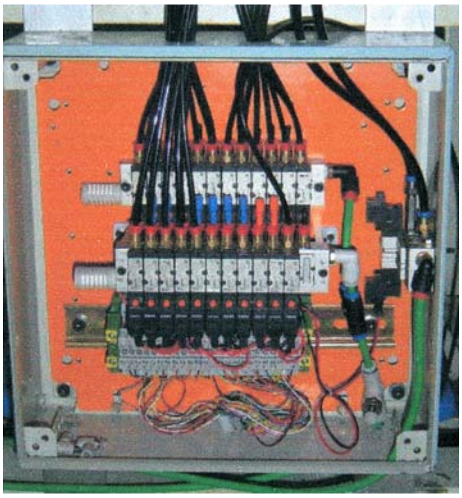


Fig. 5-6: Sets of 3/2 Solenoid Operated Pneumatic Valves (AMTLAB)

A diagram of the pneumatic system is provided in Appendix B, the components used in the development of the pneumatic system were as follows:

- Filter, Regulator and Lubricator (FRL) combination unit.
- A double acting guided cylinder.
- Pin Cylinders, tubing and accessories.
- 3/2 way operating valves with a cassette type manifold mounting.
- Air Blast Fixture.
- Flow control Valves.

The air blast fixture mentioned above was a section of strategically located stainless steel tubing that directed a blast of air at components in an attempt to clear blockages at the WBT location. It was accurately positioned in the VBF wall near the WBT and proved very effective.

6 Data Acquisition & Experiment Results

6.1 Introduction

This chapter begins by describing the tool positioning process. Tool positioning is a tool sequencing process that is based on both the component orientation issues and the function of the individual tools. An explanation of how component irregularities affected component orientation is provided. The chapter proceeds to describe the overall sequence control process across the multiple tool system. System performance is a measure of the effectiveness of the component feeding, which is monitored using strategically positioned fibre optic sensors (see Chapter 5) in the tooling area. The positioning of these sensors for accurate data generation proved to be a difficult and time consuming process.

The chapter continues by examining the WIT search process algorithm, which is considered as one of the key components in the development of the VBF tool optimisation system. This algorithm is explained with the aid of a numerical simulation of the blockage factor ($\boldsymbol{n}$). The chapter progresses by reviewing the actual individual group performance using the search process algorithm over a wide range of experimental tests on the target component. Finally, this provided an optimum performance for the individual tools that was used to evaluate the performance of the multi tool system.

6.2 Component Anomalies (Irregularities)

Various factors affecting feed rate have been discussed in previous chapters, such as VBF mechanics (Chapter 1) and tooling factors (Chapter 4). However, there were other factors to consider as component factors relating to feeding. A slight change in component attitude could be referred to as an irregularity. In this case component irregularities will be referred to as component anomalies. The six possible orientations of the right rectangular prism are shown in Figure 6-1 overleaf (Side View (A1) & Plan View (A1)). The presumption is that all of the orientations mentioned above possess a horizontal or vertical attitude with the bowl wall or track, but in reality they did not (see Side View (B1) & Plan View (B1)). The reason for these irregularities (as observed through experimentation) is probably due to the interaction between components in the vibratory bowl feeding process (see Fig. 6-1, Orientations (d) & (b)).

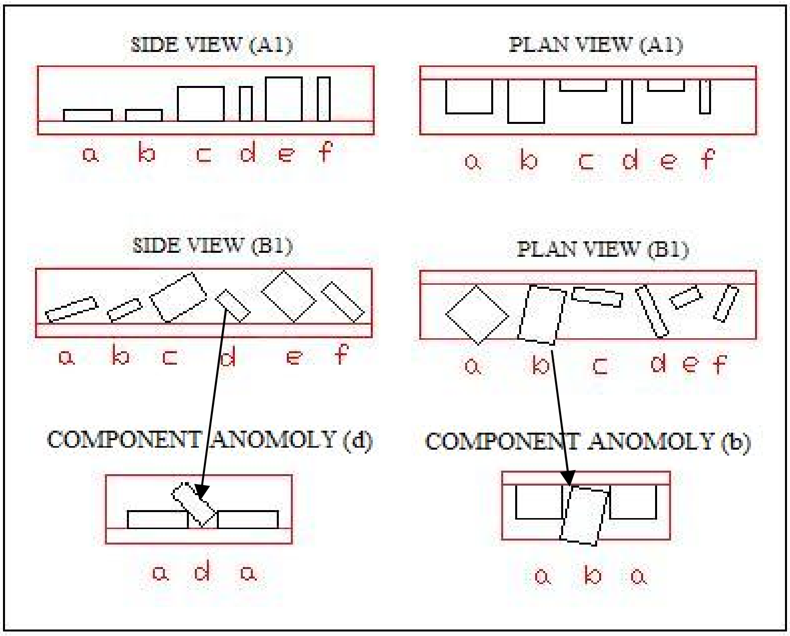


Fig. 6-1: Component Anomalies (Irregularities)

These irregularities could present feeding problems at orientation tool locations. The fact that component anomalies existed at all and that they are difficult to identify (or classify), is a factor that had to be considered in the performance of the VBF and in particular the performance of the first orientation tool encountered in the orientation system. In this particular situation the WBT is the first tool encountered by the components in the VBF and for this reason it will have to contend (filter out) with these anomalies. It is also possible that component anomalies contribute to (or are responsible for) component blockages.

6.3 The Multi Tool System Sequence Control

The multi tool system (Fig. 6-2 overleaf) consists of the WBT, the NTT and the ERT. The sequence of the orientation tools in the multi tool system is set to reduce continually the number of possible orientations of the target component until the final orientation is obtained. The objective in this case is to maximise the number of components out of each tool in the sequence. Maximising the number of components out of the WBT would maximise the number of components (in orientation ‘a’ or ‘b’) on to the NTT. The NTT when set at its optimum tool setting would maximise the number of components on to the ERT.

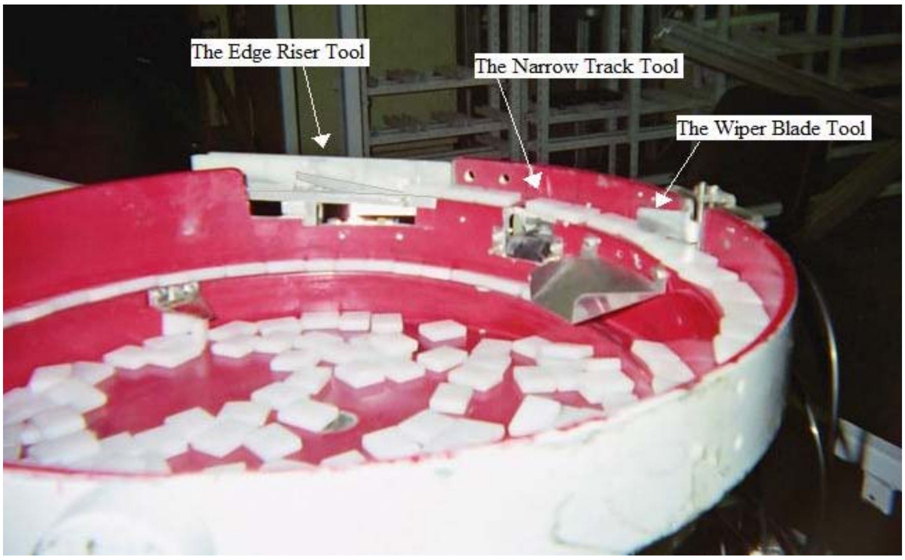


Fig. 6-2: The Position of the Orientation Tools from within the VBF

The ERT performs a function of reorientation only (see Chapter 4) and if it is set at its optimum tool setting this would maximise the number of components sent on to the delivery chute, in the desired orientation.

An algorithm specifically developed to measure tool performance at each tool setting was used in the experiments on the individual tools in the multi tool system. The first tool used is the WBT. Initially experiments were conducted on this tool to set the process parameters (batch size etc.). The performance calculations (see Appendix C) for each tool setting could then be obtained using the PLC Programmer (see Chapter 5). The optimum performance for the WBT was then taken as the maximum performance at that specific tool setting. The WBT was then set at the optimum tool setting to obtain a maximum component throughput.

The NTT experiments could now be performed as the WBT was set to provide a maximum performance. Again extensive experimentation was required to determine the performance calculations at each tool setting. The optimum performance was obtained as the maximum performance and the NTT was set at the optimum tool setting to achieve this maximum.

The ERT is the final tool in the multi tool system. Experiments could now be performed on this tool having set both the WBT and the NTT in their optimum position. A series of experiments were performed as before to determine the performance calculations at each tool setting. The optimum performance from the ERT was then taken as the maximum performance from the tool. The tool could then be set in its optimum position.

At this stage each tool used in the multi tool system had been set (consecutively and continuously) at an optimum tool setting using the optimum performance calculations. The optimum system performance could then be calculated for the multi tool system (by multiplication) using the individual optimum performance calculations for each tool. These calculations are provided at a later stage in this chapter.

6.4 Sensor Positioning for the Automatic Retrieval of Data

The automated process of monitoring the orientation tools and relating the relevant data back to the PLC is an essential requirement of the experimental system. Each orientation tool performs separate functions of orientation. They perform these functions in a similar fashion, by accepting components in specific orientations and rejecting those components in undesirable orientations. By monitoring the acceptance and rejected rates of components as they pass by an individual tool, a true value of the performance of the tool at that specific point is obtained. Component monitoring has been achieved using fibre optic sensors connected to photoelectric amplifier switches (see Section 5-7 previously) that are placed in strategic positions around each tool.

To determine the exact positions of the fibre optic sensors, a visual observation of the working tool (obtained through experimentation) and knowledge of its operation, (obtained through research), was required. The careful positioning of the fibre optic sensors is based on this experience.

In reference to the WBT, the rejection rate of components can be determined by monitoring the number of components that fall off (fall-off rate) at the WBT location. However there is a wide range of angles to consider for this tool over a specific working area. Therefore three separate reflective type fibre optic sensors were used to determine the fall-off rate. The input received from all three sensors has been combined as a single input to the PLC to give a single number for the rejection rate. The rate of accepted components passing by the tool (pass-by rate) can be monitored by a single fibre optic sensor located in the VBF track positioned directly after this tool and just before the NTT.

Problems that frequently occur at WBT locations are blockages that result in jamming (see Section 4.6.1 previously). These blockages must be accounted for in determining the performance value of the tool, as blockages tend to starve the work-head of components and may require manual intervention for clearance. Blockages do not occur on all tools but where they might be present a method of determining the consequences of these blockages must be taken into account in the performance calculations.

It was found that blockages could be detected by monitoring the pass-by rate and the fall-off rate of components over a specific time interval. Detection of a blockage can be observed when components are restricted from moving or passing the WBT, in effect causing a time delay. When a time delay occurs there will be no input pulse to the PLC from any of the fibre optic sensors monitoring either the pass-by rate or the fall-off rate. When this is detected the blockage management program (see Section 5-5 previously) is activated, and the blockage is registered in the PLC and an output results. The output in this case is a blast of air sent to the tool at that specific location. This normally clears the blockage at that point. The positions of the sensors used in all three-orientation tools can be seen in Fig. 6-3 below.

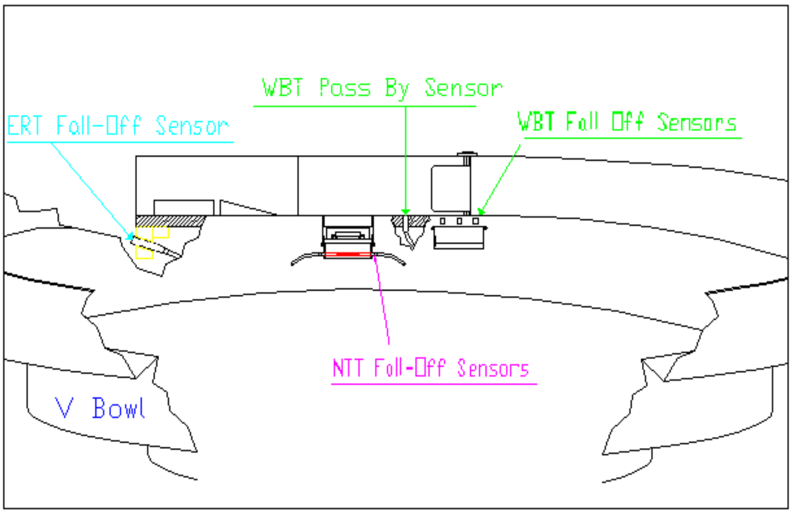


Fig. 6-3: The Position of the Fibre Optic Sensors in the AMTLAB VBF

The position of the sensors for the NTT was again determined by studying the fall-off position and the pass-by positions of components as they pass the tool. The fibre optic sensor used to count the number of components leaving the WBT (pass-by sensor, see Fig. 6-3) is used here to determine the number of components entering the NTT, as this is the same number. The number of components entering the tool minus the number of components falling-off at the NTT location determines the number that pass-by onto the ERT. This means the positioning of the through beam fibre optic sensor used to determine the fall-off rate at the NTT location is extremely important. The NTT fall-off sensor must cover a working distance of 35.4mm (see Chapter 4, Section 4.6.2) and for this reason it has been selected with a separate emitter and receiver. The NTT tool performs a function of accepting or rejecting components only (i.e. there are no reorientations or blockages involved) and therefore, the performance calculations are calculated using a modified algorithm similarly to that of the WBT. These modifications are fully explained later in this chapter.

The ERT is the final orientation tool used within this family of orientation tools. Its objective is to re-orientate the components as they leave the NTT. It achieves this objective by changing Orientation ‘a’ into Orientation ‘c’ the desired orientation. The number of components entering the ERT tool can be determined by placing a fibre optic sensor just after the NTT (just before the ERT), or, by monitoring the result of the NTT. The number of components entering the NTT minus the number of components that are rejected equals the number of components that pass through on to the ERT. The number of components leaving the ERT for this situation has been determined by placing a reflective type fibre-optic sensor just after the tool and just before the delivery chute. The number of components entering the ERT should equal the number of components leaving because the ERT tool does not reject components but merely re-orientates components in Orientation ‘a’ into Orientation ‘c’. This was of course true only if the angle and the radial position of the edge riser ledge is satisfactory for all components entering it. This latter then is the objective in terms of the setting process for the tool.

6.5 The Search Process Algorithm

The performance management program is developed to establish the optimum settings for each of the automated tools. It achieves this objective by operating on the component feeding data as outlined earlier using a specifically developed WIT algorithm within the PLC program. The algorithm is as follows:

$$\text{Performance} = \frac{[(\text{No. of Good Components Pass-Under the Wiper Blade}) - (\text{No. of Blockages} \times n)] \times [100]}{\text{No. of Components used in the Experiment}}$$

Or

$$\boxed{\text{Performance Number} = \frac{[(\text{Pass-by}) - (\text{Blockage No} \times 20)] \times 100}{\text{Experiment Quantity}}}$$

Notation expression:

$$\boxed{Performance = \frac{(N-R) - B \times n}{N}}$$

Where : **N** is the number of Input Components **R** is the number of Rejected Components
B is the number of Blockages **n** is the penalty/Cost of a Blockage

The calculation is done at the end of each experiment and before the trap settings are adjusted for the next experiment. Because of this the current values of R and B can be deleted for the next experiment. Only N (which is inputted by the user) needs to be stored in long term memory.

The penalty factor (***n***) is a constant applied to the number of blockages in the performance algorithm in order to penalise severely experiment tool settings where theses blockages are encountered. A penalty factor of n = 20 was chosen by the author (see 6.6.1 later) and applied here to reflect the cost (in terms of time/money) of a disruption to the VBF system due to a blockage. It is an arbitrary figure but it suggests that any blockage will have an effect equivalent to the loss of feeding 20 components. This figure can, of course, be set at any level considered valid. In a working situation it would be established partially as a result of experience in the specific plant e.g. if operators are close by to clear blockages, it might be set low and if not it might be set high. To validate the value of ***n*** in the equation a numerical simulation of the effect of two different values of n (n =10 and n = 20) on batches of 1000 components at 4 rejection levels (300, 200, 100, 50) is provided, (see Fig. 6-4). This shows that the value of ***n*** does not affect the outcome in terms of identifying the optimum performance, e.g., the % difference in performance between scenarios of 10 blockages and 5 blockages with ***n***=10 is a consistent 5% irrespective of the level of rejects.

Good	Rejects	Blockages	Performance with n = 10	Performance with n = 20	Difference
700	300	10	$\frac{700-100}{1000} = \frac{600}{1000} = 60\%$	$\frac{700-200}{1000} = \frac{500}{1000} = 50\%$	= 60% – 50% = 10%
700	300	5	$\frac{700-50}{1000} = \frac{650}{1000} = 65\%$	$\frac{700-100}{1000} = \frac{600}{1000} = 60\%$	= 65% – 60% = 5%
			Difference 65% – 60% = 5%	Difference 60% – 50% = 10%	
800	200	10	$\frac{800-100}{1000} = \frac{700}{1000} = 70\%$	$\frac{800-200}{1000} = \frac{600}{1000} = 60\%$	= 70% – 60% = 10%
800	200	5	$\frac{800-50}{1000} = \frac{750}{1000} = 75\%$	$\frac{800-100}{1000} = \frac{700}{1000} = 70\%$	= 75% – 70% = 5%
			Difference 75% – 70% = 5%	Difference 70% – 60% = 10%	
900	100	10	$\frac{900-100}{1000} = \frac{800}{1000} = 80\%$	$\frac{900-200}{1000} = \frac{700}{1000} = 70\%$	= 80% – 70% = 10%
900	100	5	$\frac{900-50}{1000} = \frac{850}{1000} = 85\%$	$\frac{900-100}{1000} = \frac{800}{1000} = 80\%$	= 85% – 80% = 5%
			Difference 85% – 80% = 5%	Difference 65% – 60% = 10%	
950	50	10	$\frac{950-100}{1000} = \frac{850}{1000} = 85\%$	$\frac{950-200}{1000} = \frac{750}{1000} = 75\%$	= 85% – 75% = 10%
950	50	5	$\frac{950-50}{1000} = \frac{900}{1000} = 90\%$	$\frac{950-100}{1000} = \frac{850}{1000} = 85\%$	= 90% – 85% = 5%
			Difference 90% – 85% = 5%	Difference 85% – 75% = 10%	

Fig. 6-4: A Numerical simulation of the effect on "Performance" of *n*=10 and *n*=20

In a graphical representation (not an automated system) of optimum performance results the observer may note that the difference in performance would be amplified by higher values of ***n*** (10% difference at ***n*** = 20). Another interesting observation made when performing a numerical evaluation of the algorithm (keeping N and ***n*** as constants) is that, it is possible to obtain the same performance results for different tool settings. This means that the remaining variables of R (Rejection No) and B (Blockage No) must summate (analytically) to give the same result. Therefore a high rejection rate with low blockage rate could yield the same result as a low rejection rate with high blockage rate. This may be demonstrated by setting one performance scenario equal to the other as follows;

$$\frac{(N_1 - R_1) - B_1 \times n}{N_1} = \frac{(N_2 - R_2) - B_2 \times n}{N_2}$$

By cross multiplying

$$\frac{\left[(N_1 - R_1) - B_1 \times n\right] N_2}{N_1} = \frac{\left[(N_2 - R_2) - B_2 \times n\right] N_1}{N_2}$$

Where subscripts 1 and 2 are different tool settings
$\therefore$ If $N_1 = N_2 = N$ (e.g. 1000 components) then

$$(N - R_1) - B_1 \times n = (N - R_2) - B_2 \times n$$

By equating

$$(B_2 - B_1)n = (R_1 - R_2)$$

(Figures of $R_1 = 570$, $R_2 = 370$, $B_2 = 15$, $B_1 = 5$ with $n = 20$ will satisfy this equation)

The conclusion is that it is best to set ***n***, as suggested earlier, at a value that provides a true representation of the real ‘cost’ of a blockage e.g., if the bowl output rate = 3 components per sec (180 comp/min) and a blockage takes an average of 1 minute to clear then the output is reduced by 180 components per blockage. Then ***n*** = 180 or some related figure might be used to reset the penalty for such a blockage. This performance algorithm has been applied to determine the optimum performance across the 3 member family of AMTLAB automated and semi-automated orientation tools.

6.6 Experiment Calculations for Automated/ Semi-Automated Orientation Tool’s

The WBT tool was the first tool used in the automation parameter process setup in the family of orientation tools. Initially a series of experiments were carried out on this tool on its own to access the effectiveness of the optimum tool setting process. These experiments were carried out on a small number of components during the development process in order to:

- Check the functionality of the PLC program.
- Fine tune the auto-experimentation process.
- Calibrate the fibre optic sensors.
- Assess the pre-inputted component parameters experimentally.
- Assign an appropriate penalty factor/cost of a component blockage (n).

6.6.1 The Wiper Blade Tool Experiments Results

The operation of the WBT has been described in a previous chapter (Chapter 4). This tool is considered as a prototype of a fully automated orientation tool. It could now be used to assess performance at specific heights and specific angles. The process of counting the acceptance and rejection rates for each position of the WBT tool and then calculating the specific performance value using the algorithm discussed in Section 6.5, was now also fully functional. Wide ranging feeding experiments were now carried out on the WBT using the target component. These experiments consisted of 31 height adjustment settings for each of the 26 angular settings of the WBT. The heights tested ranged between 5.6mm <starting position below the component thickness of 5.8mm> and 12.8mm <end position above the thickness of two components travelling on top of each other of 11.6mm> in incremental steps of 0.24mm per step. The WBT is rendered ineffective when two components pass by the tool on top of each other as it no longer performs satisfactorily in orientating one component only. It is known that the height above double the component thickness would yield low performance values, as of course would those below the single height. The WBT angles ranged from between 0^o <starting position perpendicular to the bowl track> to 90^o <end position parallel to the bowl track> in angular increments of 3.6^o per angle (one cycle). It was decided at this initial stage that an experiment quantity of 200 components (the experiment quantity was determined based upon the number of experiments that had to be conducted in a sufficient length of time) would be sufficient to conduct the experiments. The penalty factor of ***n*** was set at 20 (***n*** = 20) for each experiment performance calculation. This provided a reasonably true value of the effect of a blockage on the performance of the tool. Blockages (see Fig. 6-5) would be expected to occur naturally over a wide range of tool settings.

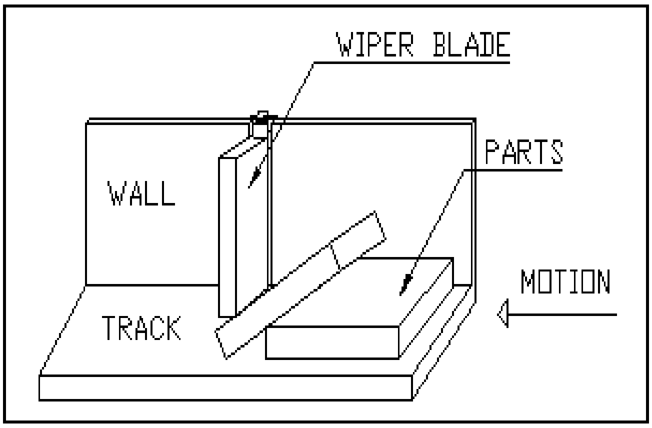
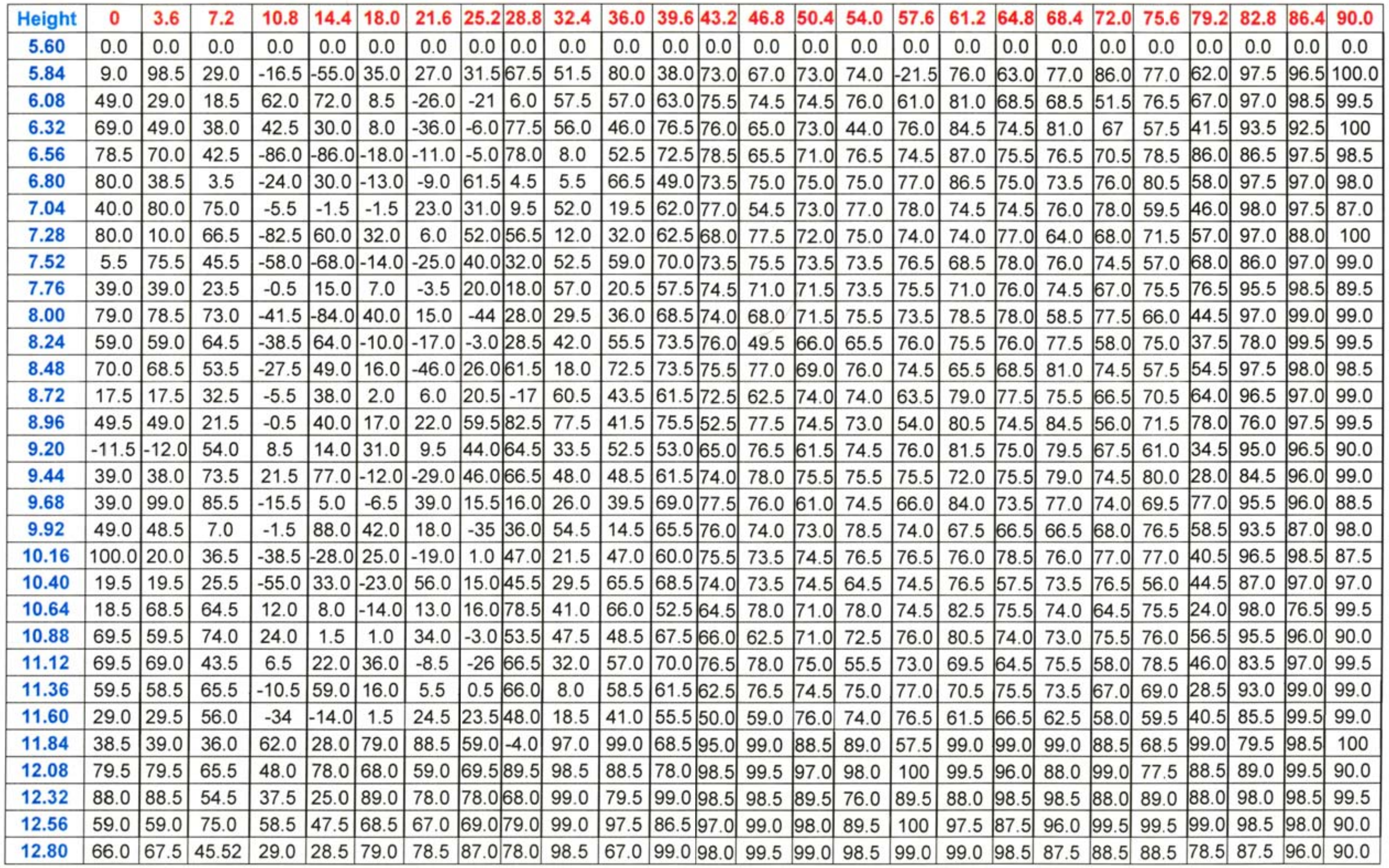


Fig. 6-5: Blockages Occur Naturally in a VBF

A poor performance value of the WBT will later affect the performance of the entire family of orientation tools selected, as this is the first orientation tool to be encountered by the components. The individual experimental values for each experiment are shown in Appendix C and their performance numbers are provided in Table 6.1 below.



Height	0	3.6	7.2	10.8	14.4	18.0	21.6	25.2	28.8	32.4	36.0	39.6	43.2	46.8	50.4	54.0	57.6	61.2	64.8	68.4	72.0	75.6	79.2	82.8	86.4	90.0
5.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.84	9.0	98.5	29.0	-16.5	-55.0	35.0	27.0	31.5	67.5	51.5	80.0	38.0	73.0	67.0	73.0	74.0	-21.5	76.0	63.0	77.0	86.0	77.0	62.0	97.5	96.5	100.0
6.08	49.0	29.0	18.5	62.0	72.0	8.5	-26.0	-21	6.0	57.5	57.0	63.0	75.5	74.5	74.5	76.0	61.0	81.0	68.5	68.5	51.5	76.5	67.0	97.0	98.5	99.5
6.32	69.0	49.0	38.0	42.5	30.0	8.0	-36.0	-6.0	77.5	56.0	46.0	76.5	76.0	65.0	73.0	44.0	76.0	84.5	74.5	81.0	67	57.5	41.5	93.5	92.5	100
6.56	78.5	70.0	42.5	-86.0	-86.0	-18.0	-11.0	-5.0	78.0	8.0	52.5	72.5	78.5	65.5	71.0	76.5	74.5	87.0	75.5	76.5	70.5	78.5	86.0	86.5	97.5	98.5
6.80	80.0	38.5	3.5	-24.0	30.0	-13.0	-9.0	61.5	4.5	5.5	66.5	49.0	73.5	75.0	75.0	75.0	77.0	86.5	75.0	73.5	76.0	80.5	58.0	97.5	97.0	98.0
7.04	40.0	80.0	75.0	-5.5	-1.5	-1.5	23.0	31.0	9.5	52.0	19.5	62.0	77.0	54.5	73.0	77.0	78.0	74.5	74.5	76.0	78.0	59.5	46.0	98.0	97.5	87.0
7.28	80.0	10.0	66.5	-82.5	60.0	32.0	6.0	52.0	56.5	12.0	32.0	62.5	68.0	77.5	72.0	75.0	74.0	74.0	77.0	64.0	68.0	71.5	57.0	97.0	88.0	100
7.52	5.5	75.5	45.5	-58.0	-68.0	-14.0	-25.0	40.0	32.0	52.5	59.0	70.0	73.5	75.5	73.5	73.5	76.5	68.5	78.0	76.0	74.5	57.0	68.0	86.0	97.0	99.0
7.76	39.0	39.0	23.5	-0.5	15.0	7.0	-3.5	20.0	18.0	57.0	20.5	57.5	74.5	71.0	71.5	73.5	75.5	71.0	76.0	74.5	67.0	75.5	76.5	95.5	98.5	89.5
8.00	79.0	78.5	73.0	-41.5	-84.0	40.0	15.0	-44	28.0	29.5	36.0	68.5	74.0	68.0	71.5	75.5	73.5	78.5	78.0	58.5	77.5	66.0	44.5	97.0	99.0	99.0
8.24	59.0	59.0	64.5	-38.5	64.0	-10.0	-17.0	-3.0	28.5	42.0	55.5	73.5	76.0	49.5	66.0	65.5	76.0	75.5	76.0	77.5	58.0	75.0	37.5	78.0	99.5	99.5
8.48	70.0	68.5	53.5	-27.5	49.0	16.0	-46.0	26.0	61.5	18.0	72.5	73.5	75.5	77.0	69.0	76.0	74.5	65.5	68.5	81.0	74.5	57.5	54.5	97.5	98.0	98.5
8.72	17.5	17.5	32.5	-5.5	38.0	2.0	6.0	20.5	-17	60.5	43.5	61.5	72.5	62.5	74.0	74.0	63.5	79.0	77.5	75.5	66.5	70.5	64.0	96.5	97.0	99.0
8.96	49.5	49.0	21.5	-0.5	40.0	17.0	22.0	59.5	82.5	77.5	41.5	75.5	52.5	77.5	74.5	73.0	54.0	80.5	74.5	84.5	56.0	71.5	78.0	76.0	97.5	99.5
9.20	-11.5	-12.0	54.0	8.5	14.0	31.0	9.5	44.0	64.5	33.5	52.5	53.0	65.0	76.5	61.5	74.5	76.0	81.5	75.0	79.5	67.5	61.0	34.5	95.0	96.5	90.0
9.44	39.0	38.0	73.5	21.5	77.0	-12.0	-29.0	46.0	66.5	48.0	48.5	61.5	74.0	78.0	75.5	75.5	75.5	72.0	75.5	79.0	74.5	80.0	28.0	84.5	96.0	99.0
9.68	39.0	99.0	85.5	-15.5	5.0	-6.5	39.0	15.5	16.0	26.0	39.5	69.0	77.5	76.0	61.0	74.5	66.0	84.0	73.5	77.0	74.0	69.5	77.0	95.5	96.0	88.5
9.92	49.0	48.5	7.0	-1.5	88.0	42.0	18.0	-35	36.0	54.5	14.5	65.5	76.0	74.0	73.0	78.5	74.0	67.5	66.5	66.5	68.0	76.5	58.5	93.5	87.0	98.0
10.16	100.0	20.0	36.5	-38.5	-28.0	25.0	-19.0	1.0	47.0	21.5	47.0	60.0	75.5	73.5	74.5	76.5	76.5	76.0	78.5	76.0	77.0	77.0	40.5	96.5	98.5	87.5
10.40	19.5	19.5	25.5	-55.0	33.0	-23.0	56.0	15.0	45.5	29.5	65.5	68.5	74.0	73.5	74.5	64.5	74.5	76.5	57.5	73.5	76.5	56.0	44.5	87.0	97.0	97.0
10.64	18.5	68.5	64.5	12.0	8.0	-14.0	13.0	16.0	78.5	41.0	66.0	52.5	64.5	78.0	71.0	78.0	74.5	82.5	75.5	74.0	64.5	75.5	24.0	98.0	76.5	99.5
10.88	69.5	59.5	74.0	24.0	1.5	1.0	34.0	-3.0	53.5	47.5	48.5	67.5	66.0	62.5	71.0	72.5	76.0	80.5	74.0	73.0	75.5	76.0	56.5	95.5	96.0	90.0
11.12	69.5	69.0	43.5	6.5	22.0	36.0	-8.5	-26	66.5	32.0	57.0	70.0	76.5	78.0	75.0	55.5	73.0	69.5	64.5	75.5	58.0	78.5	46.0	83.5	97.0	99.5
11.36	59.5	58.5	65.5	-10.5	59.0	16.0	5.5	0.5	66.0	8.0	58.5	61.5	62.5	76.5	74.5	75.0	77.0	70.5	75.5	73.5	67.0	69.0	28.5	93.0	99.0	99.0
11.60	29.0	29.5	56.0	-34	-14.0	1.5	24.5	23.5	48.0	18.5	41.0	55.5	50.0	59.0	76.0	74.0	76.5	61.5	66.5	62.5	58.0	59.5	40.5	85.5	99.5	99.0
11.84	38.5	39.0	36.0	62.0	28.0	79.0	88.5	59.0	-4.0	97.0	99.0	68.5	95.0	99.0	88.5	89.0	57.5	99.0	99.0	99.0	88.5	68.5	99.0	79.5	98.5	100
12.08	79.5	79.5	65.5	48.0	78.0	68.0	59.0	69.5	89.5	98.5	88.5	78.0	98.5	99.5	97.0	98.0	100	99.5	96.0	88.0	99.0	77.5	88.5	89.0	99.5	90.0
12.32	88.0	88.5	54.5	37.5	25.0	89.0	78.0	78.0	68.0	99.0	79.5	99.0	98.5	98.5	89.5	76.0	89.5	88.0	98.5	98.5	88.0	89.0	88.0	98.0	98.5	99.5
12.56	59.0	59.0	75.0	58.5	47.5	68.5	67.0	69.0	79.0	99.0	97.5	86.5	97.0	99.0	98.0	89.5	100	97.5	87.5	96.0	99.5	99.5	99.0	98.5	98.0	90.0
12.80	66.0	67.5	45.52	29.0	28.5	79.0	78.5	87.0	78.0	98.5	67.0	99.0	98.0	99.5	99.0	98.5	99.0	99.0	98.5	87.5	88.5	88.5	78.5	87.5	96.0	90.0

As the experiments were conducted and the results became clear it was decided that more reliable and consistent performance numbers would have to be obtained for certain experiment angles. It was also felt that the experiment quantity of 200 components was too low and that this should be increased to 1000 components per experiment for a more consistent result. The main reasons for these decisions were as follows:

- All of the experiments performed between the angles 0^O and 39.6^O proved to be inconsistent, as these results yielded very poor performance numbers. This was mainly due to the effect of numerous blockages and other stacking anomalies that caused serious problems in vibratory bowl feeding at these angles.
- The experiments conducted between the angles 79.2^O and 90^O yielded unusually high performance numbers. These performance numbers can be considered inconsistent, as components in different orientations are not rejected properly and in some cases not rejected at all. The reason for this is very clear as the angle made between the wiper blade and the VBF wall is very small. This means that the wiper blade tool cannot perform adequately and resulted in unreliable and/or inconsistent values.
- Problems also occurred at different heights; in this case the heights between 11.6mm to 12.8mm for all angles of the WBT. Between these dimensions blockages occurred naturally due to components travelling on top of each another (layering) as they passed beneath the wiper blade, often two parts high or even three. Such data was therefore considered unreliable.

These inconsistencies highlighted areas where accurate experiment data could be obtained. The WBT settings were now limited to wiper blade angles between 43.2^O and 75.6^O and wiper blade heights between 5.6mm and 11.6mm and an experiment quantity of 1000 components was picked. The value of $n = 20$ remains the same as it appeared satisfactory as the blockage amplification factor. A new set of experiments could then be run. The results of these experiments are shown in Appendix C and the performance numbers obtained are provided in Table 6.2 and in the Chart 6.1 overleaf.

HEIGHT (MM)	**ANG 43.2^{o}**	**ANG 46.8^{o}**	**ANG 50.4^{o}**	**ANG 54.0^{0}**	**ANG 57.6^{o}**	**ANG 61.2^{o}**	**ANG 64.8^{o}**	**ANG 68.4^{o}**	**ANG 72.0^{o}**	**ANG7 75.6^{o}**
5.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.84	76.0	75.0	73.0	74.5	68.0	76.0	71.0	77.0	79.0	77.0
6.08	74.0	72.5	74.5	76.0	71.0	81.0	76.5	76.5	72.5	76.5
6.32	77.0	75.0	73.0	70.0	76.0	82.5	74.5	81.0	75.0	73.5
6.56	79.0	72.0	70.5	77.5	72.5	85.0	75.5	76.5	78.5	78.5
6.80	74.0	75.0	73.0	73.0	77.0	84.5	75.0	76.5	76.0	78.5
7.04	78.0	72.5	73.0	77.0	74.0	81.5	74.5	76.0	78.0	75.5
7.28	76.3	77.5	72.0	75.0	74.0	80.0	75.0	72.0	76.0	79.5
7.52	73.8	73.5	73.5	72.0	74.5	76.5	76.0	76.0	74.5	73.0
7.76	74.8	73.0	71.5	73.5	75.5	80.5	76.0	74.5	75.0	75.5
8.00	72.8	72.0	71.5	71.5	71.5	78.5	78.0	74.5	77.5	74.0
8.24	76.3	69.5	74.0	73.5	76.0	77.0	76.0	77.5	74.0	75.0
8.48	75.8	77.0	70.0	76.0	74.5	75.5	76.5	81.0	74.5	73.5
8.72	73.8	70.5	74.0	74.5	71.5	79.0	77.5	83.5	74.5	78.5
8.96	74.3	77.5	74.5	73.0	70.0	80.5	74.5	80.5	72.0	79.5
9.20	74.0	74.5	69.5	72.5	76.0	81.5	75.0	79.5	75.5	77.0
9.44	74.5	78.0	75.5	72.0	75.5	80.0	75.5	79.0	74.5	78.0
9.68	78.5	74.0	69.0	74.5	74.0	84.0	76.5	77.0	74.0	77.5
9.92	76.5	74.0	73.0	76.5	74.0	76.5	74.5	74.5	76.0	76.5
10.16	76.0	75.0	74.5	76.5	76.5	76.0	76.5	76.0	77.0	77.0
10.40	74.5	74.5	74.5	72.5	74.5	76.5	73.5	75.0	76.5	72.0
10.64	73.0	78.0	71.0	76.0	74.5	80.5	75.5	77.0	72.5	75.5
10.88	74.5	70.5	71.0	76.0	76.0	80.5	74.0	73.0	75.5	76.0
11.12	77.0	74.0	75.0	71.5	73.0	77.5	72.5	75.5	74.0	78.5
11.36	72.5	72.5	74.5	75.0	77.0	78.5	75.5	73.5	75.0	77.0
11.60	74.0	77.0	76.0	81.5	76.5	77.5	74.5	70.5	74.0	75.5

Table 6.2: The Wiper Blade Tool Performance Results - Set 1 Redefined

Table 6-2 represents performance calculation results for a series of 260 experiments consisting of 26 height adjustment positions for each of the 10 angular positions of the WBT. These new performance results are graphed in Chart 6-1.

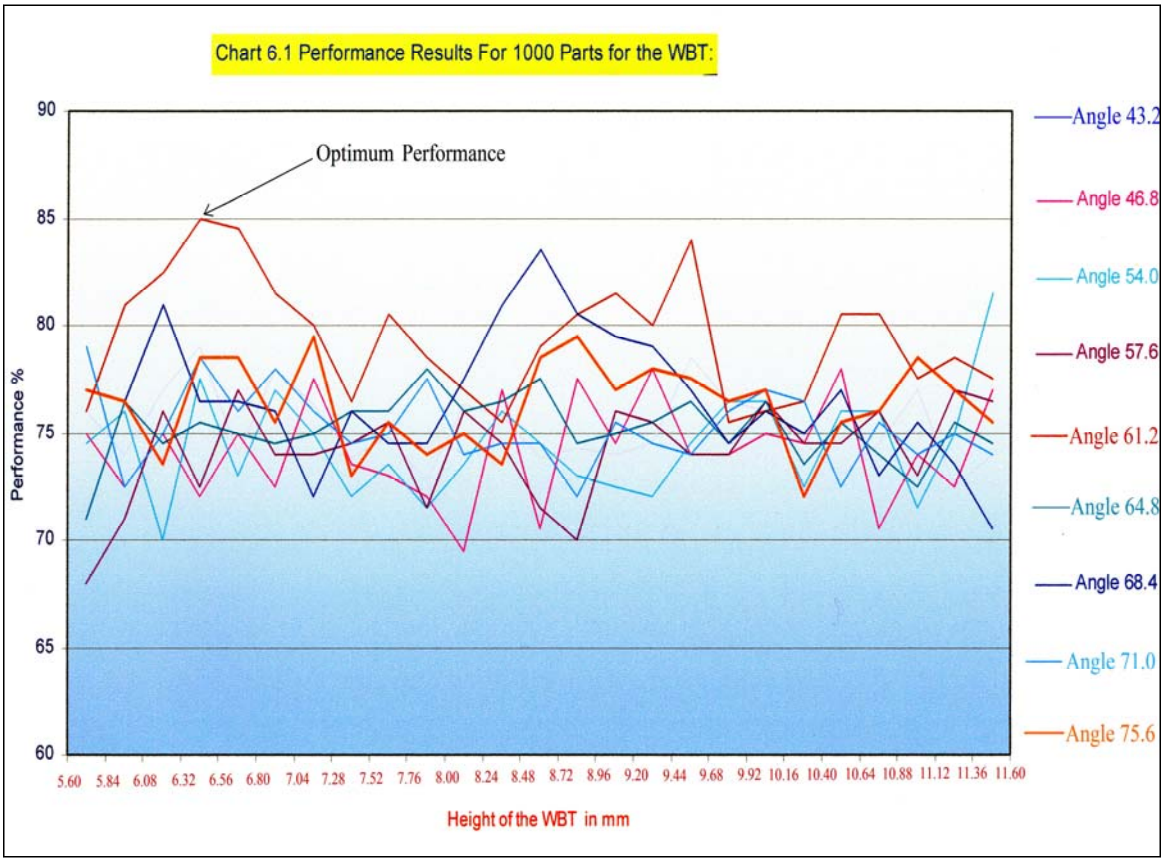


Chart 6-1: Performance Numbers for the WBT at 1000 Components Per Experiment

Increasing the batch size from 200 components to 1000 components resulted in tool optimisation where repeatable trends begin to show in the associated graphs. The Chart 6-1 shows the WBT height plotted on the X-axis against the tool performance plotted on the Y-axis. It can be seen from this Chart 6-1 and Table 6-2 that the resulting performance values range between 69.0% and 85%. An optimum performance is selected at 85%. This occurred at a WBT height of 6.56mm and at an angle of 61.2^{o} (see Chart 6-1).

From the experiment results presented in Appendix C it can be seen that, at the optimum angle of the WBT selected, that only 2 blockages occurred, 105 components passed-by successfully and 95 components were rejected. It can be see that the tool demonstrates a consistently low blockage number and a relatively low rejection rate at this angle setting for the rest of the experiments. This is the reason why the performance values obtained at this particular angle are relatively high and consistent compared to other WBT angles.

The performance values between 10.16mm and 11.6mm in the angle range of 61.2^{o} and

75.6^o (from Table 6.2) demonstrate a slight reduction in the overall performance value. This is due to component blockages and other stacking anomalies (irregularities) that disrupt the natural flow of components past the WBT, as the height of the tool (of 11.6mm) gets closer to two components high.

A visual observation of the working tool (obtained during the experiments) in the angle range 61.2^o to 75.6^o indicates that the rejection force of the WBT is greater at these angles than the blockage force acting on the tool. The wiper blade can therefore reject components consistently without disrupting the natural flow of components passing by the tool. This is also a reason why the blockage numbers registered in the PLC are low and the performance numbers are high.

The main conclusion drawn from the WBT experiments using the Table 6-1, Table 6-2 and Chart 6-1 is that the most efficient working range of angle settings for the WBT for the target component is between the angles 61.2^o and 75.6^o for height settings between 5.84mm and 10.16mm. This produced an optimum performance number of 85% with the possibility of repeatability. However the data obtained is not convincingly consistent thought-out. Intermittent stoppages due to tool unreliability and regular sensor adjustment had to be accommodated during the experimentation. The experiments need to be rerun. Insufficient project time was available to do this, so it remains as an objective for a future project in this area.

6.6.2 The Narrow Track Tool Experiments Results

The NTT is the second orientation tool used within this family of orientation tools. In this situation the experiments conducted on the orientation tool were considered as semi-automated, the adjustment of the tool being performed manually for each new position of the tool as required. In calculating the performance numbers for the various experimental positions the fibre optic sensors are again used to provide feedback to the PLC. These performance calculations are determined using the pass-by rate (acceptance rate) and the fall-off rate (rejection rate) of components at the NTT location. The performance numbers are again automatically produced by the PLC program on the basis of the modified performance algorithm overleaf. Note that the number of accepted components will not be affected by the blockage factor in this case as the blockage factor is equal to zero (n=0). The reason for this is that there are no blockages of the type mentioned on the WBT occurring with this tool.

$$\boxed{\text{Performance Number} = \frac{(\text{No of Accepted Parts} - \text{Blockage x } 0) \text{ x } 100}{\text{No of Accepted Parts} + \text{No of Rejected Parts}}}$$

The experiment quantity was decided at 500 components for all experiments conducted on the NTT. Because the WBT will reject parts, the Experiment Quantity of parts will not arrive at the NTT. Therefore the (No of Accepted Parts + No of Rejected Parts) will not equal the Experiment Quantity. The NTT developed could be moved through an experimental distance of between 0mm (start position) and 24.4mm (end position) at 0.203mm per step. This means that 120 experiments could be preformed.

The experiment quantity for each experiment is monitored by the PLC, by adding the number of components that pass-by the tool to the number of components that are rejected at the NTT location. It was decided that in order to determine the number of components travelling in either Orientation ‘a’ or Orientation ‘b’, that a visual observation would be sufficient. This observation would allow the number of components in Orientation 'a' (that were not being rejected) to be checked against the number of Components in Orientation b that were actually falling-off (rejected) at the NTT location. The result of each individual experiment is shown in Appendix C and their performance values are provided in Table 6.3 and Table 6.4 overleaf:

Experiment Number	Experiment Distance (mm)	Performance Number %	Experiment Number	Experiment Distance (mm)	Performance Number %
1	24.400	0.0	31	18.300	0.0
2	24.197	0.0	32	18.097	0.0
3	23.993	0.0	33	17.893	0.0
4	23.790	0.0	34	17.690	0.0
5	23.587	0.0	35	17.487	0.0
6	23.383	0.0	36	17.283	0.0
7	23.180	0.0	37	17.080	0.0
8	22.977	0.0	38	16.877	0.0
9	22.773	0.0	39	16.673	0.0
10	22.570	0.0	40	16.470	0.0
11	22.367	0.0	41	16.267	0.0
12	22.163	0.0	42	16.063	4.60
13	21.960	0.0	43	15.860	5.20
14	21.757	0.0	44	15.657	7.60
15	21.553	0.0	45	15.453	18.8
16	21.350	0.0	46	15.250	24.0
17	21.147	0.0	47	15.047	35.0
18	20.943	0.0	48	14.843	30.0
19	20.740	0.0	49	14.640	37.0
20	20.537	0.0	50	14.437	35.6
21	20.333	0.0	51	14.233	37.4
22	20.130	0.0	52	14.030	35.4
23	19.927	0.0	53	13.827	64.6
24	19.723	0.0	54	13.623	58.0
25	19.520	0.0	55	13.420	61.8
26	19.317	0.0	56	13.217	57.0
27	19.113	0.0	57	13.013	62.0
28	18.910	0.0	58	12.810	56.0
29	18.707	0.0	59	12.607	55.8
30	18.503	0.0	60	12.403	59.2

Table 6-3: The Narrow Track Tool Results - Set 1

Experiment Number	Experiment Distance (mm)	Performance No %	Experiment Number	Experiment Distance (mm)	Performance No %
61	12.200	60.8	91	6.100	0.0
62	11.997	59.2	92	5.897	0.0
63	11.793	56.6	93	5.694	0.0
64	11.590	25.4	94	5.490	0.0
65	11.387	16.0	95	5.287	0.0
66	11.183	10.0	96	5.084	0.0
67	10.980	9.0	97	4.880	0.0
68	10.777	2.0	98	4.677	0.0
69	10.573	3.0	99	4.474	0.0
70	10.370	1.0	100	4.270	0.0
71	10.167	0.6	101	4.067	0.0
72	9.963	0.0	102	3.864	0.0
73	9.760	0.0	103	3.660	0.0
74	9.557	0.0	104	3.457	0.0
75	9.353	0.0	105	3.254	0.0
76	9.150	0.0	106	3.050	0.0
77	8.947	0.0	107	2.847	0.0
78	8.744	0.0	108	2.644	0.0
79	8.540	0.0	109	2.440	0.0
80	8.337	0.0	110	2.237	0.0
81	8.134	0.0	111	2.034	0.0
82	7.930	0.0	112	1.830	0.0
83	7.727	0.0	113	1.627	0.0
84	7.524	0.0	114	1.424	0.0
85	7.320	0.0	115	1.220	0.0
86	7.117	0.0	116	1.017	0.0
87	6.914	0.0	117	0.814	0.0
88	6.710	0.0	118	0.610	0.0
89	6.507	0.0	119	0.407	0.0
90	6.304	0.0	120	0.204	0.0

Table 6-4: The Narrow Track Tool-Set 1

It was found that for the first 41 experiments, components in either Orientation ‘a’, or Orientation ‘b’ were not being rejected. This occurred because both orientations of the component could be sufficiently supported on the NTT ledge. However this leaves an unacceptable situation for calculating the performance values. If the equation is used here the result will provide performance values of 100%, as there are no rejected components to consider. Where the result shows no rejected components for an entire experiment the performance values have been disregarded because the tool is performing ineffectively

The opposite is also true for experiments 72 to 120, where all the components are being rejected in both orientations. These results will be disregarded when calculating the true performance of the tool. The only results that will be considered of any significant value are those results between experiments No 41 to No 72 (see Table 6-5 and again in Chart 6-2).

Experiment Number	**Experiment Distance**	**Performance Number**
	(mm)	**%**
41	16.266	0.0
42	16.063	4.6
43	15.860	5.2
44	15.657	7.6
45	15.453	18.8
46	15.250	24.0
47	15.047	35.0
48	14.843	30.0
49	14.640	37.0
50	14.437	35.6
51	14.233	37.4
52	14.030	35.4
53	13.827	64.6
54	13.623	58.0
55	13.420	61.8
56	13.217	57.0
57	13.013	62.0
58	12.810	56.0
59	12.607	55.8
60	12.403	59.2
61	12.200	60.8
62	11.997	59.2
63	11.793	56.6
64	11.590	25.4
65	11.387	16.0
66	11.183	10.0
67	10.980	9.0
68	10.777	2.0
69	10.573	3.0
70	10.370	1.0
71	10.167	0.6
72	10.370	0.0

Table 6-5: The Edge Riser Tool Results - Set 1 redefined

Table 6-5 represents performance calculation results for a series of 32 experiments that are superimposed in Chart 6-2 overleaf.

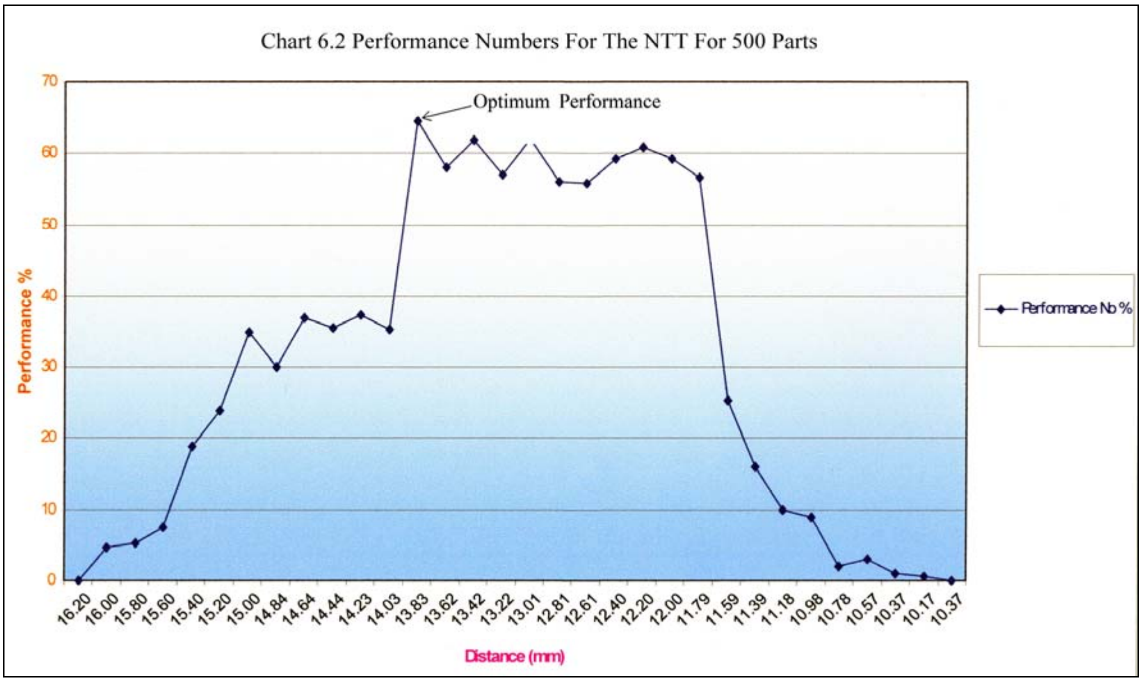


Chart 6.2: Performance Numbers for the NTT at 500 Components Per Experiment

The Chart 6.2 shows the NTT ledge distance plotted on the X axis against the tool performance plotted on the Y axis. It can be seen from Chart 6.2 and Table 6-6 that the performance of the tool gradually increases over an experiment distance from 16.2 mm to 13.83mm. After that the performance shows a steady repeatable trend resulting in tool optimisation between 55.8% and 64.6% in the associated graph. The performance gradually reduces over the remaining part of the graph from a NTT ledge distance from 11.59mm to 10.37mm. The performance from this point on will continually reduce until it reaches zero at that point. As all of the components are falling off at the NTT location. The optimum performance is calculated at 64.6% at a NTT ledge distance of 13.83mm. This is not, at all, to be considered the only method for calculating the optimum performance.

A visual observation of the working tool (obtained during the experiments) in connection with the detailed experiment results presented in Appendix C indicates that the reason why the initial performance values are low, but steadily increasing between 16.03mm up to 14.23mm is because some components in orientation ‘b’ are rejected by the tool at this point and others are passing-by. As the NTT ledge approaches the centre of mass of the component in orientation ‘b’ at 11.8mm, the rejection rate increases up until all components in orientation ‘b’ are rejected at 11.83mm. At this point the tool is working effectively demonstrating optimised performance values until the ledge approaches the centre of mass of the component in Orientation ‘a’. As the ledge approaches this point from 11.79mm downwards, components in orientation ‘a’ are beginning to be rejected until the tool reaches a NTT distance of 10.37mm where components in both orientations ‘a’ & ‘b’ are rejected by the orientation tool.

The main conclusion drawn from the NTT experiments using the Table 6-3, 6-4 & 6-5 along with Chart 6-2 is that the most efficient working distance of the tool using this particular component, occurs at a NTT ledge distances of 13.83mm and 11.79mm. This produced an optimum performance number of 64.6%. Again as the experiments could not be run without interruptions for mechanical adjustments they are not considered repeatable and are therefore considered unreliable from the point of view of the quantitative results produced.

6.6.3 The Edge Riser Tool Experiment Results

The ERT is the final orientation tool used in the multi tool system. This tool is placed just after the NTT and just before the delivery chute. In calculating the performance of each angular position of the edge riser ledge, fibre optic sensors are used again to provide sufficient data to the PLC. However the motion of adjusting the tool’s position was performed manually and is therefore considered as a semi-automated orientation tool. The rejection rate of the tool must also be observed visually, as components are continually rejected at unusual or unpredictable locations as the ERT ledge angle is changed. The performance numbers are again automatically produced by the PLC program on the basis of the modified performance algorithm see Section 6.6.2 previously. Note that the number of accepted components will not be affected by the blockage factor in this case as the blockage factor is also equal to zero (n=0). Because the NTT will reject parts, the Experiment Quantity of parts will not arrive at the ERT. Therefore the (No of Accepted Parts + No of Rejected Parts) will not equal the Experiment Quantity. The reason for this is that there are no blockages of the type mentioned on the WBT occurring with this tool.

In total, 48 experiments were performed. These were conducted from 4^o (Starting position) to 10.48^o (End position) at angular steps of 0.136^o per step. This tool is not used to reject components but serves only to re-orientate mis-orientated components from Orientation ‘a’ to Orientation ‘c’. This means that the experiments conducted show that rejected components are considered unreliable in determining the overall performance of the tool. The results of these experiments are shown in Appendix C and the performance values obtained are shown in Table 6-6 overleaf.

Experiment Number	Experiment Angle (Deg)	Performance Number %	Experiment Number	Experiment Angle (Deg)	Performance Number %
1	4.000	5.4	25	7.312	100
2	4.138	9.0	26	7.450	99.6
3	4.276	6.0	27	7.588	100.0
4	4.414	7.0	28	7.726	100.0
5	4.552	5.4	29	7.864	100.
6	4.690	5.6	30	8.002	100.0
7	4.828	8.6	31	8.140	100.0
8	4.966	10.0	32	8.278	100.0
9	5.104	6.0	33	8.416	99.4
10	5.242	4.0	34	8.554	100.0
11	5.380	7.0	35	8.692	99.6
12	5.518	8.0	36	8.830	100.0
13	5.656	16.0	37	8.968	100.0
14	5.794	31.8	38	9.106	100.0
15	5.932	36.4	39	9.244	100.0
16	6.070	43.0	40	9.382	100.0
17	6.208	80.8	41	9.520	100.0
18	6.346	83.0	42	9.658	100.0
19	6.484	93.6	43	9.796	95.2
20	6.622	96.2	44	9.934	70.0
21	6.760	98.2	45	10.072	24.0
22	6.898	100.0	46	10.210	25.0
23	7.036	100.0	47	10.348	17.0
24	7.174	100.0	48	10.486	10.0

Table 6-6: Edge Riser Tool Results - Set 1

This tool ensures that components encountering the edge riser tool in one of two orientations only (orientation ‘a’) will be presented in the desired orientation at the delivery chute. The optimum performance numbers are shown in Table 6-7 overleaf.

Experiment Number	Experiment Angle (Deg)	Performance Number %	Experiment Number	Experiment Angle (Deg)	Performance Number %
20	6.622	96.2	32	8.278	100.0
21	6.760	98.2	33	8.416	99.4
22	6.898	100.0	34	8.554	100.0
23	7.036	100.0	35	8.692	99.6
24	7.174	100.0	36	8.830	100.0
25	7.312	100.0	37	8.968	100.0
26	7.450	99.6	38	9.106	100.0
27	7.588	100.0	39	9.244	100.0
28	7.726	100.0	40	9.382	100.0
29	7.864	100.0	41	9.520	100.0
30	8.002	100.0	42	9.658	100.0
31	8.140	100.0	43	9.796	95.2

Table 6-7: Edge Riser Tool Results - Set 1 Redefined

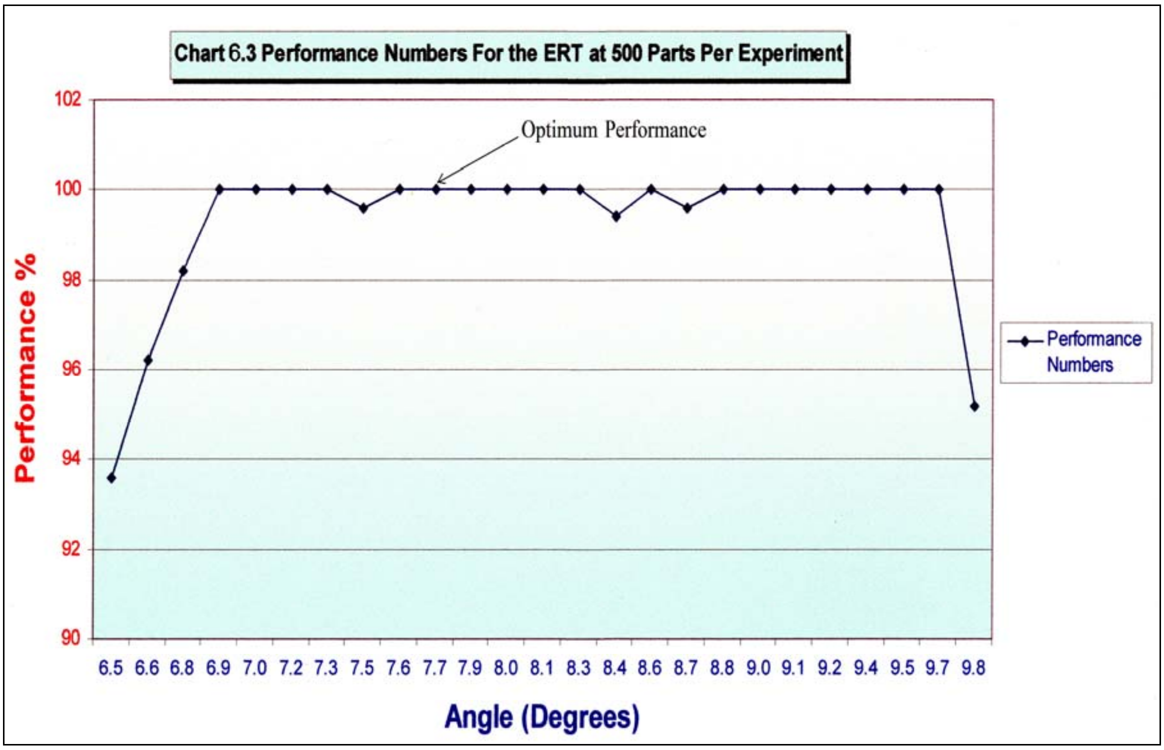


Chart 6-3: Graph of the Edge Riser Tool Performance Results

Table 6-8 represents the optimum performance calculation results for a series of 24 experiments from 6.2^{o} to 9.8^{o} consisting of 23 height adjustment positions for the ERT. These sets of experiment values are superimposed in Chart 6-3.

The layout in Chart 6-3 is similar to the NTT with 24 different experiment tool settings shown on the X-axis and the optimum performance results shown on the Y-axis. The first part of this graph from 6.62^{o} to 6.90^{o} show that the performance is gradually increasing. The reason for this gradual increase is that the number of components being correctly orientated by the ERT is steadily increasing and the fall-off rate is steadily decreasing (see Appendix C).

The second part of the graph from 6.90^{o} to 9.66^{o} shows that the performance remains fairly constant at 100%. In this area tool optimisation is achieved for the target component. These performance numbers appear very high and this is attributed to the ERT being a re-orientation tool only, as it does not reject components back into the VBF. As can be seen from Table 6-7 and Chart 6-3 there were various tooling angles for the ERT ledge that will provide this value.

The results obtained from 9.66^{o} and above, in the third part of the graph, also demonstrate a reduction in the performance values. This is attributed to the ERT ledge acting as an obstacle to the lifting and conveying action rather the promoting a smooth conveyance from the VBF track onto the edge riser ledge. As the angle of the edge riser ledge is increased the greater this obstacle becomes until at a certain point above 9.66^{o} the edge riser ledge becomes completely blocked as components cannot negotiate the climb and the tool becomes ineffective at that angle.

A visual observation of the working tool (obtained during the experiments) indicated that the ERT should be rendered ineffective at certain angles (i.e. below 6.89^{o} and above 9.66^{o}), for the target component, because the tool does not function properly as an active orientation device. An efficient edge riser tool should facilitate the reorientation process from Orientation ‘a’ to Orientation ‘c’, as an active orientation device. The probability of demonstrating a 100% efficiency is considered highly feasible but as with the WBT and the ERT the experiments could not be run without stoppages and are therefore considered unrepeatable and for this reason unreliable.

6.7 Extension of the Search Process Algorithm

The algorithm developed in the AMTLAB and applied here to obtain the performance numbers for the semi-automated orientation (the NTT and the ERT) tools is a general efficiency formula for production systems that has been adapted for this particular situation. In the case of the automated WBT is has been adapted even further to account for blockages by incorporating a penalty factor ***n***. As outlined earlier (Section 6.5) the penalty factor ***n*** is used to affect the value of the output from the tool, so that when divided by the input it produces a lower efficiency value.

It is essential that the penalty factor (*n*) was applied in the algorithm to calculate the performance values for the WBT. It was used in this case to account for component blockages (blockages can be observed visually). The use of the penalty factor in the algorithm is to some extent validated by its effect on the performance result.

When considering the reasons for a poor performance result from a VBF or any specific orientation tool within it, it should be clearly understood that not all factors that affect feed rate will be as a result of component anomalies (see section 6.2.1). In fact component anomalies might not be the reason at all. This might be determined by future experimentation using the applied algorithm. At some future point a project largely committed to examining how component feed rate is affected by factors other than component anomalies, such as those factors that affect the VBF (acceleration, velocity, hop etc.) and/or tooling factors (shape, dimensional accuracy etc) could be performed. A project of this type would be of considerable advantage, as it would demonstrate how the algorithm might be extended and might help to validate the performance results obtained in this project.

It should be emphasised that a ‘design of experiments’ approach to the AMTLAB VBF system evaluation is not considered important at this point in time. The project vision was of the design and development of a range of automated orientation tooling as a first step approach in the development of a flexible VBF. A ‘design of experiments’ approach would have been a lengthy and time consuming process, but time in this project was not sufficient. Incorporation of design of experiments concepts into the experimentation procedure is left as a project for the future.

6.8 Analysis of the Performance Results for the Multi Tool System

The efficiency of the system was defined as the number of properly orientated components delivered by the system divided by the number of components entering the system. Boothroyd [1981] developed the following matrix technique in order to simplify the calculation of the system efficiency. The process was as follows:

- Each device was represented by a matrix whose number of rows and columns depends on the number of orientations in the device's respective input and output.
- The matrices are then multiplied in the order that the components encounter the devices; the resulting single column matrix represents the performance of the system.
- This matrix was then pre-multiplied by a single row matrix representing the initial distribution of the orientations of the component. This produces the overall system efficiency.

Boothroyd carried out experiments on two different example orientation systems, one for orienting right rectangular prism components (similar to the one developed in this project) and the second for orienting cup shaped components. He reported system efficiencies of 63% and 61% respectively for these experiments.

In this case the system performance for the multi tool system on the target component is calculated by multiplying the individual performance efficiencies. Here is a review of the individual efficiencies:

- The optimum performance number for the wiper blade tool, using Table 6-2 and Chart 6-1, was calculated at 85 %. This occurred at a wiper blade height of 6.56mm and an angle of 61.2^{o}.
- The optimum performance number for the narrow track tool, using Table 6-5 and Chart 6-2, was calculated 64.6 %. This occurred at a narrow track tool ledge position of 13.84mm.
- The optimum performance number for the edge riser tool, using Table 6-7 and Chart 6-3, was calculated at 100 %. This occurred at various edge riser tool locations between the angles of 6.89^{o} and 9.66^{o}.

The optimum performance for the multi tool system is calculated as follows:

$$\begin{aligned} \textit{System Performance} &= \text{WBT x NTT x ERT} \\ &= (0.85 \text{ x } 0.65 \text{ x } 1.0) \\ &= 0.5491 \end{aligned}$$

Optimum Performance for the Multi Tool System = 54.91 %

It is noted that Boothroyd’s findings for the system efficiency is considerably higher at 63% compared to that found here at 54.91%, using a similar component and the same set of orientation tools. However, Boothroyds figure is based primarily on the number of components that are successfully orientated from the VBF system. The figure of 54.91% might appear questionable in general performance terms. However, the optimum system performance for the multi tool system, in this situation, was calculated not only on the number of components that are successfully orientated from the VBF system but also the following:

1. The number of components Rejected by the system.
2. The number of Blockages.

If the algorithm was extended even further to account for factors other than component anomalies (as explained in Section 6.7) this would probably reduce the system performance even further.

However it can be seen from the experiment results on the WBT (Appendix C) that for the optimum efficiency of 85%, only 2 blockages occurred and 110 components were rejected as undesired orientations. If no blockages were recorded then the optimum efficiency for the WBT would have increase to 89% for this particular tool setting. This would have effectively increased the multi tool system efficiency to 57.9%. The conclusion drawn is that, if the blockage factor is disregarded (or if no blockages occurred) then the system efficiency for the multi tool system developed here might be comparable to the system efficiency developed by Boothroyd. A significant factor to consider in a comparison of the above efficiencies was that the automated and semi-automated orientation tools developed in this project were only prototypes and for this reason the experiment results obtained could be considered unreliable.

7 Conclusions and Recommendations

7.1 Introduction

The objective of the project was to progress the development of a Flexible VBF. It began this process by exploring the problems associated with conventional VBFs. It progressed through to the design, development and manufacture and testing of range of programmable automated and semi-automated orientation tools. These programmable orientation tools would be used as an alternative to the fixed sequence orientation tools currently employed.

One prototype tool was fully developed to demonstrate the new technology and to establish a methodology for future automated orientation tools. This prototype tool (the WBT) proved to be technologically challenging; it involved both hardware and software developments. The most difficult part of this process for the author proved to be the software development. Stepping motor programs were completed and were incorporated into a main PLC sequence thereby creating the wiper blade orientation tool automation software. Data acquisition and performance measurement were then added to create the complete system. The process of developing these programs involved a step-by-step learning process and having achieved this they are now regarded as a personnel achievement.

The results obtained through experiments conducted with these tools lead to confidence that automated orientation tools can soon be used to replace fixed-sequence tools on a VBF. The adaptability, programmability and re-programmability of the tools make the process flexible, as tools can now be configured for different components or for a family of similar components.

As the project comes to an end, the automated orientation tool process has been demonstrated using a family of automated and semi-automated orientation tools feeding one targeted component. The successful outcome is attributed to the step-by-step design approach developed and the thorough testing of the system of individual orientations tools under PLC control before integrating them into the overall process.

In an industrial environment a project such as this is tackled only after many years of experience in 1) VBF Technology, 2) Component Feeding, and 3) Control. Invariably, in fact, in a commercial environment three different specialists at the pinnacle of their development handle these three elements. This project has therefore been an accelerated learning experience in these specialists' areas.

7.2 Summary of the Aims and Objectives

The overall goal of the AMTLAB VBF is the eventual development of an automated flexible VBF. This VBF should help to solve the high cost involved in the tool setting process for high volume industry and deliver vibratory bowl flexibility for batch production set-ups. The tool setting factors where possible cost reductions have been identified are as follows:

- It will eliminate the need for specialised tooling craftsmen who are normally associated with the tool setting process.
- The need for retooling will be eliminated as slight changes in part geometry size/shape can be accommodated with automated (adjustable) tooling.
- The high cost associated with bowl tooling or reconfiguration leading to excessive lead-times will be dramatically reduced.

The specific objectives of the project as set down in Chapter 1 were as follows:

1. To design and fully develop the first automated orientation tool (the wiper blade tool). This would be used as a prototype for future automated orientation tools. This tool should demonstrate the modularity/inter-changeability and re-programmability of prototype orientation tools for a VBF system.
2. To build a programmable system to control the automated orientation tools so that they could be adapted to new component features.
3. To design and develop further prototype mechanised and automated programmable orientation tools for VBFs.
4. To identify, study and design a wide range of further tools that would in future provide a platform for a flexible VBF system with large scale application in industry.
5. To build and test the new system by addressing the automated setting of these tools when feeding a specific targeted component.

7.3 Achievements

The detailed achievements of the project in terms of the specific objectives as set down above are now presented:

Objective 1: The Wiper Blade Orientation Tool

This tool is the fully developed prototype tool. Its particular design is unique. It was required to perform two separate functions: firstly, the height of the blade above the track must be adjustable, over a specific range but without affecting its angular position relative to the sidewall of the VBF; secondly the angle of the wiper blade must be adjustable; over a specific range again without affecting the blades height above the vibratory bowl feeder track. These have been achieved by combining the mechanical parts for both operations into a single assembly, resulting in a reliable and sophisticated automated programmable orientation tool. Furthermore, the two functions are implemented through a single motor drive linked to a clutch and locking system: hence the uniqueness of the design. The intention is that key elements of this design will be considered as standard modules from which other tools will be built. This is one aspect of ’modularity’ in relation to the development.

The WBT is controlled through the operation of the standardised stepper motor drive clutch system. This is controlled by a specifically developed PLC program. The WBT has a component operating range of between 0mm and 10mm for the height settings, and between 0^o and 90^o for the angle settings. This level of tool adjustability should accommodate a wide range of different components as well as similar components with different dimensions (family). A PLC can of course be ‘reprogrammed’ as necessary to provide different adjustment increments. If the WBT is mounted on a section of VBF track in a similar manner to that demonstrated with the edge riser tool (Chapter 3), this would demonstrate a level of tool ‘interchangeable’. When combining re-programmability, modularity and inter-changeability into a single automated orientation tool this presents a very effective and flexible orientation tool.

Objective 2: The Programmable System

The objective of developing a programmable system was achieved by software control of the orientation tools. Orientation tool control began through the development of various stepper motor PLC programs. Having demonstrated switch sequence control of a ‘Rotalink’ stepper motor, a further five PLC programs (Chapter 5) were subsequently developed to acquire knowledge and gain greater experience in this area. The success in developing the smaller PLC programs supported the development of a the main stepper motor PLC program (Appendix B).

The drive-clutch-locking system was then programmed to provided incremental position control of the orientation tools. Controlling both the stepper motor and the drive clutch system as a combined unit independent of the VBF, completed the programmable tool control, as well as providing another aspect of modularity: sections of the PLC software are reusable as modules for the automation of future tools. Automatic control and setting of the orientation tools through programmability provides a level of system adaptability. It will be possible to reprogram the system for adaptation to new component features. The process of demonstrating programmable control of the orientation tools began with the automatic testing of the tools at specific tool settings. The program may now be adjusted so that the target component with different dimensions can be accommodated.

The Automated Testing and Setting of the Multi Tool System

The ultimate aim of the AMTLAB PLC control system was to determine the optimum setting for each of the orientation tools developed for the feeding of the target component. This began with the development of the WBT programmable tooling system (mentioned above) that when combination with the NTT and the ERT in the electro-mechanical system (Chapter 5) became the AMTLAB VBF multi tooled control system.

The WBT electro-mechanical system enabled the development of a generic PLC control architecture that could be followed for future tool development this included:

1. The WBT programmable tooling system.
2. The Automated performance search process.
3. The Blockage management performance process,
4. The Optimum performance process data acquisition, calculations and storage.

The design and development of the WBT programmable tooling system proved particular interesting and has been fully described above.

The management automated performance search process involved automatically setting the programmable tool at a range of predetermined settings on batches of components in order to determine the optimum position. The process is fully automated from the point where the user inputs the maximum and minimum tool setting parameters (height & angle) to the system.

The blockage management performance process involved the use of fibre optic component counting sensors to monitor the pass-by rate of the WBT. When no components pass-by the tool, this indicated a blockage at the orientation tool location. This information was then used by the blockage management performance process (that set a chain of events in motion) in an attempt to clear the blockage. The key technical difficulty in this area was the positioning of the fibre optic sensors and the air blast for accurate and repeatable tool clearance.

The optimum position process calculation development process began with the design of a performance algorithm, based on component feed rate that was calculated using the number of components that pass-by the tool, the number of components that were rejected and the number of blockages that occurred at that tool location. This information was obtained using the carefully positioned fibre optic counting sensors. As each performance value was obtained using the algorithm it was checked with the previous maximum performance value, and if it was larger, it was stored as the new optimum. When the experiments were completed, this continually updated optimum and its associated settings would be automatically taken as the operation point of the tool, for the relevant component.

Objective 3: Further Tool Development

Having completed the WBT PLC control program to a consistent level of repeatability the two programmable tools (the NTT and the ERT) were included in the VBF system forming a multi-tooled system. Performance calculations for the individual tools were determined using a modified algorithm in the PLC control system. A combined optimum performance for the system could then be calculated.

The innovative solution to using automated orientation tools and controlling these tools intermittently from an external location by means of a programmable system is a unique approach to flexible tooling that has proved both interesting and challenging. The design and development of a PLC control architecture might now be used as a starting point for future research. The programme might be modified in the future to incorporate a 'design of experiment' strategy to further improve the optimisation process.

The Narrow Track Tool

The NTT tool is currently a semi-automated orientation tool, but has been designed towards full automation. A fully automated orientation tool would require the addition of a stepping motor as the drive unit, similar to that demonstrated with the WBT. Experiments conducted with this tool yielded an optimum performance of 64.6%. The tool itself functions reliably for the target component and is adaptable for different components. The results obtained from this tool might be confirmed by the implementation of full automation at a later stage.

The Edge Riser Orientation Tool

This tool is also currently only semi-automated but could be converted easily to full automation. The experiments conducted on this tool yielded maximum performances (100% efficiency) for specific edge riser ledge angles. These performance values can only be achieved with tools that perform a reorientation function (where the components have been previously orientated into a specific orientation). The end result demonstrates a tool that operates very reliably and functions properly for the target component. As with the NTT the results from this tool might be confirmed by the implementation of full automation at a later stage.

Objective 4: The Design and Development of Seven Prototype Programmable Orientation Tools (Appendix I)

Seven further tools were identified and designed towards programmability and future automation. Control of the tools might be achieved again using the standardised stepper motor drive clutch system developed in this project. If these tools are combined into a universal multi tooled VBF system and controlled using a PLC controller (or otherwise) this should yield wide ranging system level flexibility. The range of automated orientation tools (Step Module, Hold Down, Pressure Break, Slotted Track, Sloping Track, Cut-Out-Vee and Cut-Out-Notch) that are programmable, reprogrammable, modular and inter-changeable have hereby been developed beyond the concept phase. Further projects should implement these to yield the comprehensive flexible VBF system.

Objective 5: Experimental Test Results

Experiments were conducted for all of the orientation tools developed. The fully automated WBT provided an efficiency of 85% at the optimum tool setting. The NTT and the ERT were semi-automated and these provided efficiencies of 65% and 100% consecutively, at their optimum tool settings. The resulting multi tool system efficiency was calculated at 54.91%. It is not expected that these efficiency values are repeatable as the data obtained is not convincingly consistent through-out. This was due to unreliability found during the experimentation process in the need for regular sensor adjustments and experiment stoppages.

The design, development and experimentation of the automated and semi-automated orientation tools are considered as an achievement in terms of providing a methodology for future tool development. The research presented in this project might now be used as a starting point in the development of a fully functioning flexible VBF using automated orientation tools.

7.4 Conclusions

The main objective of this research is to contribute to the development of a flexible VBF. This has been achieved by the design, development and manufacture of automated programmable orientation tools. The first tool developed was a prototype tool (the WBT) that was fully automated. The key issues of Modularity/Interchangability and Adaptability from a mechanical, electrical and programmable point of view have been effectively demonstrated. This should enable the system to be adapted for different components. Two further tools (the NTT and the ERT) were designed and developed towards automation but are only semi-automated at present, this was due to time constraints in the project. The automated and semi-automated orientation tools that were developed were combine to form a typical VBF system An evaluation of the experiment results for the individual orientation tools and then the family of orientation tools provides basic data for future research.

These automated orientation tools can now be used as a basis for future research and the methodology developed for these tools can be repeated and/or improved upon until a fully functioning flexible VBF is established. The photograph of the completed VBF system is shown in Figure 7-1.

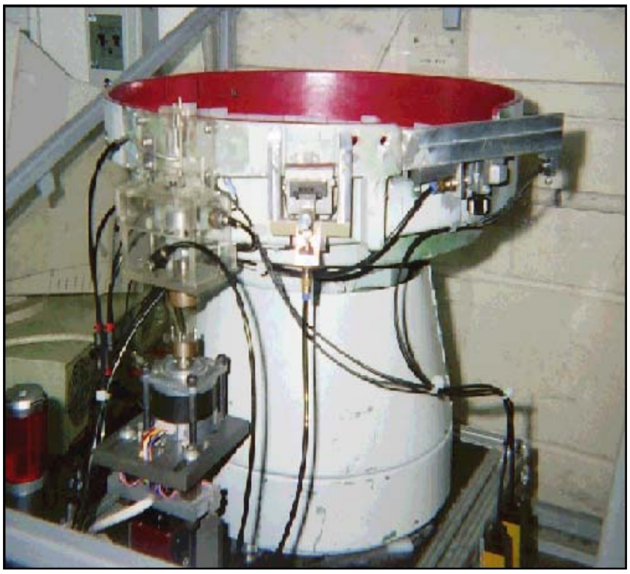


Fig. 7-1: The Completed Vibratory Bowl Feeding (AMTLAB)

7.5 Recommendations

1. It is recommended that a bulk-storage handling unit be incorporated into the VBF process. This unit would store the components in bulk quantity and when necessary release a certain quantity of these components into the vibratory bowl feeder at a controlled rate. The reason for this is that the bowl and the mass of the components in it are part of a dynamically balanced system (see Chapter 2). Maintaining a balanced VBF system should help control the feed rate.
2. In this vibratory bowl feeding process it is recommended that components that arrive at the delivery chute be returned to the storage unit by mechanical means e.g. a conveyor. This will allow a continuous uninterrupted process to develop that should help to control the volume of components in the VBF for ongoing unmanned automated experimentation.
3. This system when fully completed should be controlled directly from the PC using SCADA software. This implementation will allow the flexible VBF to be integrated into a production system such as the FMS and Process Cell that have been

developed in the AMT lab to simulate a complex factory environment.

4. Linear motors are now readily available along with the associated software. These motors make it possible to achieve linear motion with a high degree of accuracy. These might be incorporated into the actual design of the orientation tool. If so, then the need for stepping motor control might be superseded.
5. An interesting observation made during the experiment stage of the project is that the first tool used (the WBT) in the multi tool system had to contend with components that had unusual or irregular attitudes (see Chapter 6). The main function of the WBT was to reject all orientations of the target component back into the VBF, this included orientations ‘c’ ‘d’ ‘e’ and ‘f’ (see Chapter 4). The fact that it is also used to filter out component anomalies, makes its significance as the first tool in the sequence more important than what was first envisioned. Component anomalies might be responsible for component blockages. If so then this would have a direct affect on the feed rate. It is recommended that this issue should be examined in detail as part of a further research project. The results of that research might help to determine the affect that component anomalies have on the performance of the individual orientation tools; it might also help to influence decisions regarding tool sequencing; and finally it might help to target new or existing tooling technologies (such as air jet tools) to help deal with these irregularities.
6. The final recommendation made is an adjustment to the shape of the vibratory bowl. The VBF consists mainly of a rigidly shaped bowl. Changing its design to make it readily adaptable for the introduction of new tools or the switching around of the existing tools might improve flexibility. This design proposal would involve machining or sectioning of the upper layer of the bowl. All of the sections cut would be identical to each other and should be easily attached and reattached to one another and then to the bowl. This ensures that each section would fit comfortably in any position on the upper level of the bowl. An automated orientation tool could then be attached to each section. The more sections cut the bigger the possibility of providing families of orientation tools.

The end result would be the development of a versatile VBF that could accommodate various components and numerous orientation tools. This might make the VBF flexible in terms of making the process adaptable for different components that should in essence solve one of the major roadblocks in the automation of assembly (in particular) in batch production.

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Glossary

[1] AMTLAB: Advanced Manufacturing Technology Laboratory

[2] ASAR: Automated Storage And Retrieval system

[3] FMS: Flexible Manufacturing System
[4] HMI: Human Machine Interface
[5] PLC: Programmable Logic Controller
[6] SCADA: Supervisory Control And Data Acquisition
[7] VBF: Vibratory Bowl Feeder.

Appendices

Appendices List (Compact Disk Provided)

Appendix A: AutoCad Drawings.
- AutoCad Drawings that include: Assembly Drawings and Part Drawings.

Appendix B: PLC Programs (All Programs are Fully Edited and Explained).
- PLC Program, One Phase Excitation, (Clockwise Rotation).
- PLC Program, One Phase Excitation, (Anti-Clockwise Rotation).
- PLC Program, Two Phase Excitation, (Clockwise Rotation).
- PLC Program, Two Phase Excitation, (Anti-Clockwise Rotation).
- PLC Program, One/Two Phase Excitation, (Clockwise Rotation).
- PLC Program for the Wiper Blade Tool Experiments.
- PLC Program for the Narrow Track Tool Experiments.
- PLC Program for the Edge Riser Tool Experiments.
- PLC I/O list for all the PLC Programs.

Appendix C: Experiment Results.
- The WBT at 200 Parts Per Experiment.
- The WBT at 1000 Parts Per Experiment.
- The WBT at 500 Parts Per Experiment.
- The WBT at 500 Parts Per Experiment.

Appendix D: Vibratory Bowl Feeder Theory.(Boothroyd, 1981)
- Introduction.
- Mechanics of the VBF.
- Effect of Frequency.
- Effect of Track Acceleration.
- Effect of Vibration Angle.
- Effect of Track Angle.
- Effect of the Coefficient Of Friction.
- Estimate of the Mean Conveying Velocity.
- Load Sensitivity.

Appendix E: Vibratory Bowl Feeder Terminology.
- Over 50 Different Topics Discussed.

Appendix F: VBF Installation & Trouble Shooting Guide.
- Extracted from **www.mcknight.on.ca** web pages.

Appendix G: Procedures for Tuning the Base Drive Unit.
- Extracted from www.mcknight.on.ca web pages.

Appendix H: Rotalink Catalogue.
- Description of the Stepping Motor used in the project.

Appendix I: Automated Orientation Tools Designs

- Seven Conventional Tools Designed as Automated Orientation Tools.