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Designing And Modelling An Automated Packaging System.

(MSc. Thesis)

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Synopsis.

This thesis describes the design and modelling of an improved materials handling system for a beverage cap production factory called BevCap, located in Epping, Cape Town.

The factory consists of twelve production lines, which produce various types of aluminium and metal screw on caps. Each production line is fully automated except for the filling, packaging, labelling and storing procedures at the end of each production line. The finished product is counted electronically and packed into carton boxes, labelled, sealed and palletised manually. The manual materials handling procedures, at the end of each production line, are causing problems and therefore an improved automated system is required.

The materials handling problem is sub-divided into five separate design problems.

- 1) Assembling and transporting the empty boxes to the various filling points.
- 2) Filling and labelling the carton boxes automatically.
- 3) Transporting the finished product to the storage area.
- 4) Sealing the boxes before storing.
- 5) Storing and sorting the filled boxes using an automated system.

Various conceptual designs are shown for each of the above mentioned design problems and a final design presented.

An overhead chain conveyor carrying many carts is used to transport the assembled boxes to the various filling stations. Each cart is designed to hold one empty carton box. When a carton box is required at a filling station, the next available cart, on the overhead conveyor, is physically tilted using pneumatic pistons. This forces the carton box to slide

off the overhead cart and down a gravity conveyor to the filling station. At the filling station the carton box is moved into the filling position using a short flat belt conveyor. A bar code is printed on the side of the empty carton box before it is filled with newly produced caps. Once the box has been filled it is placed onto a continuously moving flat belt conveyor which transports the filled box to the sealing and storage areas. At the carton box sealing area the carton box is removed from the flat belt conveyor and sealed manually. Once sealed the box is placed back onto the flat belt conveyor and taken to the storage area. At the storage area the carton box is identified by a bar code scanner, which reads the bar code printed on the side of the carton box. From the information gathered from the bar code, the computer is able to identify in which storage area the box must be stored. A pneumatic piston is used to push the box off the first conveyor belt and onto a second conveyor belt. The second flat belt conveyor moves the filled boxes past the different storage areas. Once the box arrives at the correct storage area a second pneumatic piston is used to push the box off the conveyor belt and down a slide to the correct storage area. Therefore, each storage area, along the length of the second conveyor belt, has a single pneumatic piston to retrieve the carton boxes once the carton box arrives at the correct storage area.

The final design is modelled using the Lego Dacta system and is controlled by a computer program. The model represents the concepts of the design and is not a detailed scaled model of the actual factory layout. The model contains three production line filling stations as well as three storage areas. A Visual Basic 3.0 computer program controls the various components of the model. The model requires mains power and a constant supply of compressed air to function. The principles represented in the model are used in the actual factory design. The various components required, the cost of the components as well as the positioning of the components on the factory floor are shown in detail.

It was found that the improved materials handling system increases the amount of available factory floor space. With the bar code system in place, the possibility of errors in identification and storage of the product are drastically reduced. The processes of

assembling and sealing the carton boxes are improved and organised. It is recommended that a more detail cost analysis be done on the various components needed for the factory. The strength of the factory ceiling must also be investigated before installing the overhead chain conveyor. Finally, more detailed drawings are required for each of the components needed as well as the components positioning in the factory layout.

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1. Introduction.

This thesis sets out to design and develop a conceptual model of an improved materials handling system for a beverage cap factory, BevCap, located in Epping, Cape Town.

The factory consists of twelve production lines, which produce various types of aluminium and metal screw on caps. The production of the various caps is fully automated except for the filling, packaging, labelling and storing procedures at the end of each production line. The caps are packed into carton boxes, which are assembled on the plant, labelled, sealed and palletised manually. This procedure of manual materials handling is disorganised and has been causing problems with the production line efficiency and overall productivity. For this reason it was decided by Prof. G.N. Nurick, Department of Mechanical Engineering, and Mr. M. Nothnagel, BevCap, that an improved automated packaging system be designed and modelled.

The objectives of this thesis are,

- 1) Model the present material handling procedure at the end of each production line and layout in detail the problems associated with the present procedures.
- 2) Design a conceptual idea to improve and automate the present material handling system.
- 3) Build a model of the conceptual design using a 3-dimensional modelling medium.
- 4) Using the concepts demonstrated in the model, design the components needed to automate the actual factory.

The report begins by defining the present layout and materials handling procedure at the end of each production line, as well as the problems associated with the manual method of packing and storing the finished product. Next, the various ideas to improve and

automate the packaging procedure will be discussed in detail and a final conceptual design presented. The proposed design is modelled and simulated using the Dacta Lego system. The model will demonstrate the concepts of the automated materials handling system. The machinery needed as well as the positioning on the actual factory floor is designed and suggested for the improved materials handling design. Finally, conclusions and recommendations are made.

2. Literature Review.

The concepts of modelling, simulation, material handling and automation involved with factory design are discussed.

2.1. Modelling Techniques.

A model, according to the Oxford dictionary, is a “representation in three dimensions of existing person or thing or proposed structure, especially on a smaller scale.”

Therefore, modelling is taking an existing structure or proposed structure and defining it by means of a three-dimensional scaled model.

Modelling has been used by many engineering companies as a way of physically representing a design proposal before the manufacturing stage. Communicating a design concept is best accomplished by constructing a physical model to be examined by colleagues. Instead of a 3 dimensional object displayed on a 2 dimensional surface, which can often be interpreted in more than one way, a physical model will settle most technical problems that arise (Ref. 22). Models are used by designers for product visualisation, to check assembly, and to help avoid expensive mistakes which would not otherwise be detected until the construction of a prototype (Ref. 23).

Models can be used for various reasons, which are listed below.

- 1) Display purposes
- 2) Sales purposes
- 3) Trade shows
- 4) Conceptual Design purposes

- 5) Final Design check
- 6) Training purposes
- 7) Testing purposes

It has been shown that models used for the purpose of sales and display make up 50% of all models built (Ref. 22). For example, Boeing Corp. has released figures that indicated that 38 percent of the models built, at Boeing, are used as design concept models (Ref.

2). Scale models were also used as design tools in the development of the Bailey Bridge and the Mulberry Harbour, two of the most important engineering innovations of the 1940's. Models are also commonly found in water test tank and wind tunnels. Malcolm Nicholls Ltd. construct model motor cycles for the use of wind tunnel testing and analysis (Ref. 23).

A new form of model "making" has come about with the improvement in computer technology. Computer-aided modellers such as CAD, CADKEY 3 and many others can be used to model a 3-dimensional structure onto a 2-dimensional screen. The advantage is that the structure, once drawn on the computer, can be rotated and looked at from many angles. The hidden lines can be removed and the structure can be shaded to give the user a better feel of the 3-dimensional structure. The greatest advantage is that no physical material is needed to construct the model. Despite the growth of interest in computer-aided design techniques, physical models are often invaluable as an aid to the designer. The main advantage physical models have over computer-generated images are permanency and ease of manipulation (Ref. 23). Sometimes there is no substitute for holding the item in your hands, to feel it, study it and make sure it is "just right" (Ref. 2).

2.2. Model Simulation Techniques.

Models can also be used to simulate a situation or event. To simulate, according to the Oxford dictionary, is "to pretend to be or have or feel; imitate or counterfeit; imitate conditions of with a model." There are two means of simulating a modelled process. A computer simulation can be done or a physical model can be built which simulates the system physically.

Firstly, advanced computer programs are available, which allow the designer to model the physical structure, in 3-dimensions, on a 2-dimensional screen and simulate various scenarios to the computer model. ABAQUS, a finite element program, is a good example of modelling physical structures and then simulating various conditions on the model.

For modelling and simulating of factories, various finite element type computer programs are available. These packages help factory managers anticipate and plan around numerous potential problems. Nissan engineers, using Sima's CimStation Robotics program, were able to predict whether or not various robots, in a car assembly production area, would collide or not (Ref. 7). Boeing engineers, also using CimStation Robotics, were able to generate a program to polish the skin of a Boeing 747, using a Robot polisher, in approximately 8 hours, if the simulation program had not been used it would have probably taken months to program the robot polisher (Ref. 7). Another computer package from F&H Simulation called Taylor II Version 3.0 allows the designer to model and simulate a factory storage area in less than an hour (Ref. 7). AutoMod 7.5, from AutoSimulations Inc. also allows the designer to model and simulate production operations. McDonnell Douglas has released several simulation packages which are able to simulate robotic assembly workcells. Such a program, PLACE or Positioner Layout and Cell Evaluator helps design and analyse a robotic system using full colour animation (Ref. 1).

Programs are also available which check the physical stress on the modelled worker's bodies, as the factory simulation is running. The computer simulation can even calculate the number of kilo-joules per day a worker consumes. The high physical stress areas can also be shown on the workers body by red shaded areas. This can then inform the factory designer of possible future injuries to the work force.

The advantages of using computer-aided simulations is that they verify the design concepts, analyse the cycle time, prevent collisions, check for tool feasibility as well as simulate off-line programming. The computer simulation also allows the user to design the work cell and run the simulation using representations of actual parts and dimensions. But the greatest advantage is the amount of detailed information which can be extracted from the simulation. For example, a small change in machinery position or operation can increase the productivity of the system and the computer simulation will be able to measure the increase in productivity fairly accurately (Ref. 7)

Secondly, physical models which also simulate a design or idea can be constructed. These models represent the physical structure of the design, scaled down, but can also function as the design would in reality. The difficulty in simulating a physical model, compared to a computer model, is the amount of work required to control all the mechanical devices. Various motors, sensors, control circuitry and programming is required to simulate a factory model. The advantage is that a physical working model has much more of an impact than a 3-dimensional animated picture (Ref.22).

2.3. Material Handling Techniques.

Materials handling can be defined as, “the technology covering the movement and storage of everything in and about an establishment : the handling of raw materials and tools; the movement of components between operations and in stores, of finished products and of movement of the scrap, cutting aids and process machinery; the movement of workers in relation to the handling of material.” (Ref. 33)

Material handling is not an exact science. In fact, materials handling can cover between 15% and 85% of the cost of production (Ref. 33). The object of a handling study is to eliminate handling operations. Those that cannot be eliminated must be examined to see if they can be mechanised (Ref. 14). When mechanical equipment is put in to do the work of an operator, it is known as “mechanical handling” (Ref. 33). To create the “perfect” factory there should be a minimal amount of materials handling and hence more mechanical handling. Therefore, trucks, forklifts, cranes and man-power conveyors should be replaced with an automatic system that integrate the enter factory into one operational unit. The ideal factory would have been built for the job. In other words, constructed for the processes which are to be carried out inside it (Ref. 14).

If efficient mechanical handling is used, the following advantages can be expected,

- 1) Increase in productivity.
- 2) Upgrading of labour.
- 3) Reducing production costs.
- 4) Reduction in industrial accidents.
- 5) Reduction in damage to the products.
- 6) Increased speed of handling materials.
- 7) Consistent level of production throughout establishment.

Remember, materials handling is not an exact science. To obtain exact cost figures of the saving involved, thereby justifying the proposed improvement, is very difficult.

Improvement in production or continuity of flow, in one section, can have an effect on the following section. But, nearly every case of well-planned mechanical handling has great reductions in cost and labour. For example, the cost of a conveyor will be recovered in three years, purely on the amount of money saved in labour alone (Ref. 33).

The following simple rules should always be considered when designing a mechanical handling system (Ref. 33).

- 1) **MOVEMENT RULE** : All unnecessary movement of materials should be eliminated.
- 2) **PROCESSING RULE** : Articles should be processed while in transit whenever possible.
- 3) **THE FLOOR RULE** : Materials should never be placed directly on the floor.
- 4) **THE STORAGE RULE** : Material should be stored so as to take up the smallest amount of space and to permit flexibility in selection with minimum number of operations.
- 5) **TERMINAL EFFICIENCY** : Idle, loading and unloading times must be reduced to a minimum to increase the efficiency of the process.
- 6) **STRAIGHT LINE RULE** : Wherever possible materials should move in a straight line to its destination.
- 7) **CONVEYOR RULE** : Conveyors must be used where there is a regular or continuous flow of material.
- 8) **SPEED OF EQUIPMENT RULE** : The speed of equipment should be as high as possible taking safety and cost into account.
- 9) **WEIGHT OF EQUIPMENT RULE** : The ratio of weight of the equipment to the load carried should be as minimal as possible, to ensure low costs.

2.4. Automation of a Production Line.

Automation is widely recognised as one method of increasing productivity and reducing energy consumption, scrap rates and maintenance downtime (Ref. 25). Automation makes use of mechanical handling to perform a production task without the interference or supervisor of operators.

But automation often involves the purchase of costly robots, sophisticated controls and high-priced consultants. A viable alternative is what is known as “simple-automation”, where the components used to automate the factory are simple off-the-shelf components, such as pneumatic cylinders, conveyors, and Programmable Logic Controllers (Ref. 15). Using this method of “simple-automation” will ensure low cost, minimal design time and straightforward programming (Ref. 15). Correct planning and scheduling, coupled with automation has enabled Macsteel, a small steel mill in the United States, to produce a finished product in four to five hours, compared to the best conventional steel mills which require 72 hours to do the same. It was also found that the mill’s energy requirement had been reduced by 25 percent (Ref. 25).

Automation is not always the correct solution in improving materials handling procedures. Many companies that replace people with machinery pay more for machine upkeep than they once did on employee costs. Never assume that workers make mistakes and machines don’t, many workers make the occasional mistake, but machines with errors will continuously make mistakes, and unless supervised those mistake will only be detected once the machine has produced thousands of waste products (Ref. 24). For example, General Motors decided to build a fully automated factory to produce its new high quality car, the Saturn. The cost to produce the car started to rise when the unsupervised machines gave problems. The overall outcome was that the company is still running a loss on the investment. It was said by the manager of General Motors, “Automation replaces inexpensive assemblers with expensive maintenance and process

engineers.” (Ref. 24) It is therefore important that the automation of a factory be simple, low in machinery cost and have constant supervision over the machinery performing the tasks.

2.5. Control Systems.

Control is a very important factor in factory automation. The integration of computer software and mechanical hardware is not as easy as one would think. A common household computer cannot be required to control a mechanical system in a noisy and dirty factory. For example, small power or voltage spikes, caused by factory welding, can destroy or damage common computers. Therefore, Programmable Logic Controllers or PLC's are commonly used in factory control systems.

Programmable Logic Controllers (PLC) are a user-friendly electronic computer that carry out control functions of many types and levels of complexity (Ref. 26). The PLC system contains the follows, illustrated in Figure 2.5.

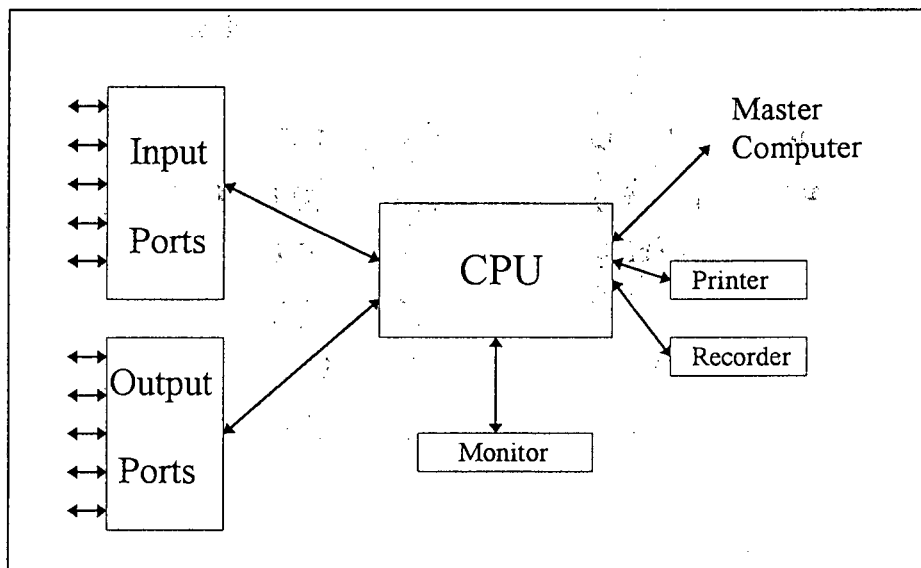


Figure 2.5 : PLC internal system.

The advantages of using PLC technology to control mechanical systems are listed below.

- 1) Flexibility - One PLC can control numerous machinery.
- 2) Implementing Changes and Correcting Errors - No re-wiring is required.
- 3) Large Quantities of Input and Output Ports - A large amount of sensors and motors can be controlled through one PLC.
- 4) Lower Cost
- 5) Pilot Running - The PLC ladder diagram can be tested before implementation.
- 6) Visual Observation - A PLC system can be attached to a screen to observe the operation of a particular machine.
- 7) Speed of Operation - PLC's are much faster than relays.
- 8) Easy Program Code - Ladder diagrams are easier than complex computer coding.
- 9) Reliability
- 10) Security - Program cannot be altered unless unlocked.

The PLC can be programmed, controlled, and operated by a person unskilled in operating computers. The PLC is programmed by drawing simple logic ladder diagrams into the PLC memory. The resulting ladder diagrams take the place of much of the external wiring required for control of a process. PC software can be used to duplicate logic ladder diagrams for testing and simulation. In this way engineers can spot errors and debug PLC ladder coding before implementation. LadderMaster 3.0 is one PC package that helps program the widely used Modicon PLC's (Ref. 10). Another PC package, Automation Master, runs a computer simulation of a plant process on the PC and interfaces it with a PLC (Ref. 27). In this way, different scenarios can be simulated on the PC and the PLC ladder diagram can be tested and checked for possible errors. This then ensures that the PLC ladder diagram will function correctly.

Computers are being used increasingly in PLC applications to provide graphic interfaces, networking, mass storage, or to run off-the-shelf application software. A PC can be interfaced with a PLC through a RS232 communications path (Ref. 12). But using the

RS232 path has its limitations. The link is relatively slow and susceptible to noise interference. To solve this problem some companies use a single box with a parallel communication paths (Ref. 12). Pro-Log Inc., however, provide interfacing between a PC and PLC, all that is needed in a 486-based processor PC for DOS and Windows applications along with a ladder logic processor with a scan time less than 1 msec (Ref. 12). The PC serves widely in factories as the engineer's console in control systems made up of PLC's (Ref. 17)

3. Modelling Medium Used.

The model must be constructed from a 3-Dimensional material and is required to simulate the functions of the proposed factory design. The model can be constructed from wood, metal or other materials. However, the *Dacta Lego* system was chosen to model the factory design. The various reason why Lego was chosen as the modelling medium used, as well as the type of Lego component available are discussed in detail.

3.1 Lego Components.

The Dacta Lego components available can be divided into two categories, electrical and mechanical components. The mechanical components consist of gears, pulleys, shafts, structural bricks and differential gear sets, shown in Appendix A. On the other hand, the electrical components available cover a wide range of sensors and drive systems. These components are listed below and shown in Appendix A.

- 1) The *Touch Sensor* is a type switch which has only two states, on or off. This type of sensor can be used as a limit switch in a mechanical system.
- 2) The *Temperature Sensor* is able to read the surrounding ambient temperature. The sensor can output its reading in either degrees Celsius or Fahrenheit.
- 3) An *Angle Sensor* is used to count the number of rotations a shaft, inserted into the sensor, rotates. Each rotation is represented by 16 counts. Therefore the angle sensor has an accuracy of 22.5 degrees. The disadvantage is that the angle sensor only functions at a rotational velocity less than 500 RPM (Appendix A).

4) The **Light sensor** is used to measure the amount of light which illuminates the surrounding area in front of the sensor, similar to the light sensors used by photographers. The light sensor contains a small red light source, which emits light, and a sensor which measures the percentage light. The sensor has a range of reading from 0 to 100% light. For example, if the sensor is placed in front of a light source, such as a 100W light bulb, the reading will be 100%.

5) A **9 Volt DC Motor** is used to drive any mechanical device. The motor uses a 9 Volt DC source to operate. The motor, however, can be set at 8 different speeds by the computer interface.

6) The **Light element** is a simple 9 Volt DC light bulb with a metal cone used to direct the intensity of the light in a forward direction.

7) A **Sound element** is a 9 Volt DC speaker which can emit two different repetitive sounds.

8) The **Lego computer interface** is used to interface the electrical hardware components, mentioned above, with the computer. The interface contains 8 output ports each able to produce an output voltage with a range from -9 to +9 Volt DC. The interface also contains 8 input ports, 4 powered and 4 non-powered. The powered input ports are used for angle and light sensors, while the non-powered ports are used for touch and temperature sensors. The interface communicates with the computer software via a 9 pin computer cable which is connected to the COM ports in the back of the computer. The Lego interface uses a 10 Volt AC transformer to power the interfaces functions.

3.2 Advantages and Disadvantages of Using Lego.

The advantages of using Dacta Lego as the modelling medium to model the improved factory are listed below.

- 1) The model can be modified and improved once built, because Lego structural components can be disassembled and reassembled when needed. This then allows the designer to build conceptual designs before they have been approved. If the model is not satisfactory it can be disassembled and re-designed and built.
- 2) Modelling with Lego is very quick and easy. To construct a model requires less time and effort than building a model from wood or metal.
- 3) The cost of Lego is cheaper when compared to the cost involved in constructing other metal and wooden models. Also the various sensors (Section 3.1) available to Lego are cheaper than their industrial counterparts.
- 4) Lego consists of a wide range of sensors and drive systems which can be controlled via a computer through a Lego interface.
- 5) Simple computer programs can be used to communicate with the interface and model such as PASCAL, C++ and Visual Basic 3.0.
- 6) The University of Cape Town has a readily available supply of Lego parts, mechanical and electrical, at their disposal. Lego is used, at the University of Cape Town, as an educational tool in the 1st year engineering program and also in the 2nd year design course.

The disadvantages of using Dacta Lego as a modelling tool are listed below.

- 1) There is a limited supply of different gear sizes. Only 8, 16, 24, and 40 toothed gears are available. Therefore, it is very difficult to obtain the required gear ratio.
- 2) The 9 Volt DC motor, which is used to drive most of the mechanical systems, is not very powerful. Therefore, large gear ratios are required for the mechanical system to function. This in turn causes the mechanical system, being driven, to move very slowly.
- 3) The Lego interface contains only 8 input and output ports. This then limits the number of sensors and drive systems in the model. It was found that only one interface port can be used on a computer at any particular time. Therefore, two separate interface ports could not be used together.
- 4) The building blocks or structural blocks have 8 mm differences, in positioning, in the horizontal direction and 3mm difference in the vertical direction, because the thinnest Lego piece is 3mm thick and the minimum width of a Lego brick is 8mm. This then makes it very difficult to place two shafts in the correct position to ensure that the shafts gears mesh correctly.

4. Present Production and Material Handling System.

The factors to be discussed are the existing factory layout at BevCap, the materials handling system at the end of each production line, and the problems associated with the present materials handling procedure. From this, an improvement on the present material handling system will be proposed and modelled.

4.1 Products Produced.

At present, there are three different types of caps produced at BevCap. The various cap types are listed below.

- 1) The *Roll On PilferProof (ROPP)* cap is an aluminium screw on cap. The cap is manufactured with a threaded inside and a perforated ring located at the base of the cap. A cap with a perforated ring is referred to as a PilferProof cap. The perforated ring is designed to break once the cap is unscrewed from the bottle. Whiskey, vodka and bottled wine screw on caps are examples of the ROPP caps produced. There are 12 different sizes of ROPP caps which can be produced at BevCap (Appendix B, Table B.1).

- 2) The *White Caps (WC)* are larger metal caps, which also contain a threaded inside. These caps are much thicker and larger than the ROPP caps. White Caps are found on peanut butter, baby food and other large bottled products. There are 9 different sizes of white caps which can be produced at BevCap (Appendix B, Table B.1).

3) The *TALOG* cap is a new product type which is being produced at BevCap. The TALOG cap is an aluminium screw on cap, similar to the ROPP cap, but contains a plastic pilferproof ring, instead of an aluminium ring as in the case of the ROPP caps.

The various types of caps produced at BevCap are listed in Appendix B, Table B.1. The numbers associated with each cap type (Appendix B, Table B.1) refers to the caps diameter and height. The caps produced may contain different external labels, depending on the customers specifications. For example, "YUM YUM PEANUT BUTTER" and "CROSS & BLACKWELL".

4.2 Production Lines.

The physical layout of the BevCap factory is illustrated in Appendix B, Drawing B.1. & B.2. The factory, at present consists of 12 production lines, 8 ROPP (Roll On PilferProof) lines, 3 WC (White Cap) lines and one TALOG line. The production lines, the products they produce, as well as the speeds in which they are produced are tabulated in Appendix B, Table B.1. It is also very important to note that there is also a new White Cap production line which is to be installed at the end of the year. It is, therefore, very important that the new factory design be compatible with changes or, most importantly, additions to the factory layout.

The product is manufactured in the follow way,

- 1) The cap labels are first pre-printed on flat aluminium or metal sheets, depending on the type of cap produced. The printing procedure is performed in a separate department.
- 2) The sheets of metal are then fed into a punching machine and the flat circular printed cap labels are removed from the sheet of metal and sent to the next manufacturing procedure.

- 3) The flat caps are then shaped and threaded by specially designed tools. In the case of the ROPP caps, the cap bottom is perforated to form the pilferproof strip.
- 4) If required, a wad or compound is inserted into the cap. The wad is a pre-made plastic disk which fits into the hollow of the cap, while the compound is a liquid solution which is injected into the hollow of the cap and is heated for a short period of time, in order to harden the liquid compound. The caps are sent through a type of burner which heats the compound inside each cap. All the White Cap products have a compound solution injected inside the cap. A burner is therefore located at the end of each White Cap production line. The ROPP production lines share a single burner, which can be seen in Appendix B, drawing B-2.
- 5) Once completed the product is sent down a short conveyor where it is counted electronically and packed into boxes.

Referring to the manufacturing procedure, mentioned above, all that is of interest, to this project, is the materials handling procedure at the end of each production line. The procedures and automated machinery used to produce the finished product is of no concern. Therefore, before starting with any design, the points where the boxes are being filled with caps, must be identified. These positions are shown in Appendix B, Drawing B.2.

4.3 Material Handling Procedure at the Filling Points.

The materials handling used in the packaging procedure can be sub divided into five sub systems. These are listed below.

- 1) Assembling the empty boxes.
- 2) Filling the empty boxes with caps.
- 3) Labelling the boxes with the correct identification labels.
- 4) Sealing the boxes.
- 5) Transporting the filled, labelled and sealed boxes to the storage areas.

Each of the 12 production lines, at BevCap, uses the same sequence of materials handling. The sequence of material handling events is illustrated in a schematic representation in Figure 4.3.

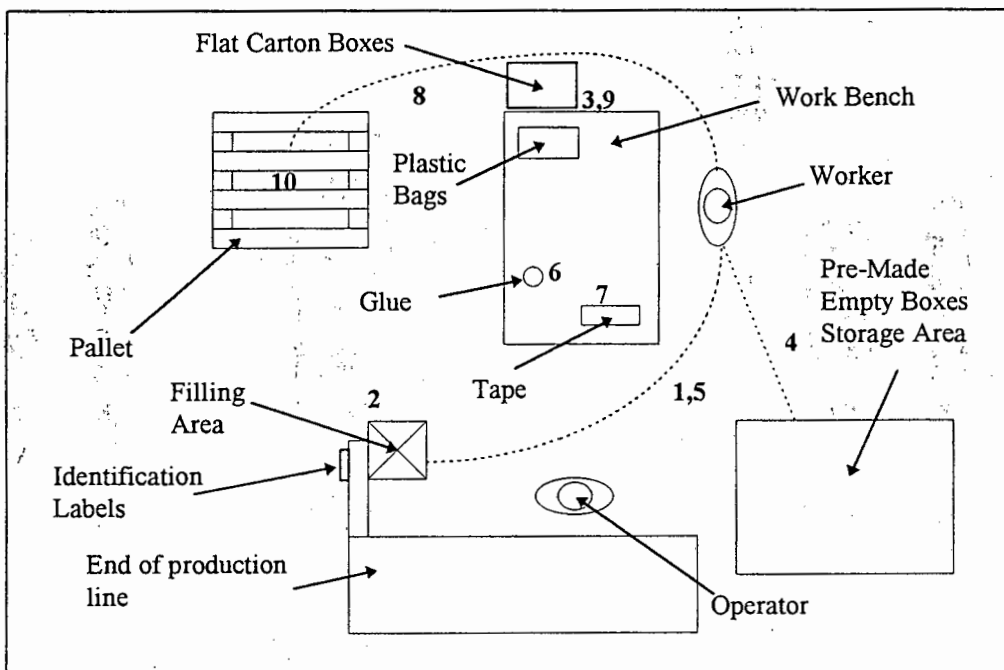


Figure 4.3 : End of the production line materials handling set-up.

(Numbers refer to statements on Page 21)

The distance the worker must walk between each area, indicated by the dotted line in Figure 4.3, may vary depending on each production line. The materials handling procedure undergoes the following pattern, (each number is referred to in Figure 4.3.)

- 1) The worker gets a pre-made empty carton box from the empty carton box storage area and moves it into the filling area.
- 2) The worker then presses a control button for the caps to start flowing into the carton box. (*Only in the WC production lines*).
- 3) The worker then walks back to the workbench and starts making more empty carton boxes. The flat carton boxes are first erected, taped and finally a plastic bag is placed inside.
- 4) Each time a carton box is made by the worker, the worker carries it to the empty carton box storage area.
- 5) Once the carton box, at the filling area, is filled with caps, the worker walks to the filling area and replaces the filled box with another empty box.
- 6) The worker then takes two identification labels, which sit near the filling area, and carries the filled box to the workbench. The box is then shaken, to move all the caps to the bottom of the box, and one identification label is placed in the box and the other is stuck to the side of the box, using the glue which sits on the workbench.
- 7) The box is then sealed using the sealing tape.
- 8) Once the box is sealed the worker carries it to the pallet and places it there.
- 9) The worker then continues to make empty boxes, as before.
- 10) Once the pallet is filled, a forklift arrives, removes the pallet and transports it to the storage area.

The location of the work benches, pallets and empty box storage areas are shown in Appendix B, Drawing B.2. In the ROPP production lines one worker is normally responsible for two or three production lines. The above mentioned materials handling procedure still applies except that the worker must monitor more filling stations at once.

4.3.1 The Carton Boxes.

There are two types of carton boxes used at BevCap. Their dimensions are shown in Appendix B, Table B.2 and tabulated in Table 4.3.1a.

Table 4.3.1a : Carton Box Dimensions

	<i>Carton Box Type REF 86</i>	<i>Carton Box Type REF 88</i>
<i>Width</i>	324 mm	327 mm
<i>Length</i>	499 mm	503 mm
<i>Height</i>	465 mm	338 mm

The REF 88 carton box is only used for the white caps (WC) production lines and is assembled by tape only. A plastic bag is placed inside and is used to hold the caps inside the box as well as protect the product from dust and dirt. The REF 86 carton box is only used for the ROPP production lines and is assembled by using staples only. It also contains a plastic bag which is placed inside before filling.

The range and mean times, for the above mentioned carton boxes, to be manually assembled is calculated in Appendix B.3, and tabulated in Table 4.3.1b.

Table 4.3.1b : Carton Box assembly times.

Carton Box Type	Range	Mean
<i>REF 88</i>	27 to 80 Seconds	47 Seconds
<i>REF 86</i>	36 to 111 Seconds	58 Seconds

4.3.2 Filling Procedure.

At present, there are two different methods of filling the empty carton boxes.

4.3.2a Two-Way Filling Method.

This method is used only on the ROPP production lines. The method requires that two boxes are always placed at the filling area at one time. The two boxes sit side by side, perpendicular to the conveyor where the final product is being transported. At the end of the conveyor, is a small flap which directs the flow of caps to either box. Therefore, once the first box has been filled, the flap switches over to its secondary position which changes the flow of caps to the second box. The worker must then replace the first box with another empty box, before the second box is filled and the flow of caps is directed towards the position of the first box. The flap changes position once the electronic counter on the conveyor belt has reached a pre-set total number of caps for that specific product, see Appendix B, Table B.1. This method will be discussed in more detail in Chapter 5, Section 5.2.1a.

4.3.2b Caption Box Filling Method.

This method is only used in the White Cap (WC) production lines. The method makes use of a caption box which is used to store the flow of caps, while the worker is replacing the filled box with a new empty box. The caption box is a small metal box, which has a small trapdoor located at the bottom. The trapdoor is controlled by a piston. The caption box lies above the empty box which is to be filled. Therefore, when a box is in position to be filled, the trapdoor opens and the caps flow from the caption box into the empty box. Once the box has been filled the trapdoor closes and the continuous flow of the caps are stored in the caption box. The caption box is large enough to give the worker ample time

to replace the filled box with an empty box. This filling method will also be discussed in greater detail in Chapter 5, Section 5.1.2b.

4.3.3 The Sealing and Labelling Method.

Once a box has been filled, the worker removes the box from the filling area and moves it to the workbench. The box is then shaken by the worker, to move the caps to the bottom corners of the box. A label is then placed, loosely, inside the box, while a second label is glued onto the side of the box. The box is then sealed by using tape. The labels used are shown in Appendix B, Figure B.5. The information on the label contains the customer's name, the product type, the order number, manufacture date and carton quantity. This is sufficient information for the product to be correctly identified at the storage area.

The range and mean times, for the above mentioned carton boxes to be labelled and sealed, is calculated in Appendix B, and tabulated below in Table 4.2.3.

Table 4.2.3 : Carton Box sealing and labelling times.

<i>Range</i>	28 to 87 Seconds
<i>Mean</i>	54 Seconds

4.3.4 Transporting the Finished Goods to the Storage Area.

The finished goods, once sealed and labelled, are placed on pallets. One pallet holds up to 42 filled boxes. Once a pallet has been filled, a forklift is used to remove the pallet and transport it to the specified storage area. A new pallet is then placed in the same position as the old pallet and the process continues.

The positions of the pallets as well as the route the forklifts use is shown in Appendix B, drawing B.1 & B.2. The storage area for the filled pallets is located in the neighbouring factory, BevCan. This, however, will be changed, and the new storage area for BevCap products will be located in the position shown in Appendix B, Drawing B.1.

4.4 Problems with the Present Material Handling System.

The various problems associated with the present materials handling system are listed below.

- 1) There is a large amount of wasted factory floor space. For each production line or set of production lines there is a workbench, empty box-storage area and pallet area. This causes a large amount of factory floor space being taken up by these objects, as seen in Appendix B, drawing B.2.
- 2) The filling process is semi-automated. The caption box and two-way filling methods function automatically; however, once the box is filled it requires a worker to replace the filled box with an empty box in a specified time. If the worker does not notice that the box is full, the caps produced will spill onto the factory floor. This will then increase the waste products and decrease the productivity of the production line.
- 3) The worker is also required to carry empty and filled boxes to and from the filling area and workbench at constant time intervals. This can be detrimental to the workers health and cause physical discomfort and possible injury.
- 4) The means of identifying the boxes at the storage area, is also a major problem. A large degree of human error is involved when placing the correct sticker to the correct box. For example, in ROPP production line numbers 6,7 and 8 one worker is used to seal

box. For example, in ROPP production line numbers 6,7 and 8 one worker is used to seal and label all the boxes once filled (Appendix B, drawing B.2). The worker might seal a box from ROPP production line 8, and accidentally place the wrong label to that box. The final result is that the customer receives a box containing the wrong product type.

5) The forklifts which transport the pallets to the storage area sometimes do not deliver the pallets to the correct sections in the storage area. For example, a forklift driver might take a pallet from ROPP production line 7, thinking that it is the pallet from ROPP production line 8, and transport it to the storage area for the pallets of ROPP production line 8. When the storage worker tries to find the pallet for the customer, it cannot be located because it has been incorrectly stored.

5. Conceptual Design of the Proposed System.

The present model, described in Chapter 4, is subdivided into five different design problems, which are listed below.

- 1) Assembly and transportation of the empty boxes to the filling points on the assembly lines.
- 2) Filling and labelling the boxes in an automatic way, without the need of worker interference.
- 3) Moving the already filled boxes to the storage area.
- 4) Sealing the filled boxes.
- 5) Identifying and sorting the filled boxes, automatically, into their pre-determined storage areas.

These five material handling procedures are to be automated using mechanical handling. The various ideas which were considered for the design of the improved materials handling system are discussed in detail. The various advantages and disadvantages of each of these systems are considered and the final concept is shown.

5.1 Assembly and Transportation of the Empty Carton Boxes to the Filling Stations.

The various solutions to the problem of assembling and transporting empty carton boxes to the filling stations are presented.

5.1.1 Assembly of the Empty Carton Boxes.

There are two options which can be considered when assembling the empty carton boxes.

5.1.1a Manual Assembly

At present, the empty carton boxes are being assembled manually, as discussed in Section 4.3.1. If the manual system of assembling boxes is to be used in the improved materials handling procedure, it must be standardised and organised correctly. To do this the following steps are recommended.

- 1) One common method of assembly should be used, either the boxes must be taped or stapled together.
- 2) If possible only one size carton box should be used.
- 3) The empty box assembly process must be done in one specified area of the factory and not in various areas across the factory.
- 4) The workers conducting the assembly must be responsible only for that job and must have no other responsibility.
- 5) The work areas or workbenches, at which the assembly is done, must be organised in such a way that the assembling procedure is physically easier for the workers to perform. This is known as ergonomic design of work areas. This will in turn decrease the time taken for a box to be assembled.

The advantages of manually assembling the empty boxes is that it is presently being done and the equipment and skilled workers are available. Also, the number of workers which are assembling the empty boxes is sufficient, at present, to cope with the speed of production. The disadvantages, however, are the month cost of labour and the speed at which the carton boxes are assembled. The average monthly earnings for a single permanent staff packer is R 2751.71 (Appendix B, Table B.6).

5.1.1b Automatic Assembly.

The use of machinery to assemble boxes can be considered. There are two types of automatic carton erection machines available. The first, a *vacuum-rail carton erector* uses compressed air and inclined rails to assemble the carton boxes. The second, a *positive displacement carton erector* uses worm screws to assemble the carton boxes (Ref. 36).

The advantages of automatic carton box assembly machines is that the machines can perform the job much faster and cheaper than the workers. The disadvantages are the initial high purchase costs as well as the regular maintenance which will be needed.

5.1.2 Transporting the Empty Carton Boxes to the Filling Stations.

The various methods of transporting the assembled empty carton boxes to the filling stations are examined.

5.1.2a Ground Conveyor System.

A ground conveyor can transport the empty carton boxes to the filling stations. An example of this method is illustrated in Figure 5.1.2a. The conveyor is a flat belt conveyor and is driven by a standard motor-gearbox set-up.

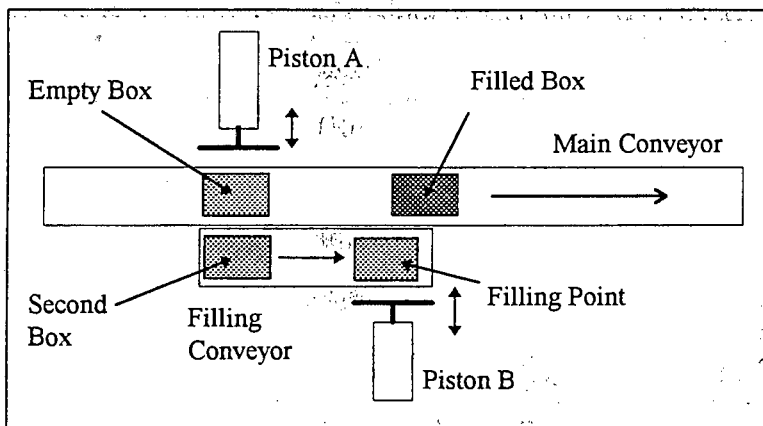


Figure 5.1.2a : Transporting empty boxes using a ground conveyor (Top View).

Referring to Figure 5.1.2a, it would be logical to use the same conveyor to transport the filled boxes to the storage area. In this way two transport problems are solved using one conveyor belt. If not, a separate ground conveyor would have to be constructed to transport the filled boxes to the storage area.

A filling conveyor (Figure 5.1.2a) will be used to move the empty boxes into the correct position to be filled. The filling conveyor will be long enough to ensure that two empty boxes can be situated on the filling conveyor at one time. Therefore, as soon as the first box is filled and is pushed onto the main conveyor by piston B (Figure 5.1.2a), the filling conveyor will move the second box into position to be filled. A new empty box would then be placed onto the main conveyor to fill the second empty

box's old position on the filling conveyor. Therefore, empty boxes are only placed on the main conveyor when needed. An empty box can only be put on the conveyor when needed, because the main conveyor's path does not run in a continuous loop. So, for example, if empty boxes were placed on the main conveyor randomly, most of them would end up with some of the filled boxes at the end of the main conveyor. A further disadvantage, is that the empty boxes would have to be put on the main conveyor at a specific time, so, the factory computer can calculate how long it would take to reach the correct filling station, in order for piston A (Figure 5.1.2a) to be activated at the correct time. If piston A is not activated in time no box will be placed on the filling conveyor or, even worse, an already filled box might be placed on the filling conveyor instead. Once the empty boxes have been placed on the main conveyor it cannot be removed or moved while moving on the main conveyor, because the computer will then not be able to predict the position of the empty box.

Also, when pushing a filled box onto the main conveyor, using piston B (Figure 5.1.2a), the control system must ensure that nothing is in front of the filled box before piston B is activated. If this is not done, the filled box might push an empty box destined for a production line further down the system. Therefore, the empty box which was pushed will not arrive at its designated filling station.

5.1.2.b Overhead Conveyor Belt System.

The overhead conveyor belt system uses a flat belt conveyor, which is constructed off the ground, to transport the empty boxes to the filling stations. This ensures that the overhead conveyor will only be used to transport the empty boxes and not the filled boxes, as in the case of the ground conveyor (Section 5.1.2a). A second conveyor, which lies below the overhead conveyor will be used to transport the filled boxes to the storage area. In this way, factory floor space is saved, as illustrated in Figure 5.1.2b.

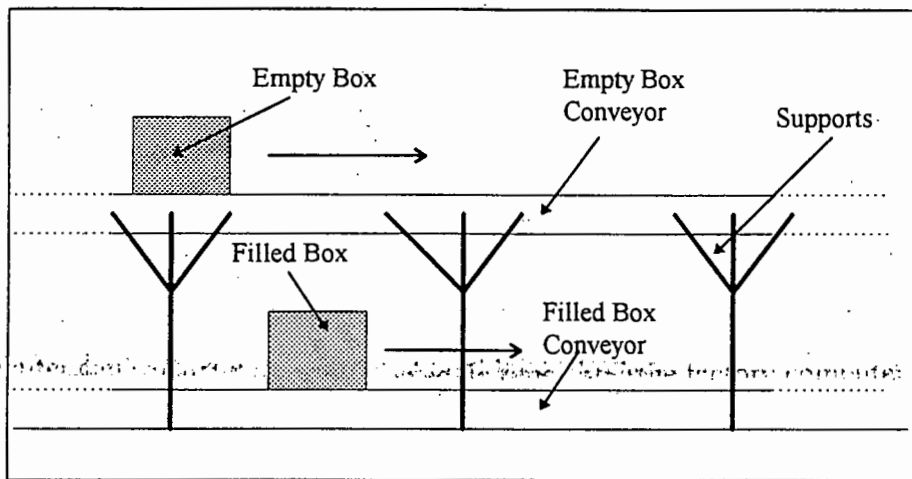


Figure 5.1.2b : Transporting empty boxes using a double conveyor system (Side View).

The conveyor moving the empty boxes moves in a continuous circular path and will be situated above the filled box conveyor (Figure 5.1.2b). In this way, the empty boxes can be randomly placed on the empty box conveyor without effecting the system.

Thus, when a box is required, the filling station can receive the next available box on the empty box conveyor. Therefore, the filling station does not have to wait for the box to be placed on the conveyor, and move the variable distance to the filling station, as is the case in the previous section (Section 5.1.2a). To retrieve a box from the top conveyor, the following system is used, and illustrated in Figure 5.1.2c.

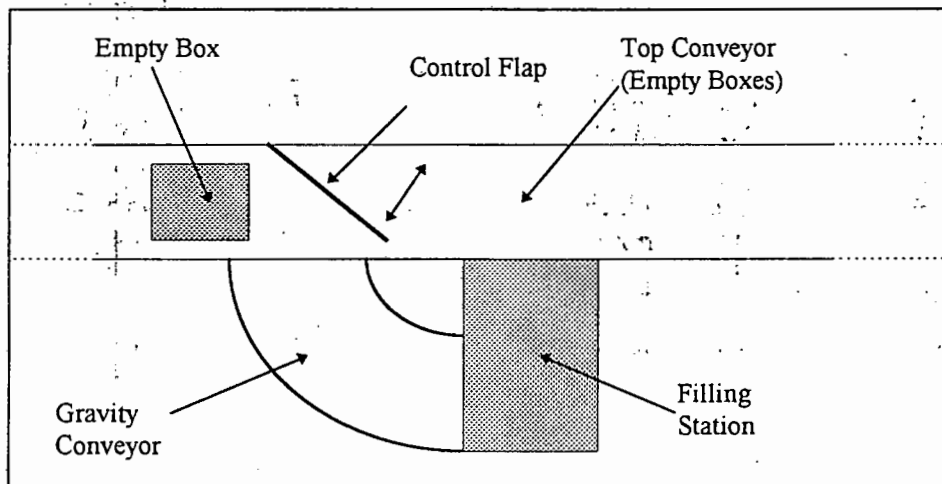


Figure 5.1.2c : Retrieving empty boxes from the top conveyor (Top View).

The flap controls the retrieval procedure and when the filling station needs a new empty box, the flap is opened and the next available box on the empty box conveyor is retrieved. The box then slides down the gravity conveyor to the filling station. The

retrieval time is short and the empty boxes can be placed randomly on the top conveyor. Also, no complicated sensory or computer coding is required.

A major disadvantage is, that the system will be bulky and might get in the way of the maintenance teams when repairs are needed to be performed.

5.1.2c Overhead Chain Conveyor System.

Overhead chain conveyors are used when a continuous flow of articles has to be transported between a number of points (Ref. 33). A major advantage is that overhead chain conveyors use little or no floor space. This system is used very successfully in bicycle manufacturing companies, as well as butcheries and automotive companies (Ref. 14).

The system uses an 'I' shaped cross-sectional beam to support and transport various 'carts' around a pre-determined path. A chain is used to drive the system and is connected to two rollers which in turn are connected freely to the 'I' beam, as shown in Figure 5.1.2d.

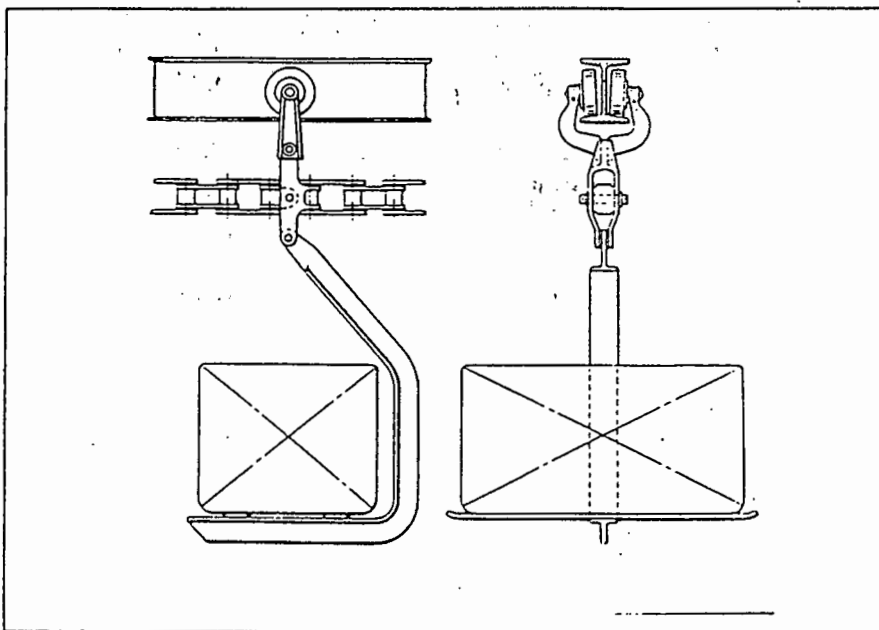


Figure 5.1.2d : Overhead conveyor railing and drive chain.

Each roller is used to support a small cart and each cart is suitable for carrying a single empty carton box. The overhead conveyor would have a continuous circular path which passes over every production line on the factory floor. The system will not interfere with any procedure on the floor, because the system would be suspended from the ceiling. When a box is required, a piston is activated, which knocks a pin in the path of the moving carts, as illustrated in Figure 5.1.2e.

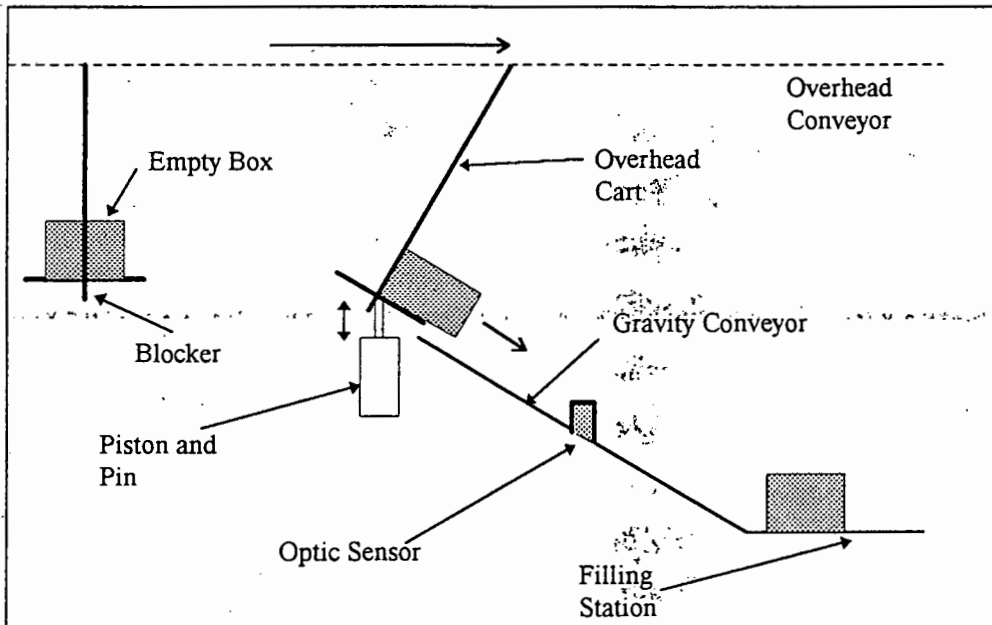


Figure 5.1.2e : The overhead conveyor cart system (Side View).

When the next cart comes around, the pin will cause the cart to tilt whereby sliding the empty box down a gravity conveyor or chute to be filled by the production line (Figure 5.1.2e). A gravity conveyor is used to hold as many boxes as required, all waiting to be filled by the production line. This type of magazine loading (Ref. 34) will be advantageous, because a new box is placed in the filling area as soon as the filled box is sent on its way.

An optic sensor is used to trigger the pistons. If the optic sensor is off, i.e. no box in front of the optic sensor, the piston will be activated. The opposite will occur if the optic sensor is turned on, i.e. a box is in front of the light sensor.

To load the continuously moving carts with newly assembled empty boxes the following procedure is used (Ref. 33), as illustrated in Figure 5.1.2f.

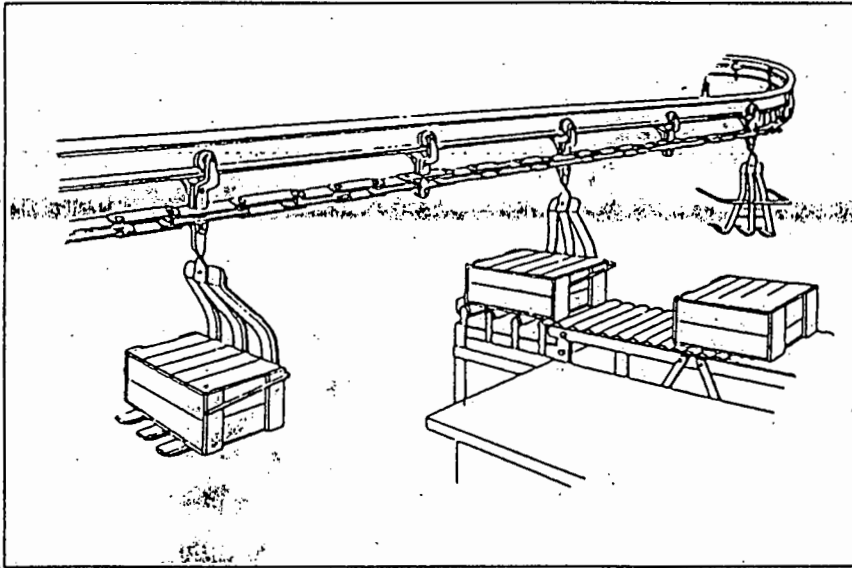


Figure 5.1.2f : Overhead conveyor loading method.

Figure 5.1.2f demonstrates a simple and easy method of loading the empty boxes onto the overhead conveyor. The empty boxes can be loaded automatically, using a piston to place the empty box into position, or manually using a worker to push the empty box into position. The only disadvantage is that the worker must make sure that an empty box is not already on the cart when trying to load the cart. If the worker tries to load a full cart with another empty box, the second empty box will be pushed off the load area, as illustrated in Figure 5.1.2g.

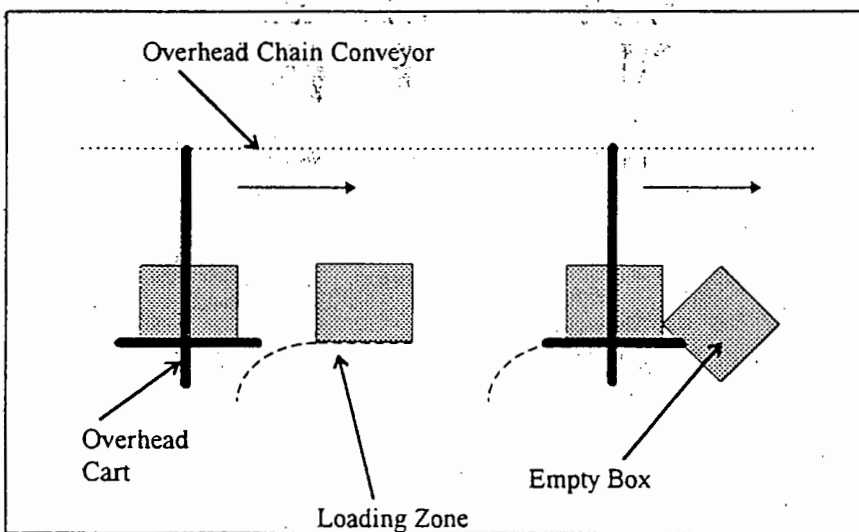


Figure 5.1.2g : Double loading the overhead carts (Side View).

5.2 Filling Stations.

Referring to the present materials handling system at the end of each production line (Chapter 4, Section 4.3), it can be seen that the filling procedure is inefficient and contains many sources of possible error. The following systems which need to be designed are listed below, and addressed in this section.

- 1) Methods of filling the boxes automatically.
- 2) Transporting the empty boxes into position to be filled.
- 3) Transporting the filled boxes out of the filling area.
- 4) Labelling or marking the boxes for identification later in the process.

5.2.1 Filling method

There are two methods used at BevCap to count and place caps into the boxes.

5.2.1a *Two-Way Filling Station (ROPP Production Lines).*

This type of filling station requires that two boxes are always at the filling area at any one time. Each box sits adjacent to the other, perpendicular to the conveyor supplying the finished caps, as illustrated in Figure 5.2.1a.

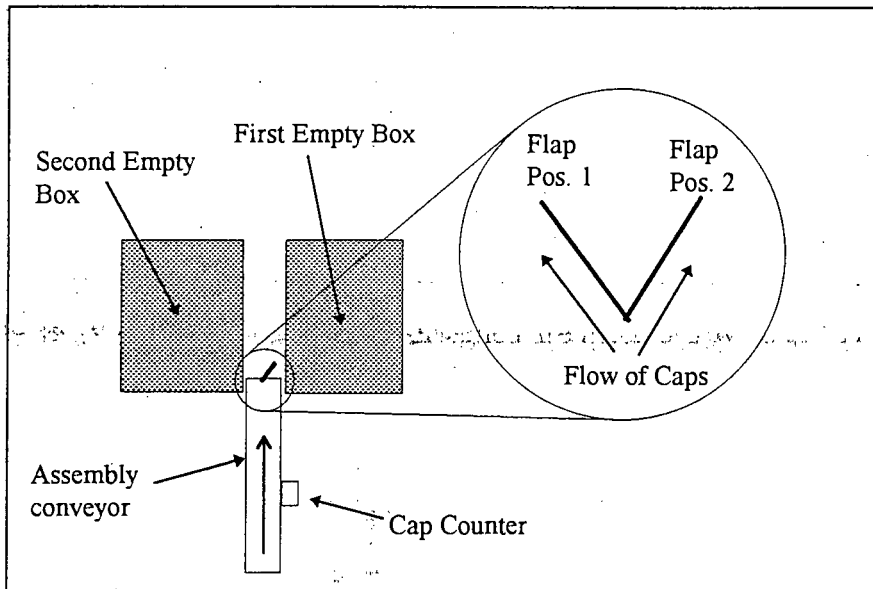


Figure 5.2.1a : The two-way filling system (Top View).

As soon as the first box is filled a solenoid is triggered and the flap (Figure 5.2.1a) tilts from right to left. This then forces the continued supply of caps to land in the second box.

When trying to automate this system, it is noted that two separate empty box supply lines or gravity conveyors (Section 5.1.2c) will be needed, one for each box position. A single gravity conveyor cannot be used. Therefore, using a two-way filling station, requires two separate gravity conveyors, to feed the empty boxes into place. This is illustrated in figure 5.2.1b.

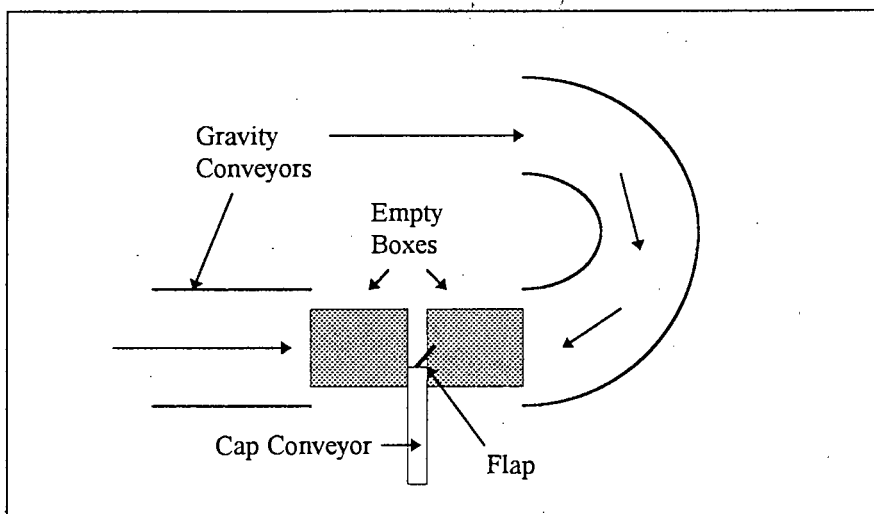


Figure 5.2.1b : Supply of empty boxes to the two way filling system (Top View).

Referring to Figure 5.2.1b, it can be seen that using two separate gravity conveyors will ensure that both filling areas will be supplied with empty boxes. However, using two gravity conveyors decreases the amount of valuable floor space in the factory.

5.2.1b Caption Box Filling Station (WC Production Lines).

The Caption box filling station only requires one box to be at the filling area at one time. This method uses a type of caption box to hold the continuously flowing caps while the operator is moving an empty box into position, as discussed in Section 4.3.2b. The caption box is a small metal box which has a trapdoor situated at the bottom of the box, as illustrated in Figure 5.2.1c.

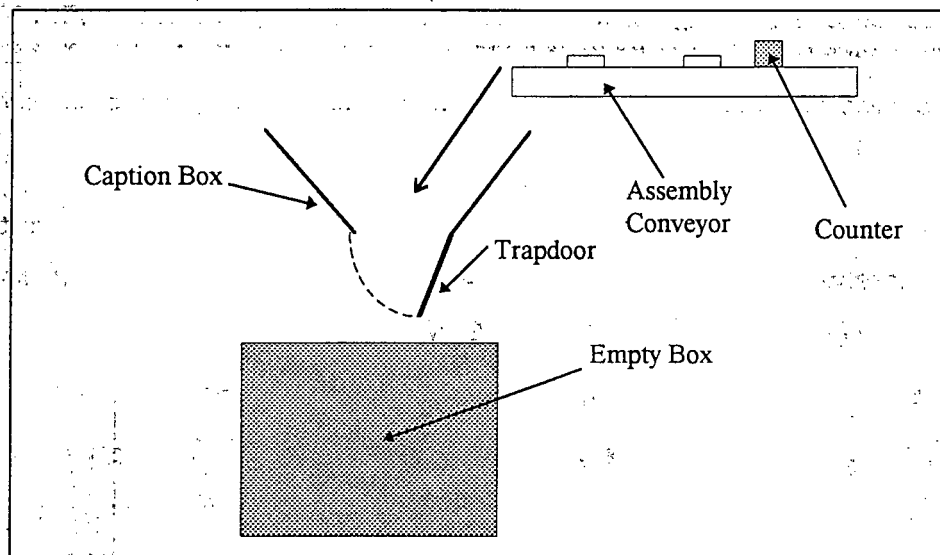


Figure 5.2.1c : The caption box filling system (Side View).

The trapdoor is controlled by a small piston. When a box is in place to be filled, the trapdoor is opened (Figure 5.2.1c) and the flow of caps falls through the caption box and into the carton box, which sits directly below the caption box. As soon as the counter has reached the specified number of caps for that box, the trapdoor (Figure 5.2.1c) closes and the continuous flow of caps are caught in the caption box area. The volume of the caption box is sufficient to give the operator enough time to remove the filled box out of the filling area and place a new empty box in its place. Once the new box is in place, the trapdoor opens (Figure 5.2.1c) and all the caps in the caption box

are placed into the new box, as well as those which are flowing in from the production line.

The advantage of this method is that there is a window of time for the old box to be moved out and the new box to come into the filling point. Therefore, only one gravity conveyor is required to feed empty boxes to the filling station, as opposed to the two gravity conveyors needed in the two-way filling system.

5.2.2 Transporting the Carton Boxes in the Filling Area.

Once the carton boxes have been filled, a device is required to move the filled carton box out of the filling area and move another empty carton box into the filling area.

5.2.2a Ground Conveyor.

A ground conveyor can be used to transport the empty boxes to the filling point as well as transporting the filled boxes out of the filling point. The filling conveyor would run from the end of the gravity conveyor to the point of filling, as illustrated in Figure 5.2.2a.

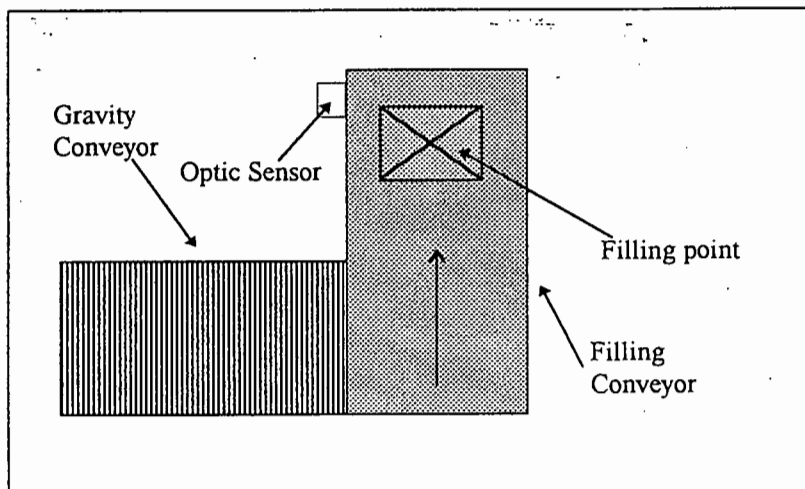


Figure 5.2.2a : Filling conveyor set-up (Top View).

The gravity conveyor (Figure 5.2.2a) is used to transport the empty boxes from the overhead chain conveyor system, discussed in section 5.1.2, to the filling area. The gravity conveyor is positioned at an incline.

The filling conveyor (Figure 5.2.2a) is controlled by the optic sensor. When a box is required to be filled, the filling conveyor will run, transporting an empty box from the gravity conveyor to the filling point. The filling conveyor will only stop once the optic sensor is activated, in other words a box has entered in front of the sensor. Once the box is filled the filling conveyor is switched on until the filled box has moved out of position and the next empty box has moved into position to be filled.

5.2.2b Piston System.

A piston system can move the empty boxes into position to be filled and move the filled boxes away from the filling point once filled. The piston system is illustrated in Figure 5.2.2b.

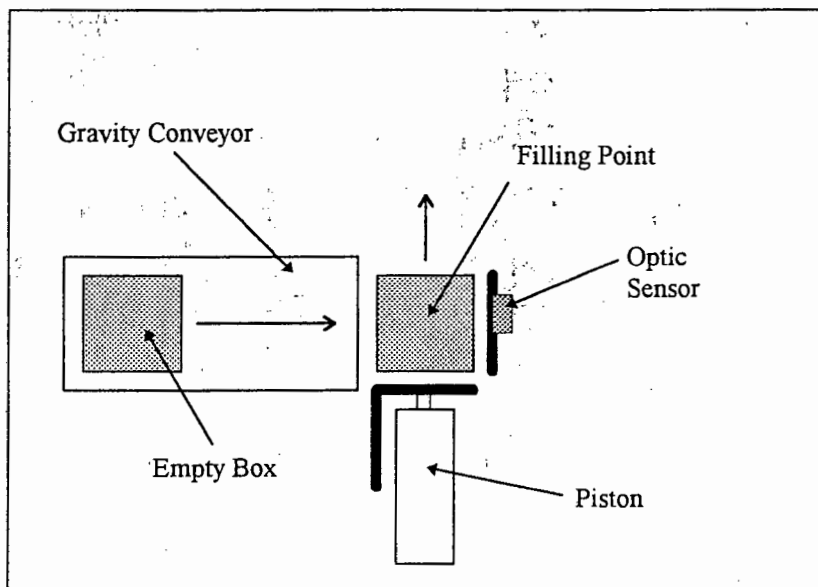


Figure 5.2.2b : Piston filling area system (Top View).

The boxes will slide down the gravity conveyor and straight into position to be filled. Once filled the piston will be activated and the filled carton box will be moved out of the filling point. When the piston returns, a new empty box will be able to slide down

the gravity conveyor and into position. The optic sensor is used to ensure that the box is correctly in position before filling.

The disadvantages of using the piston system is that there is little or no space to place the other systems which need to be near the carton box, such as the bar code printer and box shaker. The box shaker needs to grip the carton box from two opposite sides and shake the box over specified time intervals. This cannot be physically done using the piston system.

5.2.3 Labelling Method.

Bar codes are a universal way of identifying products (Ref. 28) There are two types of bar code labelling systems which are considered.

5.2.3a Pre-printed Bar Code Stickers.

A sticker dispenser device can be used to place stickers on the carton boxes. The sticker dispenser will be situated at each filling point. A pre-printed bar code will appear on each of the stickers, and, will represent each of the individual production lines. Therefore, when a box arrives at the storage area and the bar code is read, the computer will only be able to identify the production line from which the contents of the box was manufactured. The computer can then refer to its data bank and discover the product being produced on that specific production line at that time. Once this information has been gathered the box can be sorted into its correct storage area, according to its contents and customer details.

The disadvantage is, that if the box has to be identified some time later, the only information received from the bar code, will be the production line number the box came from, and not its content and customer name.

5.2.3b Bar Code Printers.

A bar code printer will also be placed at each filling station. The difference between the bar code printer and the pre-printed stickers is that the printer will be able to print the customer's name, product number and an individual bar code on the carton box.

Therefore, unlike the pre-printed bar codes, the printed bar code can store more information and make the sorting procedure much easier.

5.2.4 Carton Box Shakers.

The carton box shakers are presently being used at BevCap, but only on the white cap production line (WC 1-3). The shakers agitate the boxes periodically, while being filled. This ensures that the caps are spread to the bottom of the box and do not pile up at one spot and cause the box to overflow. The ROPP production (ROPP 1-8) lines do not have shakers at the filling stations, because the caps produced are smaller and lighter than the white caps and do not cause the same problems. However, the ROPP line boxes are being shaken by the workers before sealing.

Therefore, shakers will be situated at the end of each production line to make sure the caps are spread out over the box and are ready for sealing.

5.3 Moving the Filled Boxes to the Storage Area.

In the present materials handling system at BevCap, forklifts are used to move the pallets of filled boxes from the filling stations to the storage area. This method has been causing problems as discussed in Chapter 4, Section 4.4. The only simple way to move the filled boxes to the storage area is to use a flat belt conveyor system. Flat belt conveyor systems are very economical power installations for handling correct and intermittent flow of materials for long and short distances (Ref. 14).

The flat belt conveyor will run continuously and will transport the filled boxes from all the filling areas on the factory to the storage area. The continuously running flat belt conveyors will form the “main artery” of the factory. All finished goods will be placed on the flat belt conveyor and sent directly to the storage area to be sorted and packed.

5.4 Sealing the Filled Boxes.

The filled boxes must be sealed before entering the sorting and storage procedures. There are two possible methods to do this.

5.4.1 Manual Carton Sealing.

The manual procedure is used at present. Once a box has been filled the plastic bag holding the caps is folded close and the carton box is sealed using a strip of tape. The manual method of sealing carton boxes is disorganised and must be standardised. To accomplish this the following steps must be taken,

- 1) The workbenches must be designed to make the job of sealing the boxes easier for the workers.
- 2) The workers sealing the boxes will only be responsible for that activity and nothing else.
- 3) All the boxes will be sealed at one specified area of the factory.
- 4) The boxes will be manually removed off the main conveyor and sealed before being returned onto the main conveyor, which will transport the boxes to the storage area..

The advantages of using manual workers to seal the carton boxes, is that the system is already in place and unskilled workers are required. The disadvantages, however, are the speeds at which the workers seal the boxes, as well as the monthly cost of labour.

The average monthly earnings for a single permanent worker is R 2751.71 (Appendix B, Table B.6).

5.4.2 Automatic Carton Sealing.

There are machines which can be used to perform this task. The machines grip the filled boxes from the sides and force the top flaps of the box down, by using guide rails. A strip of tape is then placed on top of the carton box to ensure that the box has been correctly sealed (Ref. 36).

5.5 Sorting and Storage of the Filled Boxes.

The sealed carton boxes, from all 12 production lines, will be fed via a flat belt conveyor to a specified storage area. The boxes will have individual bar codes which will be used for identification purposes. The boxes must be sorted into their individual pre-determined storage areas.

The sorting system will be used to identify the boxes coming down the conveyor line and place them in the correct storage areas. The concept for solving this design problem is illustrated in Figure 5.5.

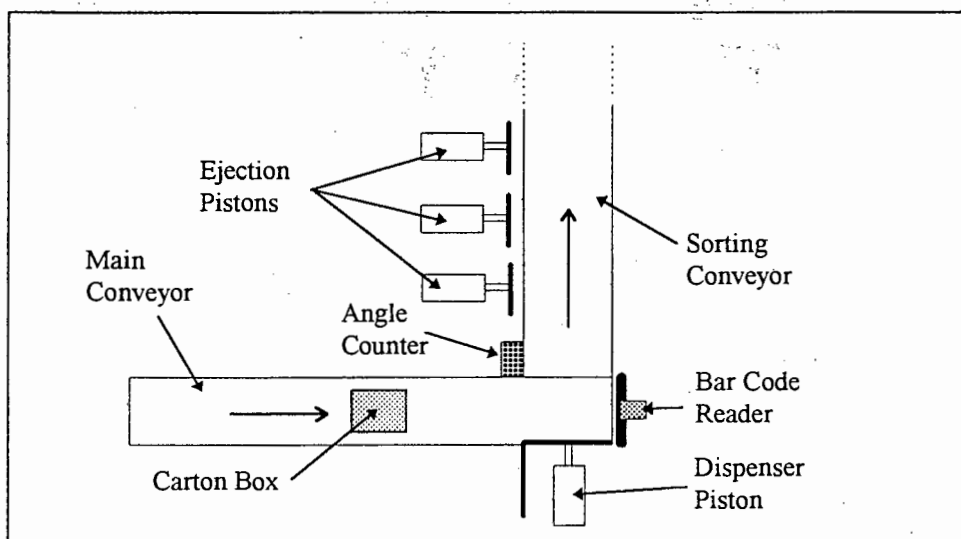


Figure 5.5 : Filled box sorting system (Top View).

Referring to Figure 5.5, the already sealed box is transported on the main conveyor and is forced to stop in front of the bar code reader. The bar code of each box is read and the box's customer name and product type is identified. The computer then refers to its data bank and finds out in which storage area the box must be kept. The computer then assigns an *angle count number* and *ejection piston number* to the box and pushes the box onto the sorting conveyor by using the dispenser piston. The *angle count number* assigned to a specific box is the actual angle counter reading when the box is in position to be ejected. The angle counter is placed on the drive shaft of the sorting conveyor and is used to measure the distance the conveyor has moved. The *ejection piston number* associated with a specific box is the piston number which must be activated when the box is in position to be ejected. Therefore, once the angle counter is equal to the *angle count number* assigned to a box, the specified piston associated with the box is activated and pushes the box into the correct storage area. The box is then placed on a pallet. Once the pallet is filled, a forklift will place it in the storage racks.

The only disadvantage, is that once the box is positioned on the sorting conveyor, it cannot be moved. If a box is moved while travelling down the sorting conveyor, The computer will not activate the ejection piston at the right time and the box will not be placed in the correct storage area.

5.6 Final Design Concept.

All the previously mentioned ideas and concepts for the improved materials handling system are weighed up against one another and a final decision is made, as shown in Table 5.6.

(Y = Accept Design)

Table 5.6 : Decision Chart

(N = Reject Design)

CONCEPT	ADVANTAGE	DISADVANTAGE	Y/N
<i>Assembly of the Empty Carton Boxes</i>			
Manual	System is already in use and requires unskilled labour.	The average monthly cost of a permanent workers is high (R 2751.71).	YES Present
Automatic	Much faster than workers. The running costs are much less.	Machines have a higher initial cost. Regular maintenance will have to be performed.	YES Future
<i>Transporting the Empty Carton Boxes to the Filling Area</i>			
Ground Conveyor	A single conveyor is used to transport the empty and filled boxes.	A large amount of sensors and computer equipment will be needed. The empty boxes are only placed on the conveyor when required at a filling station.	NO
Overhead Conveyor Belt	Empty boxes are continuously transported around the factory floor. Box can be obtained sooner.	Bulky. Waste of floor space.	NO

Table 5.6 : Decision Chart (Continued)

Overhead Chain Conveyor	Empty boxes are continuously transported around the factory. No floor space is wasted. Boxes can be collected from the conveyor quickly	The ceiling framework might have to be reinforced	YES
Filling Method			
Two-Way Method	Already in place on all 8 ROPP production lines.	Needs two separate empty box feeding chutes. Waste of floor space.	NO
Caption Box Method	Needs only one empty box feeding chutes. Saves floor space.	There is a time limit before the next empty box must be in place to be filled.	YES
Transporting Boxes at the Filling Station			
Ground Conveyor	Economical and easy	Takes up more floor space than the piston system.	YES
Piston System	Economical and easy	Not enough space to place the other mechanical devices which must be in the filling station (<i>Printer and shaker</i>)	NO
Labelling Method			
Pre-printed Bar Codes	Cheaper	Not enough individual information on the bar code, such as customers name etc.	NO

Table 5.6 : Decision Chart (Continued)

Bar Code Printers	More information can be placed on the bar code. The printer can also print different bar codes when different customers use the same production line	More expensive	YES
<i>Transporting the Filled Boxes to a Storage Area</i>			
Ground Conveyor	Economical and easy.	None	YES
<i>Sealing the Filled Boxes</i>			
Manual Method	System is already in use and it requires unskilled labour.	The average monthly cost for a permanent worker is high. (R 2751.71)	YES Present
Automatic Method	Much faster and cheaper to operate.	High initial cost. Maintenance will be needed. Breakdowns are possible.	YES Future
<i>Sorting the Filled Boxes into Pre-Determined Storage Areas.</i>			
Piston Sorting System	Easy and cheap. Requires no sensory, except a bar code reader.	If a box is moved by a worker when being sorted, it will not arrive at its correct destination	YES

6. Modelling the Proposed Design.

The model of the improved materials handling procedure, designed in Chapter 5, was constructed from Lego and is controlled via a Lego computer interface. Each section of the model, will be described in detail, as well as the computer program which controls it.

6.1 The Empty Box Transport System.

The procedure of transporting the empty boxes to the filling points is described.

6.1.1 The Overhead Chain Conveyor System.

This system, of the model, uses an overhead chain conveyor, which is suspended from the factory model ceiling, to transport the empty boxes to the filling stations.

The railing which the chain is connected to, by means of rollers, has an I-beam cross section (see Chapter 5.1.2c). Lego does not have an I-beam cross sectional piece.

Therefore a simple household curtain railing system was used to model the overhead conveyor system. Forty toothed gears are used to drive and guide the conveyor chain around the factory model floor. The drive system, used to drive the overhead chain conveyor, is illustrated in Figure 6.1.1 and shown in Appendix L, Drawings 12 & 13 and Appendix J, Photograph 6.

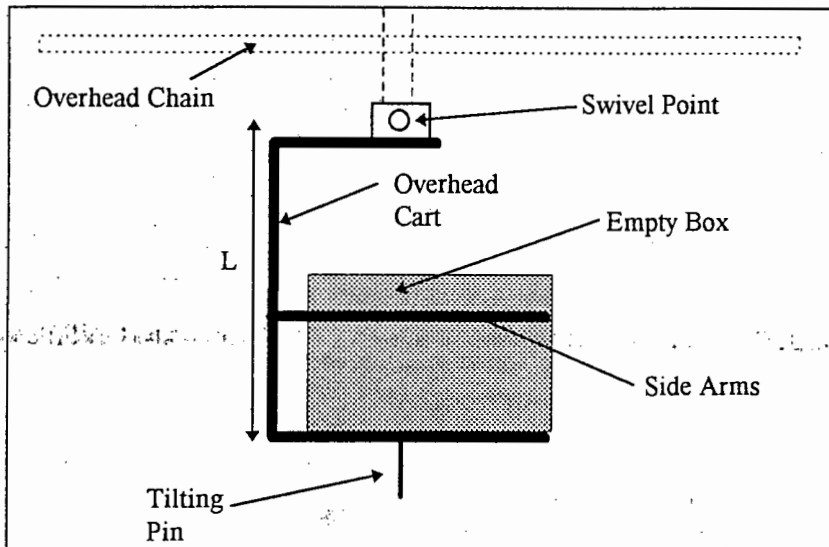


Figure 6.1.2 : Overhead cart set-up for the model

The overhead cart has the following specifications, which are calculated in Appendix F and tabulated in Table 6.1.2.

Table 6.1.2 : The overhead cart specifications for the Lego model.

Length of the Cart's Lever Arm (L).	62 mm
Length of the Tilting Pin.	12 mm
Maximum Angle of Oscillation when Conveyor is Suddenly Stopped.	0.54 Degrees
Angle of Tilt when Box is Dispensed Down the Gravity Conveyor.	33 Degrees
Time Taken to Deposit an Empty Box Down the Gravity Conveyor	2.5 Seconds

6.1.3 The Gravity Conveyor System.

The purpose of this system, is to retrieve the boxes from the overhead chain conveyor system and place them on the filling conveyor.

A piston is used to tip the overhead conveyor cart, when an empty box is required. The piston is activated by an optic sensor, which is situated near the bottom of the ramp. The optic sensor used is not a standard light sensor supplied by Lego, but a Light Dependant Resistor (LDR). The LDR changes resistance as light is placed on it. The more light there is, the lower the resistance. Therefore, with the lamp (Figure 6.1.3a) facing the LDR at all times, the resistance is always low.

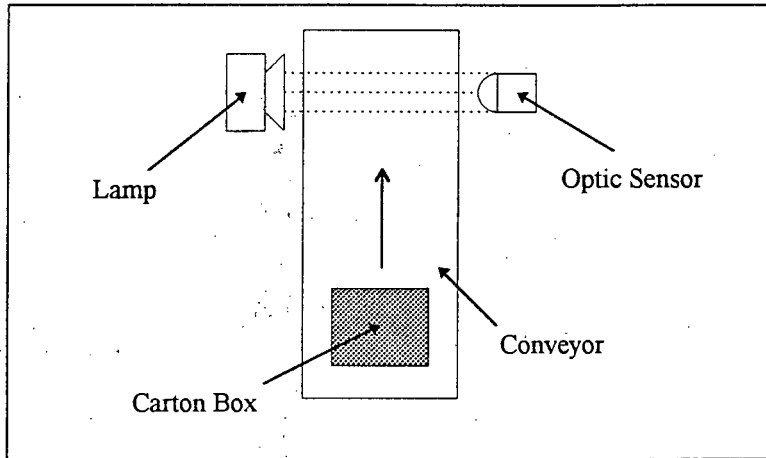


Figure 6.1.3a : Gravity conveyor optic sensor system for the model (Top View)

Except, when a box breaks the light beam between the lamp and the LDR, then the LDR's resistance will increase. This change in resistance is then manipulated, using an electronic circuit, designed in Appendix C.4 and illustrated in Figure 6.1.3b, to control the tilting piston's actions (Section 5.1.2c, Figure 5.1.2e).

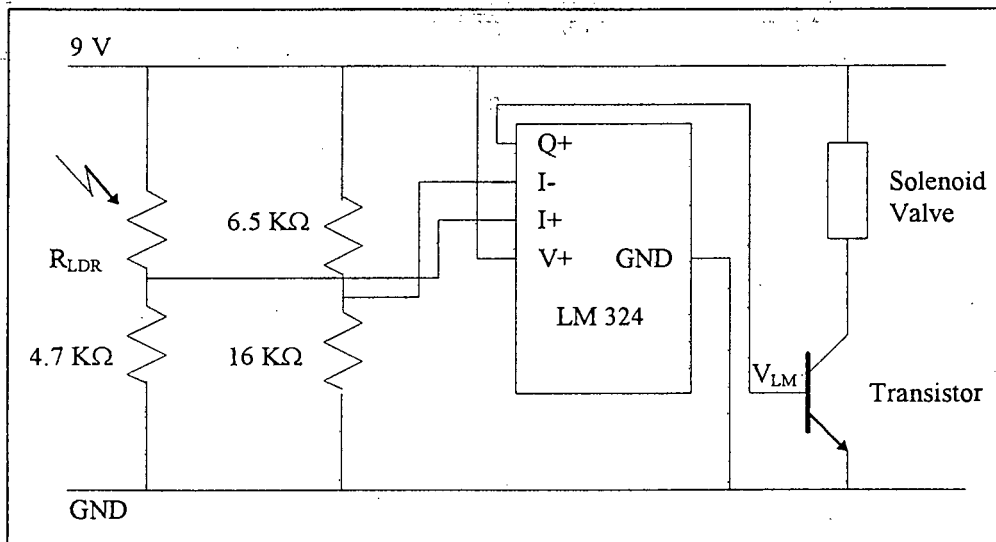


Figure 6.1.3b : Control circuit for LDR on gravity conveyor.

The piston is controlled by a 5/2 way solenoid valve, manufactured by FESTO. The solenoid valve is excellent for controlling double-action pistons, because using a 5/2 way valve the exhaust air can be collected and used again. The solenoid valve requires a 24 Volt DC power source to operate.

When the light beam is broken the piston's solenoid valve is switched off and the piston rod is forced inwards, but when the light beam is unbroken the solenoid valve is switched on and the piston rod is forced outwards. This then allows the piston rod to tilt oncoming overhead carts and collect the empty boxes.

The control system does not require input from the computer interface, but requires a +24 Volt DC supply to power the circuitry and piston solenoid valves. The power supply comes directly from the transformer in the control box. The optic sensor specifications for the gravity conveyor are calculated in Appendix C.4 and are tabulated in Table 6.1.3a

Table 6.1.3a : Gravity conveyor optic sensor specifications for the Lego model.

LDR Change in Resistance	1 K Ω to 4 K Ω
LDR Change in Voltage	13.0 Volt to 19.8 Volt
Threshold Voltage	17.1 Volt

The gravity conveyor specifications are calculated in Appendix F and tabulated below in Table 6.1.3b.

Table 6.1.3b : Gravity conveyor specifications for the Lego model.

Maximum Angle of Tilt (Before Sliding)	11.3 Degrees
Maximum Angle of Tilt (Before Toppling)	48.3 Degrees
Angle of Tilt for the Gravity Conveyor	21.6 Degrees
Length of Gravity Conveyor	100mm
Maximum Velocity of Box Down the Gravity Conveyor	2.9 m/s
Time for Box to Travel Down the Gravity Conveyor	0.25 Seconds
Number of Boxes which can be Held by Gravity Conveyor	2 Boxes

The gravity conveyor can also be seen in Appendix L, Drawing 4 and Appendix J, Photograph 4.

6.2 The Filling Stations.

The Lego model used to perform this task can be divided into four sub sections.

6.2.1 Filling Conveyor

The filling conveyor is used to move the empty boxes the short distance from the end of the gravity conveyor to the filling point, while also moving the already filled box onto the main conveyor which takes the filled boxes to the storage area. The filling conveyor only runs for short periods of time, depending on the optic sensor reading, see Section 6.2.2. A motor and gearbox set-up is used to drive the filling conveyor, as illustrated in Figure 6.2.1 and shown in Appendix L, Drawing 3 and Appendix J, Photograph 3.

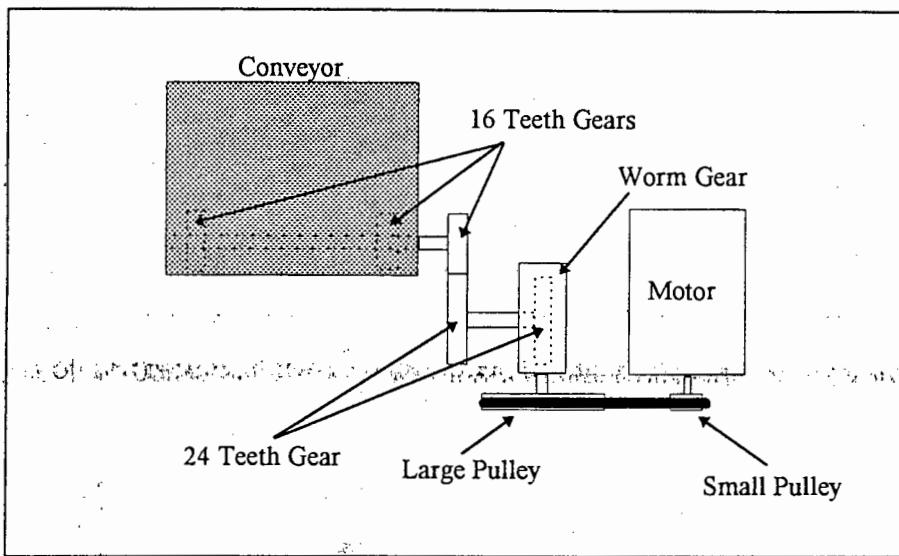


Figure 6.2.1 : The filling conveyor drive system (Top View).

The specifications, of the filling conveyor drive system, are calculated in Appendix D.4. and tabulated in Table 6.2.1.

Table 6.2.1 : Filling conveyor specification for the Lego model.

Motor Speed (RPM)	1629 RPM
Motor Torque (Normal Load)	0.98 N.mm
Drive Gear Speed	28.2 RPM
Drive Gear Torque (Normal Load)	56.4 N.mm
Drive System Gear Ratio	58 : 1
Filling Conveyor Speed	24.4 mm/s

6.2.2 Optic Sensor

The optic sensor is used to indicate to the computer via the interface whether or not a box is in position to be filled. Therefore, the filling conveyor will run until a box has interrupted the beam of light between the lamp and the optic sensor, as illustrated in Figure 6.2.2.

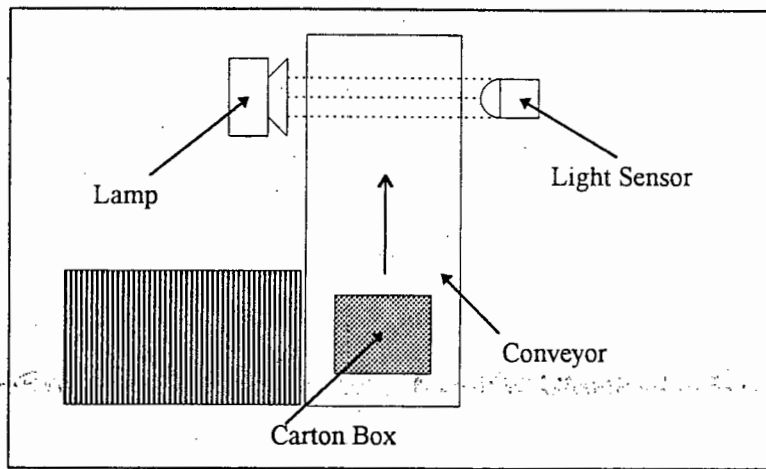


Figure 6.2.2a : Optic sensor system on filling conveyor (Top View).

A Light Dependant Resistor (LDR) is once again used as the optic sensor. As before, with the gravity conveyor (Section 6.1.3), with the lamp in place the LDR's resistance is always very low, but as soon as a box interrupts the beam of light between the LDR and the lamp, the LDR's resistance will increase. The change in resistance, which is relative to the amount of light on the LDR, is then manipulated using an electronic circuit, design in Appendix C.3. The electronic circuit is used to communicate with the computer, via the Lego interface, and indicates to the computer when a box is in position to be filled. The lamp is used to create a very large difference between the low and high resistance values, that is when a box is in the path of the light beam and when it is not. This was done because light from the surrounding area can effect the readings, but with the lamp as a permanent direct light source to the LDR, the room's surrounding light has little or no effect on the readings.

The control circuit used to interface the LDR readings with the Lego interface is shown in Figure 6.2.2b.

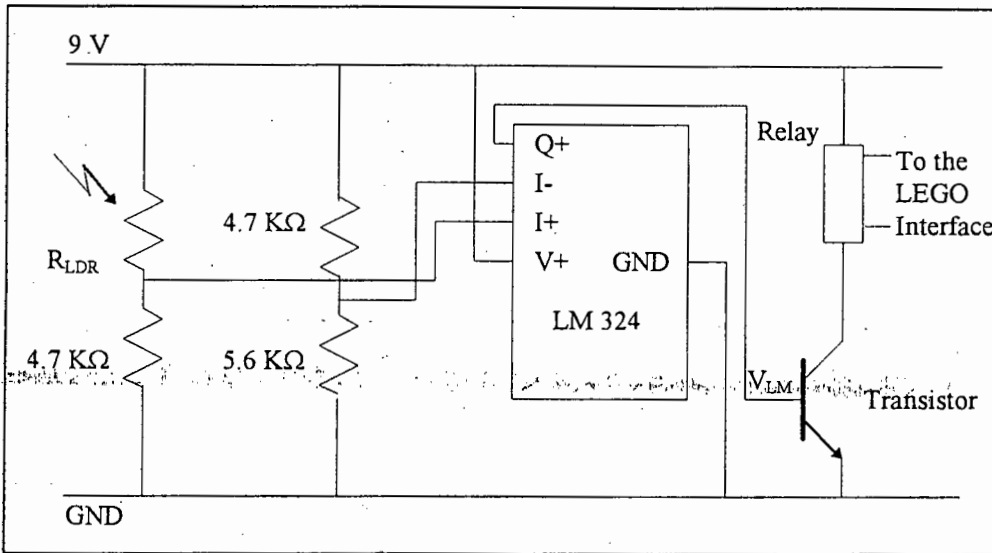


Figure 6.2.2b : The optic sensor interface circuit for the model filling conveyor.

A relay is used to communicate with the Lego interface. Once the light beam between the lamp and the LDR is broken the relay closes and the input port on the Lego interface is switched on. This is then an indication to the computer that a box is in position to be filled.

The optic sensor specification are calculated in Appendix C.3 and tabulated in Table 6.2.2.

Table 6.2.2 : Filling conveyor optic sensor specifications for the Lego model.

LDR Change in Resistance	1 KΩ to 10 KΩ
LDR Change in Voltage	7.4 Volt to 2.9 Volt
Threshold Voltage	4.9 Volt

6.2.3 The Bar Code Printer.

A sticker dispenser, built from Lego, was used to model the bar code printer. Different coloured stickers were used to represent the bar codes. Each coloured sticker would identify, to the computer, from which production line the box came.

The colours of the stickers as well as the production lines they represent are tabulated below in Table 6.2.3a.

Table 6.2.3a : Sticker Colours For Each Production Line.

Sticker Colour	Production Line
White	1
Green	2
Gold	3

The stickers are contained on a long strip of glossy paper. The paper is wound around a drum, with the stickers facing inwards towards the drum. The drum is free to rotate about its centre shaft. The strip of paper is fed around a curved metal guide, before it is attached to a second drum, as illustrated in Figure 6.2.3a.

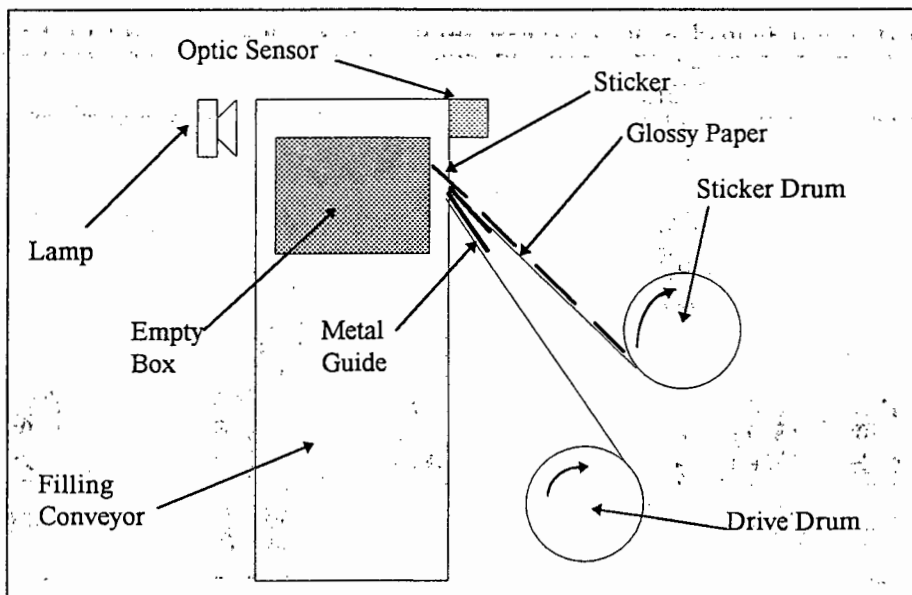


Figure 6.2.3a : The model sticker dispenser set-up (Top View).

Once a box has been filled a sticker is required to be placed on the filled box, for identification purposes. The drive drum rotates a predetermined number of revolutions and a single sticker is peeled off the glossy paper and forced onto the box, as seen in Figure 6.2.3a. To ensure that the strip of paper is always under tension when pulled around the metal guide, the sticker drum (Figure 6.2.3a) has a tensioned elastic band attached to its centre shaft and a fixed pulley. Therefore, as the sticker drum is forced to rotate, by the strip of glossy paper, the elastic band resists the rotation of the sticker drum and increases the tension in the glossy paper.

The drive system of the printer used to drive the drum, is illustrated in Figure 6.2.3b.

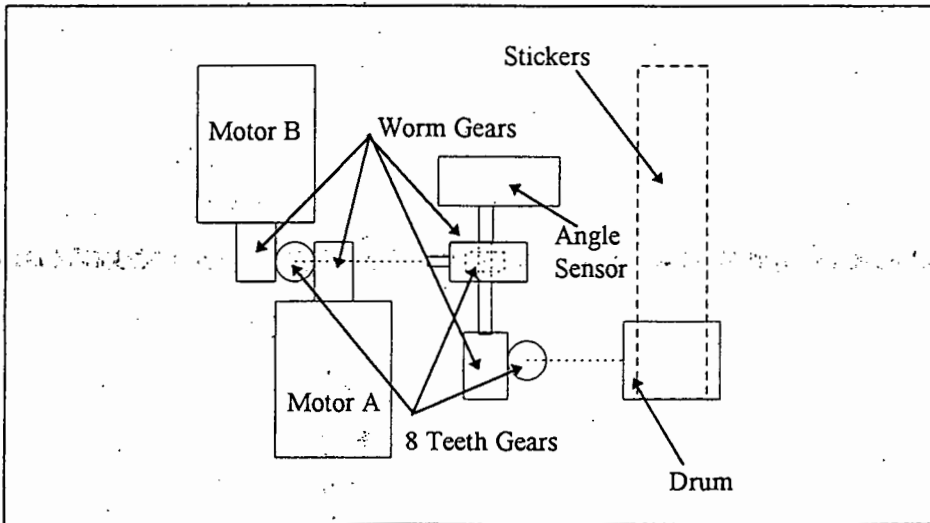


Figure 6.2.3b : The printer drive system for the model (Top View).

The specifications, of the printer drive system, are calculated in Appendix D.5. and are tabulated in Table 6.2.3b.

Table 6.2.3b : Printer drive system specifications for the Lego model.

Motor Speed	2280 RPM
Motor Torque (Normal Load)	0.73 N.mm (Per Motor)
Drive Drum Speed	4.4 RPM
Drive Drum Torque (Normal Load)	758 N.mm
Printer Gear Box Ratio	518 : 1
Sticker Tape Speed	5.53 mm/s

The reason two motors are used is because the torque required to wind the paper around the curve metal guide is 1.46 N.mm and the maximum torque a single Lego motor can deliver is 1.59 N.mm (Appendix D.1).

A standard Lego angle sensor, Figure 6.2.3b, is used to ensure that only one sticker is placed onto an adjacent box at a time. The accuracy of the sensor in relation to the system is calculated in Appendix D.5 and tabulated in Table 6.2.3c.

Table 6.2.3c : Printer system angle sensor specification for the Lego model.

Error of the Angle Sensor	22.5 degrees
Error Across the Sticker Tape	0.59 mm
Length of one sticker	19 mm
Angle Sensor Reading for Dispensing One Sticker	34 Counts

A major problem with the printer is that the angle sensor value for one sticker to be removed was calculated with the assumption that the drive drum diameter (Figure 6.2.3a) remains constant. But, unfortunately it increases as more of the glossy paper is wound around the drive drum. The glossy paper, however, is very thin, but once 5 layers of glossy paper have been wound around the drive drum the angle sensor readings may be incorrect. Therefore, a factor at which the angle sensor reading changes was calculated and incorporated into the control program. This is shown in detail in Appendix D.5.

6.3 Main Conveyor System.

The main conveyor runs perpendicular to each of the filling conveyors, and runs continuously using a motor and gearbox set-up. Located at the end of the main conveyor is the colour identification device which is used to model the bar code reader. The main conveyor drive system is illustrated in Figure 6.3.

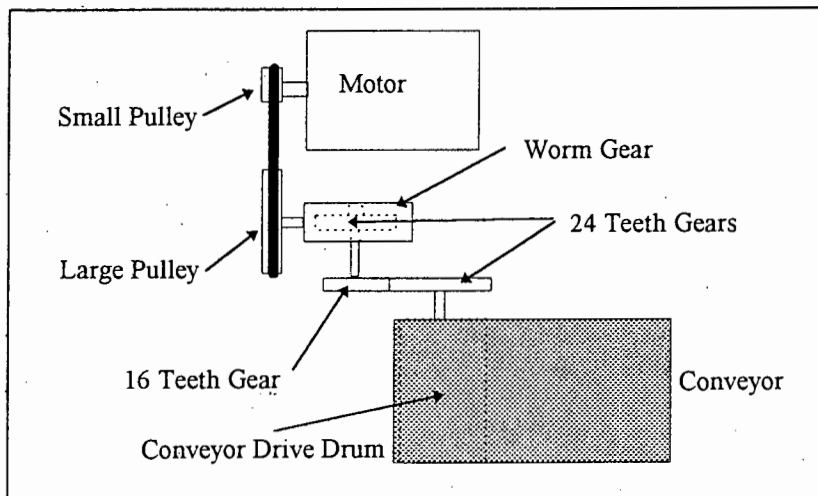


Figure 6.3 : Main conveyor drive system for the model (Top View).

The main conveyor specification are calculated in Appendix D.3 and are tabulated in Table 6.3.

Table 6.3 : Main conveyor drive system specifications for the Lego model.

Motor Speed	3494 RPM
Motor Torque (Normal Load)	0.27 N.m
Drive Drum Speed	26.9 RPM
Drive Drum Torque (Normal Load)	35.45 N.m
Drive System Gear Ratio	130 : 1
Main Conveyor Speed	42.25 mm/s

6.4 Sorting the Filled Boxes.

The function of this system is to sort the different coloured labelled boxes into different sections of the storage area. The various systems used to accomplish this are described in detail in this section.

6.4.1 Sorting Conveyor System.

The sorting conveyor system is driven by a motor gearbox set-up and is illustrated in Figure 6.4.1.

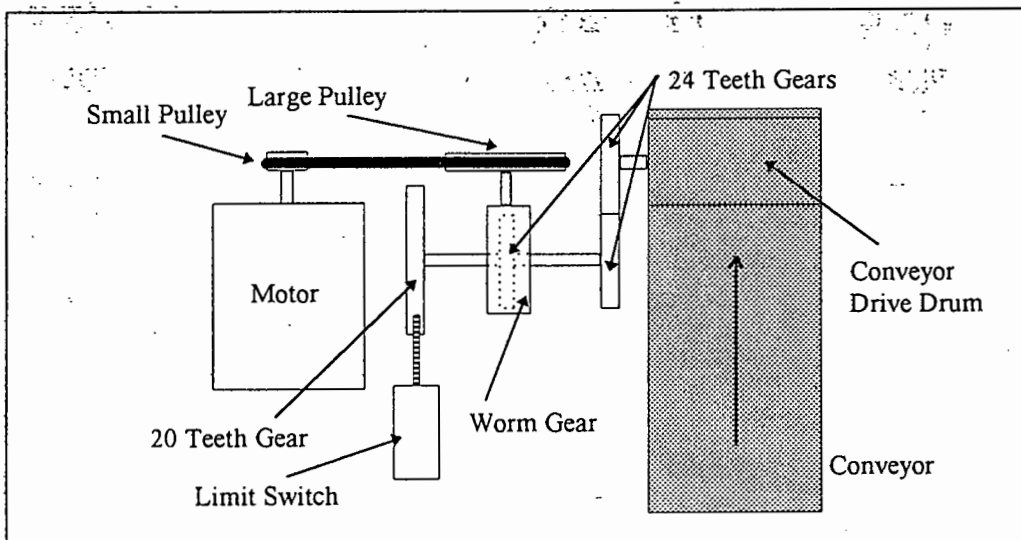


Figure 6.4.1 : The sorting conveyor drive system for the model (Top View).

The sorting conveyor drive system specifications are calculated in Appendix D.2 and tabulated below in Table 6.4.1.

Table 6.4.1 : Sorting conveyor drive system specifications for the Lego model.

Motor Speed	2896 RPM
Motor Torque (Normal Load)	0.5 N.mm
Drive Drum Speed	33.45 RPM
Drive Drum Torque (Normal Load)	43.2 N.mm
Drive System Gear Ratio	87 : 1
Conveyor Speed	52.5 mm/s

6.4.2 Colour Identification System.

A standard Lego light sensor is used to model the bar code scanner and is calibrated to read the three different coloured labels, as described hereafter.

Each colour has its own unique reflective ability. This reflective ability can be read by the Lego light sensor. If a coloured label is placed directly in front of the light sensor, the light sensor reading should be unique to that specific colour. Therefore, the sensor can identify the different colours of the labels. The reason the coloured labels have to be placed directly in front of the light sensor is to ensure that the surrounding light does not effect the readings.

A problem with the Lego light sensor is that it is permanently switched on and cannot identify when a box is directly in front of the light sensor or not. A switch was therefore introduced to indicate, to the computer, when a box is in position to be read. The switch was connected in series with the light sensor. Therefore, if the switch is open, the light sensor is switched off and once the switch is closed the light sensor is switched on. The switch was placed next to the light sensor in such a way that as a box moved down the main conveyor it would push against the light sensor and switch, whereby closing the switch and turning the light sensor on for colour

identification. Therefore, instead of using two interface ports, one for the light sensor and one for the switch, one input port was used to accomplish both tasks.

Next, the colour of each label must be identified by using the light sensor readings. A typical reading of the light percentage versus time, for a certain coloured box, is given in Figure 6.4.2a.

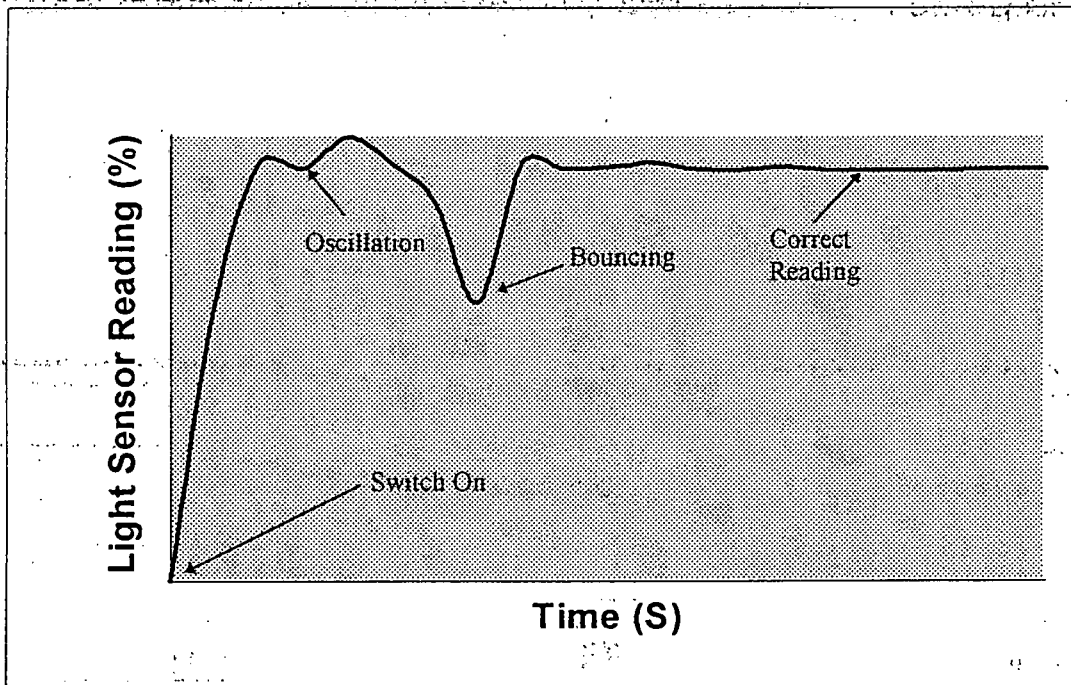


Figure 6.4.2a : Typical Lego light sensor readings over time.

Figure 6.4.2a gives an example of the light sensor reading read by the computer. As the box makes contact with the switch, and closes it, the light sensor readings increase from an off state (0%). Then there is a period of some oscillation before the reading settles to the correct percentage light for the specific coloured label. During the reading of the coloured label a sudden dip in the reading might occur, as illustrated in Figure 6.4.2a, which is caused by the 'bouncing' effect of the switch. Sometimes the box does not come into the reading area exactly perpendicular to the light sensor, which may cause the switch to 'bounce'. Therefore, 'bouncing' is basically when the switch does not close properly, and may turn off for a few milliseconds, before turning on again. This in turn causes the dip in the reading. These dips normally occur in the first 200 milliseconds, but can sometimes occur further on in the readings.

Problems can arise when the computer takes a reading whilst the light sensor reading is in a dip (Figure 6.4.2a). Therefore, the light sensor reading will be lower than the correct reading for the specific colour being identified. This in turn will cause the colour to be incorrectly identified. To solve this problem a sampling technique is used. Instead of taking only one reading, and using that as the reading for identifying the coloured label, the computer takes 6 readings and checks if they are all acceptable before using them to predict the colour of the label. For the 6 samples to be acceptable, each and every one of the samples must fall within the mean of the samples and a set range of 1% light below and above the mean. If not, another 6 samples are taken and tested to the same criteria. A graphic illustration is shown in Figure 6.4.2b.

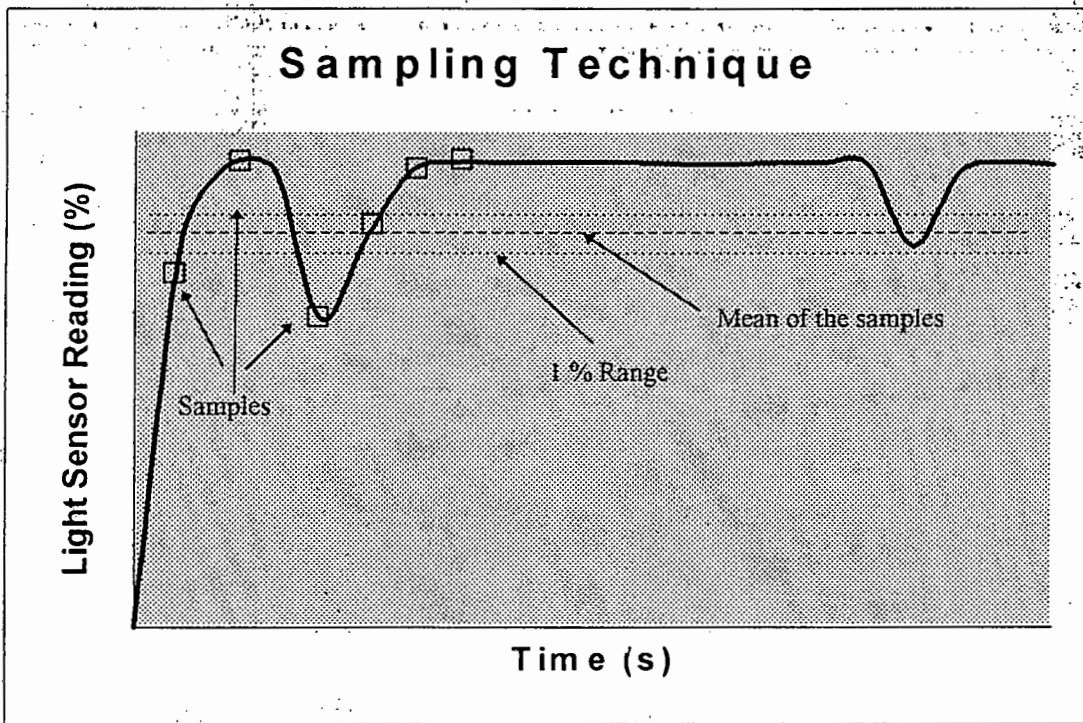


Figure 6.4.2b : Sampling technique for colour identification (Failure).

Referring to Figure 6.4.2b, most of the samples fall outside the range, therefore the sample mean is rejected and the next 6 samples are taken. The next six samples taken are shown in Figure 6.4.2c.

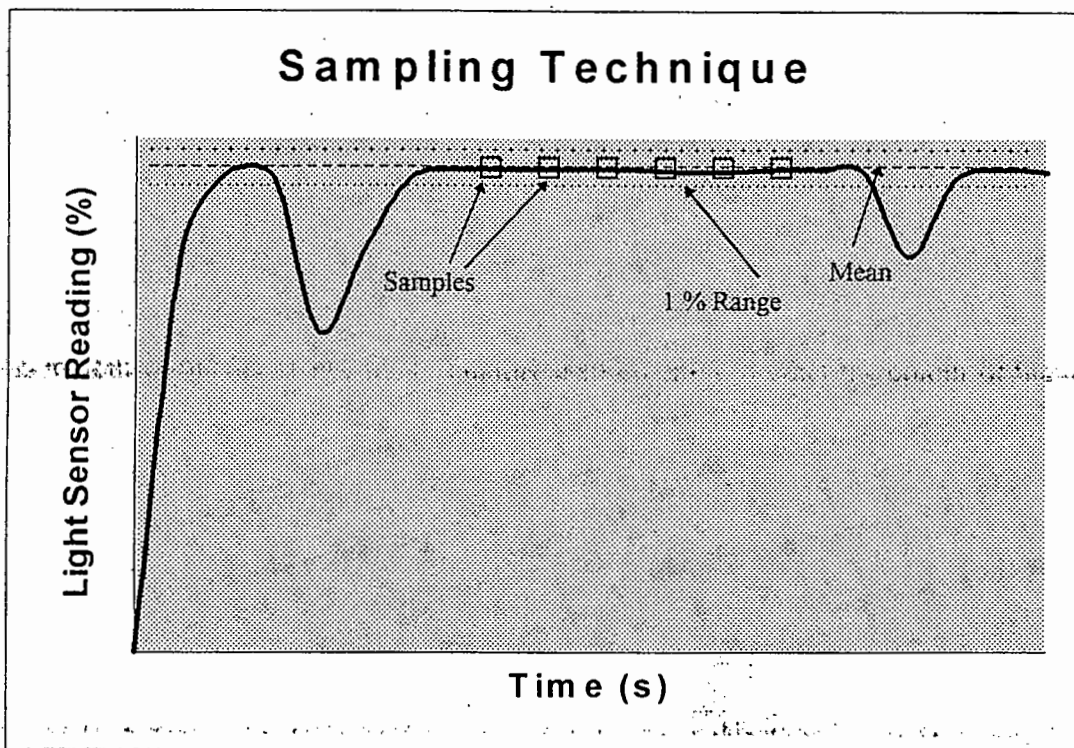


Figure 6.4.2c : Sampling technique for colour identification (Pass).

In Figure 6.4.2c all the samples lie within the range of 1%. Therefore, the sample mean is accepted and used to identify the labels colour.

Next, the various ranges of light sensor readings for each colour must be identified. This can be done by simply running the main conveyor and placing specific coloured boxes on the belt and reading the final result of the light sensor reading. This is repeated until a sufficient population of statistical results have been gathered. The mean and standard deviation for each colour is calculated, in Appendix E, and tabulated below in Table 6.4.2.

Table 6.4.2 : Mean and range of light sensor readings for each colour.

Colour	Mean (% Light)	Set Range (% Light) (4 standard deviations)
White	58.35	56.63 to 60.07
Green	48.08	46.64 to 49.52
Gold	62.93	61.21 to 64.65

A graphic representation is shown in Appendix E and Figure 6.4.2d .

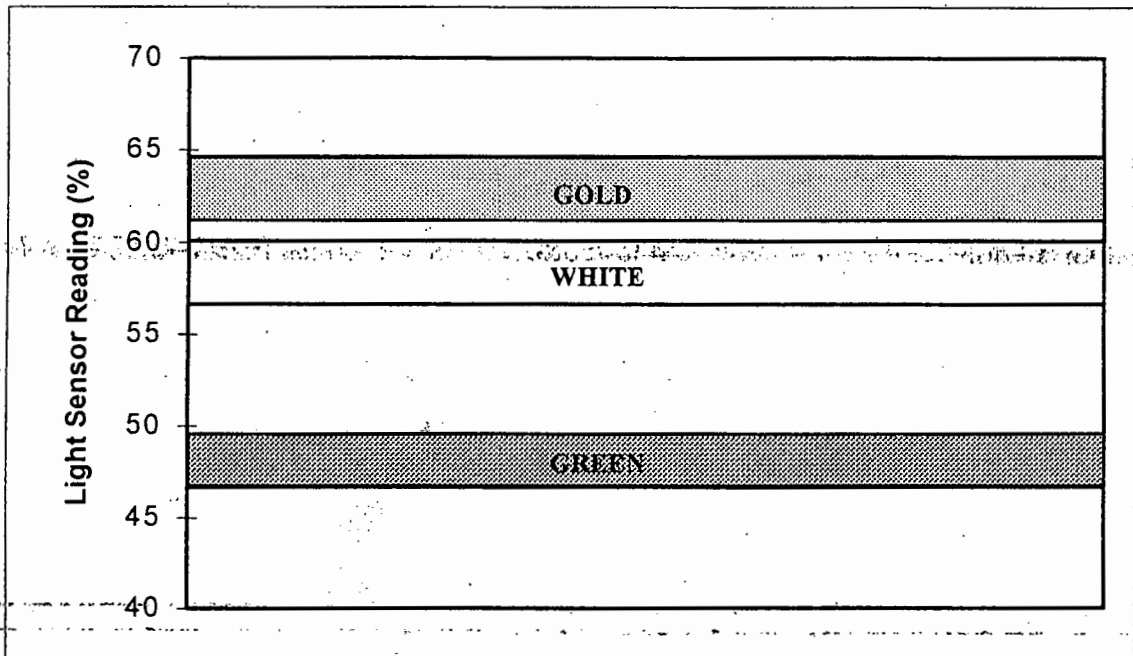


Figure 6.4.2d : Lego light sensor range-of readings for each colour.

6.4.3 Piston Sorting System

The sorting system makes use of double action pistons and a transport conveyor to sort the boxes into their pre-determined storage areas, after the colour code has been identified.

The sorting conveyor runs perpendicular to the main conveyor. Once the colour has been identified, which takes place at the end of the main conveyor, the dispenser piston pushes the box onto the continuously moving sorting conveyor, as illustrated in Figure 6.4.3.

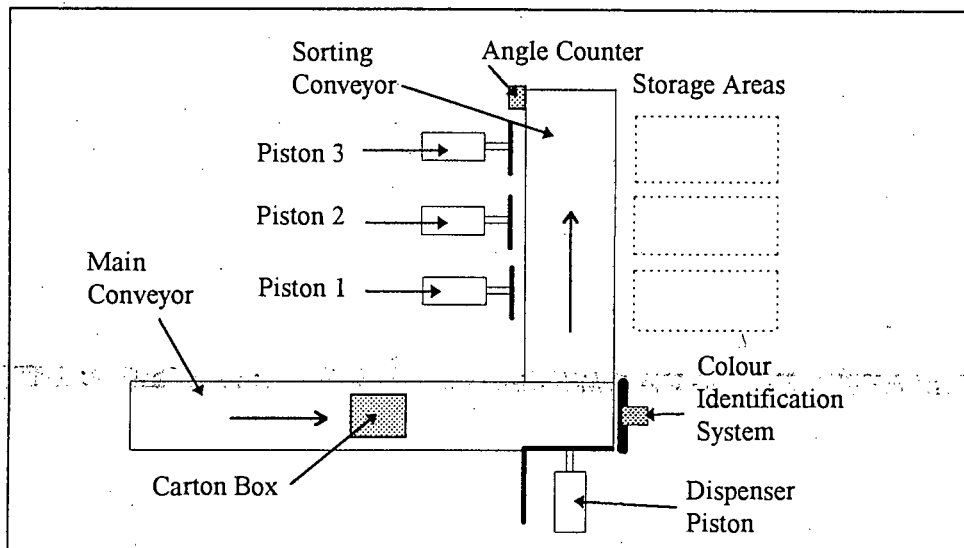


Figure 6.4.3 : Piston sorting system (Top View).

There are three pistons along the length of the sorting conveyor. Each piston is required to push a box off the sorting conveyor and into the correct storage area opposite the piston. The three pistons and associated coloured labels are tabulated in Table 6.4.3a.

Table 6.4.3a : Piston activated for coloured boxes.

Piston Number	Colour
Piston 1	Gold
Piston 2	Green
Piston 3	White

The pistons specifications calculated in Appendix D.7 are tabulated in Table 6.4.3b.

Table 6.4.3b : Sorting piston specifications for the model.

Piston Internal Cylinder Diameter	12 mm
Piston Rod Diameter	5 mm
Piston Stroke Length	28 mm
Operational Pressure	2 bar
Piston Velocity (Forward Stroke)	53 mm/s
Piston Velocity (Backwards Stroke)	56 mm/s
Time to fully open	0.53 seconds
Time to fully close	0.5 seconds
Air consumption (Forward Stroke)	9.3 ml
Air Consumption (Backward Stroke)	7.7 ml

An angle counter (Section 6.4.1), placed in the drive system of the sorting conveyor, is used to calculate when each piston must be activated in order to push the correct box off the sorting conveyor at the correct time. The angle counter (Section 6.4.1) is a purely mechanical device, which consists of a limit switch meshed to a large 20 toothed gear (Appendix L, Drawing 10). As the gear rotates the limit switch bounces back and forth from an on to an off state. The number of on and off states is then counted by the computer using the computer interface. The distance the sorting conveyor belt has travelled as well as the travelled distance of the boxes is calculated. It is more accurate to measure the distance that the conveyor has travelled than the speed it is travelling at, because the speed of the sorting conveyor can vary with changes in the load or electrical power.

The increase in the angle counter reading from when a box is pushed onto the move sorting conveyor, by the dispenser piston, until it is ejected off the sorting conveyor, by the ejection piston, is calculated in Appendix D.7 and tabulated in Table 6.4.3c.

Table 6.4.3c : Angle counter specifications for the Lego model.

Number of counts to reach piston 1	42 Counts
Number of counts to reach piston 2	63 Counts
Number of counts to reach piston 3	84 Counts

6.5 Control Box

The control box which controls the systems in the Lego model, as well as interfaces with the computer program is discussed. The control box contains four different systems,

- 1) The Lego computer interface, which is compatible with various programming languages (e.g. Pascal, Visual Basic, etc.).
- 2) A 220 volt AC mains to 9 and 12 volt AC transformer (complete with fuses).
- 3) A control circuit board, interfacing with the computer.
- 4) The pneumatic control systems, containing pressure gauges and regulator value.

The physical layout of the above mentioned control box systems are shown in Appendix L, Drawing 1, Appendix J, Photograph 11 & 12 and illustrated in Figure 6.5.

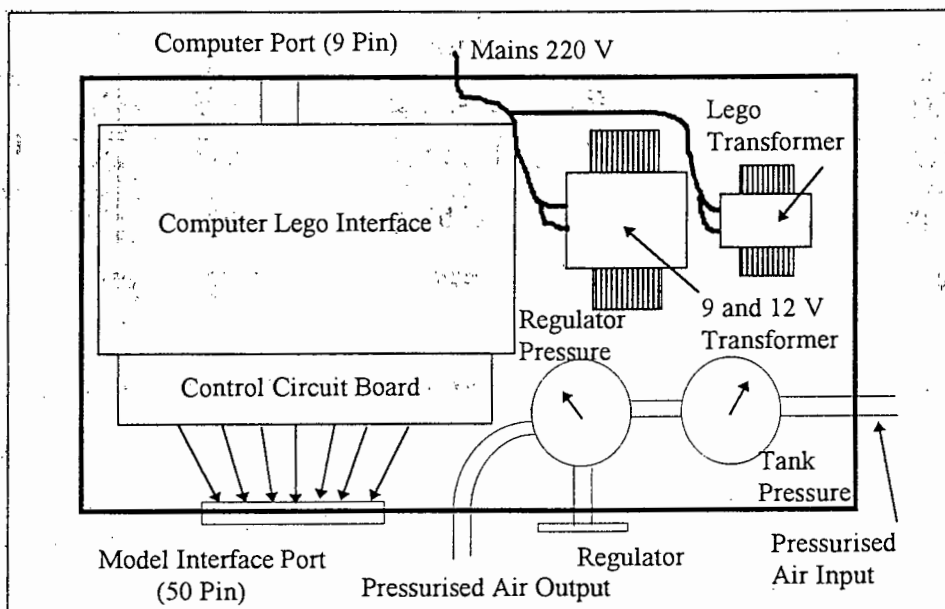


Figure 6.5 : The Lego model control box layout (Top View).

6.5.1 Lego Interface.

The Lego interface is required to interface the computer software with the various Lego input and output devices. Located at the rear end of the interface (Figure 6.5), is the 9 pin computer interface port. This port must be plugged into the COM 1 port of the computer. The interface port is connected directly to the Lego interface box, which is contained inside the control box (Figure 6.5).

The various ports and their functions are tabulated in Table 6.5.1.

Table 6.5.1 : Input and output port of the Lego interface.

OUTPUT		INPUT	
Port Letter	Function	Port Number	Function
A	Dispenser Piston	1	Production Line 1 (Light Sensor)
B	Piston A (Gold)	2	Production Line 2 (Light Sensor)
C	Piston B (Green)	3	Production Line 3 (Light Sensor)
D	Piston C (White)	4	Sorting Conveyor (Angle Counter)
E	Production Line 1 (Conveyor and Printer)	5	Colour Reader (Light Sensor)
F	Production Line 2 (Conveyor and Printer)	6	Printer 1 (Angle Sensor)
G	Production Line 3 (Conveyor and Printer)	7	Printer 2 (Angle Sensor)
H	SPARE	8	Printer 3 (Angle Sensor)

The Lego Interface is powered by a 220 Volt mains to 10 Volt AC transformer, which is provided by Lego and is situated on the far right hand side of the control box (see Figure 6.5).

6.5.2 Circuit Board

The various inputs and outputs, of the Lego Interface, are then connected to the circuit board, which is located directly below the Lego Interface box (Figure 6.5). From the circuit board, the various inputs and outputs are connected to the model, via a 50 pin computer cable. The pin numbers as well as the circuit diagrams for the circuit board are shown in Appendix K.

6.5.3 Transformers

The circuit board is powered by the 220 volt to 9 and 12 volt AC transformer. This power source is then connected to the circuit board, where it is rectified to a DC power signal. The AC signal is rectified by using a full diode bridge (Appendix C) with a high capacitance to reduce the AC ripple effect, as shown in Figure 6.5.3:

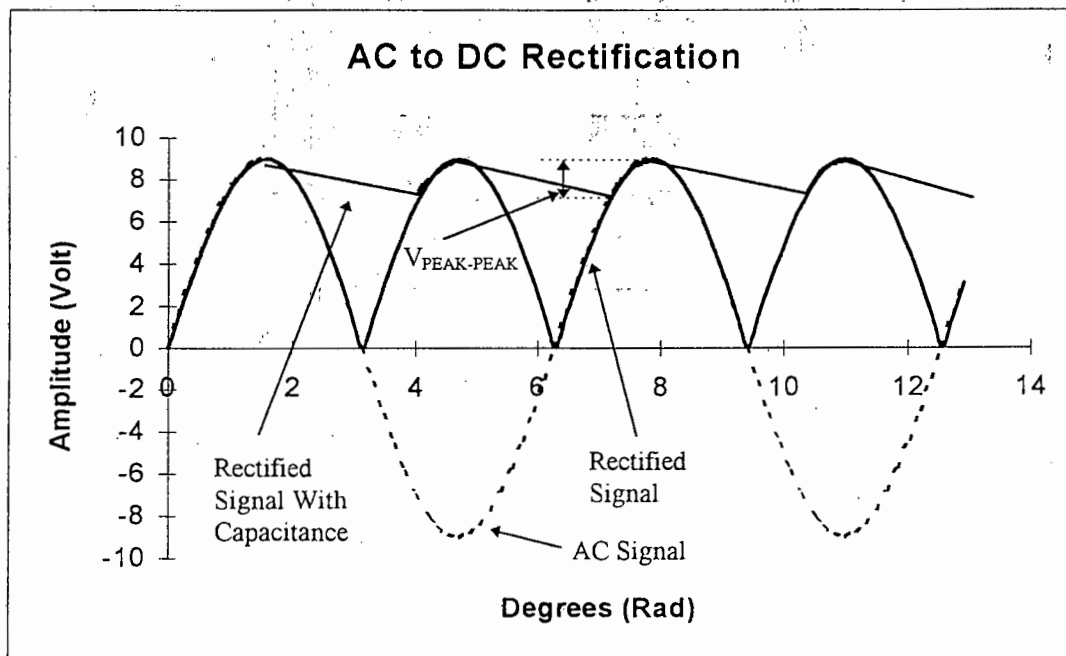


Figure 6.5.3 : Wave-forms for AC to DC rectification.

Two 1.6 Amp fuses, one for each power source, are used to prevent damage to the circuit board. If a short circuit should occur, the current through the cables would be approximately 2.5 Amps, which is the set maximum current for the transformer. This would then exceed the fuse limitation and the fuse would blow, preventing any destruction of the wiring.

The Lego interface transformer is placed next to the 9 and 12 volt transformer (Figure 6.5) and no fuses are required.

6.5.4 Pneumatic Controls

The pneumatics are placed in the bottom right hand side of the control box (Figure 6.5), and are completely separate from the circuitry of the control box.

Approximately 8 bar pressure, from the source (tank or compressor), comes into the input tube and through a pressure gauge. The pressure is then regulated to operate the system at 2 bar and is displayed on the second pressure gauge. The regulated pressure should not exceed 3 bar. If the pressure is higher than 3 bar the pipes connected to the pistons will 'pop' out of place.

6.6 Computer Program and Coding

The computer package used to interface the model with the computer is Visual Basic 3.0. The Lego Interface is compatible with this software and contains specified commands which can be used in Visual Basic 3.0 to communicate with the interface.

Approximately 90 percent of the coding is for user friendliness. These functions will not be discussed in this section. The section of coding that is of interest, is the code which controls the factory model. The flow charts for the control code can be seen in Appendix H. The computer code runs in a continuous loop, as shown in Appendix H, Figure H.1, and repeats four main sections of code. Three of these sections of code

are used to control the three separated production lines, while the fourth section is used to control the sorting procedure, as described hereafter.

6.6.1 Production Line Code.

The production line code is used to control the filling procedure at the end of each production line. The flow chart for this section of code can be seen in Appendix H, Figure H.1.2.

The program first checks if the production line is running, which means that the customer details have been entered into the computer correctly and the user has started the production line. Once the line is active, the control program starts. The program uses a variable name MODE to control the functional state of the production line. The various values of the variable MODE as well as the meaning of the values to the computer code are tabulated below in Table 6.6.1.

Table 6.6.1 : Active mode of the production line control program.

Mode = 0	Filling conveyor is set ON while the filling station waits for another empty box to enter the filling point.
Mode = 1	Filling conveyor is set OFF when an empty box arrives at the filling point.
Mode = 2	Waiting for empty box to be filled with caps.
Mode = 3	Filling complete, bar code printer is set ON.
Mode = 4	The bar code printer's angle sensor has reached its pre-set stop angle value, the printer is set OFF.
Mode = 5	The customer's order has been completed.

The MODE variable values only change once the sensors on the production line have changed state. For example, while in MODE =1 the conveyor is running and is waiting for an empty box to arrive at the filling point. MODE = 2 will only occur once the optic sensor on the filling conveyor is switched on, i.e. a box has broken the beam of light between the lamp and LDR (Section 6.2.2).

6.6.2 The Sorting Procedure Code.

The sorting system code is sub divided into two sections. The first section is used to identify the colours of the various boxes, and the second section is used to control when the three ejection pistons must be activated.

The colour identification portion of the code will only run once the Lego light sensor has been switched on (see Section 6.4.2). Once activated, the sampling procedure (described in section 6.4.2) starts. Each time the program loops another light sensor sample is taken. Only once all 6 sample readings are within the 1% set range does the code accept the light sensor reading. The colour is identified using the pre-determined ranges of light sensor reading for each colour (Appendix E). An angle count number is then stored into memory as well as the piston number relating to the angle count number for the specific box being identified. The dispenser piston is then activated and the box is sent down the sorting conveyor. The angle counter values, for each box on the sorting conveyor, are stored in a variable called POINTER and the piston numbers, associated with the angle count values, in a variable called PISTON. Both variables are arrays.

Now, the second section of code checks, continuously, if the present angle counter reading is the same as the ones stored in the variable POINTER. If so, the code identifies to which piston the reading belongs to and activates that piston. This in turn pushes the correct box off at the correct position. The flow chart for the above mentioned code is shown in Appendix H, Figure H.1.3.

6.7 Total Cost of the Lego Model.

The total cost of the Lego model is tabulated in Table 6.7

Table 6.7 : Total cost of the Lego Model.

System	No.	Cost (Rands Inc. VAT)
<i>Lego Motors</i>	9	1 026.45
<i>Light Sensors</i>	1	182.47
<i>Angle Sensors</i>	3	547.41
<i>Lamps</i>	6	288.00
<i>Structural Bricks</i>	N/A	2 210.70
<i>Mechanical Components</i>	N/A	548.20
<i>Limit Switch</i>	1	30.00
<i>Lego Interface</i>	1	1 811.41
<i>Electrical Components</i>	N/A	250.00
<i>Pneumatic Components</i>	N/A	3 260.00
<i>Pistons</i>	7	368.41
	Total	10 523.05

7. Transforming the Proposed

Model to the Actual Factory

Layout.

The ideas and concepts of the model are designed for the actual factory. The machinery needed, the positioning in the factory as well as the PLC programming which controls all the functions are presented.

7.1 Assembly and Transportation of the Empty

Carton Boxes.

The process of assembling as well as transporting the empty carton boxes to each of the filling points is discussed in detail.

7.1.1 Empty Carton Box Assembly.

The carton boxes will still be assembled manually but it is suggested that machinery be used in future. This will increase the empty box production rate as well as decrease the monthly assembly costs.

There will be two empty carton box assembly points, one for each of the two different types of carton boxes used at present. The assembly of the empty carton boxes will be performed on the two roof tops of the small building located on the factory floor (see Appendix M, Drawing 2). The overhead chain conveyor will pass alongside the rooftops of the two small buildings at the correct height, such that once a worker has completed an empty carton box it will be easy to place the box on the next available

empty cart. The specifications of the manual carton box assembly procedure are calculated in Appendix G and tabulated in Table 7.1.1a.

Table 7.1.1a : Manual carton box assembly specification.

	WC Production Lines Carton Box Assembly Area	ROPP & TALOG Production Lines Carton Box Assembly Area
<i>Carton Box Type</i>	REF 88	REF 86
<i>Minimum Number of Workers</i>	1	1
<i>Suggested Number of Workers</i>	2	2
<i>Minimum Speed of Empty Carton Box Production</i>	57 Boxes/Hour	58 Boxes/Hour

The layout of the work area, located on the rooftops of the two small buildings, is illustrated in Figure 7.1.1. and can be seen in Appendix M, Drawing 2, 3 & 4.

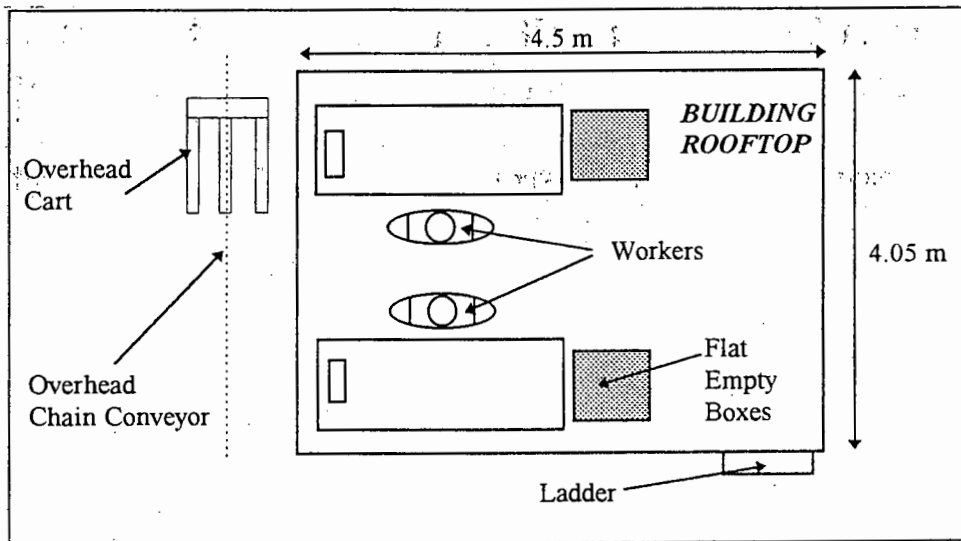


Figure 7.1.1 : Layout of the proposed empty carton box assembly area (Top View).

Referring to Figure 7.1.1, the workers job has now been made easier, compared to the present system shown and discussed in Section 4.3. Firstly, the distance the worker must move or walk to perform the empty carton box assembly has been reduced. Secondly, the worker is now only responsible for assembling empty carton boxes, in the long term this will reduce carton box assembly times and increase productivity. Finally, if more workers are required to assemble boxes, due to an increase in production line speeds, there is enough space for a third or fourth workbench. If even more workers are required it is strongly suggested that a carton box erection machine be used.

If in future, an automatic approach is required to assemble the empty carton boxes, a list of the available machinery and the technical data is shown in Appendix G, Table G.2.2. The SOCO BE 300 ABS supplied by AFCOM is the machine suggested for the procedure of carton box erection. This machine was chosen because of its production output, power consumption and cost. The machine will also fit onto the roof of the small building without out any space constraints. The carton erection machine specifications are tabulated in Table 7.1.1b.

Table 7.1.1b : Automatic carton erection machine specifications for the factory design.

Model	SOCO BE 300 ABS
Dimensions (x,y,z)	2195*2240*1740 mm
Machine Output	480 Cartons/Hour

7.1.2 Overhead Chain Conveyor.

There will be two separate overhead chain conveyor systems. One for each type of carton box used at the factory. The first overhead chain conveyor system will provide empty carton boxes for all the White Cap production lines, while the second chain conveyor will provide empty carton boxes for all the Roll-On-PilferProof lines including the TALOG line.

A continuous railing, with an I-beam cross-section, will be used to direct the path of motion of the overhead chain conveyor. The overhead chain conveyor will be suspended from the I-beam railing using double sided rollers. Connected beneath each roller will be an overhead cart which is free to swivel about its connection to the rollers, as shown in Figure 5.1.2d. The rollers will be used to hold the drive chain in place as well as hold the weight of the overhead carts. The chain will drive the system using a standard motor gearbox set-up. The path of the two overhead chain conveyors is shown in Appendix M, Drawing 3 & 4. The specifications of the overhead chain conveyors are calculated in Appendix G.3 & Appendix F and are tabulated in Table 7.1.2.

Table 7.1.2 : Overhead chain conveyor specifications for the factory design.

	ROPP Production Lines	WC Production Lines
Minimum Velocity	48.3 mm/s	47.5 mm/s
Suggested Velocity	100 mm/s	100 mm/s
Maximum Velocity	756 mm/s	756 mm/s

7.1.3 Overhead Conveyor Carts.

The overhead conveyor carts are used to transport the assembled empty carton boxes to the various filling stations. The cart is designed to swivel about its connection to the chain and roller. If an empty carton box is required, the cart is tilted mechanically, and the box being carried is forced to slide off the overhead cart and onto the gravity conveyor, as discussed in Section 5.1.2c. The overhead cart is illustrated in Figure 7.1.3, the specifications are calculated in Appendix F and tabulated in Table 7.1.3.

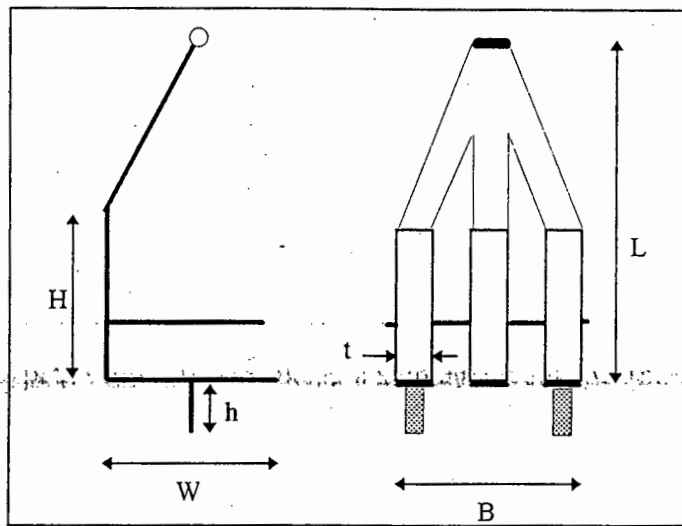


Figure 7.1.3 : Overhead conveyor cart, factory design

Table 7.1.3 : Overhead cart specification for the factory design.

Length (L)	1.5 m
Width (W)	400 mm
Breadth (B)	510 mm
Strip Thickness (t)	102 mm
Height (H)	500 mm
Tilting Arm (h)	74.4 mm
Maximum Angle of Tilt	17.7 Degrees
Time Taken for a Box to Slide Off a Cart when Tilted	4.6 Seconds
Maximum Angle of Oscillation when Overhead Conveyor Suddenly Stops.	1.5 Degrees (Speed = 100mm/s)

7.1.4 Gravity Conveyor or Chute.

A gravity conveyor or chute is used to transport the empty carton boxes from the overhead conveyor cart to the filling stations. The gravity conveyor uses metal rollers to decrease the coefficient of friction between the conveyor and the object being transported (Ref. 14).

The gravity conveyors are located at each filling station, as shown in Appendix M, Drawing 2. The specifications of the gravity conveyors are calculated in Appendix F and tabulated in Table 7.1.4a.

Table 7.1.4 a : Gravity conveyor specification for the factory design.

Angle of Tilt	30 Degrees
Conveyor Width	22 inch or 550 mm
Number of Conveyors	12 Conveyors

At the top of the gravity conveyor is the mechanical device used to tilt the overhead conveyor cart when a new empty box is required on the gravity conveyor. As in the model (Section 6.1.3) the tilting device is a pneumatic piston which, when activated, blocks the path of the tilting pin on the overhead cart (Section 7.1.2). The tilting device is illustrated in Figure 7.1.4a and its specifications are calculated in Appendix F.4 & Appendix G.4 and tabulated in Table 7.1.4b.

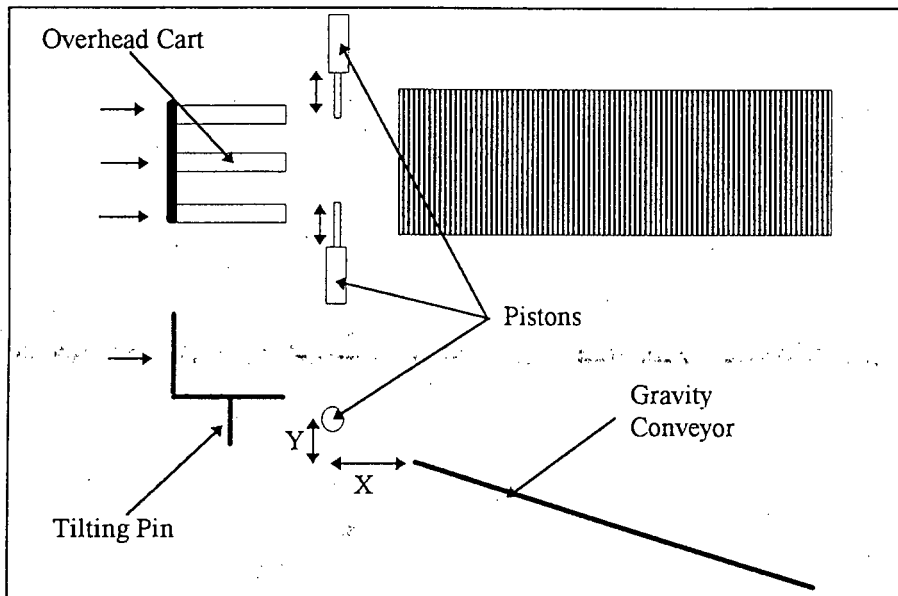


Figure 7.1.4a : Gravity conveyor tilting system, factory design.

Table 7.1.4b. Gravity conveyor cart tilting device specifications.

Piston Type	Double Action Piston
Piston Product Number	FESTO DGS-25-100
Piston Diameter	25 mm
Stroke Length	100 mm
Maximum Piston Pressure	12 bar
Suggested Operating Pressure	6 bar
Piston Orientation (See Figure 7.1.3b)	X = 186 mm Y = 75 mm

The pistons, which tilt the overhead cart, are controlled by an optic sensor. The optic sensor is used in the same way as in the model, discussed in Section 6.1.3. The sensor will indicate when the gravity conveyor is filled with empty carton boxes. The sensor itself does not need to be expensive and accurate. The object it must observe, the empty carton box, is large, non-reflective and moving at a relatively low velocity.

There are two types of optic sensors which are commonly used to accomplish this task, the retroreflective optic sensor and the opposed sensor (Ref. 32). The opposed sensor was chosen because of its optic power and reliability. The opposed sensing system is often referred to as the “direct scanning” or “beam-break” mode (Ref. 32). In the

opposed sensing system the emitter and receiver are two separate devices and are placed directly opposite each other, as illustrated in Figure 7.1.4b.

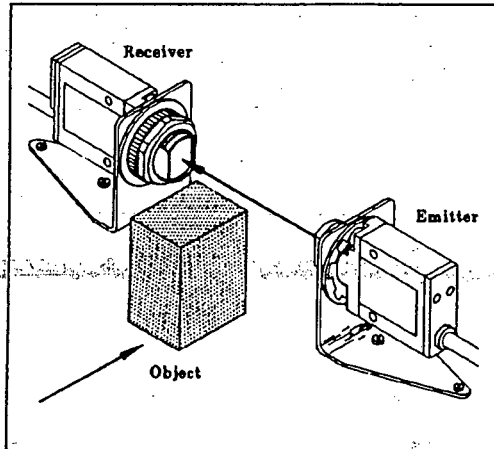


Figure 7.1.4b : Opposed sensor set-up.

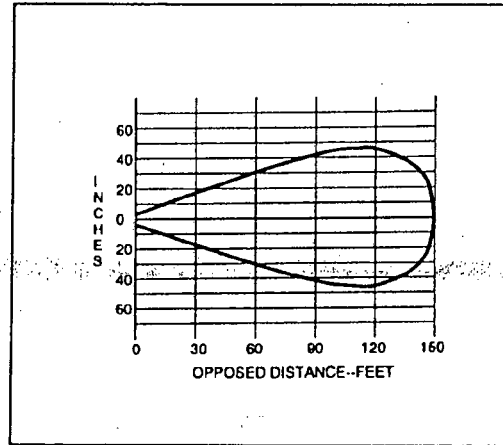


Figure 7.1.4c : Optic beam pattern.

As soon as an object breaks the light beam between the two devices it will be detected. The opposed sensor will always result in the most reliable sensing system, as long as the item to be detected is opaque to light. Opposed sensing is the most efficient sensing mode and offers the highest level of optical energy to overcome lens contamination, sensor misalignment or long scanning ranges. The beam pattern of the opposed sensor can be seen in Figure 7.1.4c.

7.2 The Filling Stations.

At the filling stations, located at the end of each production line (Appendix B, drawing B.1), the empty boxes are automatically filled, labelled and moved out of the filling area. The various procedures used at all the filling stations is discussed in detail.

7.2.1 Filling Conveyor.

The filling conveyor is required to move the empty boxes into position to be filled and move the already filled boxes onto the main conveyor. The main conveyor is discussed later in Section 7.3. The filling conveyor is a standard flat belt conveyor, which is

driven by a motor gearbox set-up. The filling conveyor is very short and runs from the end of the gravity conveyor, past the filling point and to the main conveyor, as shown in Appendix M. The filling conveyor specifications are calculated in Appendix G.6 and tabulated in Table 7.2.1.

Table 7.2.1 : Filling conveyor specifications, factory design.

Length of Conveyor	1.3 m
Width of Conveyor	350 mm
Number of Conveyors	12 Conveyors
Maximum Velocity	1000 mm/s

7.2.2 Caption Box and Cap Counter.

At the end of each production line is a small belt conveyor which transports the finished caps the short distance from the production line into the empty boxes. A small electronic optic sensor is placed on the conveyor and is used to count the number of caps which pass before they are placed inside the empty box. Each filling point at present has such electronic counters.

Once counted the caps are fed through a caption box and into the box being filled, as discussed in Section 4.3.2b and Section 5.2.1b. The White Cap (WC) lines already use this system to fill their empty boxes. However, the Roll-On-PilferProof (ROPP) lines use the two-way filling system. This should be replaced. To replace the two-way filling system with the caption box filling system, the following must be done. The solenoid controlling the rotation of the flap in the two-way filling system (Section 5, Figure 5.2.1a) must be used to open and close the trapdoor at the bottom of the caption box (Section 5, Figure 5.2.1c). The structure of the caption box must then be constructed and installed.

7.2.3 Bar Code Printers.

A bar code printer will be placed at each filling station and will be located before the filling point or caption box (Appendix M, Drawing 7). Once the carton box has been filled, the printer will print the product details onto the box as well as the products bar code. The bar code label quality must be of a high standard to be read correctly by the bar code scanner. Parameters such as bar width, spacing and contrast at different wavelengths must be checked (Ref. 3). Most bar code labels printed on site also have high first read rates (Ref. 3). The various bar code printers which were considered are tabulated in Appendix G, Table G.5.

The ATD INKJET IP9000 bar code printer supplied by J-PAK is suggested for the procedure of labelling the carton boxes. The bar code printer specifications are tabulated in Table 7.2.3.

Table 7.2.3 : Bar code printer specifications for the factory design.

Model	ATD INKJET IP9000
Dimensions (x,y,z)	119*136*46 mm
Printer Speed	1000mm/s
Label Height	3-48 mm

7.2.4 Carton Shaker on the Filling Conveyor.

Carton box shakers will be used to periodically shake the boxes while they are being filled. This will then ensure that the caps are spread equally throughout the carton box before being sealed. The carton box shakers are already in place at all the White Cap (WC) production lines. The carton box shaker must therefore be located at each filling station and will be placed directly underneath the filling conveyor.

7.3 Transporting the Filled Boxes to the Storage

Area.

The main conveyor is responsible for transporting the filled boxes from the filling stations to the storage area. A flat belt conveyor is recommended to move the filled boxes to the storage area. A typical horizontal flat belt conveyor has the following design, shown in Figure 7.3.

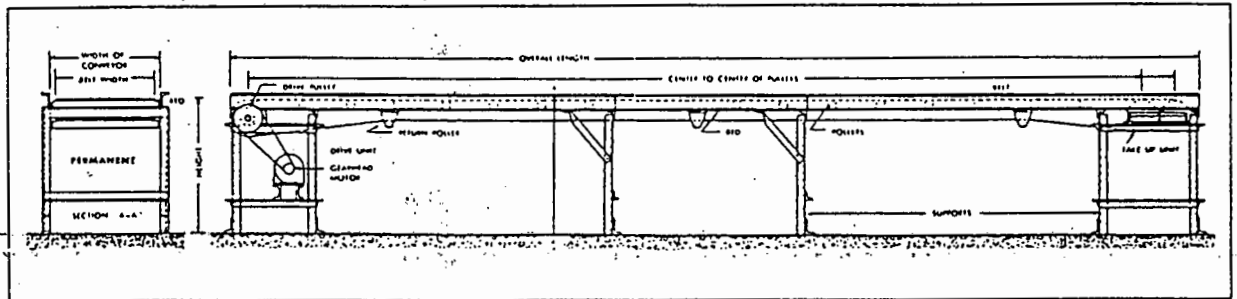


Figure 7.3 : Typical horizontal flat belt conveyor.

The specifications of the flat belt main conveyor are calculated in Appendix G.7 and tabulated in Table 7.3.

Table 7.3 : Main conveyor specifications for the factory design.

Minimum Speed	10.4 mm/s
Suggested Speed	106 mm/s
Number of Main Conveyors	11
Accumulated Length of the Main Conveyor	105 m
Belt Width	550 mm

The conveyor belt is driven by a motor gearbox set-up, illustrated in Figure 7.3. The conveyor belt will be located through the factory and placed perpendicular to each filling conveyor (Appendix M, Drawing 3). Eleven conveyors will be used to make up the entire transport system. The conveyors will be connected in sequence to one another, and each conveyor will have its own drive system. The reason for using several conveyors instead of one is because of routine maintenance and possible failures. If one of the conveyors has a mechanical problem the others will still be able

to function and not all the boxes will be left stationary. In this way the entire transport system does not rely on one conveyor belt system.

The motor and gearbox, which drives the various conveyors, will be a standard unit for each conveyor. If maintenance is needed, the motor and gearbox can be replaced by maintenance workers in a short period of time. Therefore, the downtime for each conveyor will be reduced.

7.4 Sealing the Filled Boxes.

The carton boxes will still be sealed manually but it is suggested that machinery be used in future.

The boxes will be sealed before arriving at the storage area. The specifications of the manual carton box sealing procedure are calculated in Appendix G.8 and tabulated in Table 7.4.1.

Table 7.4.1 : Manual carton box sealing specifications for the factory design.

Minimum Number of Workers Needed	3
Suggested Number of Workers	4
Maximum Speed of Carton Box Sealing	115 Boxes/Hour

The layout of the work area for sealing the filled carton boxes, is illustrated in Figure 7.4 and shown in Appendix M, Drawing 5 & 6.

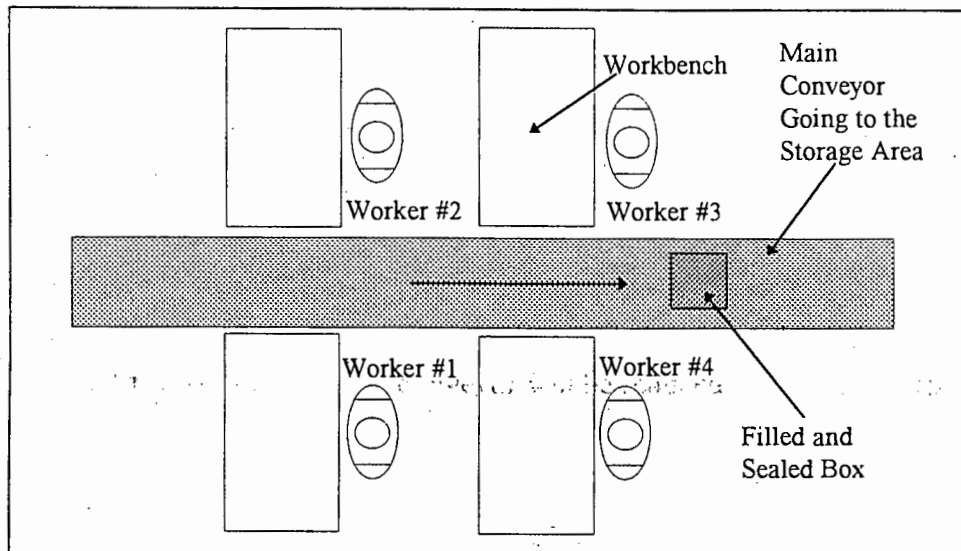


Figure 7.4 : Layout of empty box sealing area for the factory design (Top View).

Referring to Figure 7.4, the workers will wait until a filled carton box arrives down the main conveyor. The box will then be removed from the main conveyor and sealed by the nearest worker on the workbench. Once sealed the box will be placed back onto the main conveyor where it will be sorted and stored. The job of sealing the carton boxes manually has been made much easier when compared to the present method (Section 4, Figure 4.3). The worker is now only responsible for sealing the carton boxes and the distance the worker must walk, carrying the heavy carton box, has been reduced.

If in future an automatic approach is required to seal the carton boxes, a list of the available machinery is tabulated in Appendix G, Table G.8.2. The SIAT SM44 supplied by AFCOM is suggested to be used to seal the carton boxes. This carton sealer was chosen because of its maximum output, power consumption, price and overall size. The automatic carton box sealer specifications are tabulated in Table 7.4.2.

Table 7.4.2 : Automatic carton sealer specifications for the factory design.

Model	SIAT SM44
Machine Dimensions (x,y,z)	1080*2550*1850 mm
Production Output	350 - 450 Cartons/Hour

7.5 Sorting and Storage of the Filled Boxes.

The sorting system receives the filled and sealed boxes via the main conveyor and must sort the boxes into their various storage areas, depending on the box's bar code. The layout of the system is designed and modelled in Section 5.5 and Section 6.4 respectively. In this section, the components and their positioning in the factory layout are discussed.

7.5.1 Bar Code Scanner.

The bar code scanner is located at the end of the main conveyor and is responsible for reading the bar codes printed on each filled carton box. The location of the bar code scanner can be seen in Appendix M, Drawing 6. Bar code data entry systems have been shown to be 75% faster and 15,000 times more accurate than manual data entry (Ref. 3). The bar code scanner selected is shown in Appendix G, Table G.9 and has the following specification, tabulated in Table 7.5.1.

Table 7.5.1 : Bar code scanner specifications for the factory design.

Model	MICROSCAN MS 710 RASTER
Dimensions (x,y,z)	63*87*34 mm

7.5.2 Sorting Conveyor.

The sorting conveyor is used to transport the sealed and filled boxes past the various storage areas. A standard conveyor belt, similar to that used by the main conveyor system (section 7.3), is used. The sorting conveyor specification are calculated in Appendix G.7 and tabulated in Table 7.5.2.

Table 7.5.2 : Sorting conveyor specification for the factory design.

Minimum Speed	10.4 mm/s
Suggested Speed	106 mm/s
Conveyor Length	34.7 m
Belt Width	350 mm

7.5.3 Piston Sorting System.

The pistons which are used to physically move the boxes onto and off the sorting conveyor have two different functions. The first, is the dispenser piston, which pushes the carton box onto the sorting conveyor once the box's bar code has been identified. The second, is the ejection piston, which pushes the carton box off the sorting conveyor once the box has reached the correct storage area. There is only one dispenser piston, which lies parallel to the sorting conveyor, and 13 ejection pistons, each lying perpendicular to the sorting conveyor (Appendix M, Drawing 5).

The piston specifications are calculated in Appendix G.10 and tabulated in Table 7.5.3.

Table 7.5.3 : Sorting piston specifications for the factory design.

Piston Number	Festo DC-100-500	Festo DC 100-300
Function	Dispenser Piston	Ejection Piston
Piston Diameter	100 mm	100 mm
Stroke Length	500 mm	300 mm
Maximum Pressure	12 bar	12 bar
Operational Pressure	6 bar	6 bar
Maximum Piston Force	4300 N	4300 N
Air Consumption	30 litres/stroke	18 litre/stroke
Solenoid Valve	Festo MCH-5/2-1/2	Festo MCH-5/2-1/2

The first ejection piston is for the boxes which cannot be identified, while the other 12 ejection pistons are for the boxes from each of the production lines (Appendix M, Drawing 6).

7.5.4 Palletising and storage.

Once the carton boxes have been sorted into specific storage areas they are manually placed on a pallet. Once a pallet is filled a forklift is used to place the pallet the correct storage rack, as shown in Appendix M, Drawing 5.

7.6 The Control System.

Programmable Logic Controllers (PLC) will be used to control all the systems in the factory. The various PLC programs which control the function of the materials handling process are shown and discussed.

7.6.1 Ground and Overhead Conveyor Systems.

The main conveyor, sorting conveyor and overhead chain conveyors run continuously and require no PLC programming. All that is required is electrical wiring to allow for a manual start and emergency stop button for each one of the above mentioned conveyor systems.

7.6.2 Gravity Conveyor Cart Tilting Device.

The two pistons placed on top of the gravity conveyor are used to tilt the passing overhead conveyor carts so that their contents, empty carton boxes, can be sent down the gravity conveyor (Section 7.1.3). In the factory model the piston is controlled by an electronic circuit board (Section 6.1.3). As in the model, an optic sensor is placed on the gravity conveyor to identify whether or not the gravity conveyor has sufficient carton boxes. The physical set-up of the system is shown in Figure 7.1.4a.

The requirements of the PLC program are;

- 1) If the optic sensor is switched on, i.e. a box is in front of it, the solenoid valve must be switched off.
- 2) If the optic sensor is switched off, i.e. a box is not in front of it, the solenoid valve must be switched on.
- 3) There must be a master ON and OFF button, to control the system.

Considering the above requirements, the ladder diagram for the PLC program was designed and is shown in Appendix I, Figure I.1.1.

7.6.3 Filling Station System.

The set-up of the filling area located at the end of each production line, is illustrated in Figure 7.6.3.

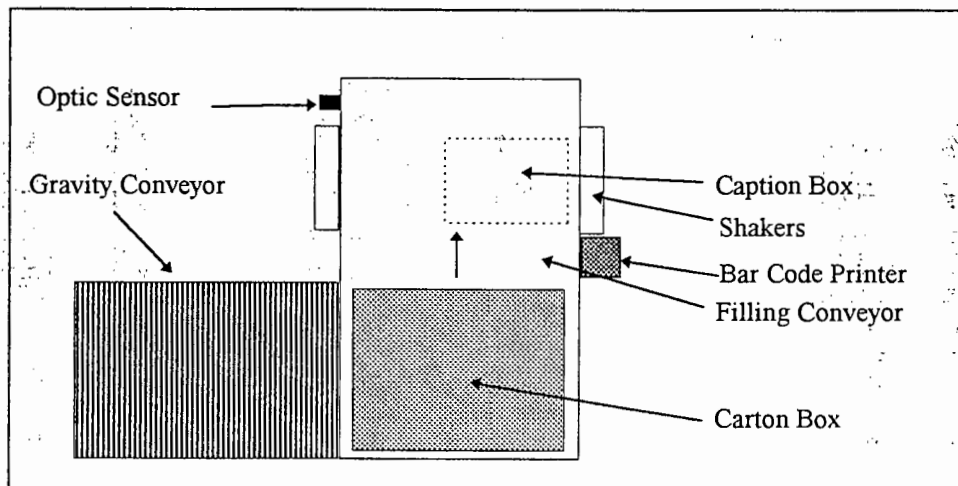


Figure 7.6.3 : Filling procedure set-up for the factory model.

Referring to Figure 7.6.3, the requirements of the PLC program are,

- 1) If the optic sensor is switched off, i.e. no box is in front of the optic sensor, the filling conveyor must be switched on.

- 2) If the optic sensor is switched on, i.e. a box is in front of the optic sensor, the filling conveyor must be switched off, unless a box has been filled and is leaving the filling station and moving onto the main conveyor.
- 3) Before a box enters into the position to be filled, a bar code must be printed onto the side of the carton box. This is done while the box is moving on the filling conveyor.
- 4) Once a box has entered in front of the optic sensor and the filling conveyor has been switched off, the carton box trapdoor must be opened.
- 5) The box must be periodically shaken by the carton box shaker while being filled.
- 6) Once the box has reached its required number of caps, the carton box piston must close the carton box trapdoor
- 7) Once filled the filling conveyor must be switched on to move the next empty box into position to be filled
- 8) Once the total number of boxes, needed by the customer, has been reached the production line must switch off and wait for the next customer order.
- 9) There must be a master ON and OFF button.
- 10) The PLC program must interface with a central computer to receive the information on : the number of boxes needed, the number of caps per box as well as the customer's name and details.

The PLC Ladder diagram is shown in Appendix I, Figure I.2.1.

7.6.4 Sorting System.

The sorting system layout is illustrated in Figure 5.5 and the requirements of the PLC program are,

- 1) Once a box has hit the blocker at the end of the main conveyor, its bar code must be read by the bar code scanner.
- 2) Once a box's bar code is identified an *angle count number and ejection*

piston number must be stored into memory for that specific carton box, as discussed in Section 5.5.

- 3) Once identified the dispenser piston must be activated to push the box onto the sorting conveyor.
- 4) Once the angle counter has reached the pre-determined angle, set by the computer for a specific box, the corresponding ejection piston must be activated (Section 5.5). For example, Piston 1.
- 5) The system must be able to handle many boxes simultaneously on the sorting conveyor.
- 6) The system must have a master ON and OFF button.
- 7) The system must interface with the central factory computer.

The PLC ladder diagram is shown in Appendix I, Figure I.3.2.

7.7 Total Cost of the Proposed System.

The total cost of the proposed system is tabulated in Table 7.7

Table 7.7 : Total cost of the proposed system.

System	No.	Cost (Rands Inc. VAT)
<i>Carton Box Assembly Machine</i>	1	186 116
<i>Bar Code Printers @ R71,686 each</i>	12	860 232*
<i>Filling Conveyors</i>	12	23 196
<i>Gravity Conveyors @ R17,519.52</i>	12	210 234
<i>Tilting Pistons @ R 483 each</i>	24	11 592
<i>Main Conveyor</i>	12	154 852
<i>Overhead Chain Conveyor</i>	2	284 000
<i>Carton Box Sealer</i>	1	140 905
<i>Bar Code Scanner</i>	1	7 525
<i>Sorting Conveyor</i>	1	44 460
<i>Sorting Pistons</i>	Dispenser	1 752
	Ejection	20 424
<i>Solenoid Valves</i>	25	28 300
	Total	1 973 588

* This printer price includes the printer's control box, but if one control box can be used for all the printers the price will be drastically reduced.

8. Conclusions.

Based on the work of this thesis, the following conclusions are drawn.

- 1) The Lego model of the proposed design operates correctly and uses the correct principles of control and materials handling. The Lego model, however, is only used to illustrate the concept physically and is not an exact replica of the proposed system. The conveyor lengths and positioning of the production lines are not precisely to scale with the actual factory layout. The limitations of Lego (Chapter 3) allows Lego only to be used to model concepts and not model detailed machine components.
- 2) Due to the limitations of Lego, various non-Lego components had to be used, such as the pneumatic solenoid valves, provided by Festo, and the various electronic components used for the control of the system. However, it must be noted that Lego is very compatible with non-Lego devices and can be manipulated to interact with these devices to improve the function of the system being modelled.
- 3) The Lego interface is an excellent Analogue to Digital (ADC) and Digital to Analogue converter (DAC). The computer code used to interface the PC with the Lego interface is simple and user-friendly. A major problem with the Lego interface, is the limited number of outputs and inputs. This then limits the number of drive systems and sensor used in the model.
- 4) The concepts demonstrated by the Lego model are transferred to the actual factory layout and the components needed as well as the positioning is suggested. The model corresponds well with the design presented for the actual factory layout.

- 5) The improved design of the material handling procedure at the end of each production line will increase the amount of free space available on the factory floor. The areas where empty boxes are stored on the factory floor (Appendix A, Drawing A.1) will no longer be needed. The empty boxes will be stored and transported on the overhead chain conveyor system, which is suspended from the ceiling.
- 6) The use of bar codes, for identification purposes, will drastically reduce the amount of human error associated with incorrect identification and storage.
- 7) The manual labour jobs have been improved. The workers are only responsible for one job at a time and not numerous jobs as seen in the present system. This should reduce the time taken for a manual procedure to be performed.
- 8) The work areas have also been improved. The workers will be required to walk less distance and lift heavy loads over shorter distances. This will decrease the chances of possible injury and improve the workers working conditions and environment.
- 9) All the drive systems either use, compressed air or mechanical gearboxes to drive the various system in the factory design. The gearboxes which drive the conveying systems do not have to travel at the exact velocities specified in the thesis. If a less expensive conveyor gearbox is found which runs a conveyor system slightly faster than calculated it should be used. Simple standard gearbox units require less time to replace if a breakdown or mechanical failure occurs. This will in turn reduce the factories downtime and increase productivity.
- 10) The one advantage of modelling a concept first is that the control program can be fine tuned for the model, long before it is implemented in the factory. The PLC program used to control the factory systems is designed from the control program for the Lego model. These two sets of computer code are identical in the manner they function.

11) The estimated cost of the proposed design is R 1 973 588 while the cost of the Lego model is estimated to be R 10 523. The cost of the model is inexpensive when considering that all the Lego components can be re-used for other design projects in the future.

12) The Lego model does not demonstrate the empty box assembly procedure as well as the carton box sealing procedure. These two procedures are done manually and were not modelled in the Lego model. The procedures, however, are designed for the actual factory layout.

9. Recommendations.

Based on the conclusions the following are recommendations.

- 1) A more detailed cost analysis must be performed on the various components needed for the improved factory design. The cost per month of operating the system must also be investigated.
- 2) An investigation must be performed to check the strength and stability of the factory ceiling beams and supports, before the overhead chain conveyor is installed.
- 3) More detailed design and component drawings must be done for each of the components and systems modelled.
- 4) The layout of the factory must be checked for human accessibility.
- 5) The design should be implemented over several years in the following sequence.
 - i) The filling conveyors and bar code printers should be installed at each production line.
 - ii) The main conveyor system should be installed.
 - iii) The sorting conveyor and bar code scanner system should be installed.
 - iv) The overhead chain conveyor system should be installed.
 - v) The carton box erection and sealing machines should be installed.

In this way the cost of installing the entire factory design can be spread out over a few years and the total cost does not have to be paid at once.

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Appendix A

Lego Components and Specifications

9864
Green building plates (8 x 16 stud)
3 x

9969
Pulley wheels
Tyres
Spoked hubs

8 x 4 x 12 x

9876
Large turntables
2 x

9970
Small cross axles (2 to 6 stud lengths)
4 x 8 x 12 x 12 x

9971
Large cross axles (8 to 12 stud lengths)
8 x 8 x 8 x

9960
Crane hook, cam, propeller
1 x 8 x 4 x

9961
Pulley belts
8 x Ø24 4 x Ø26 4 x Ø28 4 x Ø33

9972
Red plates with/without holes
24 x 8 x 8 x 8 x 8 x 4 x 8 x 4 x 2 x 2 x 2 x

9962
Flat tiles
4 x 4 x 2 x 2 x

white/grey/red/blue/yellow/black
red/blue/yellow/black
red/yellow/black
white/blue/yellow/red/black

9963
Axle extenders, small pulleys, bushes, universal joints, piston rods
12 x 32 x 24 x 16 x 4 x

9973
Black plates with/without holes
24 x 8 x 8 x 8 x 8 x 4 x 8 x 4 x 2 x 2 x 2 x

9964
Connector pegs
Bush/cross axles
16 x 32 x 8 x 8 x

9965
8 teeth gear wheels
16 teeth gear wheels
16 x 8 x

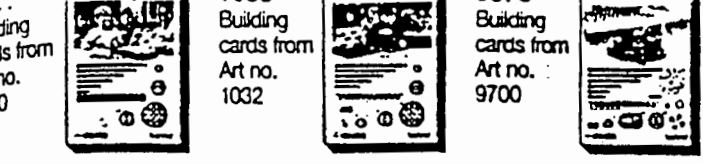
9974
Yellow plates with/without holes
24 x 8 x 8 x 8 x 8 x 4 x 8 x 4 x 2 x 2 x 2 x

9966
24 teeth gear wheels
40 teeth gear wheels
12 x 4 x

9967
Bevel gears
Differential house
Mini differential house
Crown gears
12 x 1 x 1 x 4 x

9968
Pulley wheels
Tyres

9968
Pulley wheels
Tyres



Electrical components



9859
9 volt motor

1 x

9860
9 volt battery box including two-way switch

1 x

9861
9 volt connecting wires (25 and 128 cm long)

4 x

9865
9 volt sensor including rotating disc

1 x 1 x

9863
9 volt bricks transparent red, yellow, green

6 x 2 x red 2 x yellow 2 x green

9867
9 volt sensor

1 x

9868
9 volt plugholders, helices (3 m and 10 cm) Flat tiles

1 x 12 x 2 x

1 x 1 x 1 x 1 x 1 x 1 x

2 x red 2 x blue 2 x yellow 2 x black

1 x 1 x 1 x 1 x 1 x

9831
9 volt battery box including two-way switch

1 x

9833
9 volt transformer

1 x

9883
9 volt motor

1 x

9830
9 volt light brick, transparent bricks, parabols

1 x 2 x 2 x 2 x 2 x 2 x 2 x

9885
9 volt sound element

1 x

9886
9 volt electric plates

3 x

9887
9 volt electric wires (10, 25.6 and 128 cm long)

2 x 2 x 2 x

9888
9 volt touch sensor

1 x

9889
9 volt temperature sensor

1 x

9890
9 volt light sensor

1 x

9891
9 volt angle sensor

1 x

Output devices

	Voltage	Power Consumption	Revolutions
motor without load	9V	appr. 40 mA	appr. 4200 RPM
motor with normal load	9V	appr. 160 mA	appr. 1600 RPM
mp	9V	appr. 30 mA	
und element	9V	appr. 0.2 mA	

Input devices

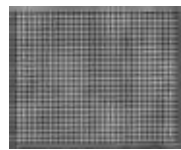
Type	Sensor Range	Measuring	Accuracy	Range Limits
non powered	digital			
non powered	analog	-20° to +50°C	± 1°C at 25°C	appr. ±1°C
powered	digital	16 positions per revolution		max. 500 RPM w/function
powered	analog	0.6-760 Lux		

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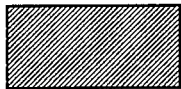
B.1 Factory Production Lines.

The factory layout and various production lines are shown in Drawing B.1. and Drawing B.2 respectively. The products produced as well as the speeds at which the products are produced are tabulated in Table B.1.

Referring to Drawing B.1 and B.2,



- Pallets containing filled boxes.



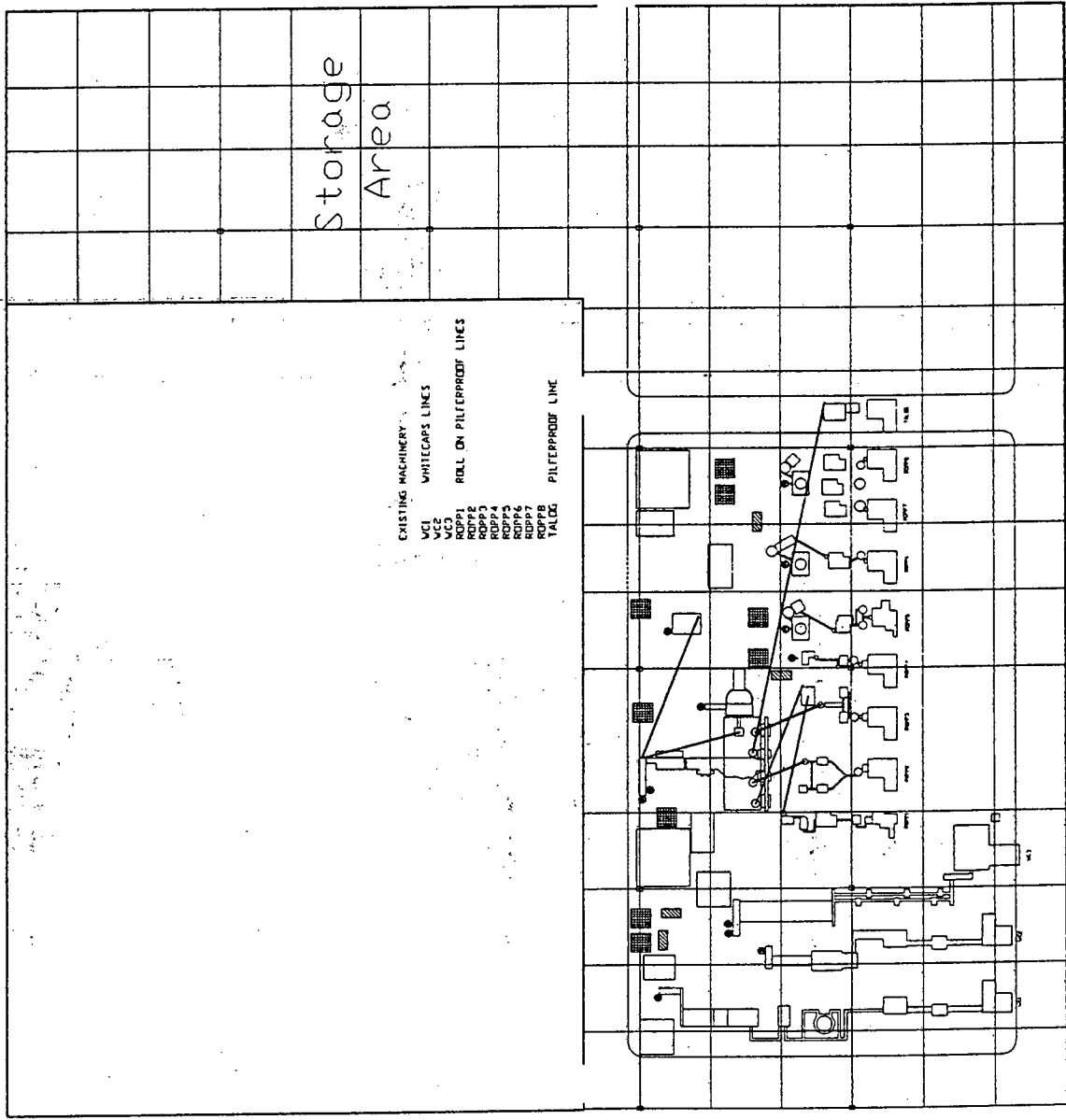
- Workbenches.



- Filling Points.

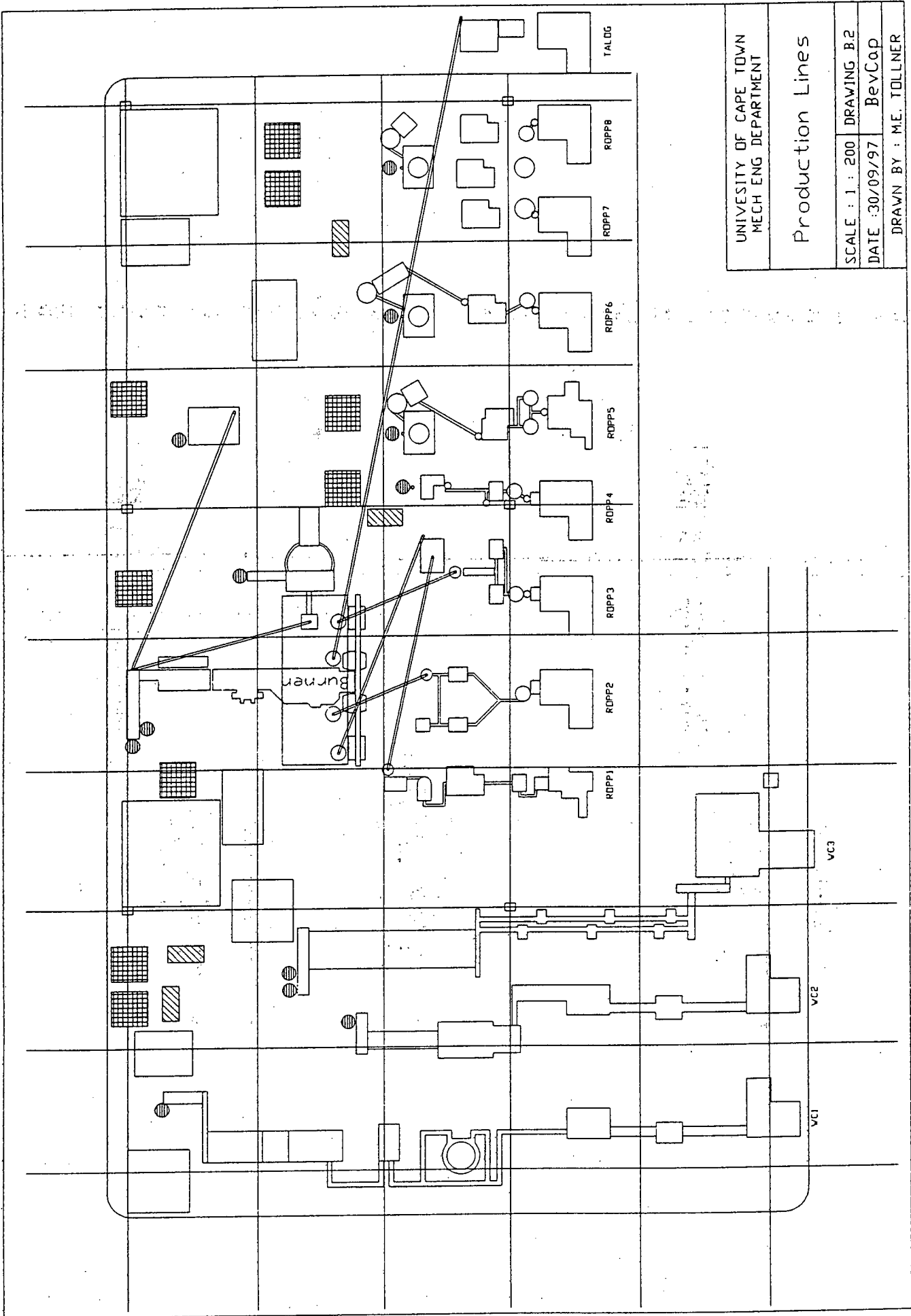


- Empty Box Storage Area.



UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT	
Factory Layout	
SCALE : 1 : 500	DRAWING B.1
DATE : 30/09/97	BevCap
DRAWN BY : M.E. TOLLNER	





UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT	
Production Lines	
SCALE : 1 : 200	DRAWING B.2
DATE : 30/09/97	BevCap
DRAWN BY : M.E. TOLLNER	

Table B.1 : Production line specifications.

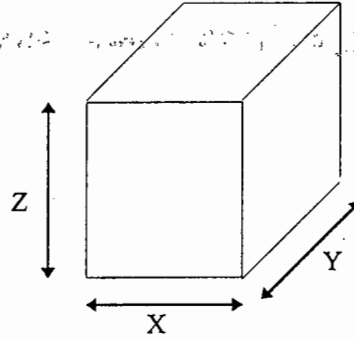
Line	Product	Variation	Maximum Line Speed / EMU (Closures / Hour)	Count Per Carton	Carton Fill Rate (Cartons / Hour)	Maximum carton Fill Rate (Cartons / Hour)	Annual Sales Quantity (Units)	Annual Sales Quantity (Cartons)
Whitecaps								
Line 1	51 PT		20 000	2 000	10		24 974 500	12 488
	53		20 000	1 600	13		12 341 200	7 714
	63		20 000	1 200	17	17	16 253 009	13 545
Line 2	43		20 000	3 000	7		14 217 860	4 740
	48		20 000	2 500	8		3 748 500	1 499
	63		20 000	1 200	17		16 253 009	13 545
	82		14 400	700	21	21	2 867 170	4 096
Line 3	38		19 000	2 000	10		23 781 550	11 891
	70		17 700	950	19	19	37 549 170	39 526
ROPP								
Line 1	30 x 23		10 500	3 000	4	4	10 775 600	3 592
Line 2	31.5 x 17	wad / compound	20 000	4 000	5		22 613 400	5 654
	31.5 x 18	compound	20 000	3 700	6	6	21 484 850	5 807
Line 3	28 x 15	duogrip	25 000	5 000	5	5	33 978 700	6 796
	28 x 15.7	duovent	25 000	5 000	5		145 000	29
Line 4	30 x 18	wad / compound	17 100	4 500	4	4	13 138 300	2 920
Line 5	30 x 34	expanded polystyrene wad	11 100	2 000	6		16 402 365	8 202
	30 x 35	steran face wad / embossing	11 100	1 800	7	7	9 635 085	5 353
Line 6	30 x 34	expanded polystyrene wad	11 100	2 000	6		16 402 365	8 202
	30 x 35	steran face wad / embossing	11 100	1 800	7	7	9 635 085	5 353
Line 7	30 x 44		11 100	1 500	8	8	4 828 100	3 219
Line 8	30 x 50		11 100	1 000	12	12	not yet operational	-
Line 9	talog		25 000	5 000	5	5	not yet operational	-
TOTALS						115		164 171

B.2 Carton Box Dimensions.

The carton box dimensions are tabulated below in Table B.2.

Table B.2 : Carton box dimensions.

	REF 86	REF 88
X	324 mm	327 mm
Y	499 mm	503 mm
Z	465 mm	338 mm



B.3 Time to Manually Assemble Boxes.

The times taken for workers to assemble the boxes was measured using a stop-watch.

The results are presented in this section.

B.3.1 REF 88 Boxes.

The recorded times for assembling the REF 88 boxes are tabulated below in Table B.1.1.

Table B.1.1 : REF 88 Assembly times (All Values in seconds)

52.64	48.38	45.56	49.02	54.35
47.91	29.69	35.13	36.81	34.97
80.37	52.48	49.75	35.45	33.58
26.69	42.13	75.89	34.58	45.78

Therefore,

Mean = 47.47 Seconds

Standard Deviation = 13.96 Seconds

Therefore, the range of times for a REF 88 carton box to be assembled is,

Range : 26.69 to 80.37 Seconds

B.3.2 REF 86 Boxes.

The recorded times for assembling the REF 86 boxes are tabulated below in Table B.1.2.

Table B.1.2 : REF 86 Assembly times (All Values in seconds)

42.67	110.67	54.56	53.56	59.98
35.87	67.80	66.57	45.65	43.45
67.89	80.76	45.67	42.34	48.02
54.67	52.56	56.89	60.50	78.90

Therefore,

Mean = 58.45

Standard Deviation = 17.26

Therefore, the range of times for a REF 88 carton box to be assembled is,

Range : 35.87 to 110.67 Seconds

B.4. Time to Seal and Label Boxes.

The recorded times for sealing and labelling the REF 88 and REF 86 boxes are tabulated below in Table B.2.

Table B.1.1 : Sealing and labelling times (All Values in seconds)

40.59	55.39	40.72	29.49	29.03
41.04	41.54	28.11	34.49	42.16
40.53	56.47	69.07	79.30	71.62
70.38	70.44	72.42	86.54	83.95

Therefore,

Mean = 54.16 Seconds

Standard Deviation = 19.59 Seconds

Therefore, the range of times for sealing and labelling a carton box is,

Range : 28.11 to 86.54 Seconds

B.5 Identification Labels.

An illustration of the identification labels used are shown in Figure B.5.

71006899		CARTON QUANTITY:	700
DESCRIPTION		CROSSE & BLACKWELL	
SIZE:		82mm RTS CAPS	
ORDER NO:		CUSTOMER:	NESTLE
WAREHOUSE FROM:	DESIGN CODE:	LINE COMPOUND:	MANUFACTURE DATE:
WCRM		289	21 OCT 1996
CARTON NO:	SHIFT:	LINE NO:	PACKERS NO:
	D/S	2	554 2578

Figure B.5 : Identification labels

B.6 Labour Costs.

The labour costs is shown in Table B.6.

Table B.6 : Labour Costs.

Worker	Earnings Feb-Oct 96	Monthly Salary
	(Rands)	(Rands)
Permanent		
Number of Workers 9		
Whitecap		
Permanent 1	24 701.68	2 744.63
Permanent 2	28 685.89	3 187.32
Permanent 3	22 599.71	2 511.08
Permanent 4	25 921.48	2 880.16
Permanent 5	22 137.43	2 459.71
Permanent 6	24 234.64	2 692.74
ROPP		
Permanent 1	25 180.01	2 797.78
Permanent 2	23 795.92	2 643.99
Permanent 3	25 631.85	2 847.98
AVERAGE MONTHLY EARNINGS		2 751.71

B.7 Forklift Operating Cost.

Table B.7 : Forklift operating Cost.

Item	Unit		Cost
Operating costs			
Normal	month		3 594.00
Extra	hour		4.96
Tyres	each		700.00
Operating hours	(Hours)	(Extra Hours >150)	
Jan-96	162	12	3 653.52
Feb-96	150	0	3 594.00
Mar-96	160	10	3 643.60
Apr-96	95	0	3 594.00
May-96	45	0	Breakdown
Jun-96	115	0	3 594.00
Jul-96	105	0	3 594.00
Aug-96	45	0	Breakdown
Sep-96	164	14	3 663.44
Oct-96	169	19	3 688.24
Average Monthly Cost		R	3 721

Appendix C

Electrical Design for the Lego Model

C.1 Design of a Circuit to Drive Two Motors, Using One Output Port.

A circuit must be designed which can control the filling conveyor and printer drive motors from the same output port. The output port can output a +9, -9 or 0 Volt DC signal. For this, a circuit is design to meet the above mentioned requirements. The only problem is that the two motors can never run simultaneously, therefore the above mentioned motors where chosen, because, the printer and filling conveyor motors will never need to run together.

To do this the following simple circuit was designed, and is illustrated in Figure C.1.

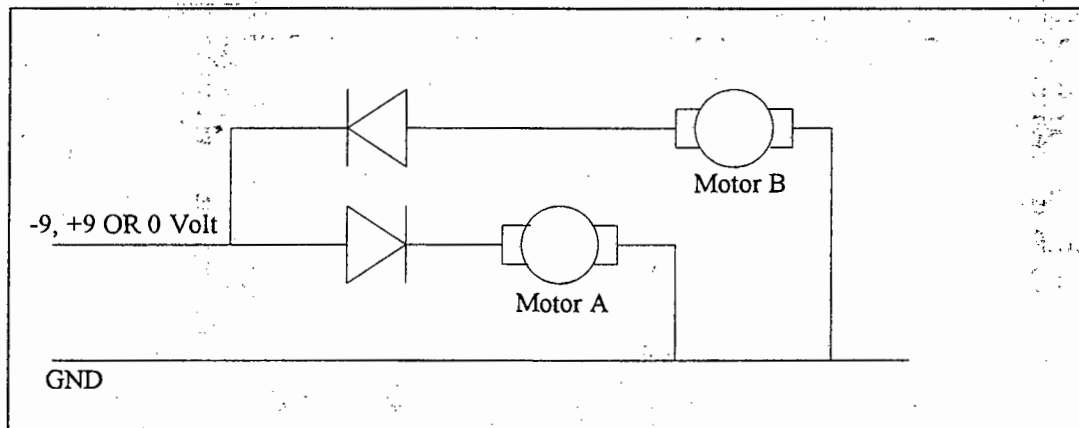


Figure C.1 : Drive circuit for controlling two motors using one output port.

When the output is set at +9 Volts, only motor A will run and motor B will be stationary. This is because the current to motor B is being blocked by the diode. Likewise, if the output is set at -9 Volts, then motor B will run and motor A will be stationary, for the same reasons as before. Finally, when the output is set to 0 Volts, both motors will be stationary.

The only disadvantage with this system, is that, there is a small voltage drop across the diodes. The voltage drop V_{DIODE} is approximately 0.7 Volts. Therefore, instead of 9 Volts going to each of the motors, only 8.3 Volts is. The difference in voltage, is small enough not to effect the performance of the motors by much.

C.2 Design of the Solenoid Valve Control Circuit.

The only problem encountered with controlling the solenoid valves, was, that they required a 24 Volt DC to trigger, while the Lego Interface only supplies 9 Volts DC. As a result a relay switch was used to supply the 24 Volts, on command, without damaging the interface. The simple circuit is shown in Figure C.2.

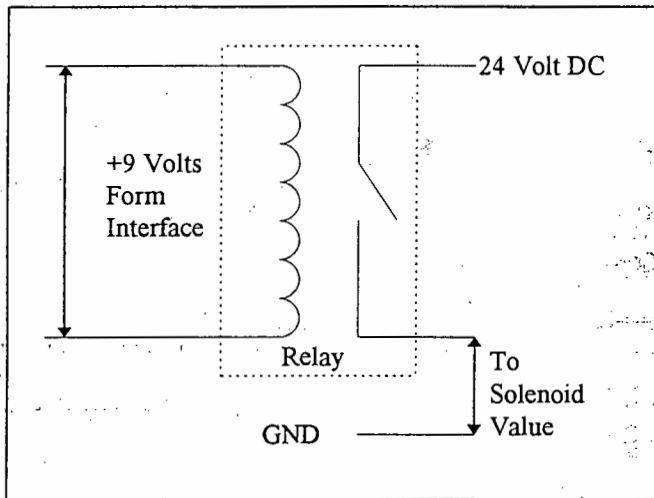


Figure C.2 : Solenoid valve control circuit.

When the interface output is set to +9 Volts, the relay coil charges and closes the switch built in it. This allows the +24 Volts source to flow through the solenoid valve. Which, then activates the valve.

C.3 Design of the Light Sensor System on the Filling Conveyor.

A Light Dependent Resistor (LDR), is used to measure the change in light. The set-up of the light sensor at the end of the filling conveyor is illustrated in Figure C.3.1.

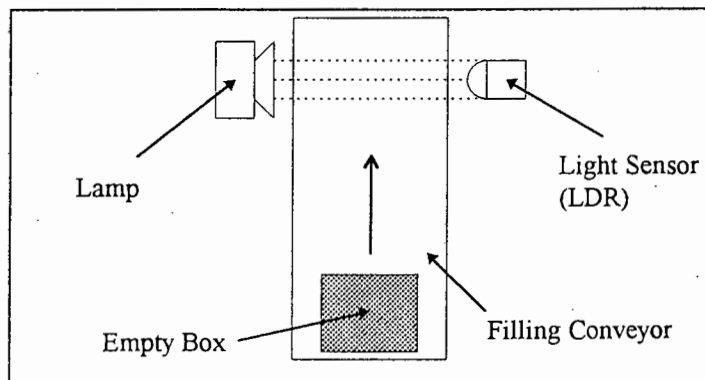


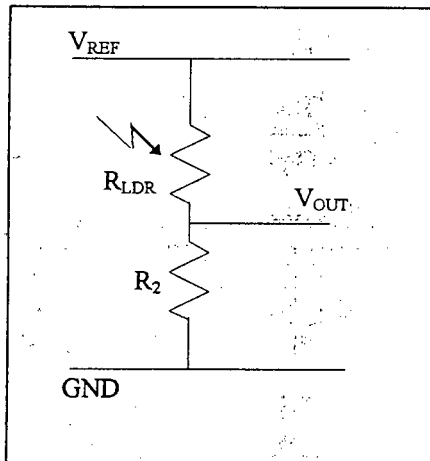
Figure C.3.1 : Light sensor set-up on the filling conveyor.

The LDR resistance changes are shown below :

When exposed to the full light of the lamp $R_{LDR} = 1 \text{ K}\Omega$

When blocked by a box $R_{LDR} = 10 \text{ K}\Omega$

Firstly the change in resistance must be converted into a change in voltage, so it can be compared by a comparator. A simple voltage divider is used to solve this problem and is illustrated in Figure C.3.2.



Where,

$$V_{OUT} = \frac{R_2}{R_{LDR} + R_2} \cdot V_{REF}$$

A 9 Volt source is used as the reference voltage (V_{REF}). The change from the minimum to the maximum voltage must be as large as possible. Therefore, R_2 must be designed accordingly.

Figure C.3.2 : Voltage divider for LDR resistor.

If R_2 is too high, the voltage difference will be low. Therefore, R_2 must be lower than the maximum R_{LDR} resistance ($10 \text{ K}\Omega$), and high enough in resistance not to cause too much current. Let's say,

$$R_2 = 4.7 \text{ K}\Omega$$

Therefore,

$$V_{OUT} = \frac{4.7}{R_{LDR} + 4.7} \cdot 9$$

$$R_{LDR} = 1 \text{ K}\Omega \quad V_{OUT} = \frac{4.7}{1 + 4.7} \cdot 9 = 7.42 \text{ Volts}$$

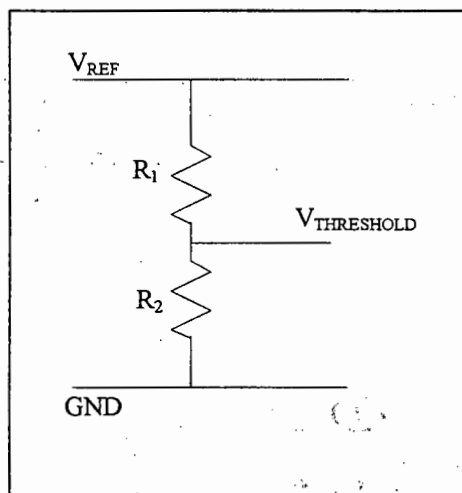
$$R_{LDR} = 10 \text{ K}\Omega \quad V_{OUT} = \frac{4.7}{10 + 4.7} \cdot 9 = 2.877 \text{ Volts}$$

The voltage difference between the two readings, is 4.54 Volts, which is large enough to prevent any errors from occurring. A threshold voltage was then set. This voltage was used as a trigger voltage for the comparator. So, if V_{OUT} falls below the threshold voltage, i.e. a box is in the path of the light sensor, the comparator will trigger.

Looking at the above maximum and minimum voltage, a threshold voltage was set.

$$V_{THRESHOLD} = 5 \text{ V}$$

A voltage divider was used to obtain the set threshold voltage, as illustrated in Figure C.3.3.



Where,

$$V_{THRESHOLD} = \frac{R_2}{R_1 + R_2} \cdot V_{REF}$$

$$V_{REF} = 9 \text{ V}$$

Set,

$$R_1 = 4.7 \text{ K}\Omega$$

$$R_2 = 5.6 \text{ K}\Omega$$

Figure C.3.3 : Voltage divider for threshold voltage.

So,

$$V_{THRESHOLD} = \frac{5.6}{4.7 + 5.6} \cdot 9 = 4.86 \text{ Volts}$$

A LM 324 Comparator chip was used to compare the two voltages, V_{OUT} and $V_{THRESHOLD}$. The LM 324 comparator chip and pin numbers are shown in Figure C.3.4

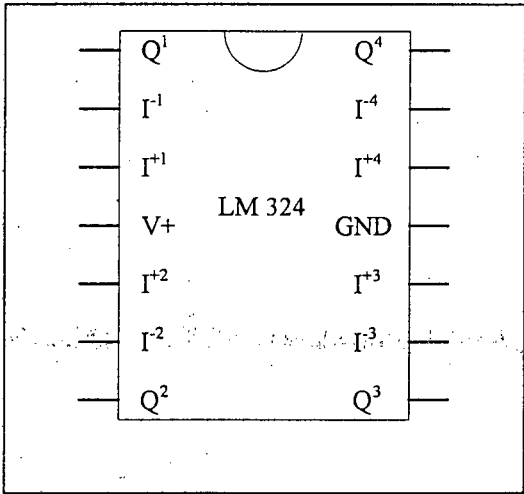


Figure C.3.4 : LM 324 comparator.

Therefore using the comparator the circuit looks as follows, Figure C.3.5.

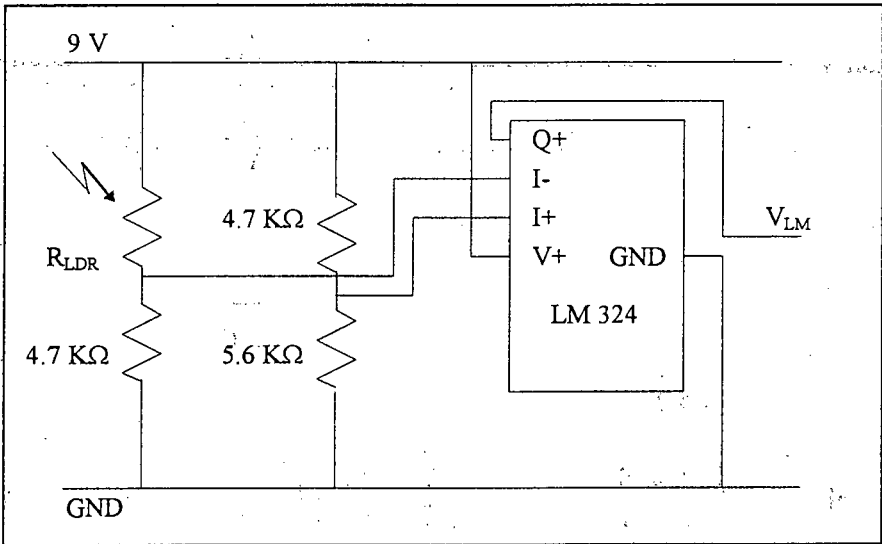


Figure C.3.5 : Comparator circuit for filling conveyor light sensor.

A state-time graph, Figure C.3.6, shows what happens when a block travels in front of the light sensor system.

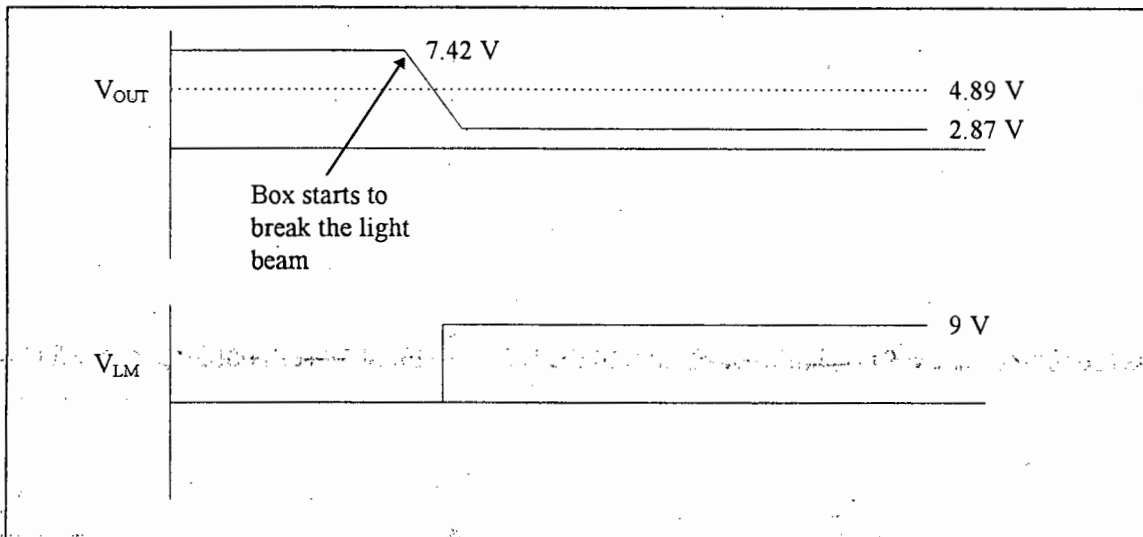
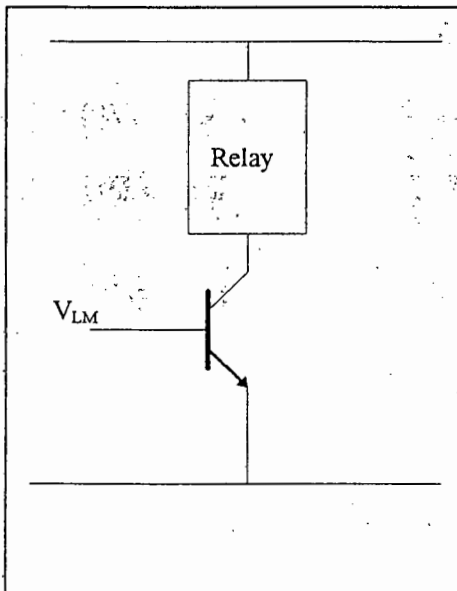


Figure C.3.6 : State-Time graphs for the comparator output of the filling conveyor light sensor.

Now, the voltage from the output of the comparator needs to charge a relay. The relay is used to indicate to the computer, through the Lego interface, that a box has entered into position to be filled. The LM 324 chip outputs +9 Volts, but, with no large current to back it up. Therefore, the relay, which relies on current to charge, cannot charge. Therefore, a current source is needed to help the comparator output charge the relay. For this a transistor was used and is illustrated in Figure C.3.7.



As the LM 324 output goes high (9V), the transistor closes and current flows through the relay whereby charging it.

Figure C.3.7 : Transistor current source.

C.4 Design of the Gravity Conveyor Light Sensor System.

This system works in the same way as the filling conveyor light sensor system, mention in Section C.3 above. The system, uses a Light Dependent Resistor (LDR) to identify if a box is in front of it or not. The LDR resistance changes are shown below.

When exposed to the full light of the lamp $R_{LDR} = 1K\Omega$

When blocked by a box $R_{LDR} = 4K\Omega$

The reason the LDR resistance is much lower than the LDR resistance of the filling conveyor light system, is because it is exposed to more surrounding light, i.e. the light from the sun or surrounding lamps. The above R_{LDR} maximum resistance was measured in a fully illuminated room. For example, in a dark room, the R_{LDR} resistance is approximately 20 K Ω , when blocked by a box. The circuit was therefore designed around the worse case scenario, that being a fully illuminated room.

To convert the change in resistance to a change in voltage, a voltage divide was used and is illustrated in Figure C.4.1.

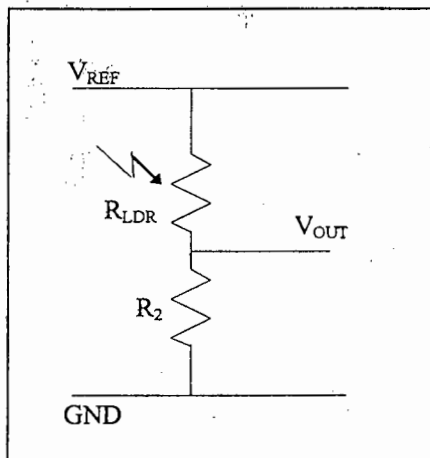


Figure C.4.1 : Voltage divider for LDR resistor.

Where,

$$V_{OUT} = \frac{R_2}{R_{LDR} + R_2} \cdot V_{REF}$$

Let,

$$V_{REF} = 24 \text{ Volts}$$

$$R_2 = 4.7 \text{ K}\Omega$$

$$R_{LDR} = 1 \text{ K}\Omega \quad V_{OUT} = \frac{4.7}{1+4.7} \cdot 24 = 19.79 \text{ Volts}$$

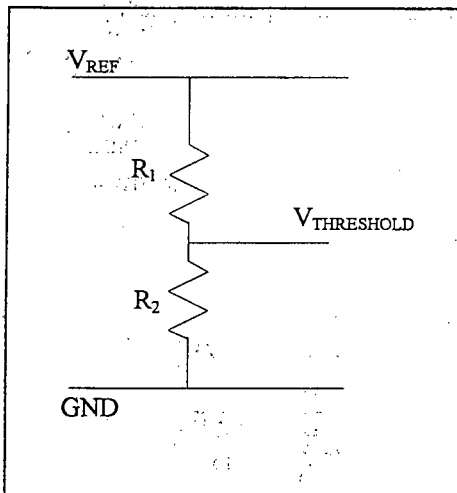
$$R_{LDR} = 4 \text{ K}\Omega \quad V_{OUT} = \frac{4.7}{4+4.7} \cdot 24 = 12.96 \text{ Volts}$$

A threshold voltage was set next. The threshold voltage was set closer to the upper limit voltage (19.79 Volts). This was done in case the model is placed in a brighter environment, as this might cause the maximum R_{LDR} value to be lower than predicted.

The following threshold voltage was set.

$$V_{THRESHOLD} = 17 \text{ Volts}$$

A voltage divider was used to obtain this set voltage, Figure C.4.2 illustrates this.



Where,

$$V_{THRESHOLD} = \frac{R_2}{R_1 + R_2} \cdot V_{REF}$$

$$V_{REF} = 24 \text{ V}$$

Set,

$$R_1 = 6.5 \text{ K}\Omega$$

$$R_2 = 16 \text{ K}\Omega$$

Figure C.4.2 : Voltage divider for threshold voltage.

$$\text{So,} \quad V_{THRESHOLD} = \frac{16}{6.5+16} \cdot 24 = 17.07 \text{ Volts}$$

As before, in the filling conveyor light sensor system, a LM 324 comparator was used to compare the two voltages, V_{OUT} and $V_{THRESHOLD}$. The comparator then gives an output voltage (V_{LM}), of 0 or 24 Volts, depending on its state. A transistor was then

used to increase the current from the LM 324 output to charge the solenoid valve. The final circuit is shown in Figure C.4.3.

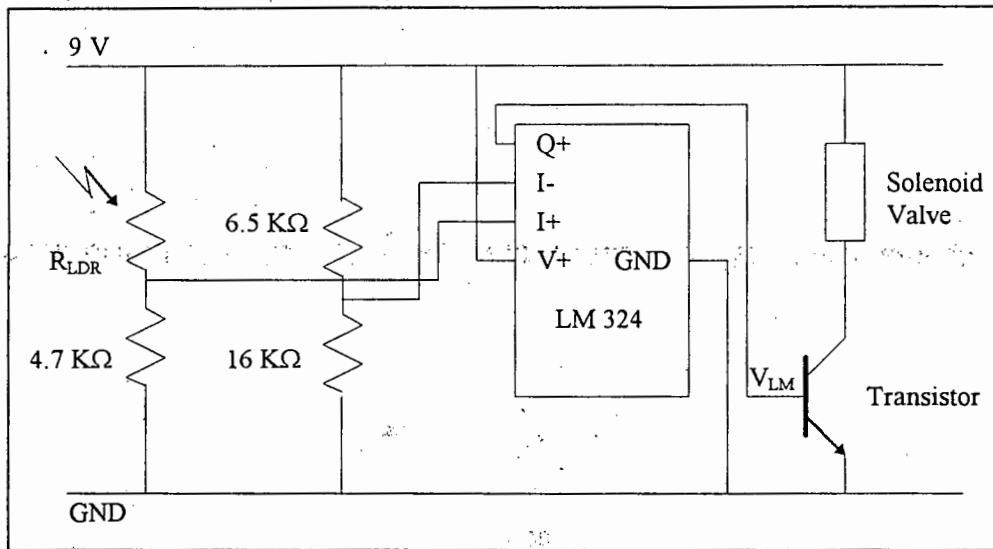


Figure C.4.3 : Comparator circuit for light sensor system on the gravity conveyor.

A State-Time graph of the above circuit, Figure C.4.3, as a box blocks the light beam, is shown in Figure C.4.4.

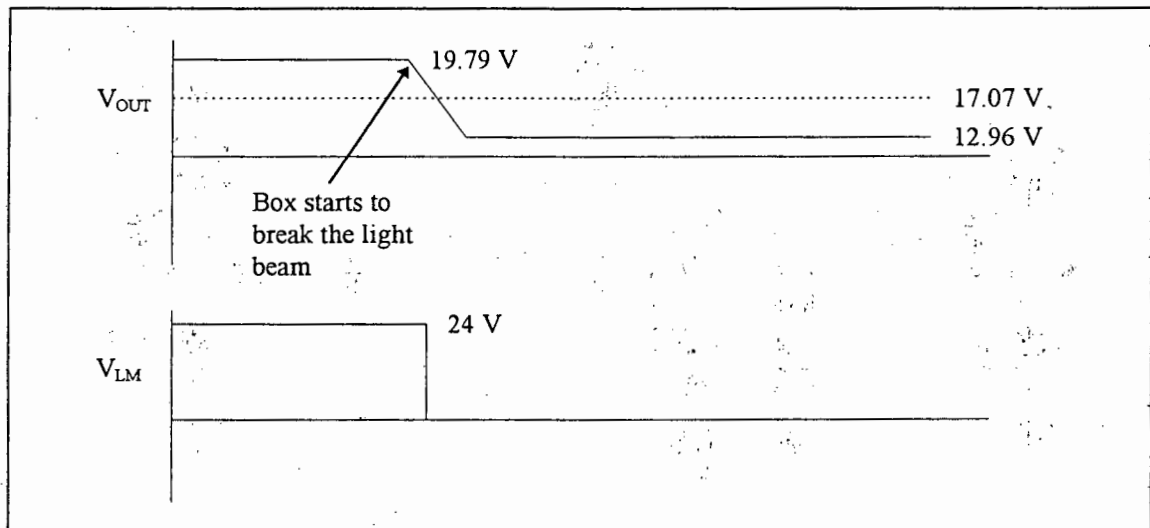


Figure C.4.4 : State-Time graph for comparator circuit.

C.5 Design of the 9 and 24 Volts DC Power Sources.

The DC power source which is used to drive the above mentioned circuitry needs to be built. The interface has it's own 9 Volts 7VA DC supply. The 9 Volts needed to drive the above mentioned circuitry cannot be obtained from the Lego interface, this is because of a problem with power. The Lego power supply has enough difficulty trying to keep its own systems running, let alone the other circuits. Therefore, a more powerful transformer is needed. A perfect transformer was found, which runs off mains and has two 9 and two 12 Volt outputs. It also has a current limitation of 2.5 Amps. This is compared to the Lego interface power supply which has a 0.7 Amp current limitation.

The only problem is, that the output of the transformer is AC not DC. Therefore a full-diode bridge had to be used, and is illustrated in Figure C.5.1.

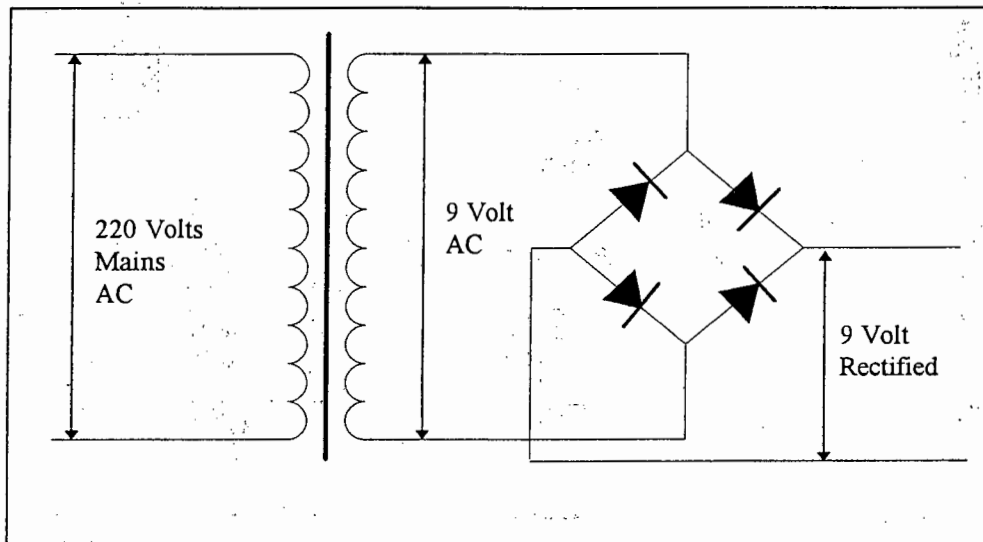


Figure C.5.1 : Full-bridge AC to DC rectifier, 9 volts.

The diode bridge rectifies the AC signal into a DC signal, but the signal has still got an AC ripple and must be 'smoothed out' by using a capacitor. The capacitor is put across the 9 Volts rectified signal, the larger the capacitance the smoother the DC signal will be, as illustrated in Figure C.5.2.

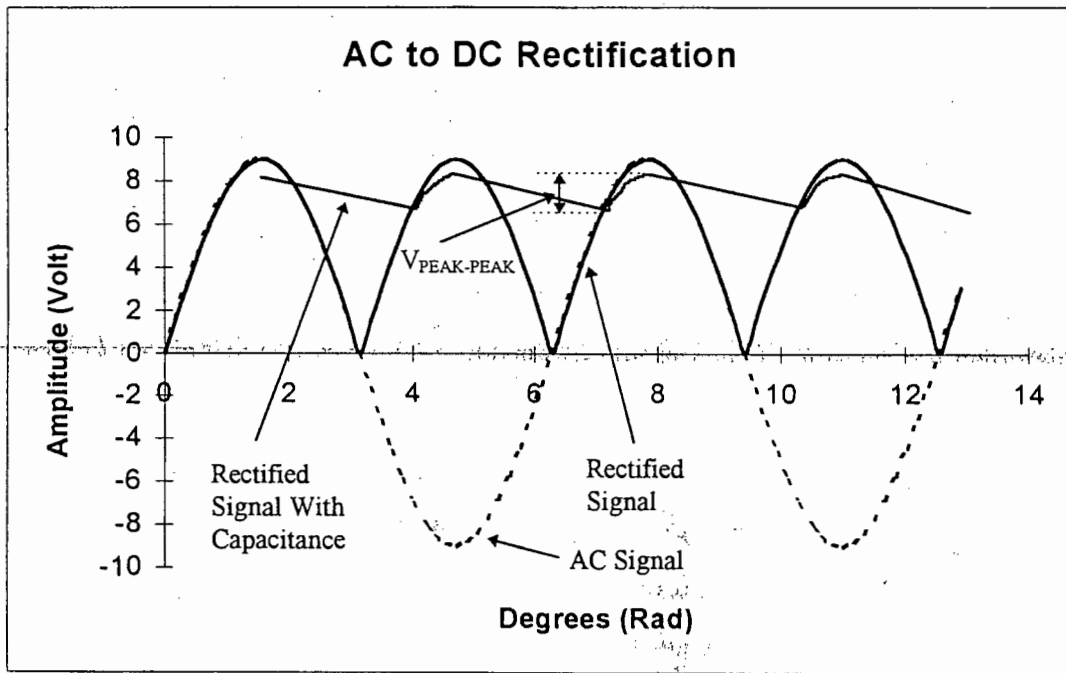


Figure C.5.2 : Wave-forms for AC to DC rectification.

From Figure C.5.2, it can be seen that the capacitance 'smoothens' the signal to a more presentable DC signal. But there is still some AC ripple, as shown in Figure C.5.2. The size of this AC signal depends on the capacitance and load current values. The AC peak-peak voltage can be calculated by using the following formula.

$$\Delta V_{\text{peak-peak}} = \frac{I_{\text{load}}}{2 \cdot f \cdot C}$$

where,

$$I_{\text{load}} = 0.6 \text{ Amp (Maximum load)}$$

$$f = 50 \text{ Hz}$$

$$C = 1000 \mu\text{F}$$

So,

$$\Delta V_{\text{peak-peak}} = \frac{0.6}{2 \cdot 50 \cdot 0.001} = 6 \text{ Volts}$$

Therefore,

$$\text{AC Ripple : } V_{\text{RIPPLE}} = 3 \text{ V}$$

The amount of AC ripple is suitable for the purpose of this power source. We do not want the AC ripple to be 9 Volts. In so, the relays of the light sensor comparators would switch on and off at a frequency of 25 Hz, because the V_{OUT} and $V_{THRESHOLD}$ voltages would be equal at 0 Volts and the comparator would latch.

For the 24 Volt DC supply, the two 12 Volt terminals were used together to obtain the 24 Volt source, as illustrated in Figure C.5.3. The signal was then rectified in the same way as the 9 Volt supply.

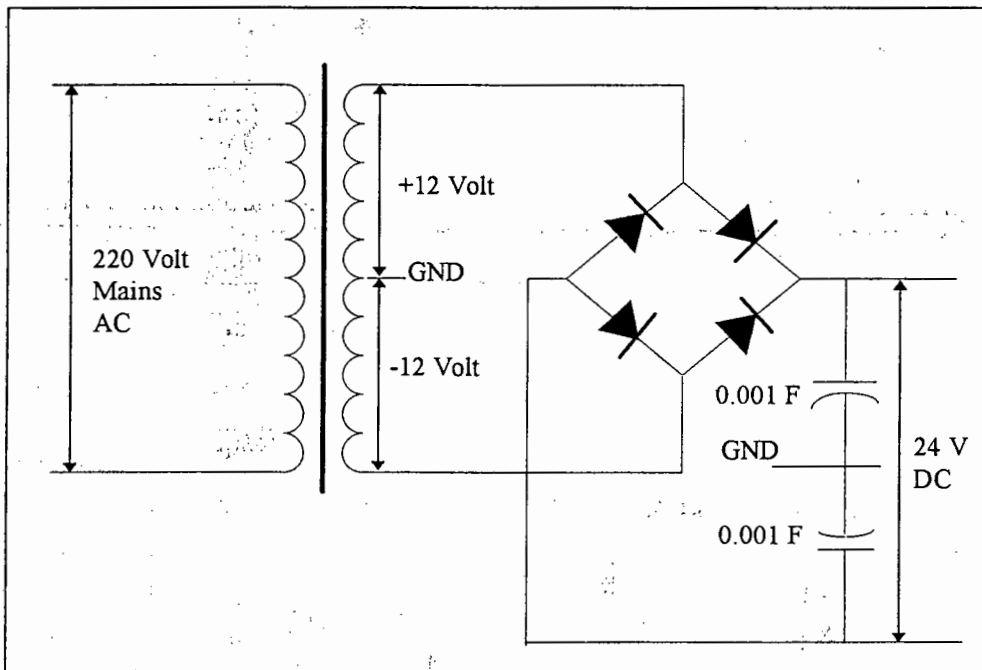


Figure C.5.3 : Full-bridge AC to DC rectifier, 24 volts.

The AC peak-peak voltage can be calculated by using the following formula.

$$\Delta V_{peak-peak} = \frac{I_{load}}{2 \cdot f \cdot C}$$

where,

$$I_{load} = 0.1 \text{ Amp (Maximum load)}$$

$$f = 50 \text{ Hz}$$

$$C = 1000 \mu\text{F}$$

So,

$$\Delta V_{\text{peak-peak}} = \frac{0.1}{2 \cdot 50 \cdot 0.001} = 1 \text{ Volt}$$

Therefore,

$$\text{AC Ripple : } V_{\text{RIPPLE}} = 0.5 \text{ V}$$

This is suitable for the needs of the 24 Volt DC power supply

Appendix D

Mechanical Design for the Lego Model

D.1 Calculating the Motor Speed vs. Torque Graph.

The motor speed and torque calculation were done in my undergraduate thesis. The results of this work are shown in this section.

Four different Lego motors were tested and the results are shown in Table D.1. A Lego apparatus was used to obtain the torque vs. rotational velocity results. The apparatus, consisted of a gear box which was connected to the motor being tested, an angle sensor and a drum. The drum, connected to the other end of the gearbox, would wind up various weights tied to the end of the string. The angle sensor was used to measure the rotational velocity of the motor lifting the weights. By changing the weight, at the end of the string, the amount of torque on the motor could be varied.

Table D.1 : Torque vs. Rotational Velocity relationships for four different Lego motors.

Torque (N.mm)	Speed (RPM)			
	Motor A	Motor B	Motor C	Motor D
0	4253	4320	4000	4275
0.253	3510	3555	3225	3750
0.308	3353	3443	2993	3600
0.376	3195	3285	2745	3555
0.441	3060	3083	2610	3375
0.598	2498	2655	2228	3060
0.808	2093	2160	1778	2678
0.931	1823	1913	1530	2250
1.116	1395	1238	1060	1620
1.190	1148	1035	1035	1238
1.252	810	810	810	1034
1.326	338	248	520	608

From the results in Table D.1, the best-fit motor speed vs. torque curve must be found. It is known that for DC motors, the torque vs. rotational velocity curve is linear. Therefore, a best-fit linear curve must be calculated from the data in Table D.1. This is done by using the following formulas, for best-fit linear curves.

$$y = a_1 \cdot x + a_0$$

where,

y = Values of motor speed, in RPM.

x = Values of Torque, in N.mm.

a_1 and a_0 = Constants.

For,

$$a_1 = \frac{n \cdot \sum x \cdot y - \sum x \cdot \sum y}{n \cdot \sum x^2 - (\sum x)^2}$$

$$a_0 = \bar{y} - a_1 \cdot \bar{x}$$

Given,

$$n = 48$$

$$\bar{x} = \frac{\sum x}{n} = 0.72034$$

$$\sum x = 8.644078$$

$$\sum x^2 = 33.786$$

$$\bar{y} = \frac{\sum y}{n} = 2308.292$$

$$\sum y = 110788$$

$$\sum x \cdot y = 56243.51$$

Therefore,

$$a_1 = -2654.34$$

$$a_0 = 4220.32$$

So,

$$\omega = -2654.34 \cdot \tau + 4220.32 \quad \dots 1$$

The graph of Motor speed (ω) vs. Torque (τ) is plotted in Figure D.1.

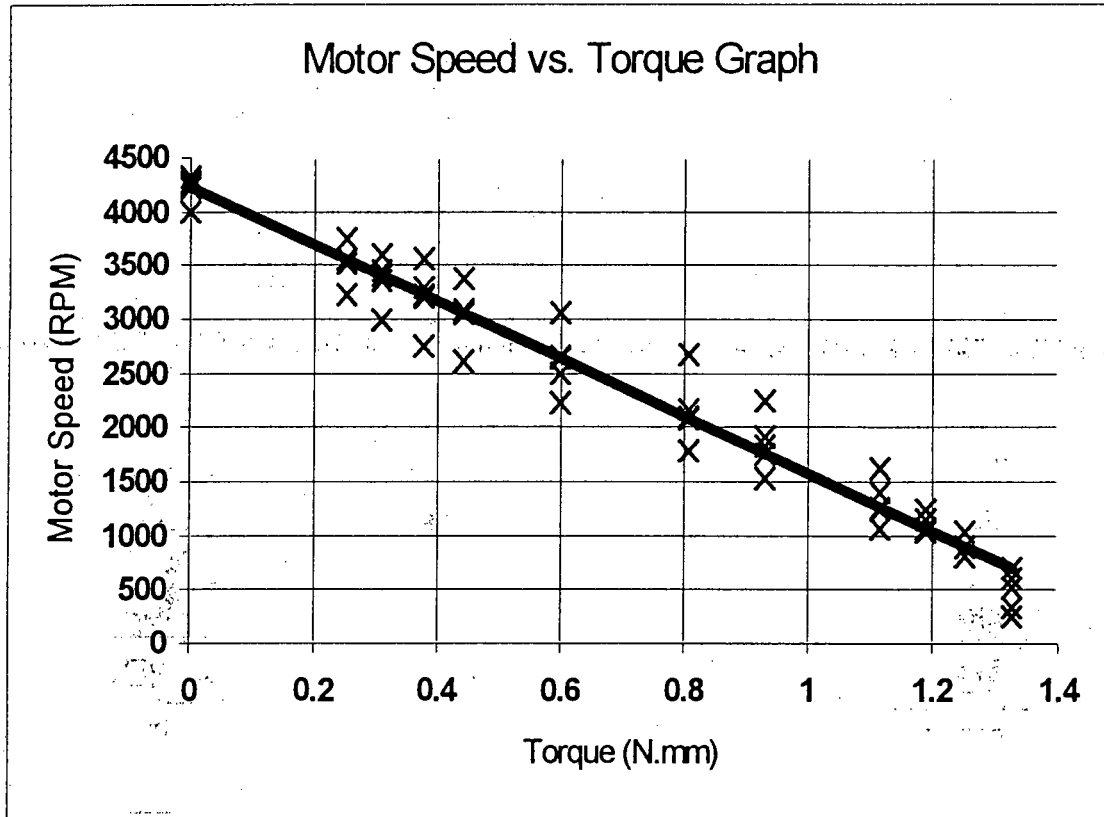


Figure D.1 : Torque vs. Rotational Velocity for the Lego motor.

D.2 Sorting Conveyor System.

The physical layout of the sorting conveyor drive system, gearbox and angle counter is illustrated in Figure D.2.

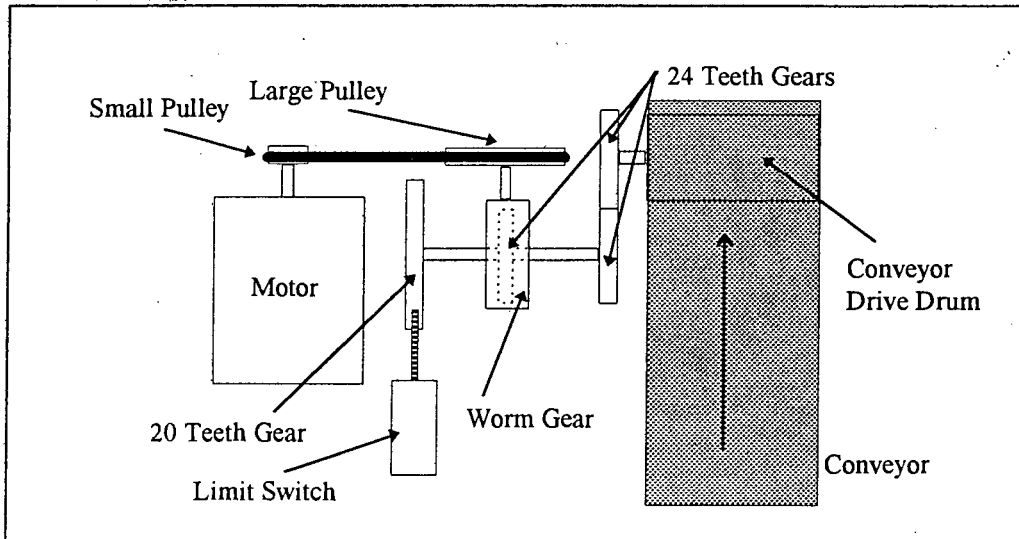


Figure D.2 : Sorting conveyor drive system.

Where,

Large Pulley Diameter = 22.2 mm

Small Pulley Diameter = 6.18 mm

The Diameter of the Drive Drum = 30 mm

The gear ratio between the worm gear and the 24 toothed gear was calculated next. To do this, various physical measurements were taken. Unfortunately the gears are so small in size, that for example, a 1mm error in the thread width reading, could change the value of the gear ratio drastically.

Therefore, the gear ratio between the worm gear and the 24 toothed gear was measured. This was done by placing two angle sensors, one on each shaft, and rotating one shaft approximately 200 times. The ratio can then be calculated by dividing the two angle sensor readings. It was found that the,

Gear Ratio Between the Worm and the 24 Toothed Gear = 24.096 : 1

From the above information the overall gear ratio, for the sorting conveyor drive system, can be calculated.

$$\text{Gear Ratio} = \frac{6.18}{22.2} \cdot \frac{1}{24.096} \cdot \frac{24}{24} = 0.01155$$

$$\text{OR} = 86.58 : 1$$

Therefore, the drive motor must complete 86.58 revolutions before the conveyor drum completes one revolutions, and one revolution of the drum causes the conveyor to move forward by,

$$\text{Distance} = \pi \cdot d_{\text{drum}} = 94.25 \text{ mm/rev}$$

It was measured, by using the Lego angle sensor, that the motor speed under normal load was.

$$\omega_{MOTOR} = 2896.1 \text{ RPM}$$

Therefore,

$$\omega_{DRUM} = \frac{2896.1}{86.58} = 33.45 \text{ RPM}$$

$$V_{CONVEYOR} = \frac{2896.1}{86.58} \cdot \frac{94.25}{1000} \cdot \frac{1}{60} = 0.0525 \text{ m/s}$$

$$\text{OR} = 52.5 \text{ mm/s}$$

From these values of rotational velocity the torque on the motor shaft and the drive drum shaft can be calculated, using equation 1.

$$\tau_{MOTOR} = \frac{2896.1 - 4220.32}{-2654.34} = 0.5 \text{ N.mm}$$

$$\tau_{DRUM} = 0.5 \cdot 86.58 = 43.194 \text{ N.mm}$$

Accuracy of the Angle Counter.

The angle counter is connected on the same shaft as the conveyor drum. Therefore, for one revolution of the drum the angle counter counts 20 steps. From this the angle of each step can be calculated.

$$\text{Angle of each count} = \frac{1}{20} \cdot 360 = 18 \text{ degrees}$$

The error of the counter is therefore 18 degrees. It is important to know the error in the angle counter, because the sorting system relies on its readings to predict when a

box must be ejected off the sorting conveyor. The error in the angle counter must therefore be translated into error in distance across the conveyor.

$$ERROR = \pi \cdot d_{drum} \cdot \frac{18}{360} = 4.712 \text{ mm}$$

Therefore the conveyor belt will move 4.712 mm before the next count is made by the angle counter. So the piston may hit a box off the conveyor 4.712 mm to early or to late. This is acceptable considering that the boxes are 32mm in width.

D.3 Main Conveyor System.

The physical layout of the main conveyor drive system and gearbox is illustrated in Figure D.3.

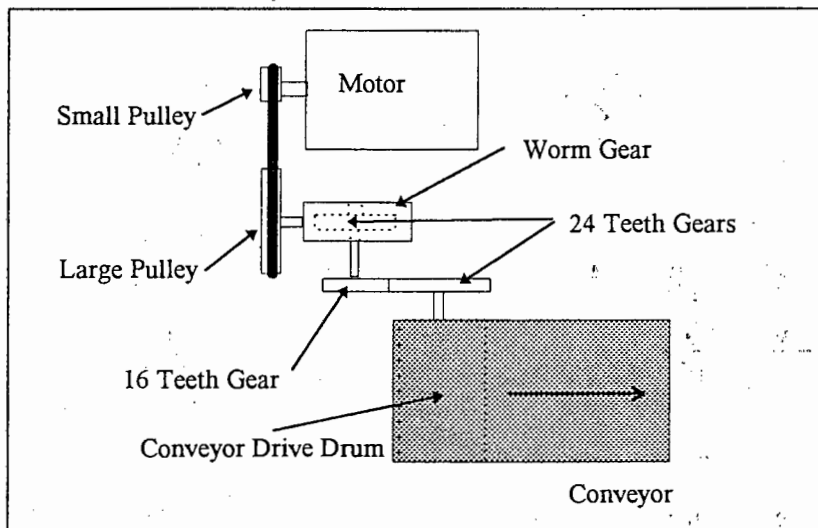


Figure D.3 : Main conveyor drive system.

Where,

- Large pulley diameter = 35mm
- Small pulley diameter = 6.18 mm
- Conveyor drum diameter = 30 mm
- Worm to 24 toothed gear ratio = 24.096 : 1

The overall gear ratio is,

$$\text{Gear Ratio} = \frac{6.18}{35} \cdot \frac{1}{24.096} \cdot \frac{16}{24} = 0.004885$$

$$\text{OR} = 204.7 : 1$$

Therefore the drive motor rotates 204.7 times for each revolution of the conveyor drum. Where one revolution of the drum is,

$$\text{Distance} = \pi \cdot d_{\text{drum}} = 94.25 \text{ mm/rev}$$

It was measured, by using the Lego angle sensor, that the motor speed under normal load was.

$$\omega_{\text{MOTOR}} = 3493.5 \text{ RPM}$$

Therefore,

$$\omega_{\text{DRUM}} = \frac{3493.5}{204.7} = 17.06 \text{ RPM}$$

$$V_{\text{CONVEYOR}} = \frac{3493.5}{204.7} \cdot \frac{94.25}{1000} \cdot \frac{1}{60} = 0.02681 \text{ m/s}$$

$$\text{OR} = 26.81 \text{ mm/s}$$

From these values of rotational velocity the torque on the motor shaft and the drive drum shaft can be calculated, using equation 1.

$$\tau_{\text{MOTOR}} = \frac{3493.5 - 4220.32}{-2654.34} = 0.273 \text{ N.mm}$$

$$\tau_{\text{DRUM}} = 0.273 \cdot 204.7 = 55.88 \text{ N.mm}$$

D.4 Filling Conveyor System.

The physical layout of the filling conveyor drive system and gearbox is illustrated in Figure D.4.

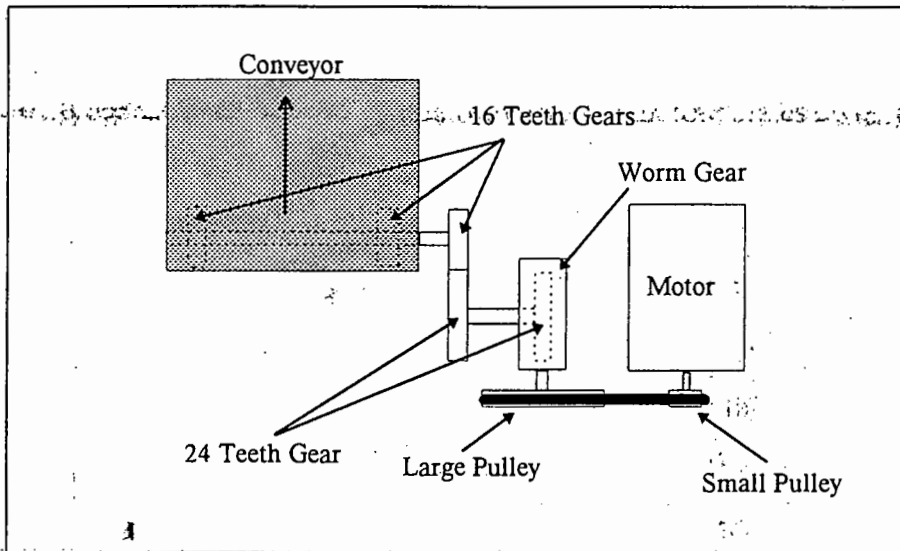


Figure D.4 : Filling conveyor drive system.

Where,

Large pulley diameter = 22.2 mm

Small pulley diameter = 6.18 mm

Worm to 24 toothed gear ratio = 24.096 : 1

The overall gear ratio of the filling conveyor drive system is.

$$\text{Gear Ratio} = \frac{6.18}{22.2} \cdot \frac{1}{24.096} \cdot \frac{24}{16} = 0.0173$$

$$\text{OR} = 57.8 : 1$$

Therefore the drive motor rotates 57.8 times before the conveyor drive gears rotate once. If the conveyor drive gears rotate once then the conveyor moves 8 conveyor tiles forward. Therefore,

$$\text{Length} = 8 \cdot 6.5\text{mm} = 52 \text{ mm/rev}$$

It was measured, by using the Lego angle sensor, that the motor speed under normal load was.

$$\omega_{MOTOR} = 1628.8 \text{ RPM}$$

Therefore,

$$\omega_{GEARS} = \frac{1628.8}{57.8} = 28.18 \text{ RPM}$$

$$V_{CONVEYOR} = \frac{1628.8}{57.8} \cdot \frac{52}{1000} \cdot \frac{1}{60} = 0.02442 \text{ m/s}$$

$$\text{OR} = 24.42 \text{ mm/s}$$

From these values of rotational velocity the torque on the motor shaft and the drive gear shaft can be calculated, using equation 1.

$$\tau_{MOTOR} = \frac{1628.8 - 4220.32}{-2654.34} = 0.976 \text{ N.mm}$$

$$\tau_{DRUM} = 0.976 \cdot 57.8 = 56.43 \text{ N.mm}$$

D.5 Printer Drive System.

The physical layout of the printer drive system and gearbox is illustrated in Figure D.5.1.

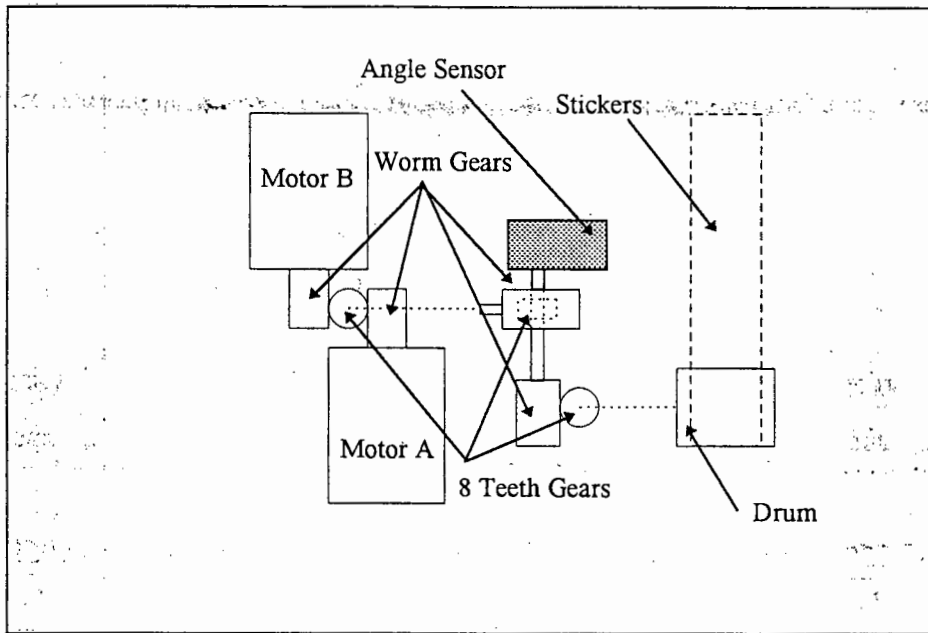


Figure D.5.1 : Printer drive system.

Where,

Gear ratio between the worm and 8 teeth gear = 8.032 : 1

Diameter of the drum = 24 mm

The overall gear ratio of the printer drive system is.

$$\text{Gear Ratio} = \frac{1}{8.032} \cdot \frac{1}{8.032} \cdot \frac{1}{8.032} = 0.0019299$$

$$\text{OR} = 518.169 : 1$$

Therefore the drive motor rotates 518.169 times before the drum rotates once. If the drum rotates once, then the sticker paper wound up is,

$$\text{Length} = \pi \cdot d_{\text{DRUM}} = 75.398 \text{ mm/rev}$$

It was measured, by using the Lego angle sensor, that the motor speed under normal load was.

$$\omega_{\text{MOTORS}} = 2279.94 \text{ RPM}$$

Therefore,

$$\omega_{\text{DRUM}} = \frac{2279.94}{518.169} = 4.4 \text{ RPM}$$

$$V_{\text{CONVEYOR}} = \frac{2279.94}{518.169} \cdot \frac{75.398}{1000} \cdot \frac{1}{60} = 0.00553 \text{ m/s}$$

$$\text{OR} = 5.53 \text{ mm/s}$$

From these values of rotational velocity the torque on the motor shaft and the drive drum shaft can be calculated, using equation 1.

$$\tau_{\text{MOTORA}} + \tau_{\text{MOTORB}} = \frac{2279.94 - 4220.32}{-2654.34} = 0.731 \text{ N.mm}$$

$$\tau_{\text{DRUM}} = 2 \cdot 0.731 \cdot 518.169 = 757.59 \text{ N.mm}$$

Accuracy of the Angle Sensor.

The angle sensor is used to make sure that only one sticker comes onto the empty box.

For one revolution of the angle sensor shaft, 16 steps are counted by the angle sensor.

From this the angle of each step can be calculated.

$$\text{Angle of each count} = \frac{1}{16} \cdot 360 = 22.5 \text{ degrees}$$

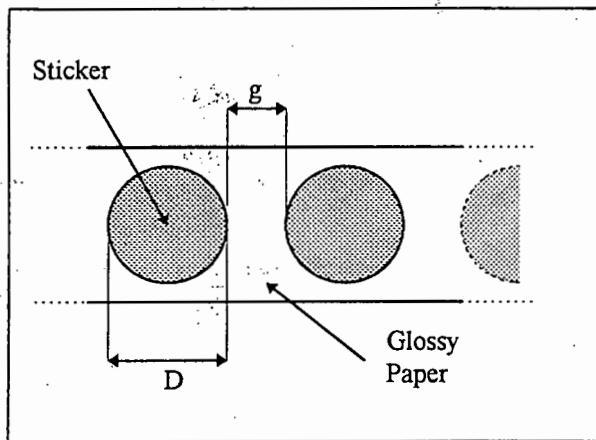
The error of the angle sensor is therefore 22.5 degrees. It is important to know the error in the angle sensor, because the printer relies on its readings to predict when a

single sticker has come onto the box. The error in the angle sensor must therefore be translated into error in distance across the strip of stickers.

$$\text{Error across the strip of stickers} = 0.5867 \text{ mm}$$

Therefore, the strip of stickers will move 0.5867 mm before the next count is made by the angle sensor. So the sticker might be 0.5867 mm ahead or behind its set position.

This is acceptable considering that the stickers are 19mm in length, as illustrated in Figure D.5.2.



Where,

$$D = 19\text{mm}$$

$$g = 1.6\text{mm}$$

Figure D.5.2 : Sticker dimensions.

Angle Sensor Reading for the Removal of One Sticker.

For a single sticker to be removed off the glossy paper and onto a box, the drive drum of the printer must rotate a specified number of rotations.

$$\begin{aligned} \text{Distance the glossy paper is required to move} &= 19 + 0.8 \text{ mm} \\ &= 19.8 \text{ mm} \end{aligned}$$

Therefore,

$$\begin{aligned} \text{Angle sensor reading} &= \frac{19.8}{\pi \cdot D} \cdot 8.032 \cdot 16 = 33.747 \\ &\approx 34 \text{ angle counts} \end{aligned}$$

Change in Drive Drum Thickness.

As the drive drum releases sticker from the glossy paper and onto various boxes, the drive drum's diameter increases, because of the empty glossy paper is being continuously wound onto the drive drum. The change in the angle sensor reading as the drum diameter increase must be measure and incorporated in the control program.

To calculate the change in thickness a long strip of glossy paper was allowed to be wound by the drive drum. The angle sensor reading as well as the length of glossy paper wound was then measured. The following equations are then used.

$$\frac{\text{Angle}_{\text{MEASURED}}}{16 \cdot 8.032} = \text{Drum}_{\text{REV}}$$

$$\text{Length}_{\text{EXPECTED}} = \pi \cdot 24 \cdot \text{Drum}_{\text{REV}}$$

$$\text{Error} = \text{Length}_{\text{MEASURED}} - \text{Length}_{\text{EXPECTED}}$$

$$\text{Angle}_{\text{EXPECTED}} = \frac{\text{Length}_{\text{MEASURED}} \cdot 8.032 \cdot 16}{\pi \cdot 24}$$

Where,

$\text{Angle}_{\text{MEASURED}}$ = Angle Sensor reading once the glossy paper is fully wound.

$\text{Length}_{\text{MEASURED}}$ = Length of glossy paper fully wound.

$\text{Angle}_{\text{EXPECTED}}$ = Angle reading of the sensor calculated from the measured length of glossy paper.

$\text{Length}_{\text{EXPECTED}}$ = Length of glossy paper calculated from the measured angle sensor reading.

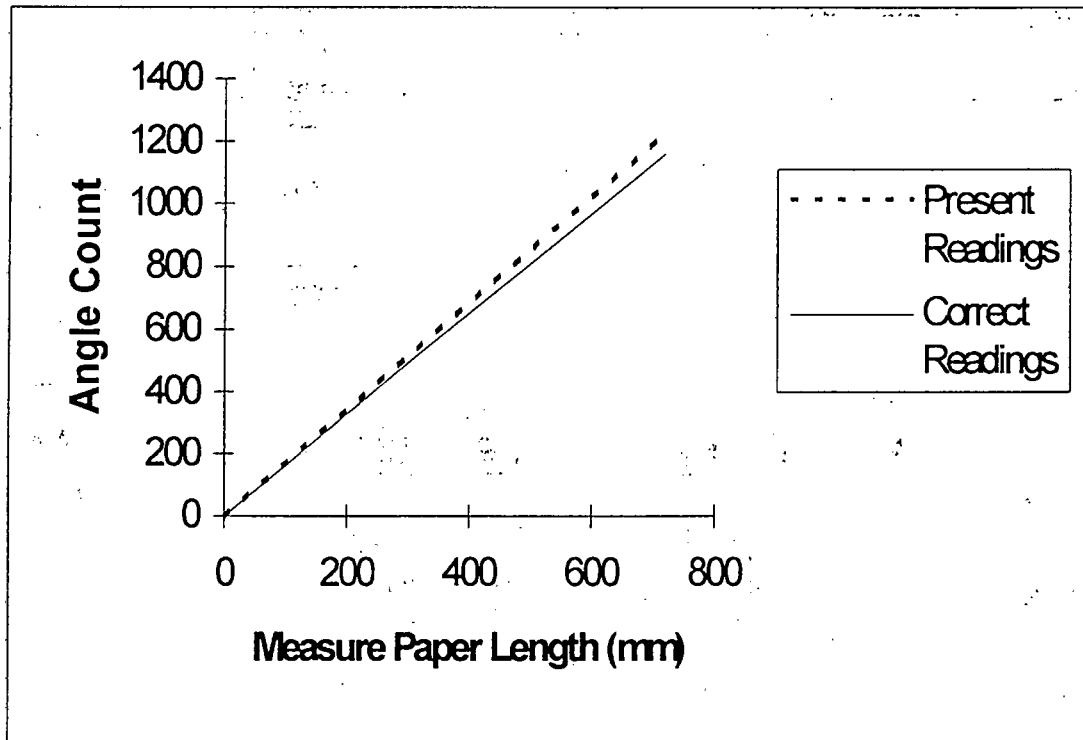
It is obvious that the measured length of glossy paper will be greater than the expected length measured from the angle sensor reading. This is because the angle sensor assumes that the diameter of the drum stay constant, but in reality the diameter increase fractionally. As the diameter increase so does the length of paper wound per

revolution of the drum. Three different lengths of paper were tests and the results are tabulated below, Table D.5.

Table 5.2 : Change in drive drum diameter results.

	Test 1	Test 2	Test 3
Angle _{MEASURED}	512 counts	870 counts	1161 counts
Length _{MEASURED}	313 mm	539 mm	720 mm
Length _{EXPECTED}	300.4 mm	510.4 mm	681.2 mm
Error	12.6 mm	28.6 mm	38.8 mm
Angle _{EXPECTED}	534 counts	919 counts	1227 counts

A graph of the above result is then plotted, Figure D.5.3.



The Mathematical relationship between the two lines can be calculated as follows.

$$y_M = A \cdot x_M$$

Present Line :

$$A = \frac{\text{Angle}_{\text{EXPECTED}}}{\text{Length}_{\text{MEASURED}}}$$

Correct Line :

$$y_c = B \cdot x_c$$
$$B = \frac{\text{Angle}_{\text{MEASURED}}}{\text{Length}_{\text{MEASURED}}}$$

Where, $x_c = x_m$

Therefore,

$$y_m = K \cdot y_c$$
$$K = \frac{A}{B}$$

For the above three test results the *mean* K value is,

$$K = 1.0516$$

Therefore, the predicted angle count value when the printer must stop must be divide by the K factor to obtain the correct angle sensor value, due to the increasing diameter of the drum.

D.6 The Overhead Conveyor System.

The physical layout of the overhead conveyor drive system and gearbox are illustrated in Figure D.6.

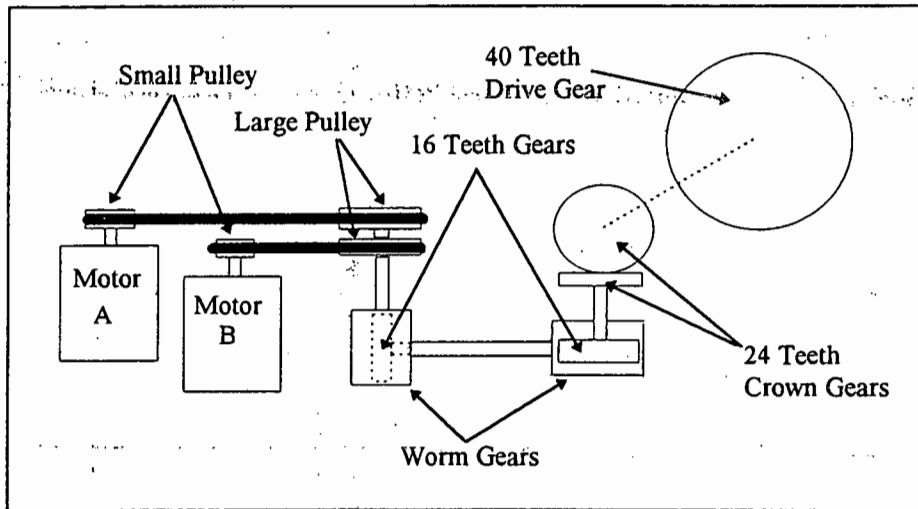


Figure D.6 : Overhead conveyor drive system.

The overall gear ratio of the overhead conveyor drive system is.

$$\text{Gear Ratio} = \frac{618}{22.2} \cdot \frac{1}{16.064} \cdot \frac{1}{16.064} \cdot \frac{24}{24} = 0.001078$$

$$\text{OR} = 926.98 : 1$$

Therefore the drive motor rotates 926.98 times before the drive gear rotates once. If the drive gear rotates once, then the length of chain which is move is,

$$d_{\text{GEAR}} = 40\text{mm}$$

$$\text{Length} = \pi \cdot d_{\text{GEAR}} = 125.66 \text{ mm/rev}$$

It was measured, by using the Lego angle sensor, that the motor speed under normal load was.

$$\omega_{\text{MOTOR}} = 3284.19 \text{ RPM}$$

Therefore,

$$\omega_{\text{GEAR}} = \frac{3284.19}{926.98} = 3.54 \text{ RPM}$$

$$V_{\text{CONVEYOR}} = \frac{3284.19}{926.98} \cdot \frac{125.66}{1000} \cdot \frac{1}{60} = 0.00742 \text{ m/s}$$

$$\text{OR} = 7.42 \text{ mm/s}$$

From these values of rotational velocity the torque on the motor shaft and the drive gear shaft can be calculated, using equation 1.

$$\tau_{\text{MOTOR A}} + \tau_{\text{MOTOR B}} = \frac{3284.19 - 4220.32}{-2654.34} = 0.3527 \text{ N.mm}$$

$$\tau_{\text{DRUM}} = 0.3527 \cdot 926.98 = 326.926 \text{ N.mm}$$

D.7 Piston System.

The forces, velocities and timing of the various pistons used in the model will be calculated. Double action pistons are used in the model, their dimensions are shown below.

Internal cylinder diameter (D) = 12 mm

Rod diameter (d) = 5 mm

Operating Pressure (p) = 2 bar

Stroke Length = 28 mm

From this information the time for the piston to stroke fully forwards and fully backwards can be calculated. Firstly for the piston to stroke full forwards,

$$F_N = A \cdot p - F_F$$

Where,

F_N = Effective Piston Force.

F_F = Frictional Force (3-20% of F_N)

A = Useful Piston Area ($\frac{D^2 \cdot \pi}{4}$)

Therefore,

$$A = \frac{12^2 \cdot \pi}{4} = 113.1 \text{ mm}^2$$

$$\text{OR} = 1,131 \text{ cm}^2$$

$$F_N = A \cdot p - 0.2 \cdot F_N$$

$$F_N = \frac{A \cdot p}{1.2}$$

So,

$$F_N = \frac{1.131 \cdot 2}{1.2} = 1.885 \text{ kp}$$

$$\text{OR} = 18.85 \text{ Newtons}$$

For the graph D.7.1, it can be seen that for the above mentioned piston the velocity is,

$$V_{\text{PISTON}} = 53 \text{ mm/s}$$

Therefore,

$$\text{Time for piston to fully open} = 0.528 \text{ seconds}$$

Next, for the piston to stroke full backwards,

$$F_N = A' \cdot p - F_F$$

Where,

F_N = Effective Piston Force.

F_F = Frictional Force (3-20% of F_N)

A' = Useful Piston Ring Area $\left(\frac{(D^2 - d^2) \cdot \pi}{4} \right)$

Therefore,

$$A = \frac{(12^2 - 5^2) \cdot \pi}{4} = 93.46 \text{ mm}^2$$

$$\text{OR} = 0.9346 \text{ cm}^2$$

So,

$$F_N = \frac{0.9346 \cdot 2}{1.2} = 1.5576 \text{ kp}$$

$$\text{OR} = 15.576 \text{ Newtons}$$

For the graph D.7.1, it can be seen that for the above mentioned piston the velocity is,

$$V_{\text{PISTON}} = 56 \text{ mm/s}$$

Therefore,

$$\text{Time for piston to fully close} = 0.5 \text{ seconds}$$

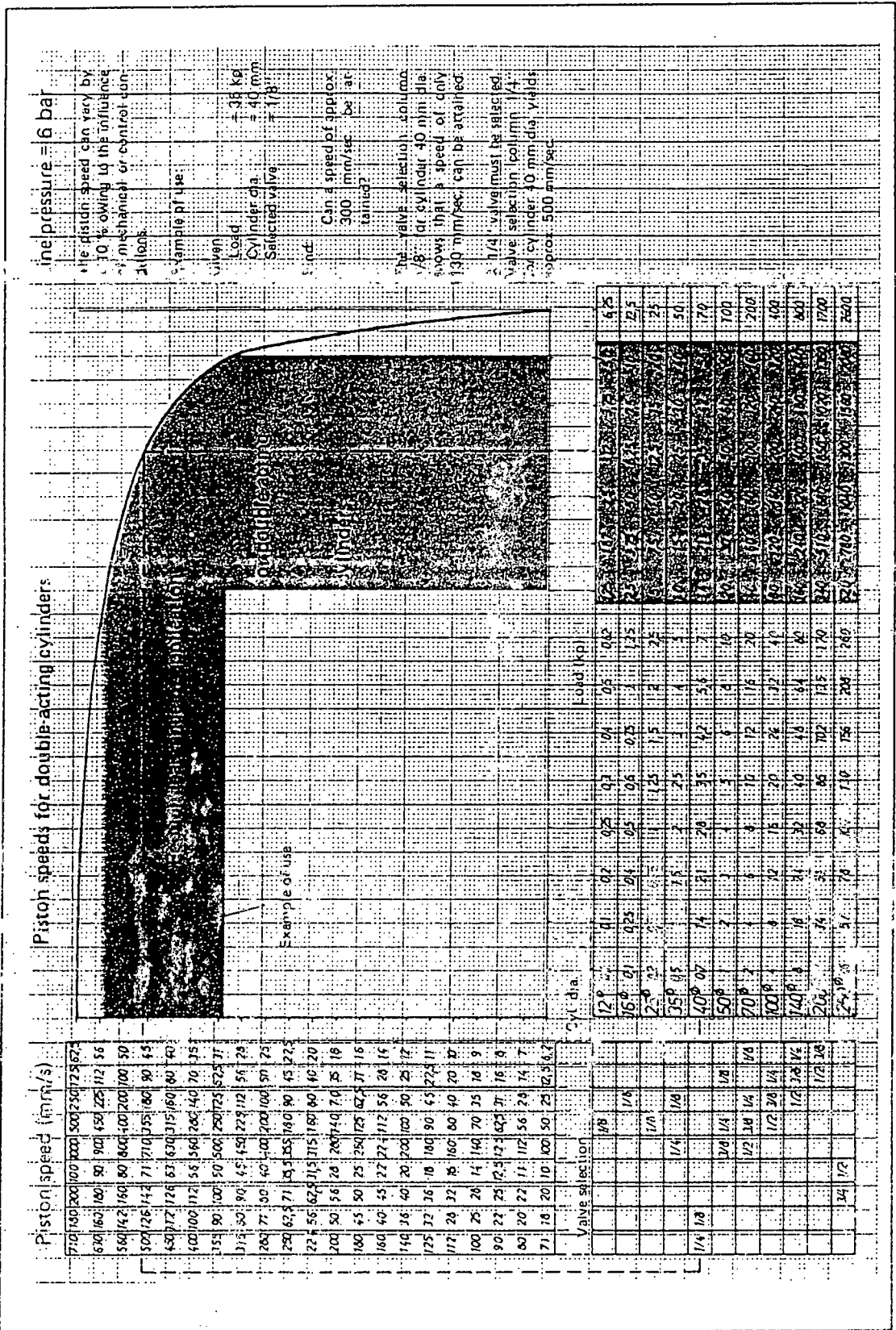


Figure D.7.1 : Piston Speed vs. Piston Load graph.

Air Consumption

The amount of air consumed by the piston stroking back and forth is calculated. The air consumed is calculated as follows,

$$\text{Air Consumption} = \text{Compression Ratio} * \text{Piston Area} * \text{Stroke Length}$$

Where,

$$\text{Compression Ratio} = \frac{1.033 + p}{1.033}$$

So,

$$\begin{aligned} \text{Air Consumption (Forward Stroke)} &= \frac{1.033 + 2}{1.033} \cdot \pi \cdot \frac{0.012^2}{4} \cdot 0.028 \\ &= 0.000009297 \text{ m}^3 \\ &= 9297.82 \text{ mm}^3 \\ &= 9.297 \text{ ml} \end{aligned}$$

$$\begin{aligned} \text{Air Consumption (Backwards Stroke)} &= \frac{1.033 + 2}{1.033} \cdot \pi \cdot \frac{(0.012^2 - 0.005^2)}{4} \cdot 0.028 \\ &= 0.000007683 \text{ m}^3 \\ &= 7683.6 \text{ mm}^3 \\ &= 7.683 \text{ ml} \end{aligned}$$

The consumption of air can also be read of Figure D.7.2.

$$\text{Air consumption} = 0.9 \text{ NI/cm of stroke}$$

$$\text{Volume} = 2.52 \text{ NI}$$

$$\begin{aligned} \text{(for one stroke)} \quad &= 2.52 \cdot \frac{1.033 + 2}{1.033} \\ &= 7.3989 \text{ ml} \end{aligned}$$

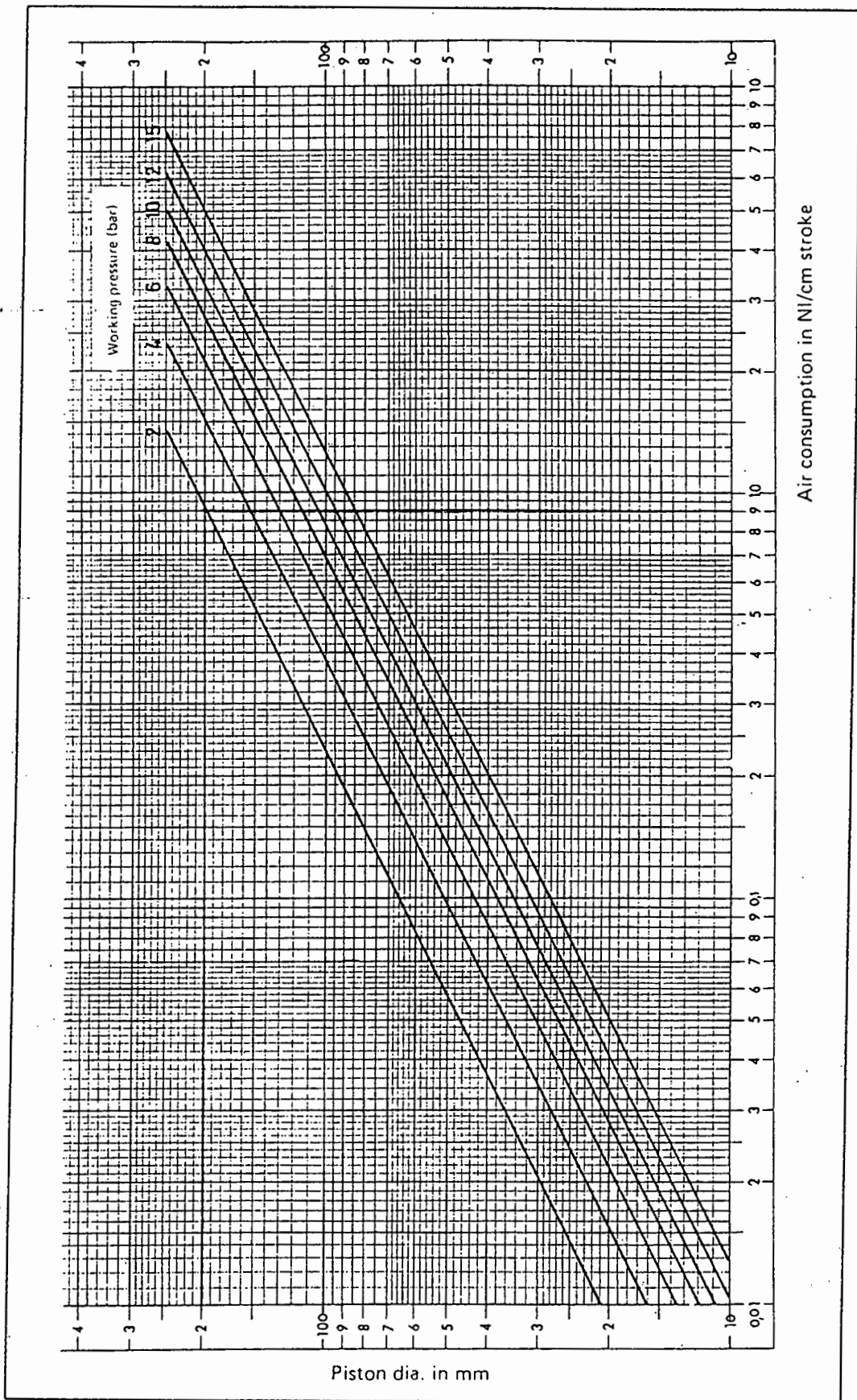


Figure D.7.2 : Air consumption chart.

Dispenser Piston Timing

The maximum frequency the dispenser piston may operate, is calculated. If two boxes are on the sorting conveyor, and the space between them is small, the piston knocking the first box off the sorting conveyor, might interfere with the second box. Therefore, the minimum distance between two boxes on the sorting conveyor must be calculated, and from this the maximum frequency at which the dispenser piston can knock boxes onto the sorting conveyor can be calculated.

Firstly, The time for a piston to knock a block off the sorting conveyor is.

$$\text{Time} = 0.528 + 0.5 = 1.28 \text{ seconds}$$

The sorting conveyor speed,

$$V_{\text{CONVEYOR}} = 52.5 \text{ mm/s}$$

Therefore the minimum spacing between the boxes must be,

$$\text{Spacing} = 52.5 \cdot 1.28 = 67.2 \text{ mm}$$

The frequency of the dispenser piston is therefore,

$$\text{Frequency} = \frac{1}{1.28} = 0.781 \text{ Hz}$$

But, it takes 1.31 seconds for a box, on the main conveyor, to come into position to be read and ejected by the dispenser piston. Therefore there is no possibility of two boxes being within the minimum spacing on the sorting conveyor.

Next, the amount the angle counter, on the sorting conveyor gearbox, must count before the specified piston is activated, to eject a box off the sorting conveyor, must

be calculated. The distances from the dispenser piston to the ejection pistons are tabulated in Table D.7.1.

Table D.7.1 : Distance from dispenser piston to ejection pistons.

To the black ejection piston	20 cm
To the green ejection piston	30 cm
To the white ejection piston	40 cm

It has been calculated that the angle counter counts once for every 4.712 mm travelled along the sorting conveyor. From this the angle counter readings for each ejection piston are calculated and are tabulated in Table D.7.2.

Table D.7.2 : Ejection piston angle counts

Black Ejection Piston	42 counts
Green Ejection Piston	63 counts
White Ejection Piston	84 counts

Appendix E

Colour Identification System

E.1 Light Sensor Readings for each Coloured Label.

The different coloured labelled boxes are fed into the colour identification system and the following results were taken, Table E.1.1.

Table E.1.1 : Light sensor readings for the different coloured labels.

Number	Gold (% light)	Green (% light)	White (% light)
1	62.89	47.95	58.64
2	63.05	47.64	58.49
3	63.67	48.42	59.11
4	63.05	48.58	58.64
5	62.42	48.42	58.01
6	62.89	48.58	58.49
7	63.67	47.64	57.70
8	63.52	47.95	58.49
9	62.89	47.84	57.70
10	62.42	47.95	58.17
11	62.89	48.42	58.64
12	62.42	48.58	58.49
13	63.52	47.64	59.11
14	63.05	47.95	58.49
15	62.89	48.52	58.33
16	63.05	47.64	58.01
17	62.10	47.95	57.70
18	62.42	48.42	58.49
19	63.05	47.95	57.70
20	62.73	47.64	58.64

Therefore, the mean and standard deviations for each colour can be calculated, and are tabulated in Table E.1.2.

Table E.1.2 : Mean and standard deviation light sensor readings for each colour.

	Gold	Green	White
Mean	62.93	48.08	58.35
Standard deviation	0.43	0.36	0.43

E.2 Range of Light Sensor Readings.

A range of light sensor reading are now defined for each coloured label. The range of readings are calculated by using 99.99 percentage success reading rate. Therefore 99.99 percent of the time a white label will be identified as a white label. The ranges are calculated by using a normal standard deviation from the mean light sensor reading of each coloured label.

$$z = \frac{X_1}{\sigma}$$

$$-z = \frac{X_2}{\sigma}$$

Where,

X_1 and X_2 - Range values from the mean (μ).

μ - Mean of the sensor reading for a specific coloured label.

σ - Standard deviation from the mean.

The range of light sensor reading must be large enough to ensure that the probability of a colour being read incorrectly is as close to zero percent as possible. But not to large that two different colour share part of the same range of readings.

Set, $z = 4$ (which ensures that 100 percent of the reading fall within this range.)

The result for the range of readings for the three different colour labels are tabulated below, Table E.2.

Table E.2 : Range of light sensor readings for each coloured label.

	Gold	Green	White
X Value	1.72 %	1.44 %	1.72 %
Mean	62.93 %	48.08 %	58.35 %
Range	61.21 % to 64.65 %	46.64 % to 49.52 %	56.63 % to 60.07 %

A graphic representation of the tabulated result is shown in Figure E.2.

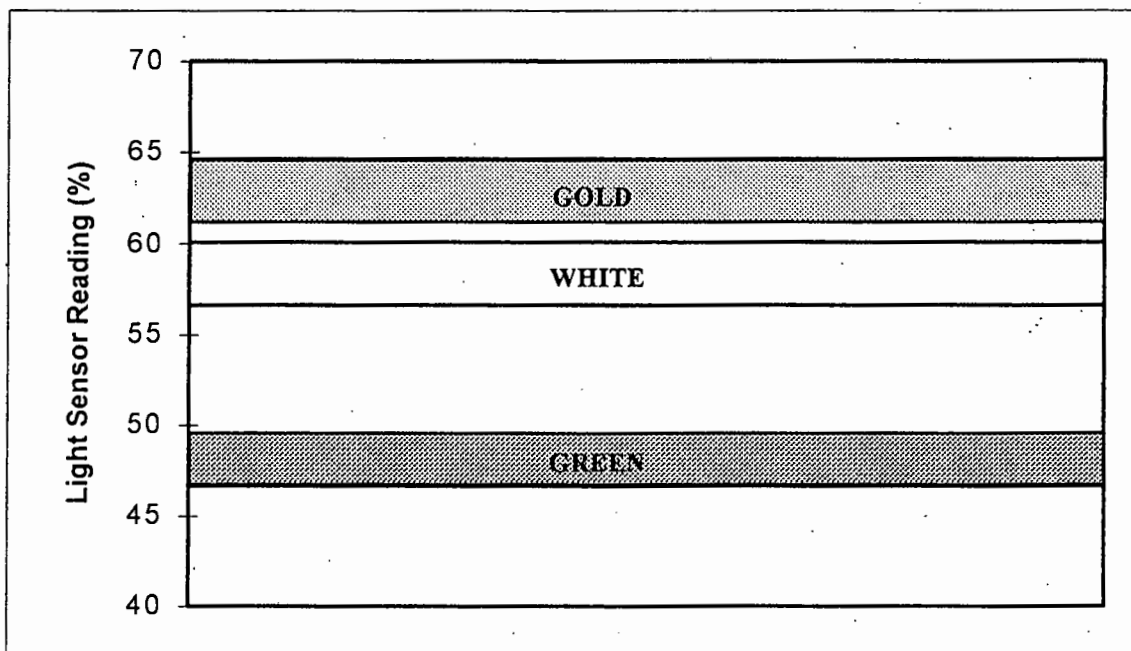


Figure E.2 : Light sensor range of readings for each colour.

Appendix F

Carton Box Handling Calculations

F.1 Tilt Angle Before Sliding off the Overhead Conveyor Carts and down the Gravity Conveyors.

The forces acting on the box as it is being tilted are shown in Figure F.1.

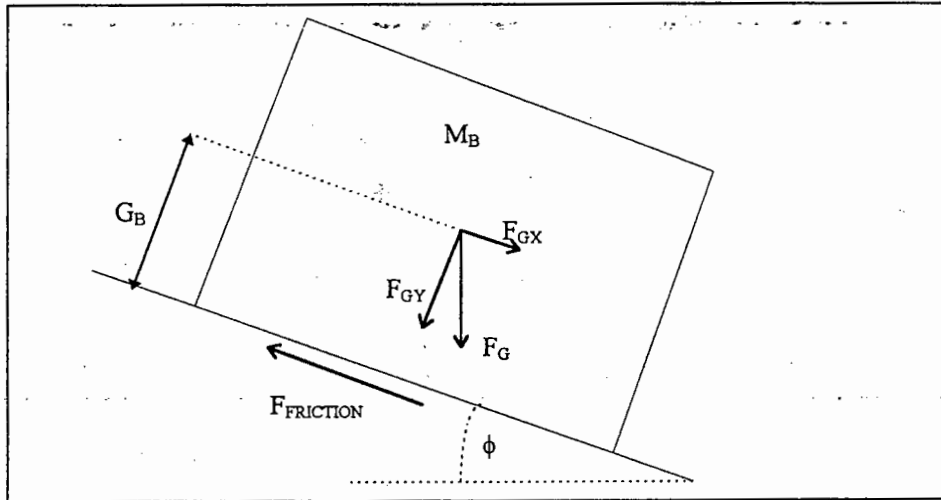


Figure F.1 : Forces acting on a tilting box.

Where,

F_G = Force on the box due to gravity.

F_{GX} and F_{GY} = The x and y components of F_G .

$F_{FRICITION}$ = The force due to friction.

M_B = Mass of the box.

G_B = Centre of gravity of the box.

ϕ = The angle of tilt.

Therefore,

$$F_G = M_B \cdot g$$

$$F_{GX} = M_B \cdot g \cdot \sin(\phi)$$

$$F_{GY} = M_B \cdot g \cdot \cos(\phi)$$

$$F_{FRICITION} = \mu \cdot F_{GY}$$

$$F_{FRICITION} = \mu \cdot M_B \cdot g \cdot \sin(\phi)$$

Where, μ is the friction coefficient. So for the box to start sliding the frictional force must be less than the x component of the gravitational force.

$$M_B \cdot g \cdot \sin(\phi) = \mu \cdot M_B \cdot g \cdot \cos(\phi)$$

$$\sin(\phi) = \mu \cdot \cos(\phi)$$

$$\tan(\phi) = \mu$$

Therefore the mass of the box has no effect on the sliding angle, just the friction coefficient (μ). Now the minimum angle of tilt on the overhead conveyor cart can be calculated.

For the model, lets assume the coefficient of friction between the plastic cart and box is 0.2. Then,

$$\phi = \tan^{-1}(\mu) = 11.31 \text{ degrees tilt}$$

For the gravity conveyor in the factory design, the coefficient of friction is 0.09 for a load less than 10lb (Ref. 33). Then,

$$\phi = \tan^{-1}(\mu) = 5.143 \text{ degrees tilt}$$

F.2 Toppling Angle of a Box on an Incline.

The forces and moments on the box are shown in Figure F.2.

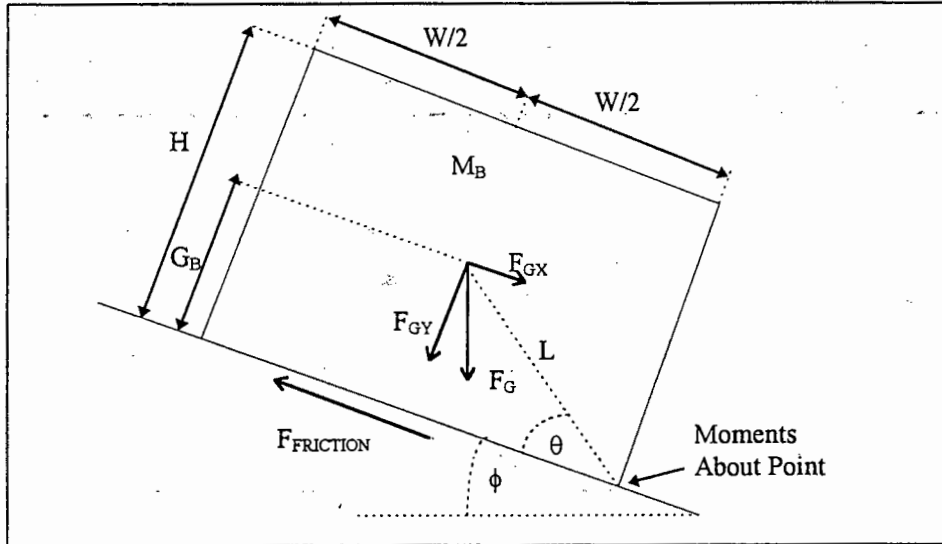


Figure F.2 : Toppling forces on box.

Where,

W = the width of the box.

H = Height of the box

L = Moment arm.

Moments are taken about the point shown in Figure F.2. The angle of tilt is then calculated for the moment when the box will topple over.

$$\text{Moment due to } F_{GY} = M_B \cdot g \cdot \cos(\phi) \cdot \sin(90 - \theta) \cdot L$$

$$\text{Moment due to } F_{GX} = M_B \cdot g \cdot \sin(\phi) \cdot \sin(\theta) \cdot L$$

These two moments are acting in opposite directions, and for toppling to occur the moment due to F_{GX} must be greater than the moment due to F_{GY} .

So,

$$M_B \cdot g \cdot \cos(\phi) \cdot \cos(\theta) \cdot L = M_B \cdot g \cdot \sin(\phi) \cdot \sin(\theta) \cdot L$$

$$\cos(\phi) \cdot \cos(\theta) = \sin(\phi) \cdot \sin(\theta)$$

$$\tan(\phi) = \frac{\cos(\theta)}{\sin(\theta)}$$

$$\tan(\phi) = \frac{W}{2 \cdot G_B}$$

So,
$$\phi = \tan^{-1}\left(\frac{W}{2 \cdot G_B}\right)$$

Therefore, it can be seen that the toppling effect is only dependent of the dimensions of the box. For the factory model the dimensions of the wooden boxes are,

$$H = 21 \text{ mm}$$

$$W = 32 \text{ mm}$$

$$G_B = 10.5 \text{ mm}$$

Therefore, the maximum angle of tilt, for the model, is,

$$\theta = \tan^{-1}\left(\frac{10.5}{16}\right) = 33.275 \text{ degrees}$$

$$\phi = \tan^{-1}\left(\frac{32}{2 \cdot 10.5}\right) = 56.725 \text{ degrees}$$

For the factory design the dimensions of the folded open carton boxes used are tabulated in Table F.2.

Table F.2 : Carton box dimensions (Folded up).

	WC Production Line Box	ROPP Production Line Box
Width (W)	324 mm	327 mm
Height (H)	627 mm	501.5 mm
Wall Thickness (t)	3 mm	3 mm
Centre of Gravity (G_B)	224.94 mm	167.99 mm

WC Production Line Box

$$\theta = \tan^{-1}\left(\frac{224.94}{162}\right) = 54.24 \text{ degrees}$$

$$\phi = \tan^{-1}\left(\frac{324}{2 \cdot 224.94}\right) = 35.76 \text{ degrees}$$

ROPP Production Line Box

$$\theta = \tan^{-1}\left(\frac{167.99}{163.5}\right) = 45.78 \text{ degrees}$$

$$\phi = \tan^{-1}\left(\frac{327}{2 \cdot 167.99}\right) = 44.22 \text{ degrees}$$

F.3 Length of the Pin on Overhead Carts.

The length of the pins of the overhead cart effect the amount of tilt the overhead cart experiences when being unloaded, as illustrated in Figure F.3.1.

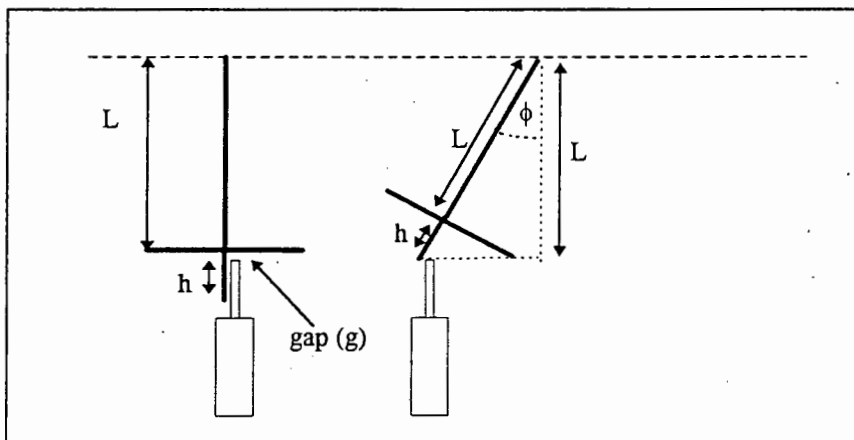


Figure F.3.1 : Tilting angle of the overhead cart.

Where,

L - Length of the overhead cart.

h - Length of the Pin.

g - Gap between the piston and the floor of the cart.

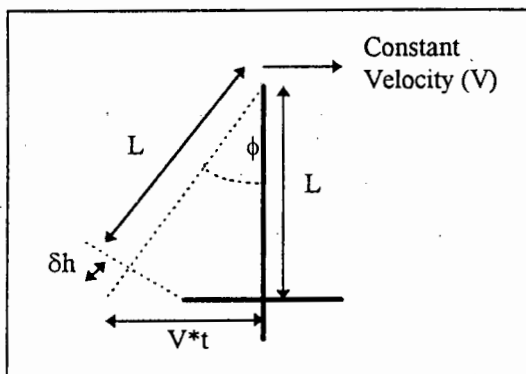
ϕ - Angle of tilt.

D - Maximum distance from the pin to the start of the gravity conveyor.

Therefore, the maximum angle of tilt will be.

$$\phi = \cos^{-1}\left(\frac{L - g}{L + h}\right)$$

The maximum angle of tilt must be greater than the minimum angle for sliding (Section F.1) and less than the maximum angle before toppling (Section F.2). Also the angle of tilt must also be calculated to give the carton box sufficient time to slide off the overhead cart and onto the gravity conveyor. From the above criterion the tilt angle for the overhead cart is designed.



Firstly, the time taken for the carton box to slide off the overhead cart and onto the gravity conveyor is calculated.

Figure F.3.2 shown the change in the tilt angle.

Figure F.3.2 : The Change in tilt angle in relation to the change in pin length (h)

The acceleration of a carton box sliding down the bottom of the overhead cart is.

$$Acceleration = g \cdot (\sin \phi - \mu \cdot \cos \phi)$$

Therefore the acceleration changes with respect to the tilt angle (ϕ) because the tilt angle change with respect to time.

The distance the carton box must slide off the overhead cart is calculated as follows.

$$\cos \phi = \frac{L}{L + \delta h}$$

$$\sin \phi = \frac{V \cdot t}{L + \delta h}$$

$$(L + \delta h)^2 = (V \cdot t)^2 + L^2$$

$$(L + \delta h) = \sqrt{(V \cdot t)^2 + L^2}$$

$$s = \int a \cdot t \cdot \delta t$$

$$s = \int g \cdot (\sin \phi - \mu \cdot \cos \phi) \cdot t \cdot \delta t$$

$$s = \int g \cdot \left(\frac{V \cdot t}{L + \delta h} - \mu \cdot \frac{L}{L + \delta h} \right) \cdot t \cdot \delta t$$

$$s = \int \frac{g}{L + \delta h} \cdot (V \cdot t^2 - \mu \cdot L \cdot t) \cdot \delta t$$

$$s = \int \frac{g}{\sqrt{(V \cdot t)^2 + L^2}} \cdot (V \cdot t^2 - \mu \cdot L \cdot t) \cdot \delta t$$

The final equation, above, is then calculated using the MathCad computer package and a value of time (t) was found. From this the maximum tilt angle can be calculated as well as the length of the tilting pin (h). A graph of displacement vs. time is shown in Figure F.3.3 and represents the boxes displacement off the cart as the cart is being tilted, using the above equation.

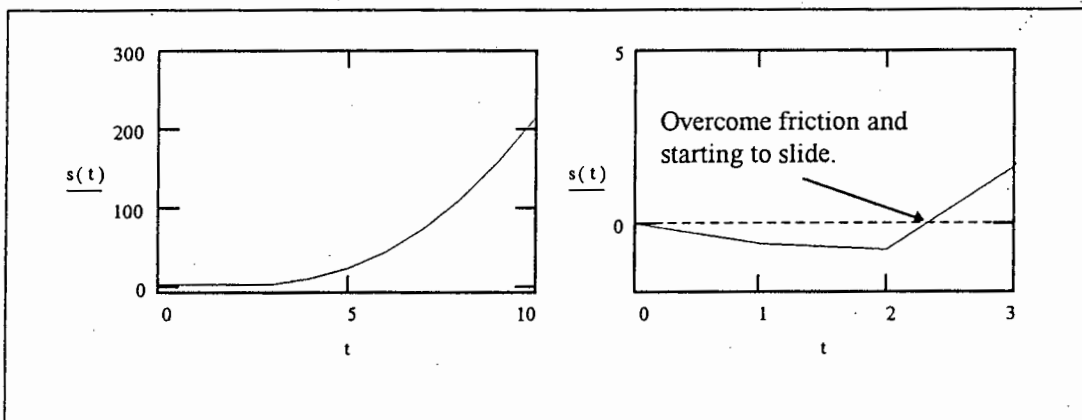


Figure F.3.3 : Graphs of displacement (s) over time (t).

The negative displacement, in Figure F.3.3 is when the frictional force is greater than the tilting force and is ignored.

For the Lego model,

$$L = 62 \text{ mm}$$

$$V = 9.42 \text{ mm/s}$$

$$g = 9.81 \text{ m/s}^2$$

$$\mu = 0.2$$

$$s = 32 \text{ mm}$$

It was found that,

$$t = 2.531 \text{ seconds}$$

Therefore,

$$\phi = \sin^{-1}\left(\frac{V \cdot t}{L}\right) = 33.05 \text{ degrees}$$

and,

$$h = \frac{L}{\cos \phi} - L = 11.97 \text{ mm}$$

For the factory design,

$$L = 1.5 \text{ mm}$$

$$V = 100 \text{ mm/s}$$

$$g = 9.81 \text{ m/s}^2$$

$$\mu = 0.2$$

$$S_{\text{REF88}} = 163.5 \text{ mm}$$

$$S_{\text{REF86}} = 162 \text{ mm}$$

It was found that,

$$t = 4.557 \text{ seconds}$$

Therefore,

$$\phi = \sin^{-1}\left(\frac{V \cdot t}{L}\right) = 17.69 \text{ degrees}$$

and,

$$h = \frac{L}{\cos \phi} - L = 74.4 \text{ mm}$$

F.4 Positioning of the Piston used to Tilt the Overhead Cart.

The piston is placed in front of the gravity conveyor and is used to tilt the continuously moving overhead carts. The pistons configuration is illustrated below, Figure F.5.

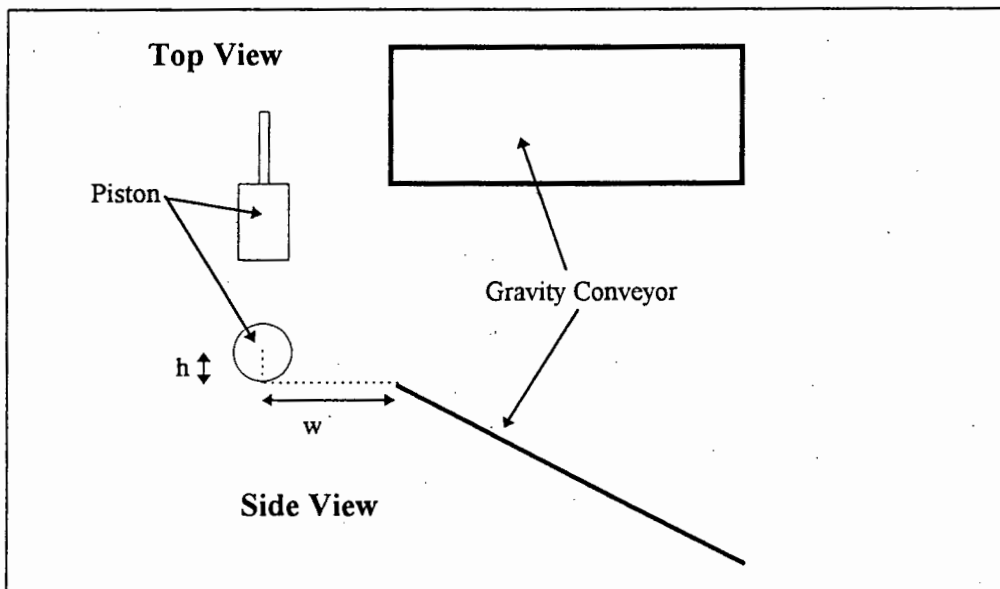


Figure F.5 : Gravity conveyor piston positioning.

Where,

h = Length of the tilting pin on the overhead cart (section F.3)

$$w = \sqrt{\left(\frac{W}{2}\right)^2 - h^2}$$

For the Lego model,

$$h = 11.97 \text{ mm}$$

$$W = 48 \text{ mm}$$

Therefore,

$$w = 20.80 \text{ mm}$$

For the factory design,

$$h = 74.4 \text{ mm}$$

$$W = 400 \text{ mm}$$

Therefore,

$$w = 185.65 \text{ mm}$$

F.5 Sliding off the Overhead Conveyor Carts when the Overhead Conveyor Stops.

If, for some reason, the overhead conveyor suddenly stops the empty boxes being carried in the carts should not fall out due to the oscillating carts. In this section, the maximum cart oscillation angle is calculated. The above mentioned scenario is illustrated in Figure F.5.

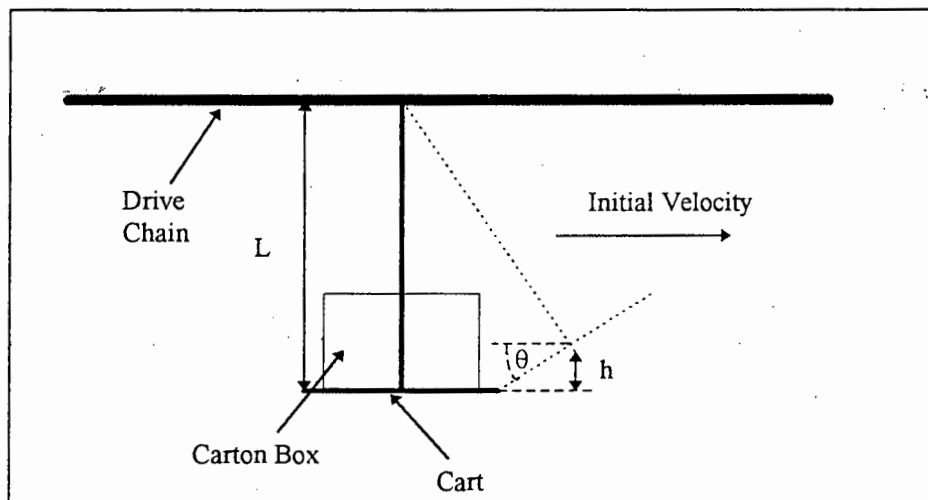


Figure F.5 : Cart oscillation diagram

Where,

L = Length of the cart.

h = Maximum oscillation height.

θ = Maximum angle of tilt.

The drive chain, cart and box are travelling at a constant speed, when suddenly the drive chain locks and the cart start to oscillate around its hinge, as illustrated in Figure F.6. The maximum height of the oscillation is calculated. (Assume that there is no damping coefficient C)

Using a conservation of energy,

$$\frac{1}{2} \cdot M \cdot V^2 = M \cdot g \cdot h$$

$$h = \frac{V^2}{2 \cdot g}$$

The tilt angle,

$$\cos(\theta) = \frac{L-h}{L}$$

$$\theta = \cos^{-1}\left(\frac{L-h}{L}\right)$$

For the Lego model,

$$V = 7.42 \text{ mm/s}$$

$$L = 62 \text{ mm}$$

Therefore,

$$h = 0.0028 \text{ mm}$$

$$\theta = 0.54 \text{ degrees} \ll 11.31 \text{ degrees}$$

So, the boxes inside the overhead cart will not be able to fall out if the overhead cart suddenly stops.

For the factory design,

$$V = 100 \text{ mm/s}$$

$$L = 1500 \text{ mm}$$

Therefore,

$$h = 0.51 \text{ mm}$$

$$\theta = 1.49 \text{ degrees} \ll 11.31 \text{ degrees}$$

So, the boxes inside the overhead cart will not be able to fall out if the overhead cart suddenly stops. The maximum speed the overhead conveyor can therefore transport the empty box is.

$$\text{Assume } \theta = 11.31 \text{ Degrees}$$

Then,

$$h = 29.13 \text{ mm}$$

$$V = 756 \text{ mm/s}$$

F.6 Velocity and Time for a Box Sliding Down a Gravity Conveyor.

To calculate the final velocity of a box before it hits the filling conveyor, the following information is needed.

- Velocity of the box when it enters the gravity conveyor once it has left the overhead cart.
- The length of the gravity conveyor.
- The tilt of the gravity conveyor.

Firstly, the initial velocity must be calculated and is done so as follow,

$$u = \frac{ds}{dt} \quad \dots 1)$$

Use the equation of motion calculated in section F.4.

Secondly, the acceleration down the gravity conveyor is calculated.

$$\begin{aligned} \text{Acceleration} &= \frac{M_B \cdot g \cdot \sin(\phi) - \mu \cdot M_B \cdot g \cdot \cos(\phi)}{M_B} \\ &= g \cdot (\sin(\phi) - \mu \cdot \cos(\phi)) \end{aligned}$$

using,

$$V^2 = u^2 + 2 \cdot a \cdot s$$

Therefore,

$$V = \sqrt{u^2 + 2 \cdot g \cdot (\sin(\phi) - \mu \cdot \cos(\phi)) \cdot s_{\text{Conveyor}}} \quad \dots 2)$$

and,

$$\begin{aligned} s_{\text{Conveyor}} &= u \cdot t + \frac{1}{2} \cdot a \cdot t^2 \\ t &= \frac{-u \pm \sqrt{u^2 + 2 \cdot a \cdot s_{\text{Conveyor}}}}{a} \quad \dots 3) \end{aligned}$$

The above answer can also be obtained by using the conservation of energy theory.

Therefore for the Lego model,

$$s_{\text{Conveyor}} = 100 - 32 \text{ mm} = 68 \text{ mm} \quad (\text{Width of the box} = 32 \text{ mm})$$

$$\mu = 0.2$$

$$\phi = 21.6 \text{ degrees}$$

$$g = 9.81 \text{ m.s}^{-1}$$

The result are tabulated in Table F.6.1.

Table F.6.1 : Carton Box velocity down the model gravity conveyor.

Time to exit overhead cart (Section F.4)	2.531 Seconds
Velocity when entering gravity conveyor (u), using Equ. 1.	2.445 m/s
Velocity at the bottom of the gravity conveyor, Using Equ. 2.	2.892 m/s
Time to reach the bottom of the gravity conveyor, Using Equ. 3.	0.25 seconds

Appendix G

Factory Layout Design

G.1 Production Line Speeds.

The number of boxes produced at each line as well as the speeds of production can be seen in Appendix B, Table B.1. The minimum and maximum speeds of production for each group of production lines are tabulated in Table G.1. (The TALOG line is included in the ROPP production line speeds)

Table G.1 : Number of boxes produced per hour.

	Maximum Number	Minimum Number
<i>ROPP Production Lines</i>	58 Boxes/Hour	55 Boxes/Hour
<i>WC Production Lines</i>	57 Boxes/Hour	27 Boxes/Hour
<i>Total</i>	115 Boxes/Hour	82 Boxes/Hour

G.2 Assembly of the Empty Carton Boxes.

The number of workers required to assemble the carton boxes is calculated. All carton boxes will be taped together. The time taken for a worker to manually tape a box together was measured in Appendix B.3.1 and is tabulated in Table G.2.

Table G.2 : Range of times for manually assembling a carton boxes by tape.

<i>Mean</i>	47.47 Seconds
<i>Range</i>	26.69 Seconds to 80.37 Seconds

For the box assembly on the WC production lines.

$$\begin{aligned}\text{Minimum Number of Workers} &= \frac{57 \cdot 26.69}{3600} = 0.42 \text{ worker} \\ &= 1 \text{ worker}\end{aligned}$$

$$\begin{aligned}\text{Maximum Number of Workers} &= \frac{57 \cdot 80.37}{3600} = 1.27 \text{ worker} \\ &= 2 \text{ workers}\end{aligned}$$

For the box assembly on the ROPP production lines.

$$\begin{aligned}\text{Minimum Number of Workers} &= \frac{58 \cdot 26.69}{3600} = 0.43 \text{ worker} \\ &= 1 \text{ worker}\end{aligned}$$

$$\begin{aligned}\text{Maximum Number of Workers} &= \frac{58 \cdot 80.37}{3600} = 1.29 \text{ worker} \\ &= 2 \text{ workers}\end{aligned}$$

The available machinery which can be used to assemble the carton boxes automatically is tabulated in Table G.2.2.

Table G.2.2 : Machinery for automatic carton box assembly.

Manufacturer	SIAT	SOCO	LITTLE DAVID	PATTYN
Model	F144	BE 300 ABS	CF 40 T	23/30 MAXI
Supplier	AFCOM	CONTICHEM	PAC KING	UNIVERSAL SUPPLY
Carton Capacity (x,y,z)	150*200*120 mm 350*450*500 mm	200*300*130 mm 400*620*500 mm	152*178*102 mm 406*609*406 mm	140*200*190 mm 360*450*555 mm
Machine Dimensions (x,y,z)	2*2.35*1.88 m	2.195*2.24*1.74m	2.41*3.25*1.3 m	2.23*2.584*2.21 m
Magazine Capacity	150 Cartons	80 Cartons	150 Cartons	N/A
Power Consumption	0.75 kW	0.6 kW	1.1 kW	3.6 kW
Operating Principle	Vacuum	Vacuum	Vacuum	Mechanism
Voltage	220/380V 50Hz 3 - Phase	220/380V 50 Hz 3 - Phase	110 V 60 Hz Single - Phase	220/380V 50 Hz 3 - Phase
Output	600 Cartons/Hour	480 Cartons/Hour	840 Cartons/Hour	1200 Cartons/Hour
Price	R 161,078	R 186,116	R 315,000	R 512,724

G.3 Overhead Chain Conveyor System.

The spacing between each overhead cart is 3 m. Referring to the maximum production speed, tabulated in Table G.1, the minimum speed of the overhead chain conveyor is,

$$\text{ROPP Overhead Chain Conveyor} \quad \text{Speed}_{\text{MINIMUM}} = \frac{58 \cdot 3}{60 \cdot 60} = 0.04833 \text{ m/s}$$

$$= 48.33 \text{ mm/s}$$

$$\text{WC Overhead Chain Conveyor} \quad \text{Speed}_{\text{MINIMUM}} = \frac{57 \cdot 3}{60 \cdot 60} = 0.0475 \text{ m/s}$$

$$= 47.5 \text{ mm/s}$$

The above calculated speed is the minimum speed at which the overhead chain can move. The conveyor speed will be set at twice the above calculated value. To ensure that empty boxes are transported from the overhead carts without problems and that the overhead conveyor system does not have to be adjusted when new production lines are added. The overhead conveyor specification are tabulated below in Table G.3.

Table G.3 : Overhead chain conveyor specifications

Type of Railing	I-Beam
Number of Carts (WC Lines)	12 Carts
(ROPP Lines)	25 Carts
Spacing Between Carts	3 m
Total Length of Chain (WC Lines)	33.924 m
(ROPP Lines)	72.673 m
Height Above Ground (Bottom of Cart)	2.7 m
Cost	R 284 000

G.4 Gravity Conveyor.

The gravity conveyor specifications are tabulated below in Table G.4.1.

Table G.4.1 : Gravity conveyor specifications.

Angle of Tilt	30 Degrees
Conveyor Width	22 " or 550 mm
Conveyor Length	4.45 m
Number of Gravity Conveyors	12 Conveyors
Cost	R 17 519.52 (For One)

At the top of the gravity conveyor are the two pistons used to tilt the overhead conveyor cart. The pistons used as well as their specifications are tabulated below in Table G.4.2.

Table G.4.2 : Tilting pistons specifications.

Piston Type	Double Action Piston
Product Name	FESTO DGS-25-40
Piston Diameter	25 mm
Piston Stroke Length	40 mm
Maximum Pressure	12 bar
Operating Pressure	6 bar
Weight	0.6512 kg
Thrust (6 bar)	250 N
Cost	R 483

G.5 Bar Code Printer.

The various types of bar code printers available are listed below in Table G.5.

Table G.5 : Bar code printer available.

Manufacturer	MARSH	ATD INKJET	WILLET	INTERMECH
Model	HI-RES BC-192	IP9000	2600 SERIES 2	3400
Supplier	AFCOM	J-PAK	HG MOLENAAR	SCANTECH
Interface Port	RS-232	RS-232	RS-232	RS-232, RS-422
Dimensions (x,y,z)				
Controller	500*600*400 mm	110*390*290 mm	External control	External control
Printer	100*150*50 mm	119*136*46 mm	580*695*610 mm	277*438*249 mm
Ink	Glycol based	Enviro Friendly	Carbon transfer	Carbon transfer
Label Height	4.8 - 28.6 mm	3 - 48 mm	104 mm	104 mm
Print Speed	1270 mm/s	1000 mm/s	125 mm/s	51-128 mm/s
Print Substrate	Porous Carton	Porous Carton	Adhesive Label	Adhesive Label
Software	WYSIWYG GRAPHICS	Menu Driven	IBM PC	Intermech language
Type	Ink Jet	Ink Jet	Thermal transfer	Thermal transfer
Cost	R 64,280	R 71,686	R 56,297	R 17,923

G.6 Filling Conveyor.

The speed of the filling conveyor can vary between to limiting factors. The filling conveyor must run fast enough to deliver a box from the gravity conveyor to the filling point before the caption box overflows with caps, and the conveyor must run slower than the maximum printer speed of the bar code printer.

From the above information the filling conveyor specifications are calculated and tabulated below in Table G.6.

Table G.6 : Filling conveyor specification.

Type of Conveyor	Flat Belt Conveyor
Type of Bed	Rollers
Width of Conveyor	14 " or 350 mm
Width of Rollers	16 " or 400 mm
Velocity	
Min	12.5 mm/s
Max	1000 mm/s
Length of Conveyor	1.3 m
Number of Conveyors	12 Conveyors
Cost	R 23 196 (For Twelve Units)

G.7 Main Conveyor and Sorting Conveyor Systems.

The speed at which these two conveyor must operate is calculated. For the worse case scenario the minimum speed of operation will be when all the boxes produced, on the various production lines, lie exactly next to one another on the main conveyor.

G.8 Sealing the Filled Boxes.

The number of workers required to seal the filled boxes is calculated. The average and range of times for a worker to seal a filled carton box was measured in Appendix B.4 and is tabulated in Table G.8.1.

Table G.8.1 : Range of times taken to seal a filled carton box.

Mean	54.16 Seconds
Range	28.11 Seconds to 86.54 Seconds

The maximum number of boxes produced per hour on all the production line can be seen in Table G.1. For all the production lines the number of workers require to seal box is,

$$\text{Number of Workers} = \frac{115 \cdot 86.54}{3600} = 2.76 \text{ workers}$$

A list of the automatic machinery which can seal carton boxes is tabulated below in Table G.8.2.

Table G.8.2 : Machinery for automatically sealing carton boxes.

Manufacture	SIAT	PATTYN
Model	SM44	P12
Supplier	AFCOM	COLUMBIT
Carton Capacity		
(x,y,z)	Min 140*200*150 mm	210*300*200 mm
	Max 500*600*500 mm	300*700*650 mm
Machine Dimensions	1080*2550*1850 mm	1825*4760*1830 mm
(x,y,z)		
Power Consumption	0.16 kW	1.5 kW
Machine Output	350 - 450 Cartons/Hour	720 Cartons/Hour
Price	R 140,905	R 356,786

G.9 Bar Code Scanner.

The specifications of the bar code scanner is tabulated in Table G.9.

Table G.9 : Bar code scanner.

Manufacturer	MICROSCAN
Model	MS 710 RASTER
Supplier	SCANTECH
Communications Interface	RS-232 Port
Dimensions (x,y,z)	63*87*34 mm
Mass	0.255 kg
Operating Life	10000 hrs at 50 deg C
Operating Range	50-250 mm
Scan Rate	300-550 Scans/Min
Cost	R 7,525

G.10 Sorting Piston Calculations.

The pistons used to sort the filled boxes are chosen and calculated. Double acting cylinder must be used. The pistons chosen, Ref. 31, is the FESTO DC-100-500 used as the dispenser piston and the FESTO DC-100-300 used as the ejection pistons..

The piston specification are tabulated below, Table G.10.

Table G.10 : Sorting piston specifications.

Piston Name	DC-100-500	DC-100-300
Piston Diameter	100 mm	100 mm
Stroke Length	500 mm	300 mm
Max. Pressure	12 bar	12 bar
Operating Pressure	6 bar	6 bar
Total Length (Closed Position)	691 mm	491 mm
Piston Rod Diameter	22 mm	22 mm
Weight	12.56 kg	9.28 kg
Connection	G 3/8	G 3/8
Mounting	Foot Mounting front and rear, Type HC	Foot Mounting front and rear, Type HC
Cost	R1,752	R1,702

The force of the piston can be measured using the following graph provided by Festo (Ref. 31), Figure G.10.1. (Assume operational pressure to be 6 bar)

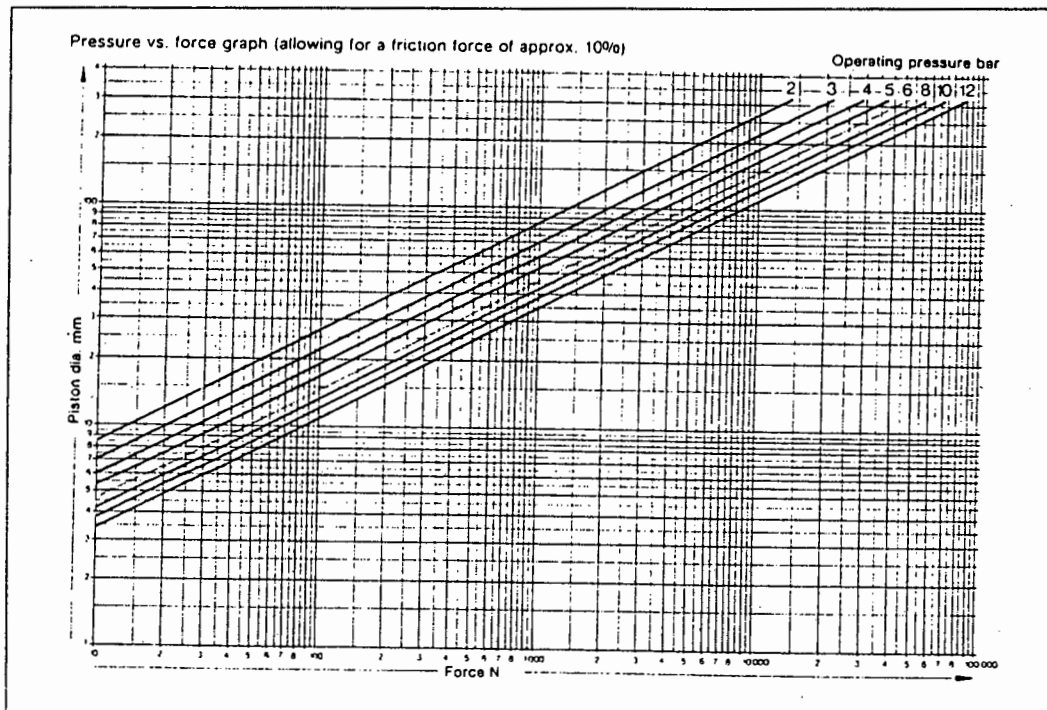


Figure G.10.1 : Pressure vs. Force Graph for a double acting piston.

Maximum Force = 4300 N (Pressure Force Graph)

Due to buckling stress, the permissible load of a piston which has a long stroke length is smaller than that provided by the maximum permissible working pressure and piston surface. This load may not exceed certain maximum values which are related to the stroke length and piston rod diameter. Figure G.10.2 shows this relationship.

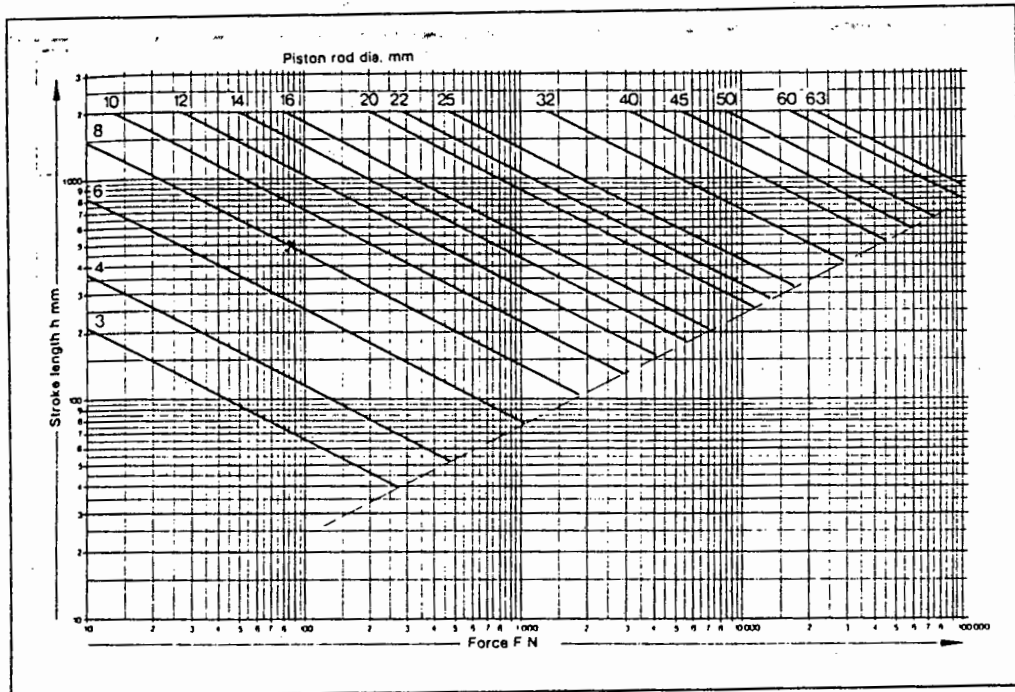


Figure G.10.2 : Graph of bulking loads for a double acting piston.

Referring to Figure G.10.2,

Piston Rod Diameter = 17 mm (Stroke Length 300mm)

Piston Rod Diameter = 21 mm (Stroke Length 500mm)

But the actual piston rod diameter is 22mm therefore the piston doesn't exceed the maximum permissible bulking forces.

The heaviest carton box the piston system can push off the conveyor belt is.

$$Force = \mu \cdot m \cdot g$$

$$m = \frac{force}{\mu \cdot g}$$

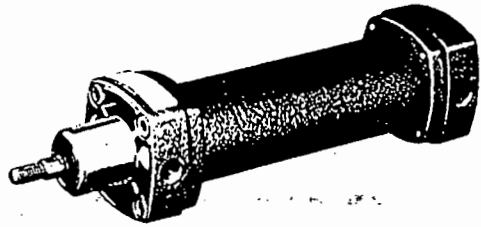
Where,

$$\mu = 0.2$$

$$g = 9.81$$

Therefore,

$$Mass = 2191.6 \text{ kg}$$



The amount of air consumed for one stroke can be measured using the following graph shown in Figure G.10.3.

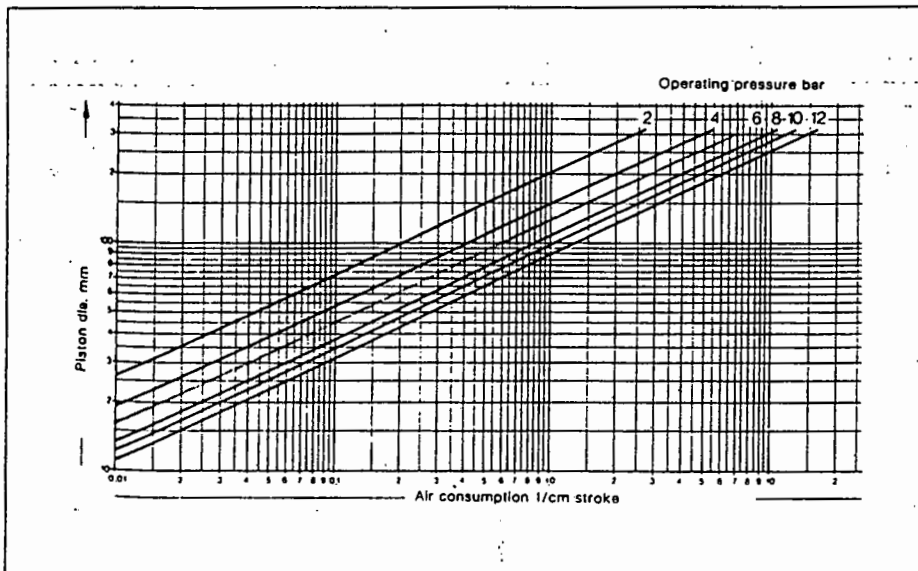


Figure G.10.3 : Air consumption graph for a double acting piston.

$$Volume = 0.6 \cdot 50 = 30 \text{ litres (Stroke Length 500mm)}$$

$$Volume = 0.6 \cdot 30 = 18 \text{ litres (Stroke Length 300mm)}$$

The speed at which the piston move can be measured using the graph shown in Figure G.10.4.

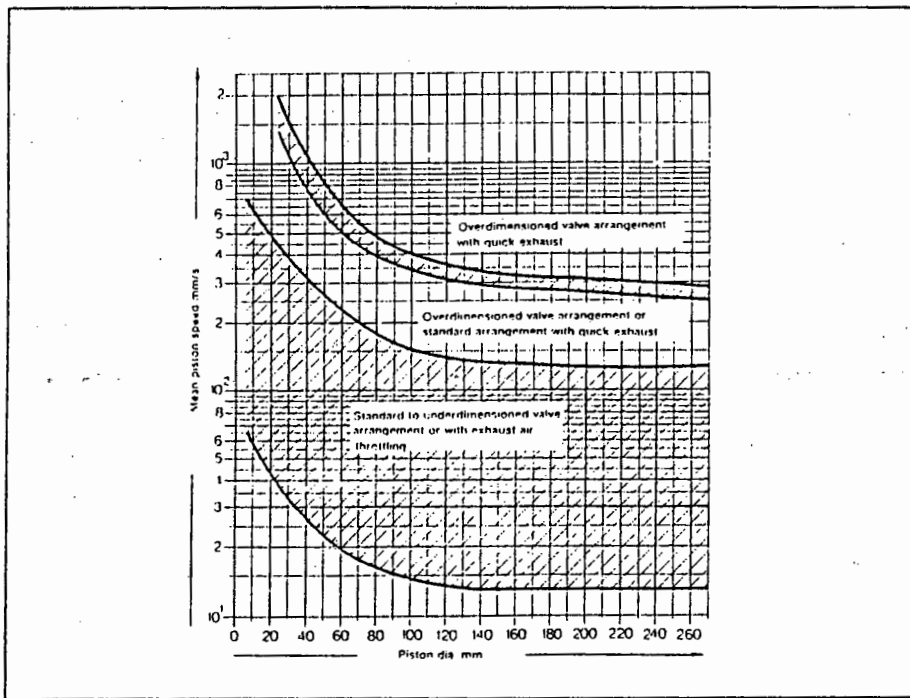


Figure G.10.4 : Piston speed graph for double acting piston.

Referring to Figure G.10.4, a speed of 300mm/s is required for the ejection piston, such that the piston comes from a fully closed position to a full open position in 1 seconds.

For such a speed an over dimensioned valve arrangement or standard arrangement with quick exhaust is required (Figure G.10.4).

G.11 Solenoid Values.

Solenoid valves are needed to control the piston's actions. The solenoid valve must have a large enough connection to ensure that the piston velocity is high, especially for the larger ejection pistons in the sorting system. The following solenoid valve was chosen and is tabulated in Table G.11.1.

Table G.11.1 : Solenoid valves used to control the pistons.

Valve Type	5/2 Way Solenoid Valve
Product Number	MCH-5/2-1/2
Design	Poppet valve, with return spring
Mounting	Through hole on mounting
Connection	G 1/2
Nominal Size	14 mm
Standard Nominal Flow Rate	3700 l/min
Pressure Range	2 to 10 bar
Response Time (6 bar)	On : 16 ms Off : 70 ms
Weight	1.280 kg
Voltage	220 V 50 Hz
Cost	R1,132

The valve will have unthrottled exhaust to increase the speed of the ejection piston, as shown in Figure G.11.1

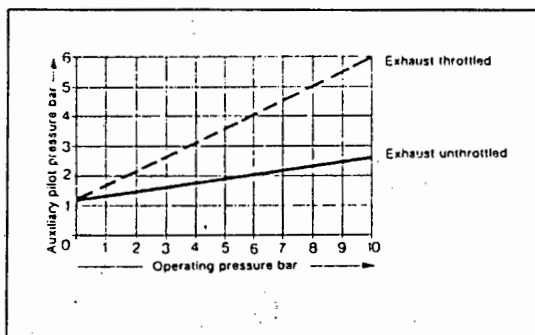


Figure G.11.1 : Throttled and unthrottled valve.



Appendix H

Lego Model Control Flow Charts

H.1 Flow Charts for Control Procedure.

H.1.1 Flow Chart : Level 1.

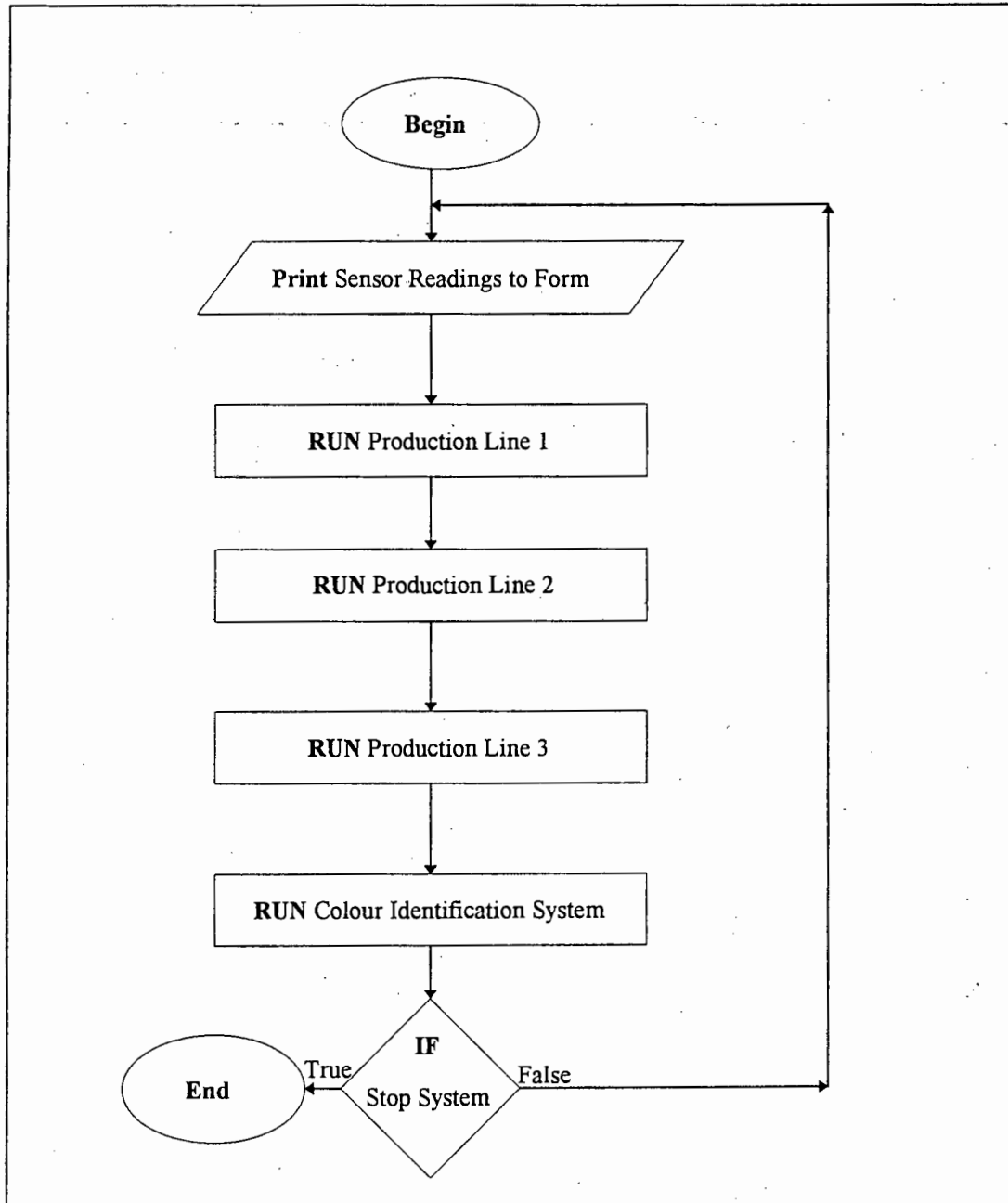


Figure H.1 : Control system flow chart : Level 1

H.1.2 Flow Chart : Level 2 (Production Lines).

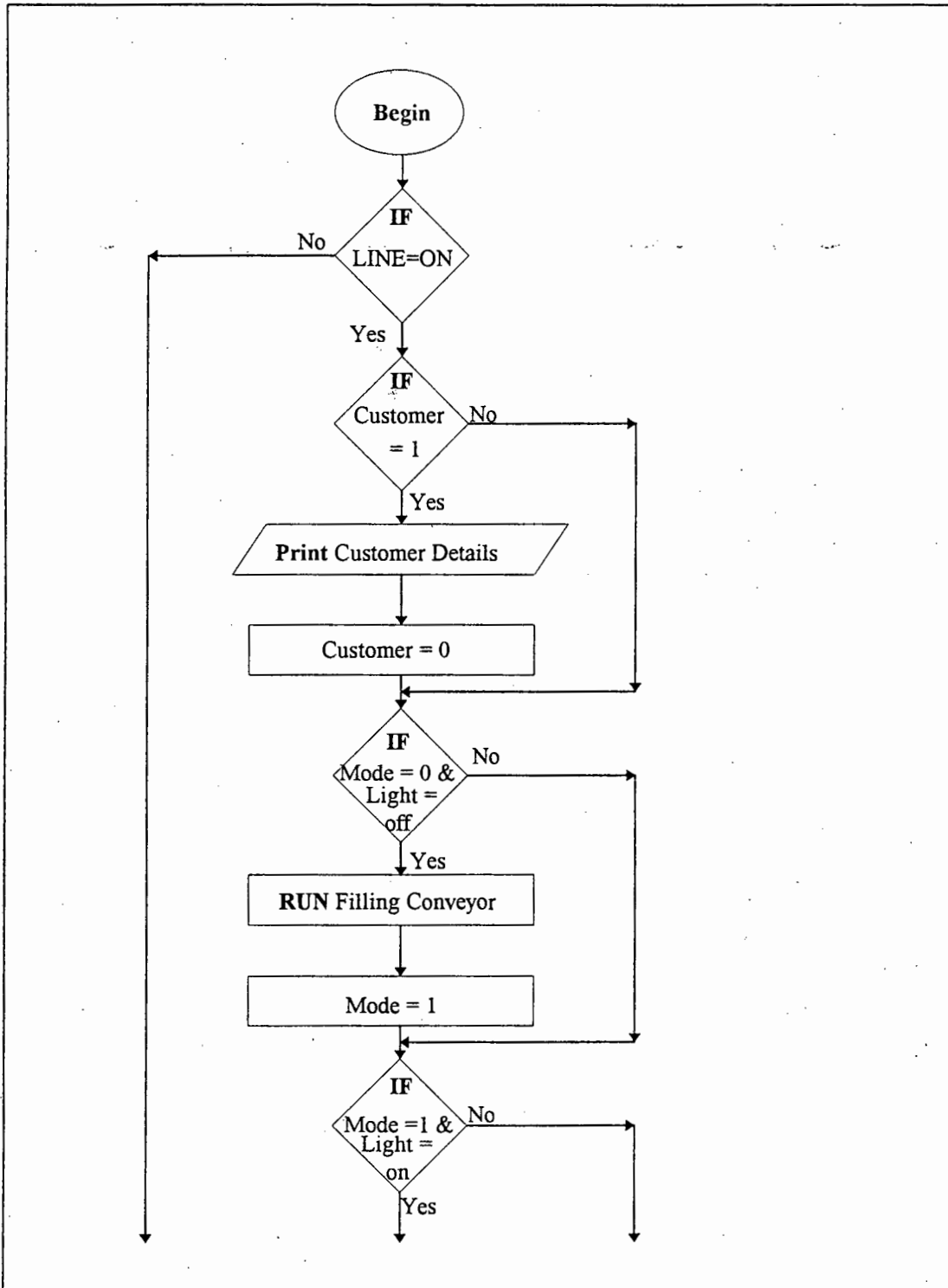


Figure H.1.2 : Production line control flow chart.

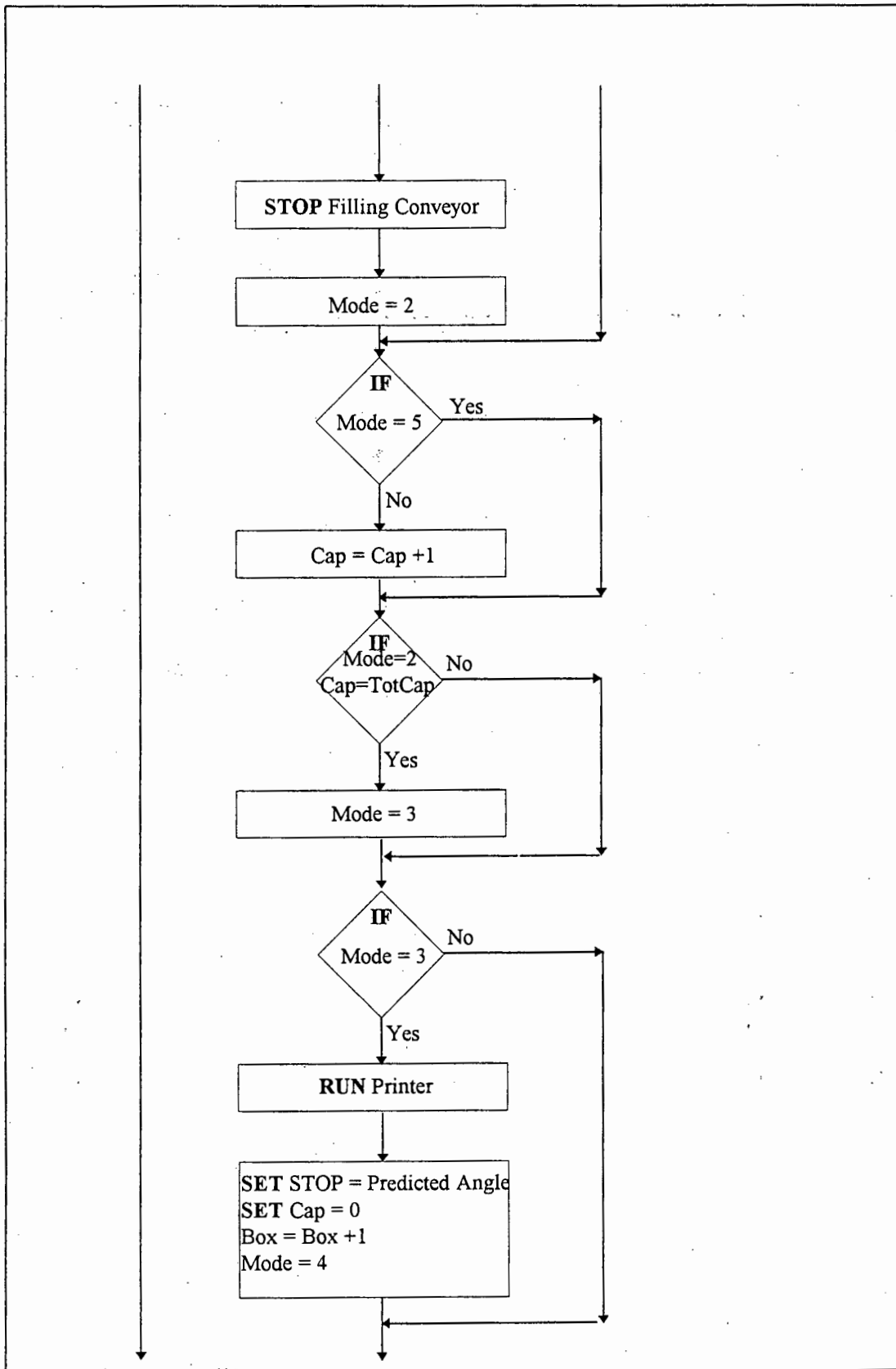


Figure H.1.2 : Production line control flow chart.

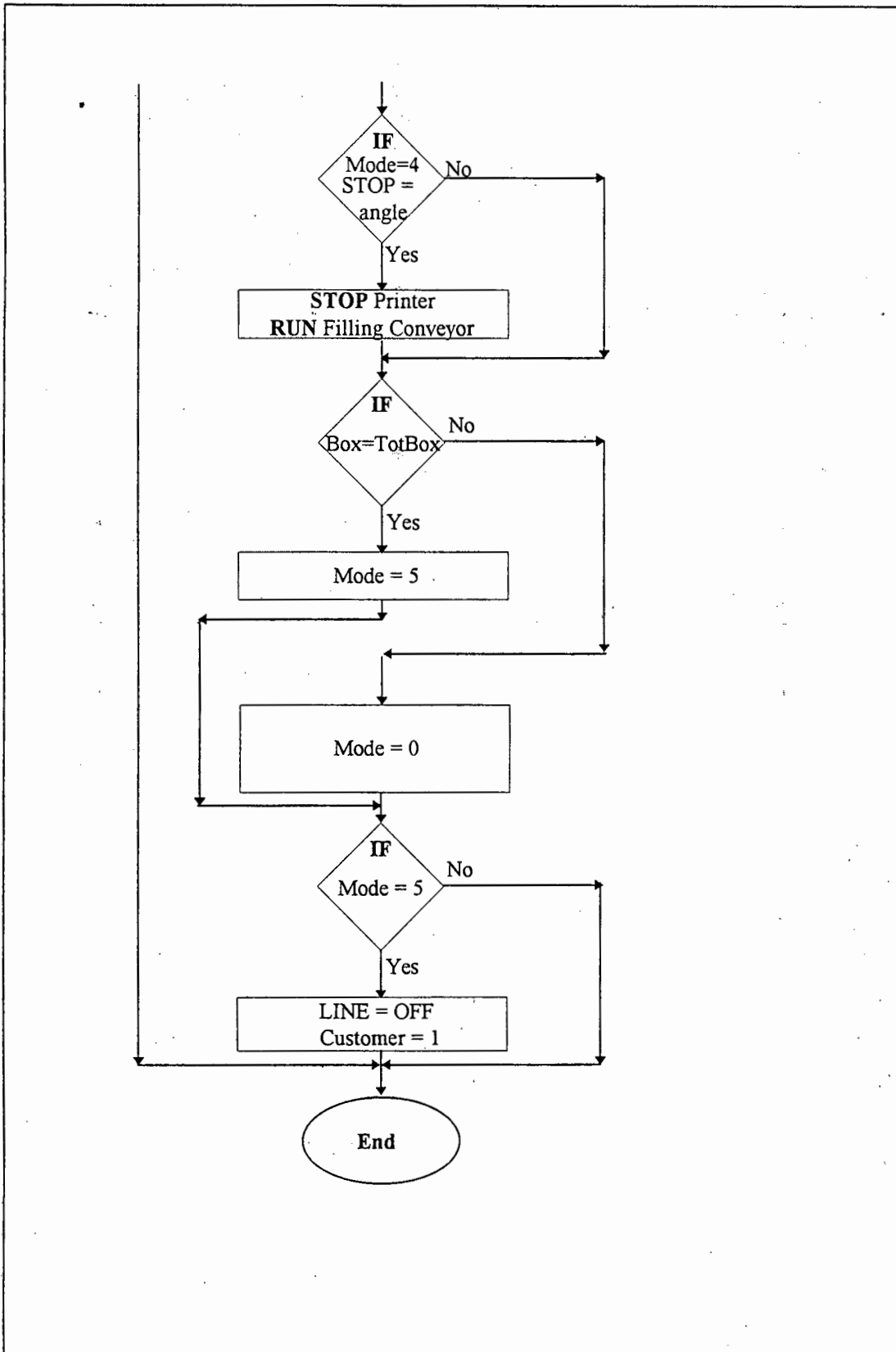


Figure H.1.2 : Production line control flow chart.

H.1.3 Flow Chart : Level 2 (Sorting System).

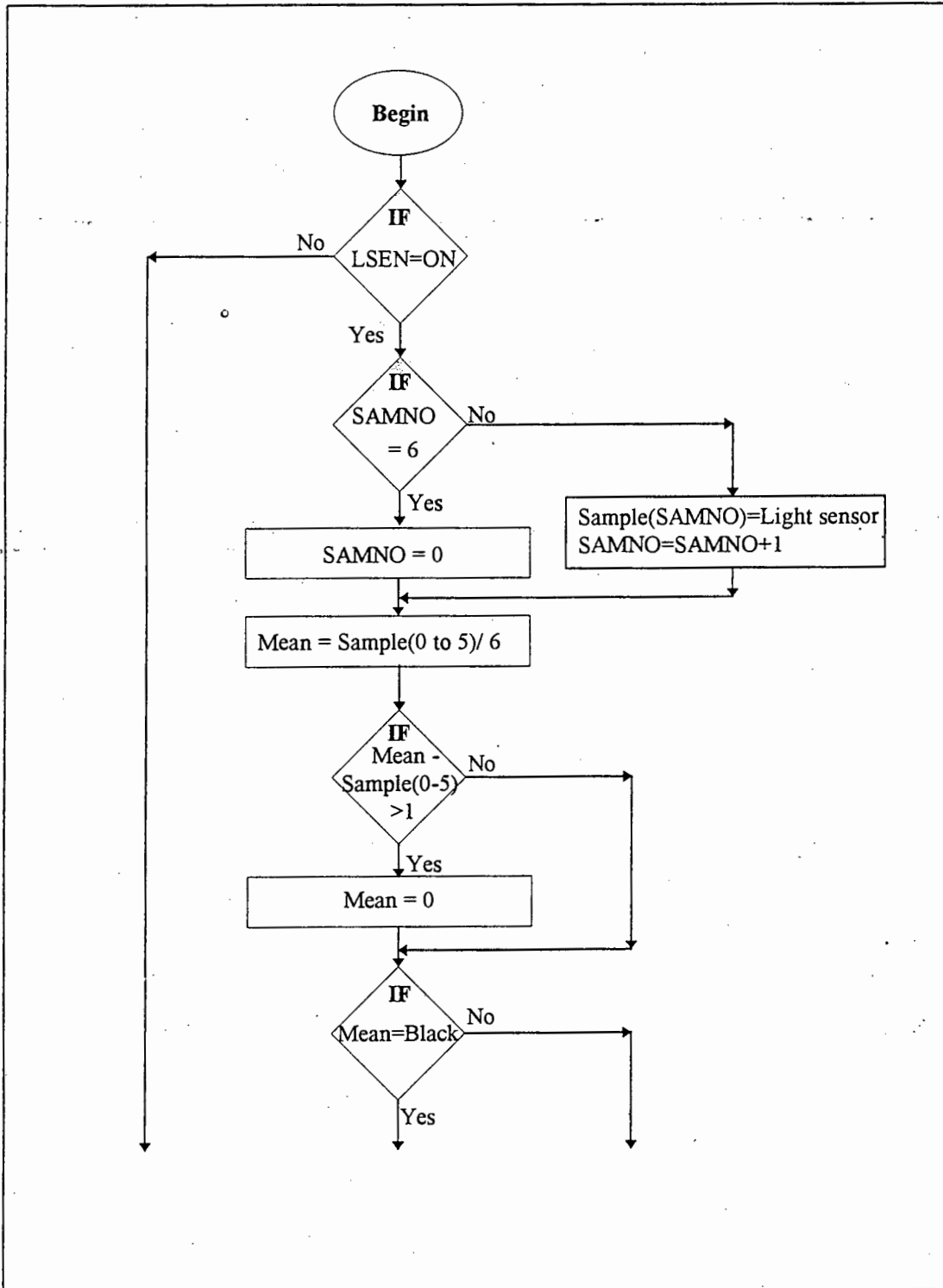


Figure H.1.3 : Sorting system flow chart.

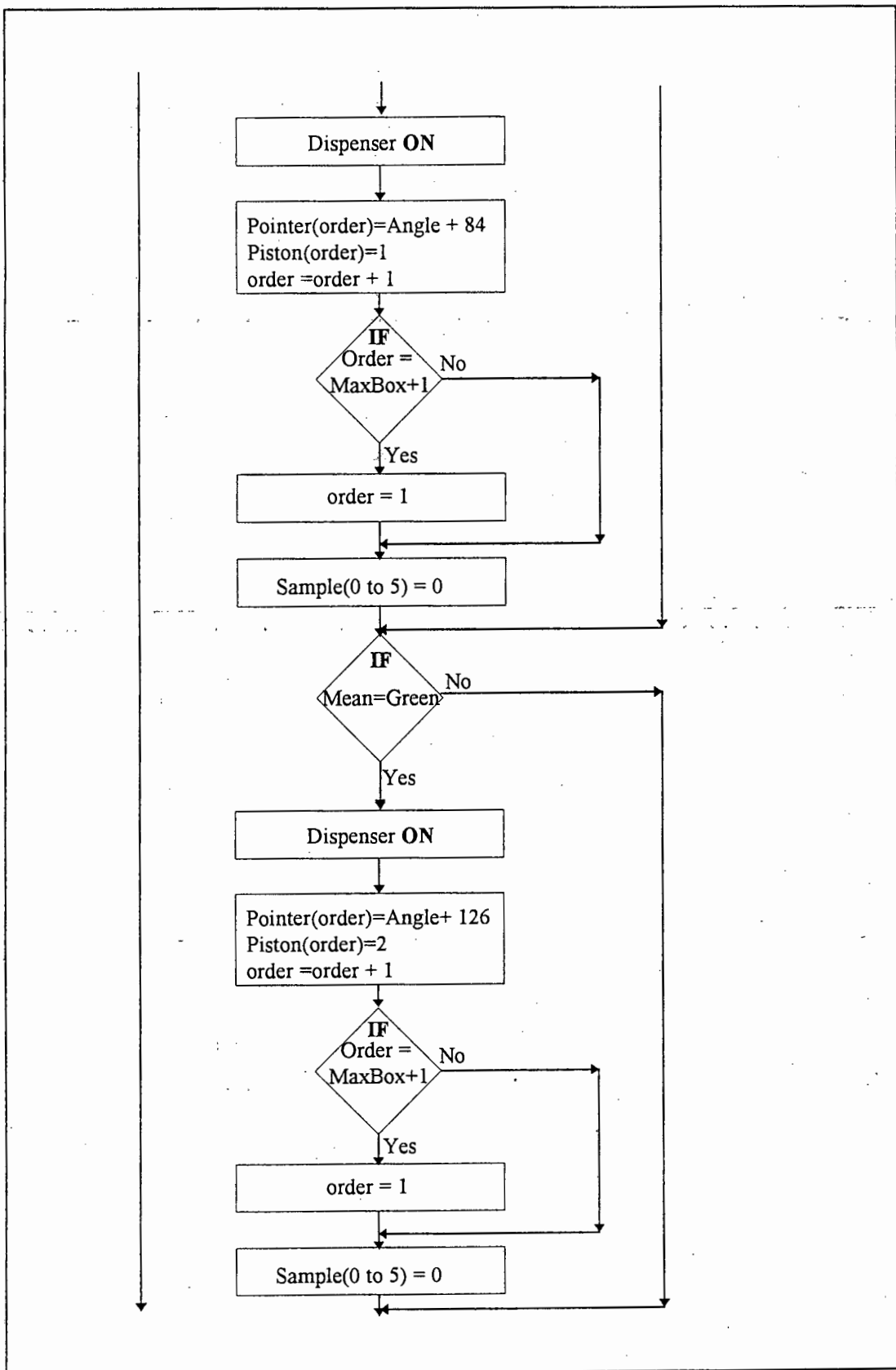


Figure H.1.3 : Sorting system flow chart.

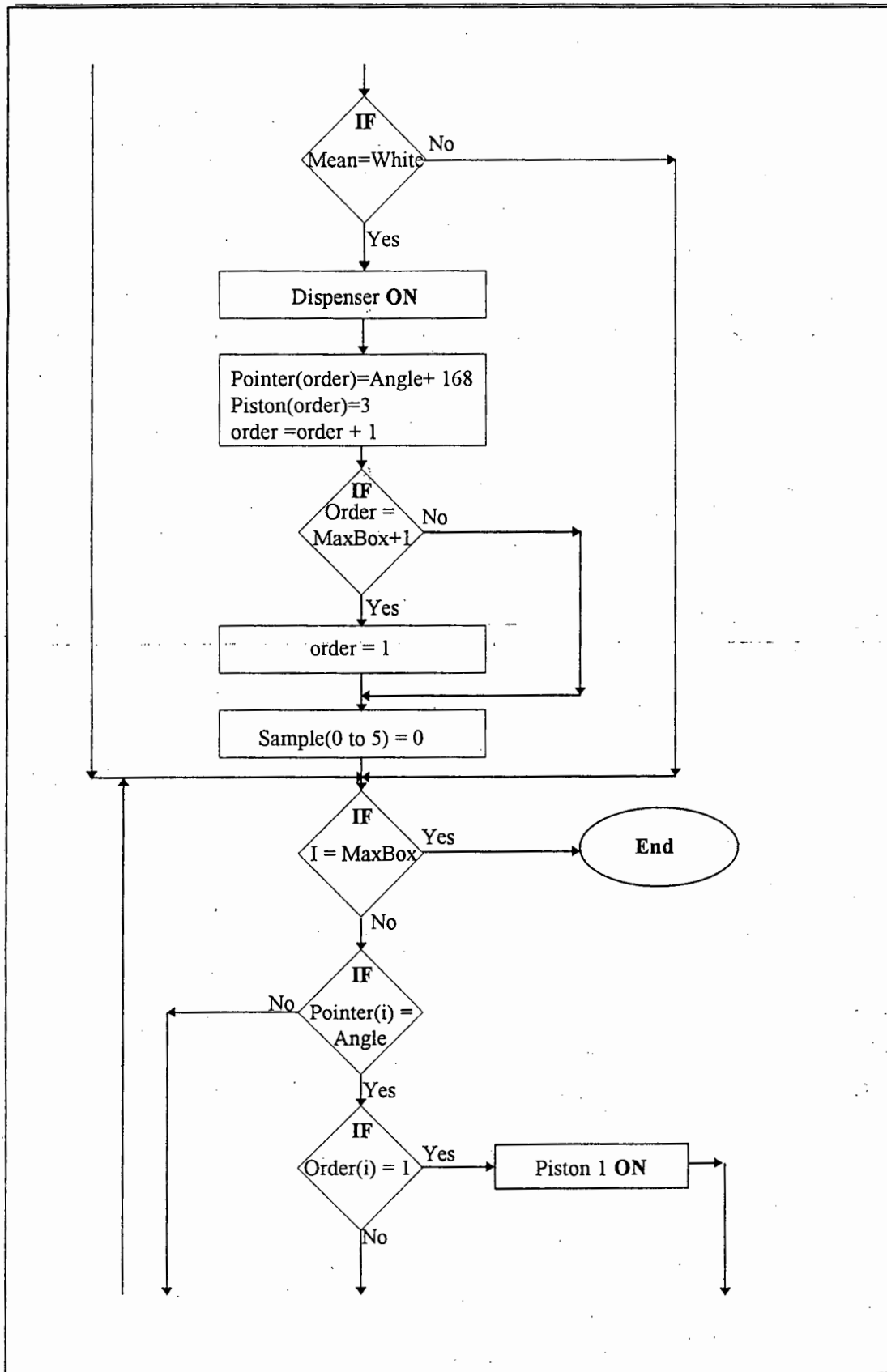


Figure H.1.3 : Sorting system flow chart.

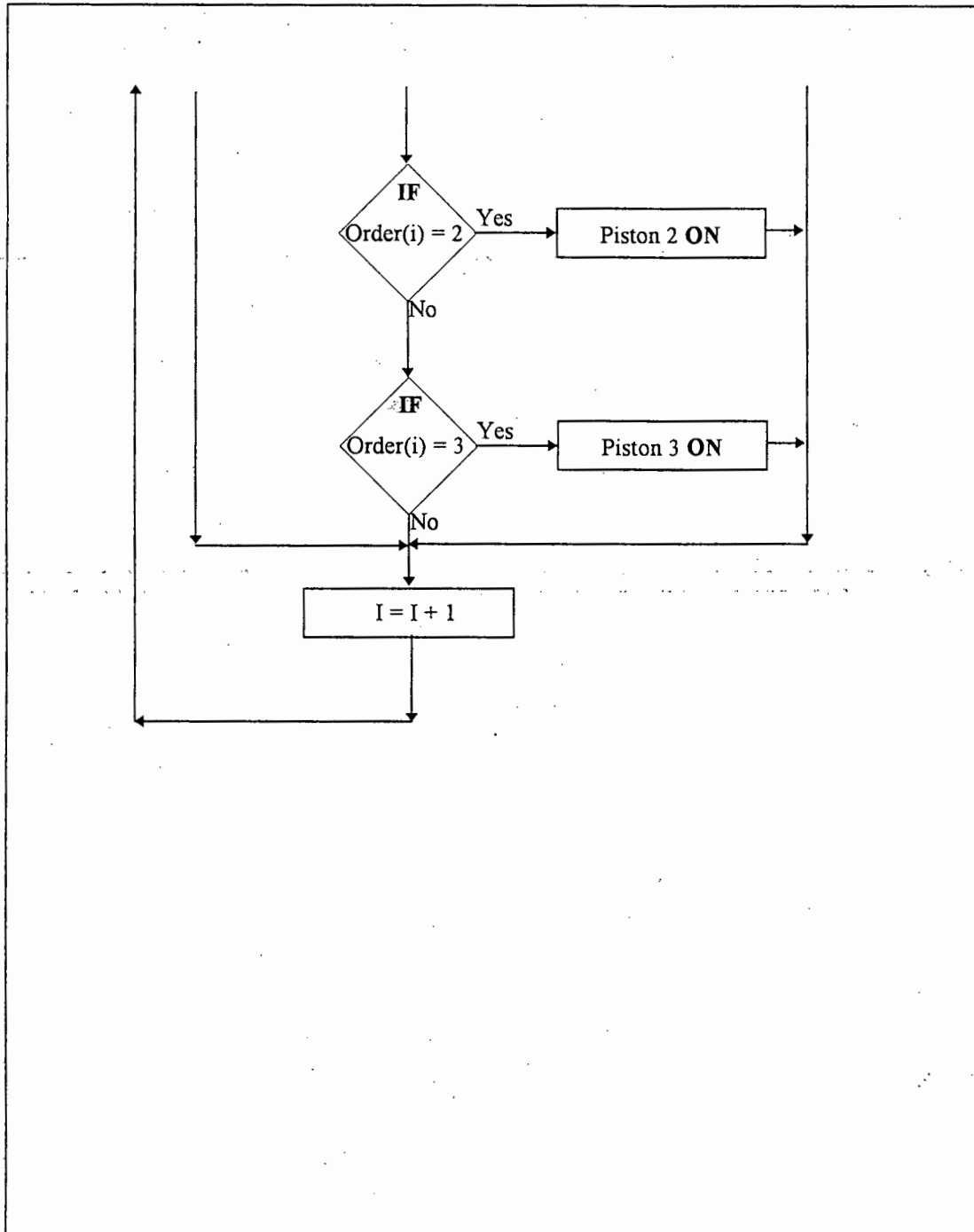


Figure H.1.3 : Sorting system flow chart.

Appendix I

PLC Control Ladder Diagrams

I.1 Controlling the Gravity Conveyor Box Collection

Piston.

The ladder diagram for the PLC program is shown in Figure I.1.1.

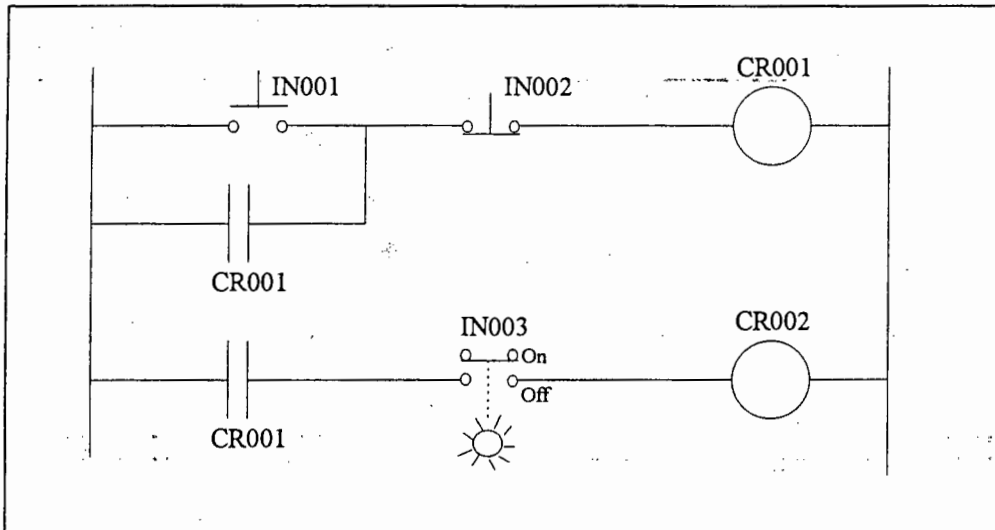


Figure I.1.1 : PLC ladder diagram for gravity conveyor solenoid.

- Where,
- IN001 - Start Button.
 - IN002 - Stop Button.
 - IN003 - Light Sensor.
 - CR001 - Starting Coil.
 - CR002 - Piston Solenoid Valve.

The state time graph for the above PLC ladder diagram, is shown in Figure I.1.2.

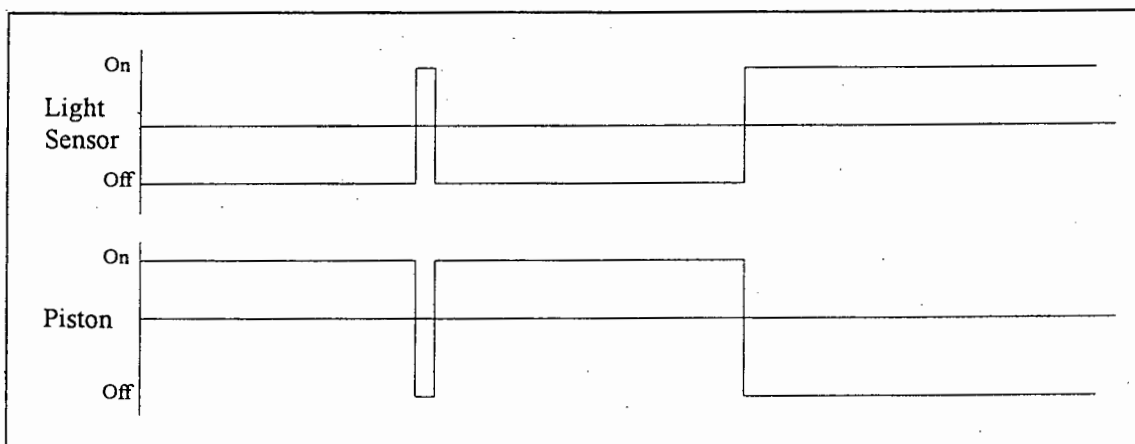


Figure I.1.2 : State-time graph for gravity conveyor PLC program

The small spike in the state-time graph is a box which passes the light sensor, but does not stay in front of the light sensor. The piston turns off for a small amount of time. This can be corrected by using a light sensor which has a large or slow reaction time. In other words if a box has to pass the light sensor, the sensor would remain on. The sensor would only turn off if the box had to stay in front of the light sensor for a large amount of time.

I.2 Control of the Filling Procedure.

The PLC ladder diagram is shown in Figure I.2.1.

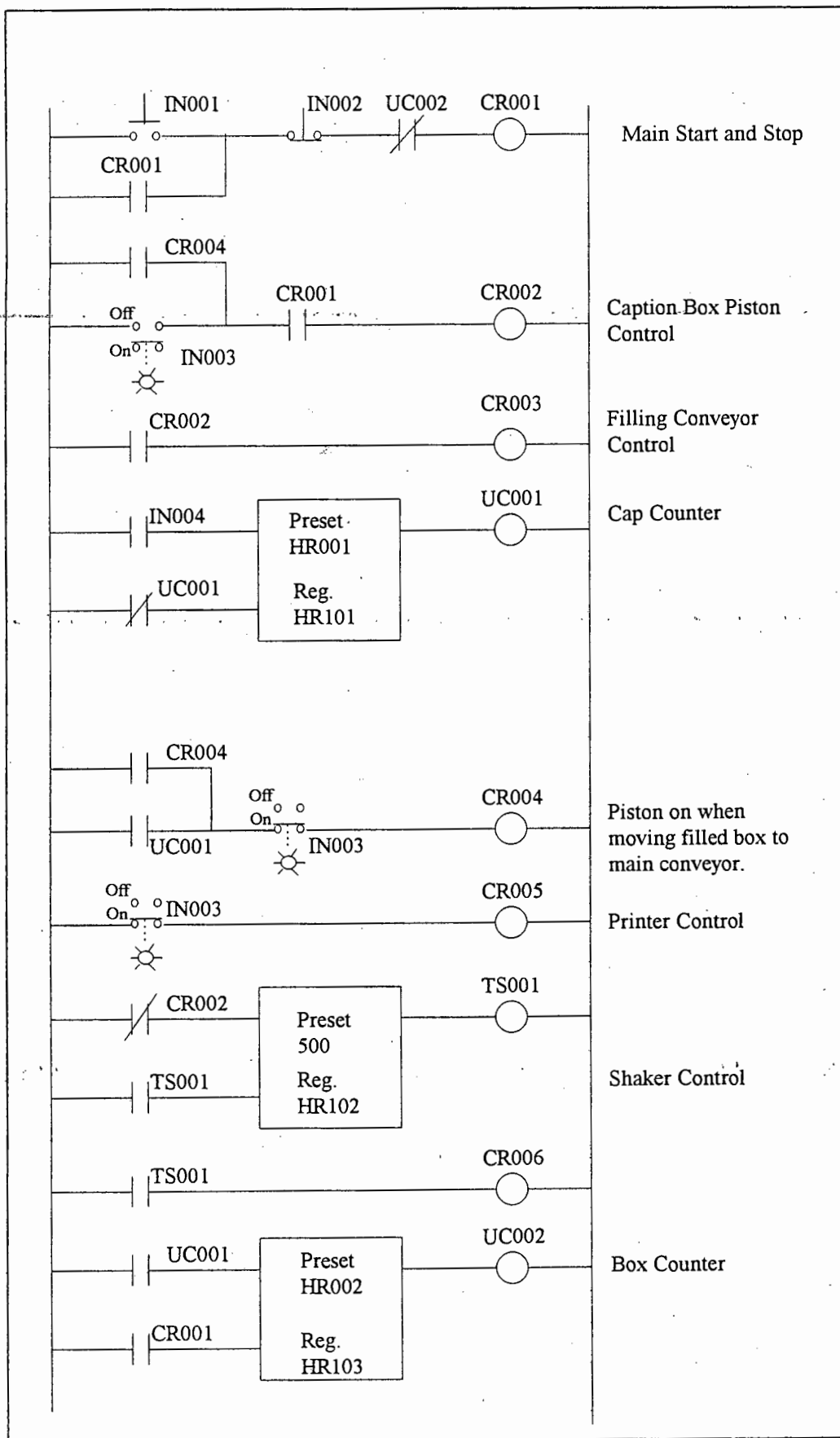
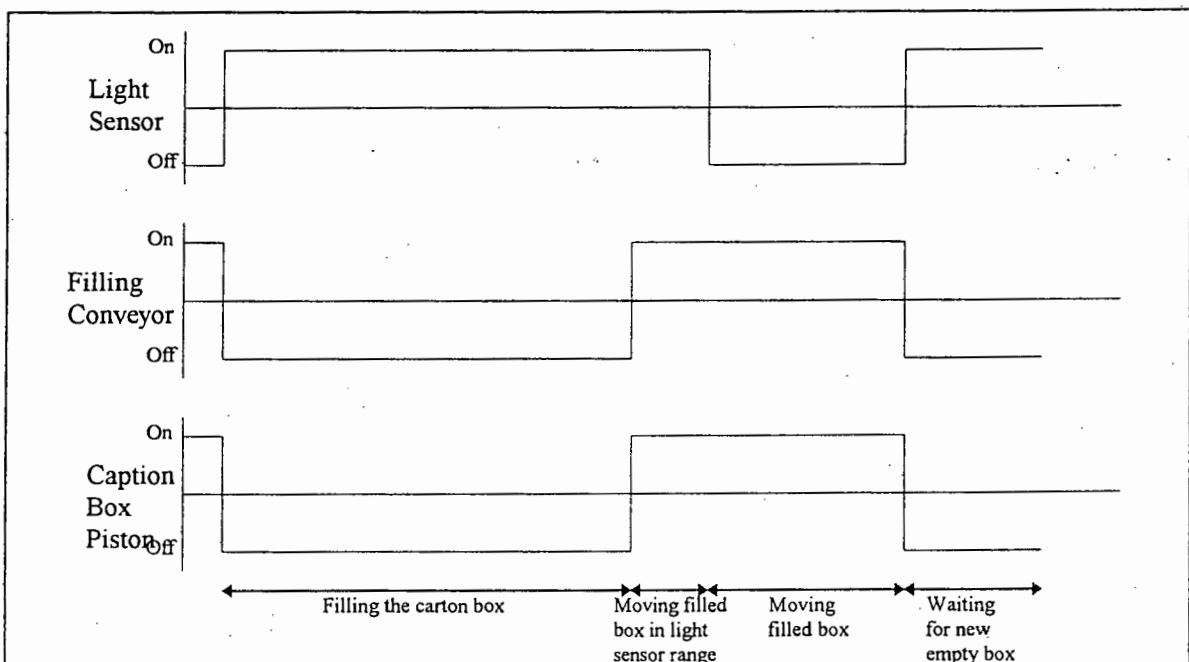


Figure I.2.1 : PLC ladder for filling conveyor system.

- Where,
- IN001 - Start Button.
 - IN002 - Stop Button.
 - IN003 - Light Sensor.
 - IN004 - Cap Counter.
 - CR001 - Start Coil.
 - CR002 - Caption Box Piston.
 - CR003 - Filling Conveyor.
 - CR004 - Moving Filled Box Coil.
 - CR005 - Printer Coil.
 - CR006 - Shaker Coil.
 - UC001 - Cap Counter.
 - UC002 - Box Counter.
 - TS001 - Shaker Timer.
 - HR001 - Number of Caps per Box.
 - HR002 - Number of Boxes.
 - HR101 - Register were Counting takes place.
 - HR102 - Register were Timing takes place.
 - HR103 - Register were Counting takes place.

The state-time graph for filling system PLC ladder diagram is shown in Figure I.2.2.



FigureH.2.2 : State-time graph for filling system PLC program.

I.3 The Carton Box Sorting Area.

Each piston is assign a certain number of angle count variable slots. Each variable slot can store the ejection angle count for a certain box travelling on the filling conveyor. Once that value has been reach by the angle counter on the sorting conveyor. The piston is activated and the box will be moved off the sorting conveyor and into the correct storage area. A graphic example of how the angle count numbers are manipulated is illustrated in Figure I.3.1.

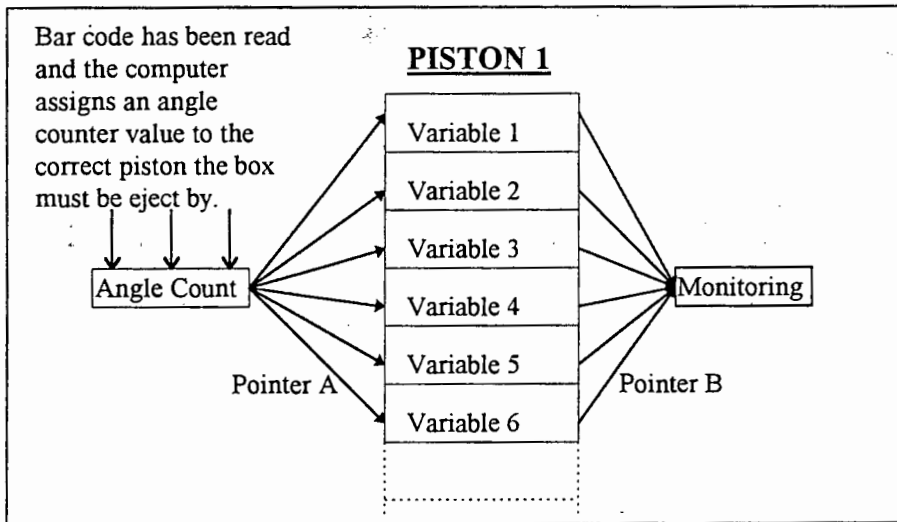


Figure I.3.1 : Angle counter value handling.

Pointer A and pointer B control which block or variable is being used, either for monitoring or inserting values.

The PLC ladder diagram is shown in Figure I.3.2.

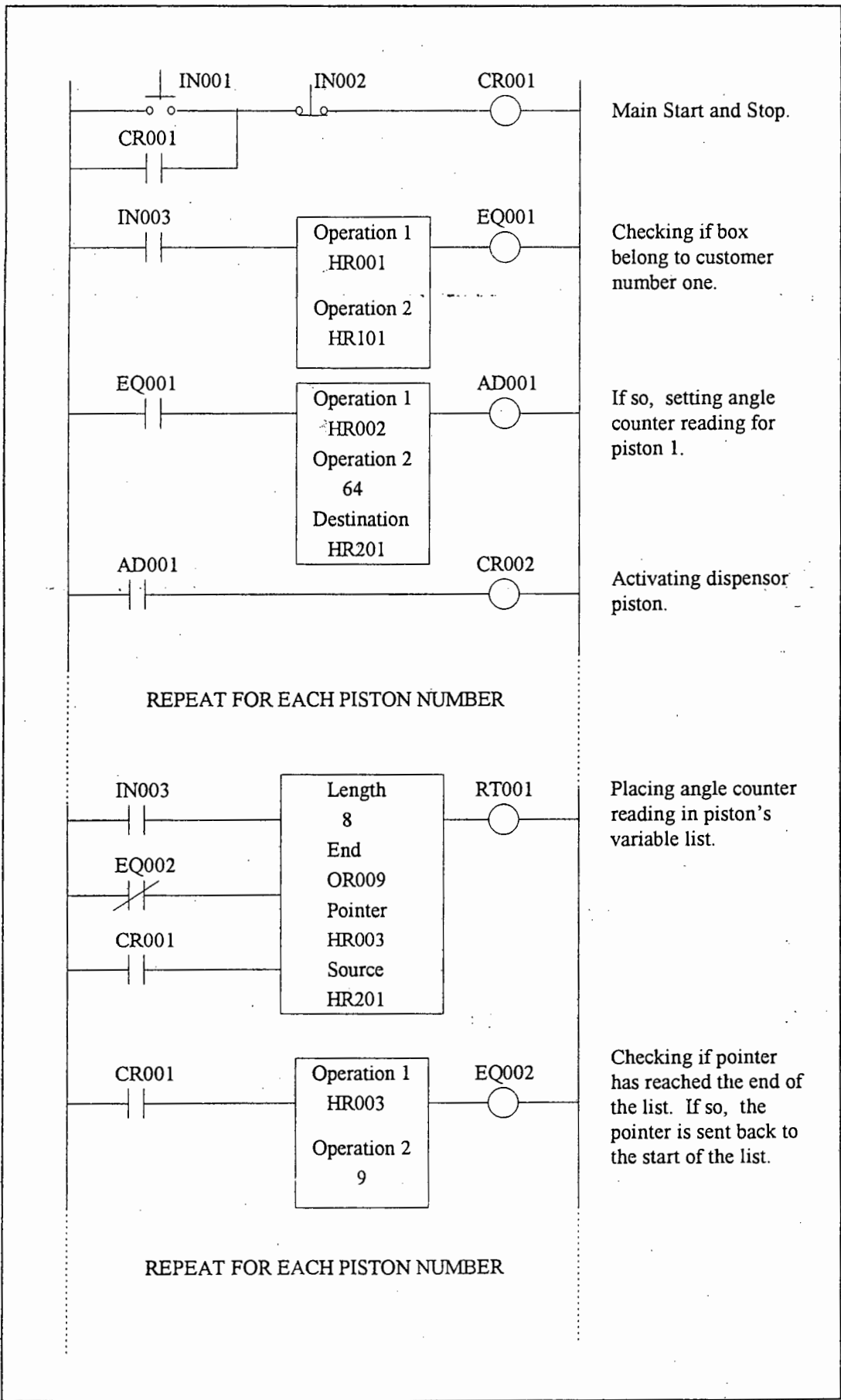


Figure I.3.2 : The PLC ladder diagram for the sorting system.

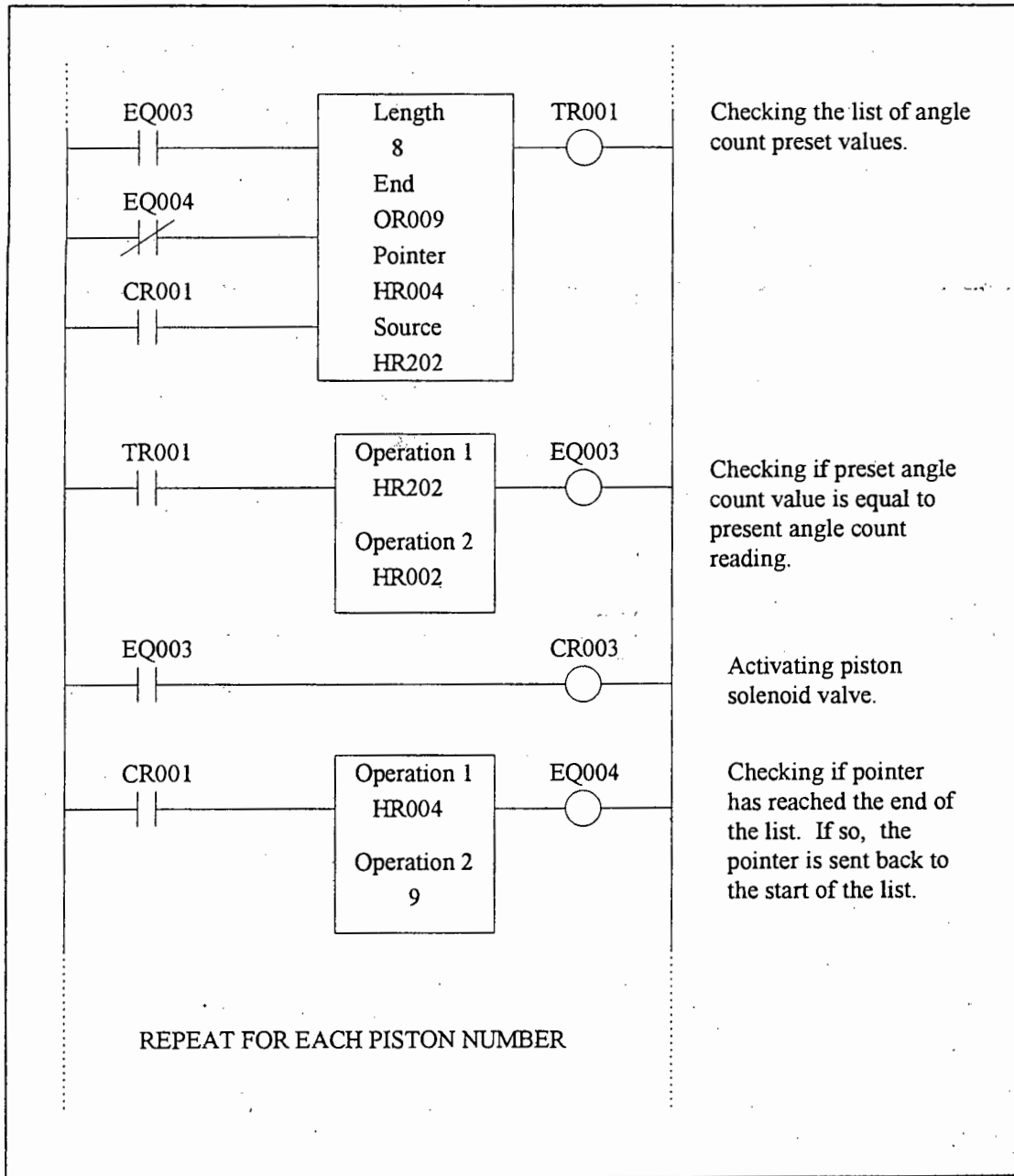


Figure I.3.2 : The PLC ladder diagram for the sorting system.

- Where,
- IN001 - Start Button.
 - IN002 - Stop Button.
 - IN003 - Bar Code Reader.
 - CR001 - Starting Coil.
 - CR002 - Dispenser Piston Solenoid Value.
 - CR003 - Piston 1 Solenoid Value.
 - HR001 - Bar Code Value.

HR002 - Angle counter reading.

HR003 - Pointer A.

HR004 - Pointer B.

HR101 - Customer's Number.

HR201 - Box Preset Angle Counter Value.

HR202 - Monitoring Angle Counter Value for Piston 1.

OR001 to OR009 - List of Angle Counter Values for Piston 1.

EQ001 to EQ004 - Equal Function.

AD001 - Addition Function.

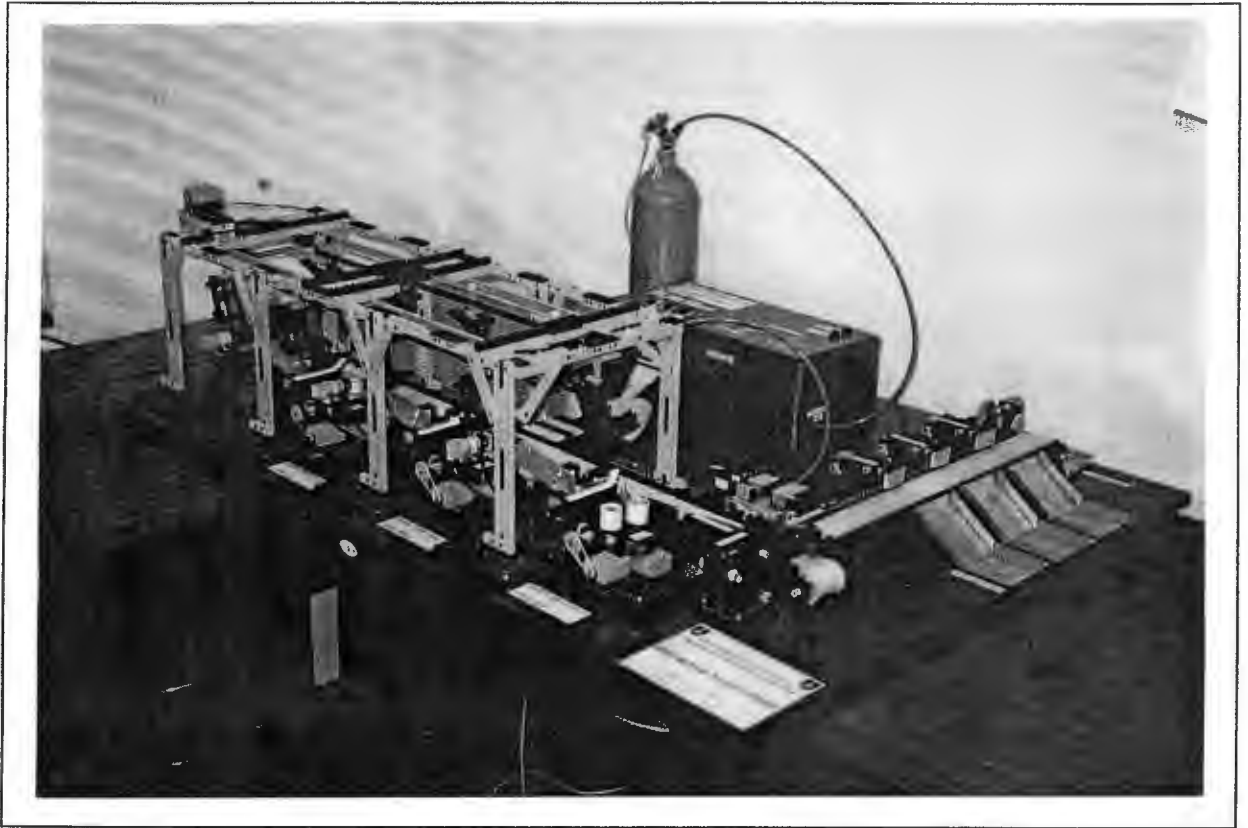
RT001 - Transfer to List Function.

TR001 - Transfer form List Function.

Appendix J

Model Photographs

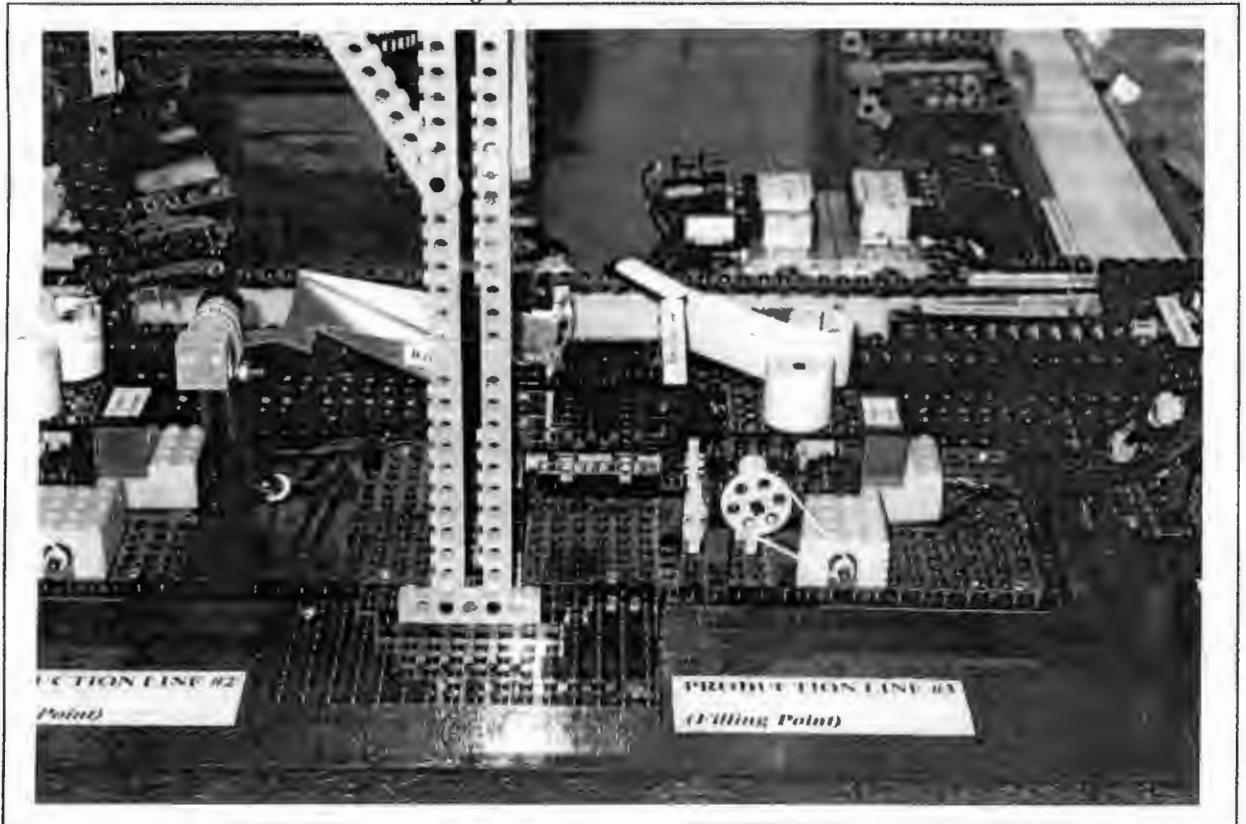
Photograph 1 : Lego Factory Model



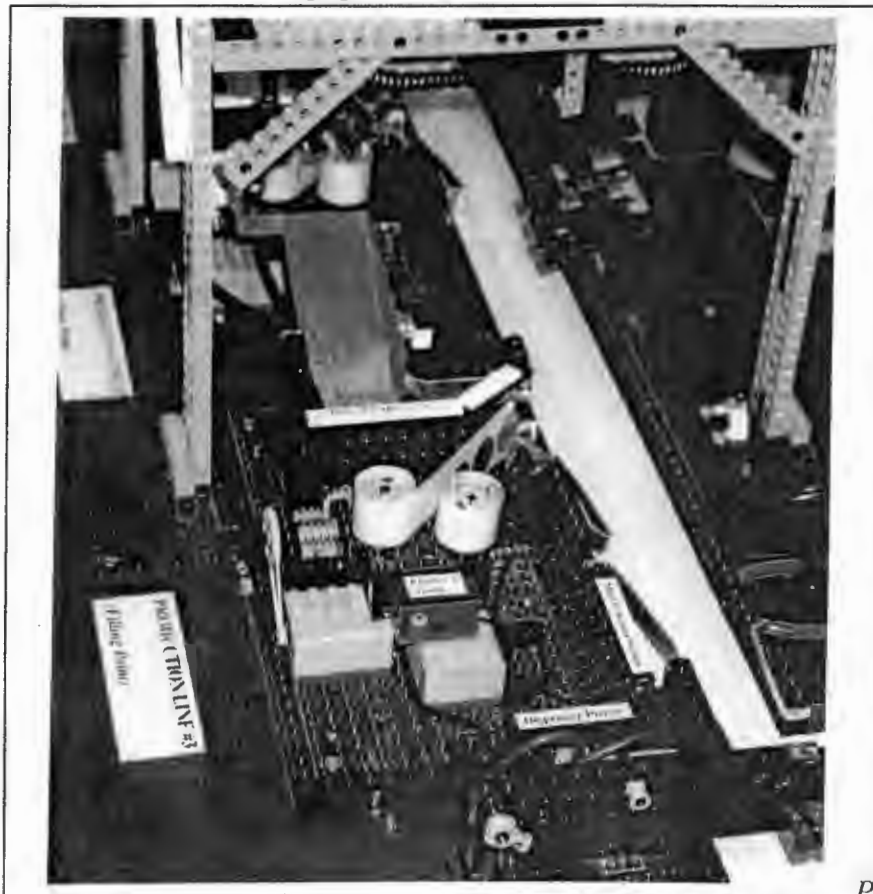
Photograph 2 : The Three Production Lines.



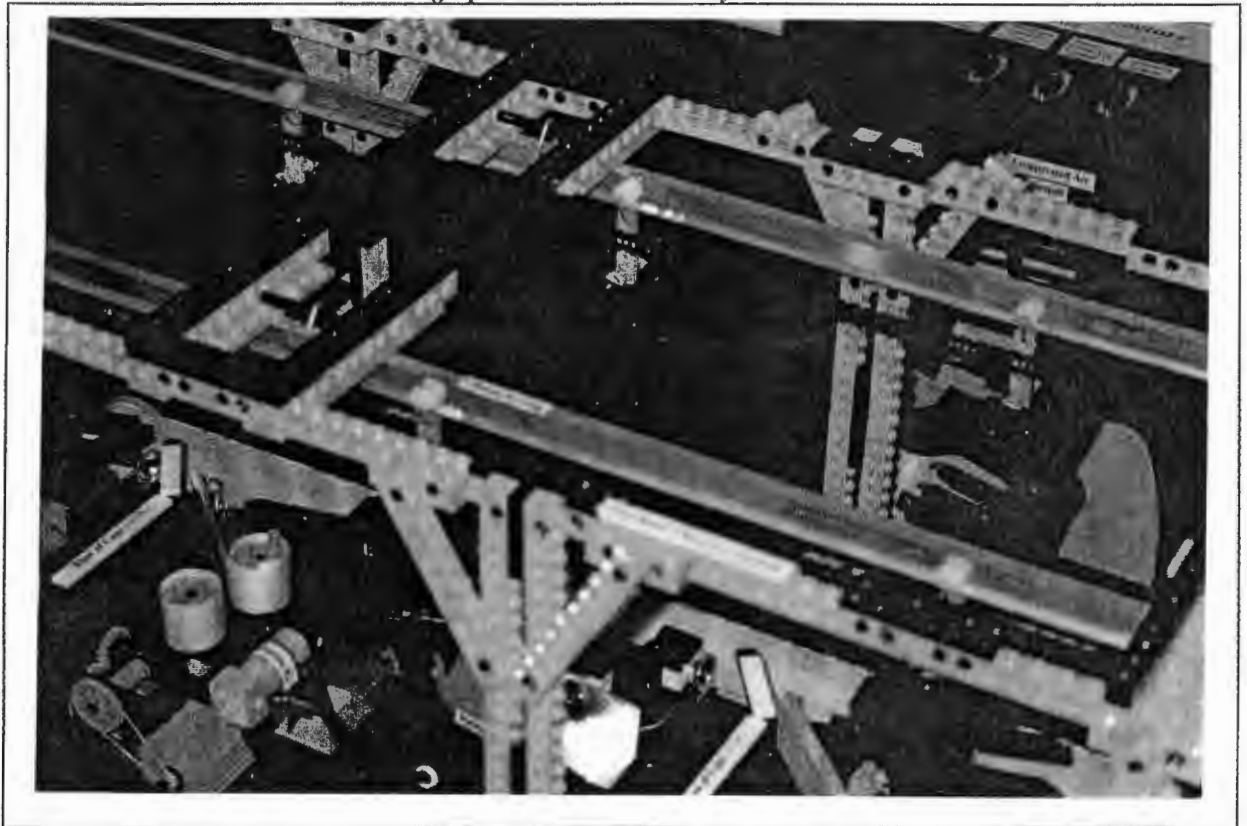
Photograph 3 : Production Line



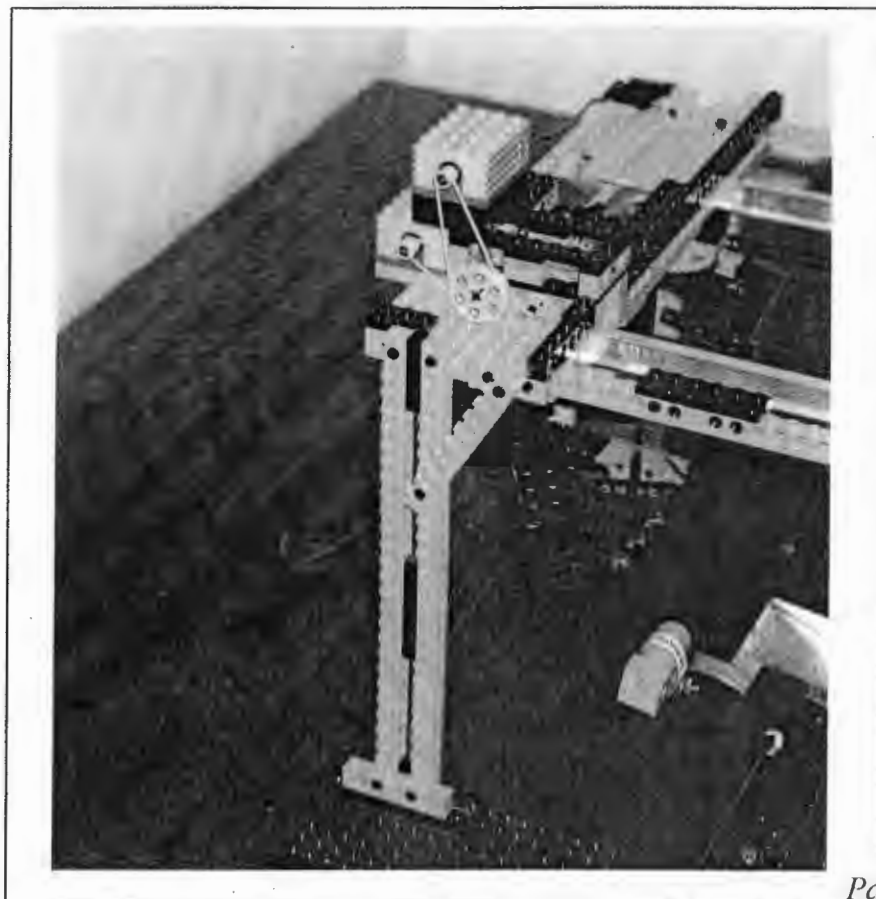
Photograph 4 : Production Line.



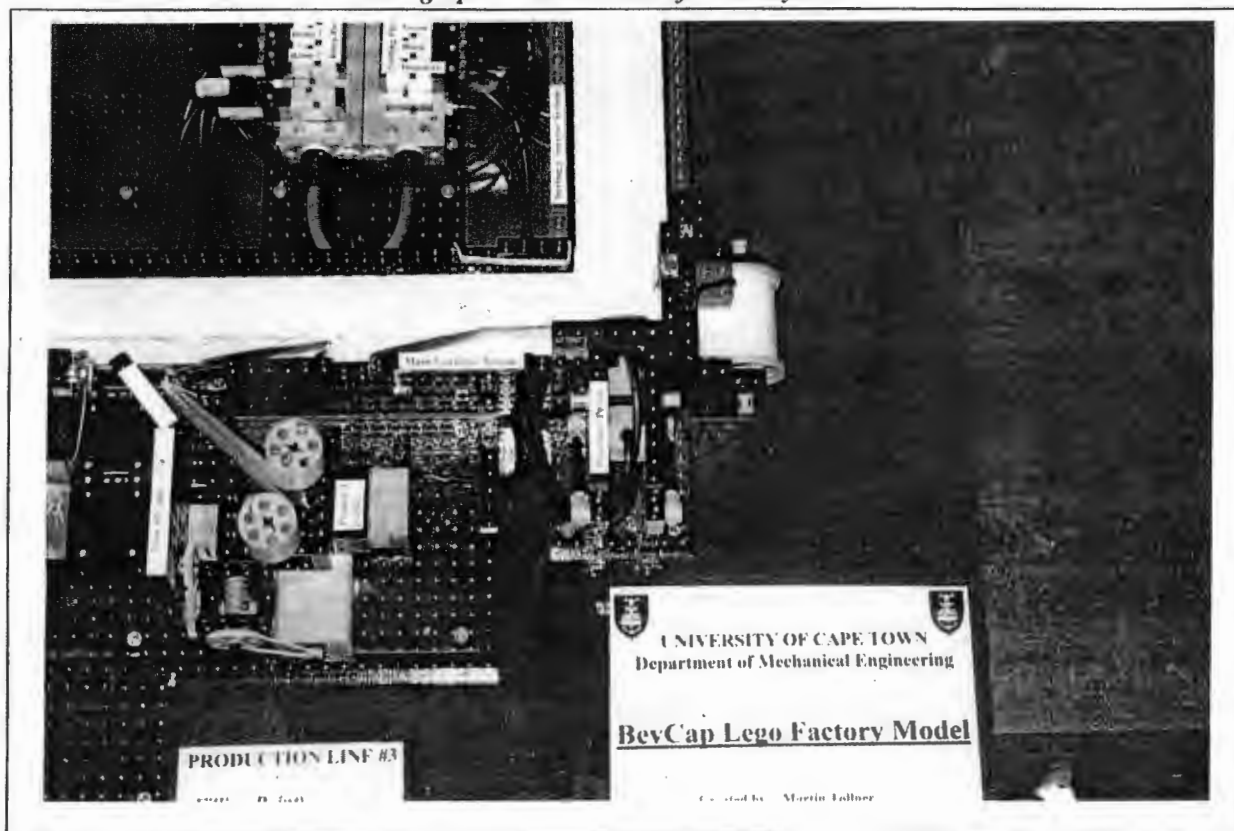
Photograph 5 : Overhead conveyer chart



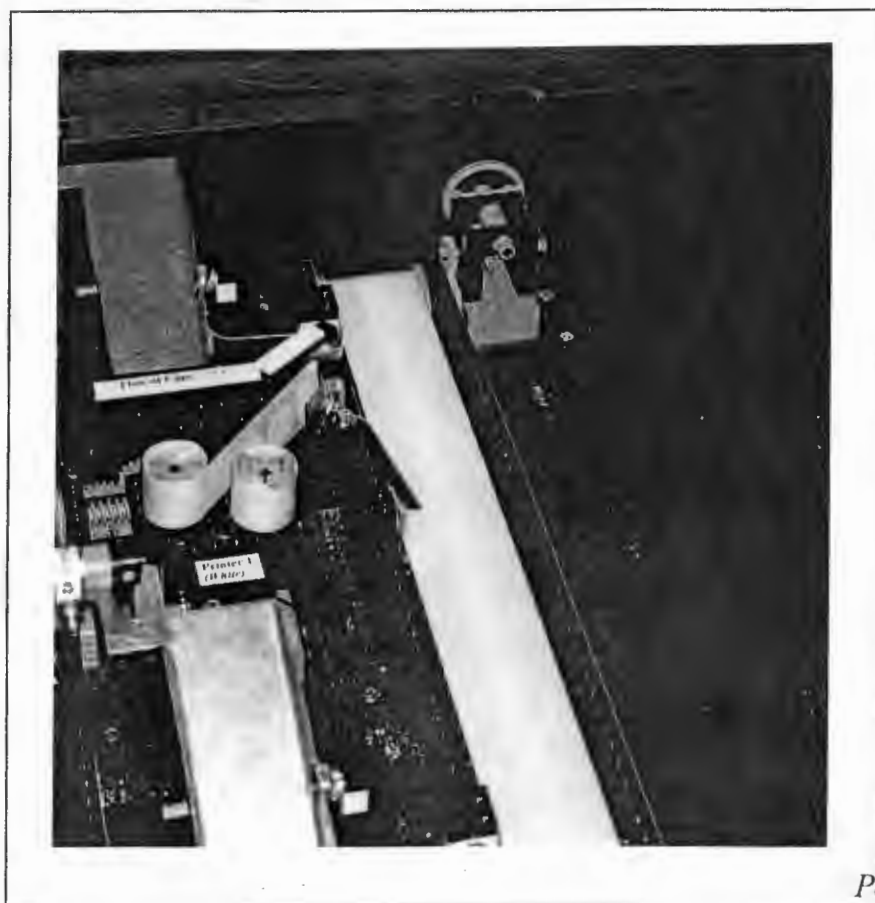
Photograph 6 : Overhead conveyer drive system.



Photograph 7 : Colour identification system.



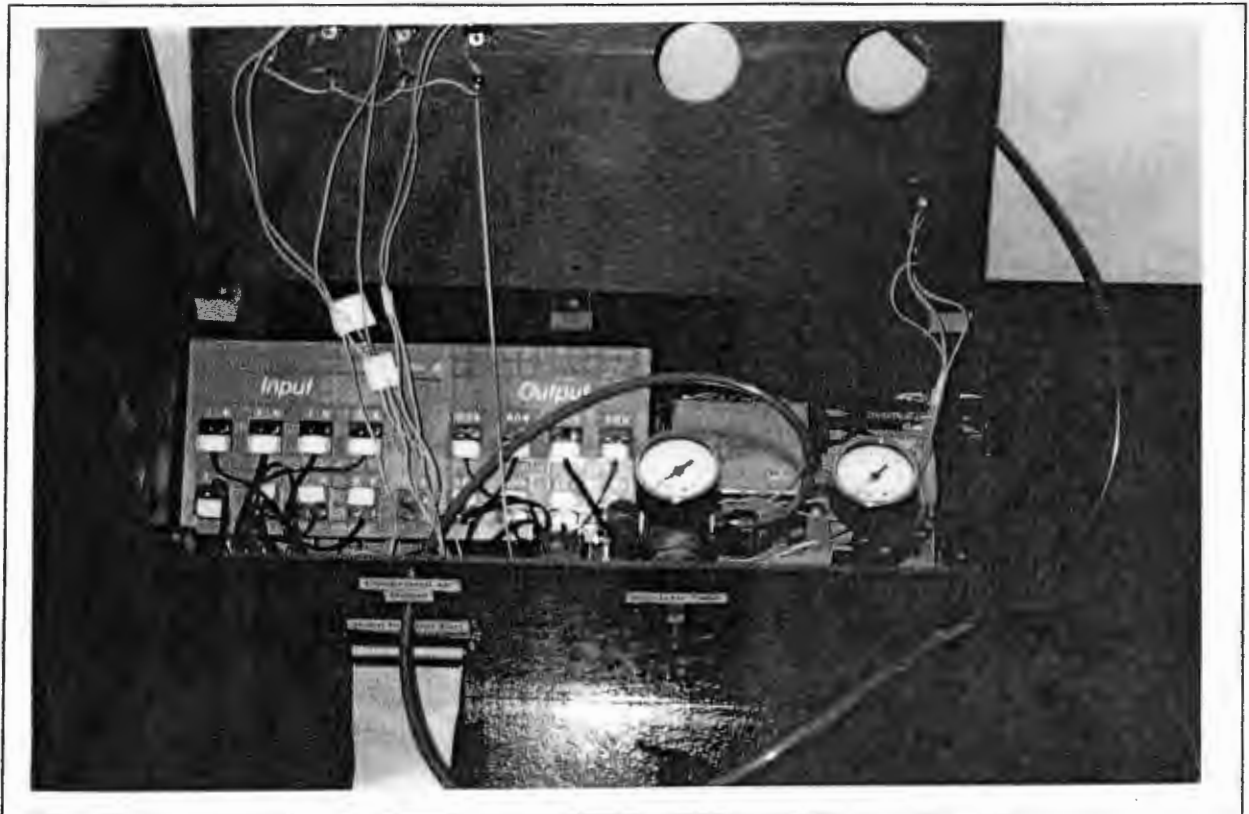
Photograph 8 : Main conveyor drive system.



Photograph 11 : Control box and air supply.



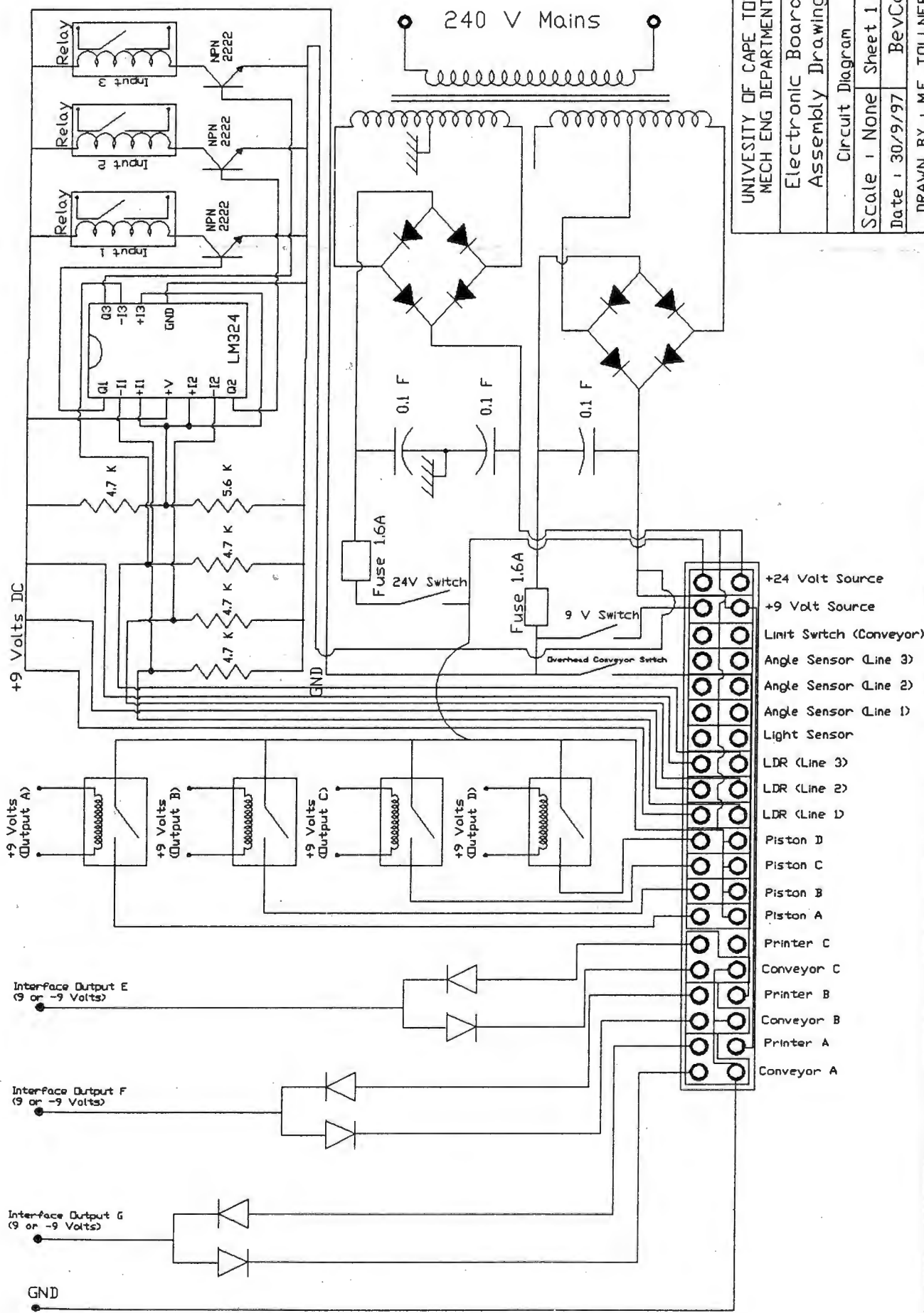
Photograph 12 : Inside control box.



Appendix K

Model Electrical Drawings

UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT
Electronic Board Assembly Drawing
Circuit Diagram
Scale : None Sheet 1 of 7
Date : 30/9/97 RevCap
DRAWN BY : M.E. TOLLNER



+9 Volts DC

+9 Volts (Output A)

+9 Volts (Output B)

+9 Volts (Output C)

+9 Volts (Output D)

Interface Output E
(9 or -9 Volts)

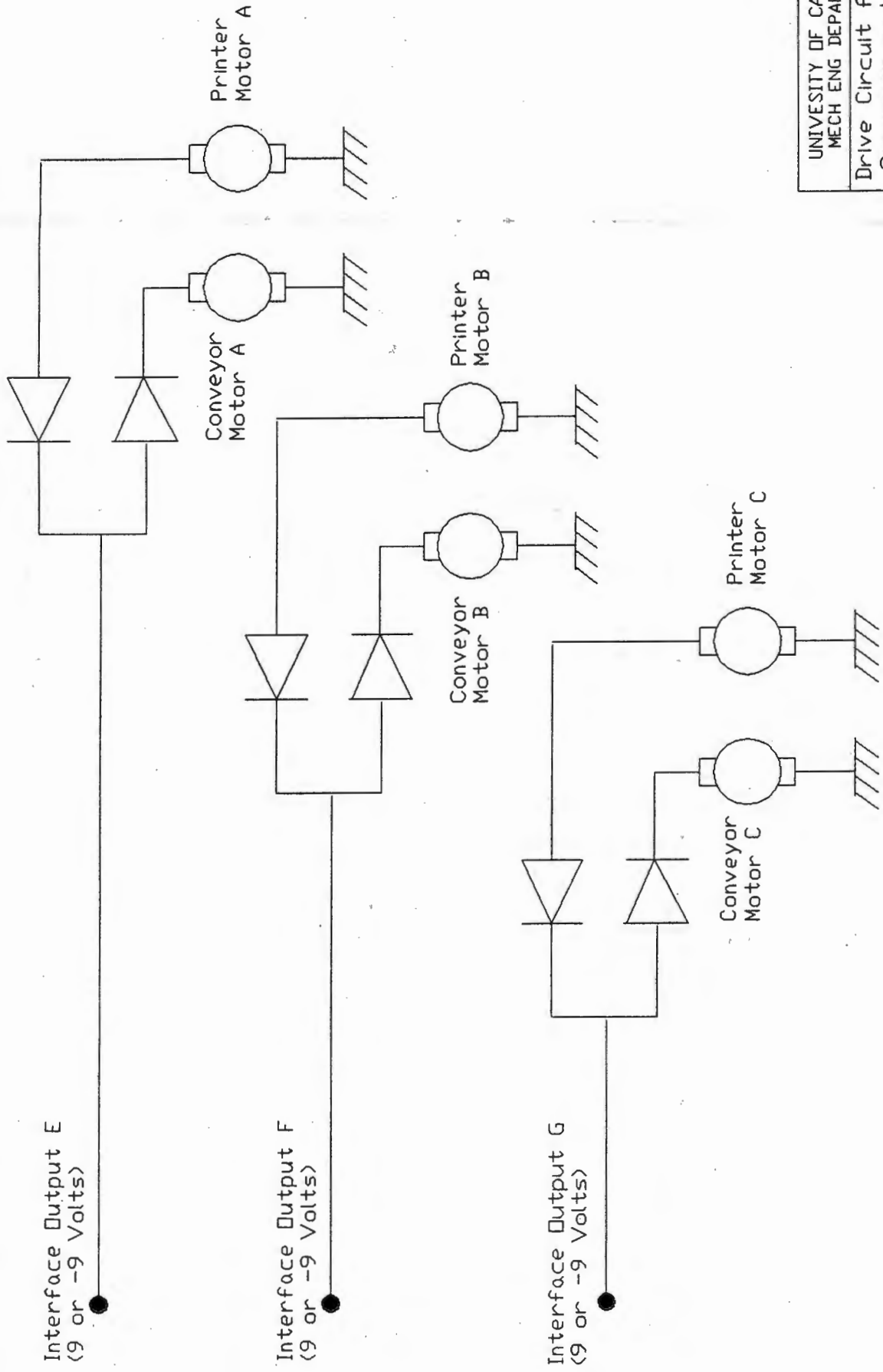
Interface Output F
(9 or -9 Volts)

Interface Output G
(9 or -9 Volts)

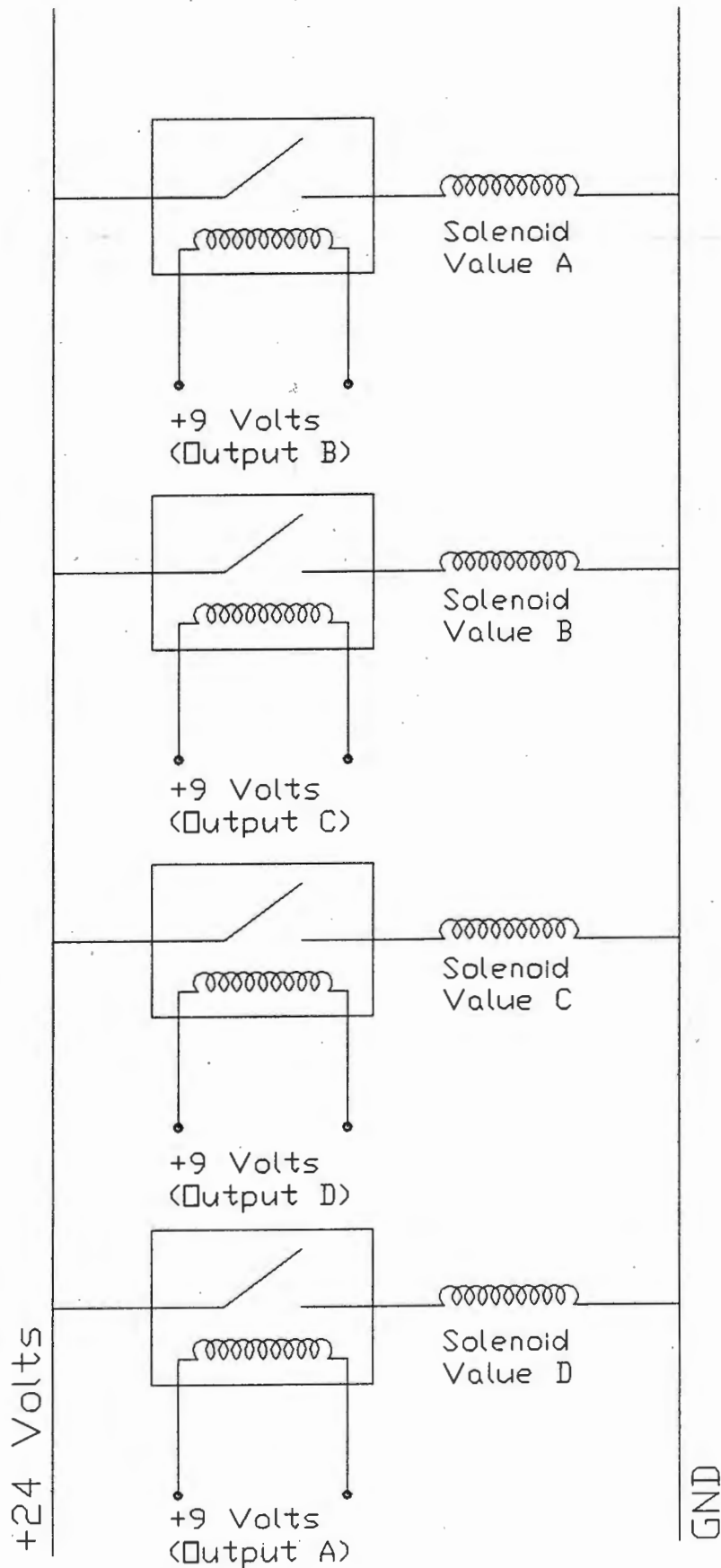
GND

240 V Mains

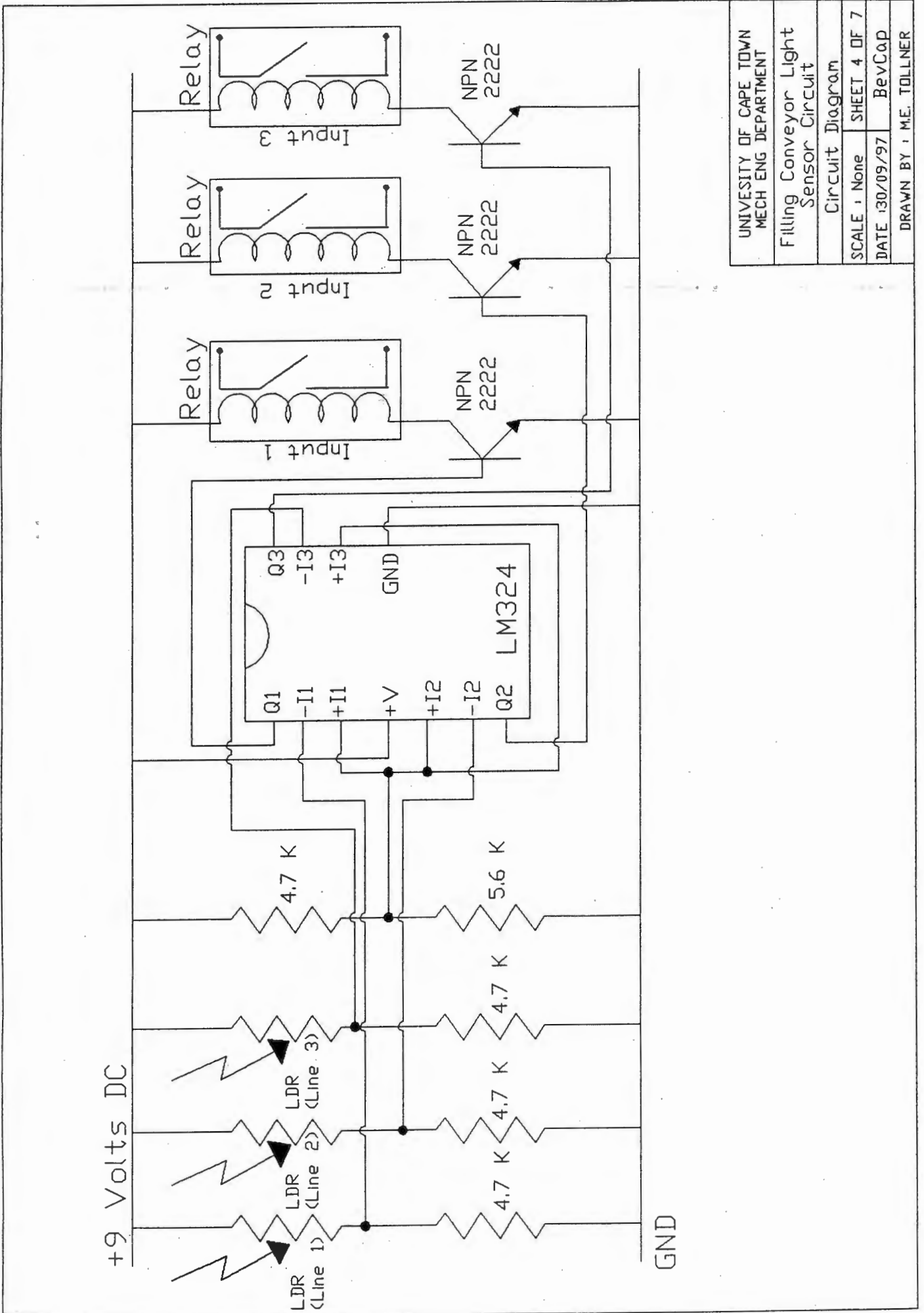
- +24 Volt Source
- +9 Volt Source
- Limit Switch (Conveyor)
- Angle Sensor (Line 3)
- Angle Sensor (Line 2)
- Angle Sensor (Line 1)
- Light Sensor
- LDR (Line 3)
- LDR (Line 2)
- LDR (Line 1)
- Piston D
- Piston C
- Piston B
- Piston A
- Printer C
- Conveyor C
- Printer B
- Conveyor B
- Printer A
- Conveyor A



UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT	
Drive Circuit for Filling Conveyor and Printer	
Circuit Diagram	
Scale : None	Sheet 2 of 7
Date : 30/9/97	BevCap
DRAWN BY : M.E. TOLLNER	

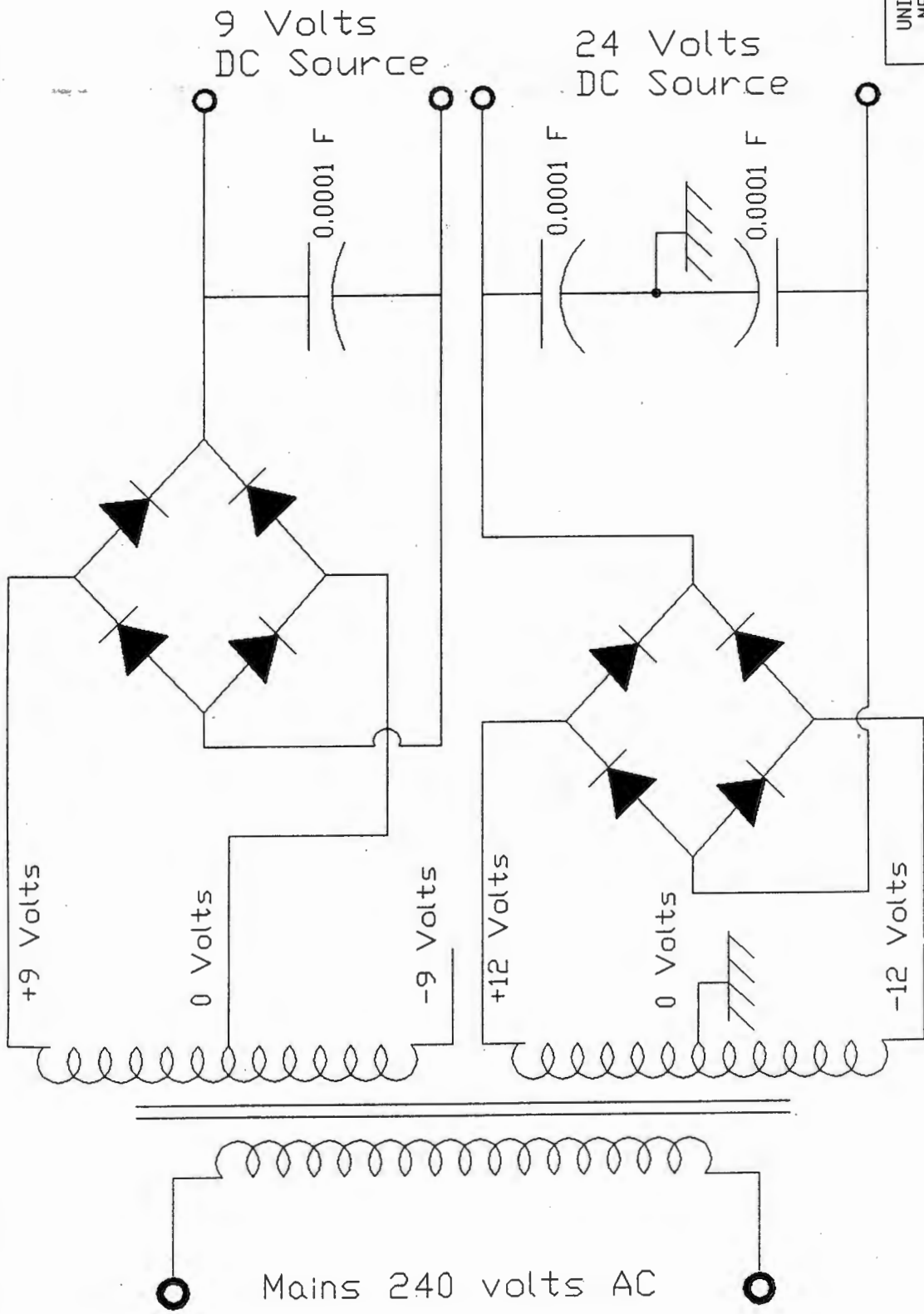


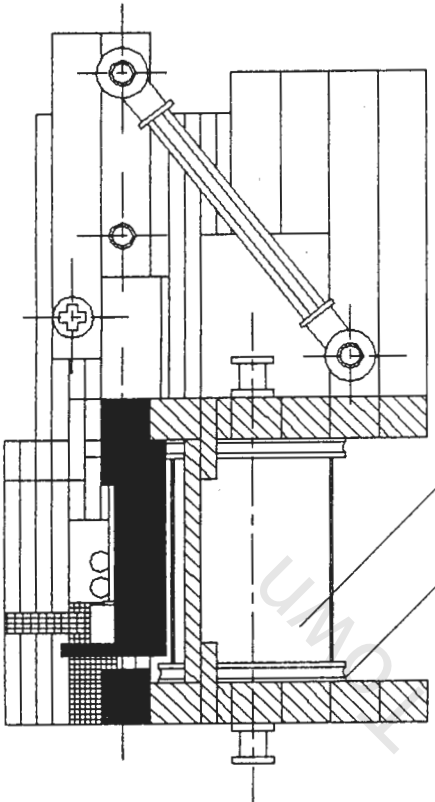
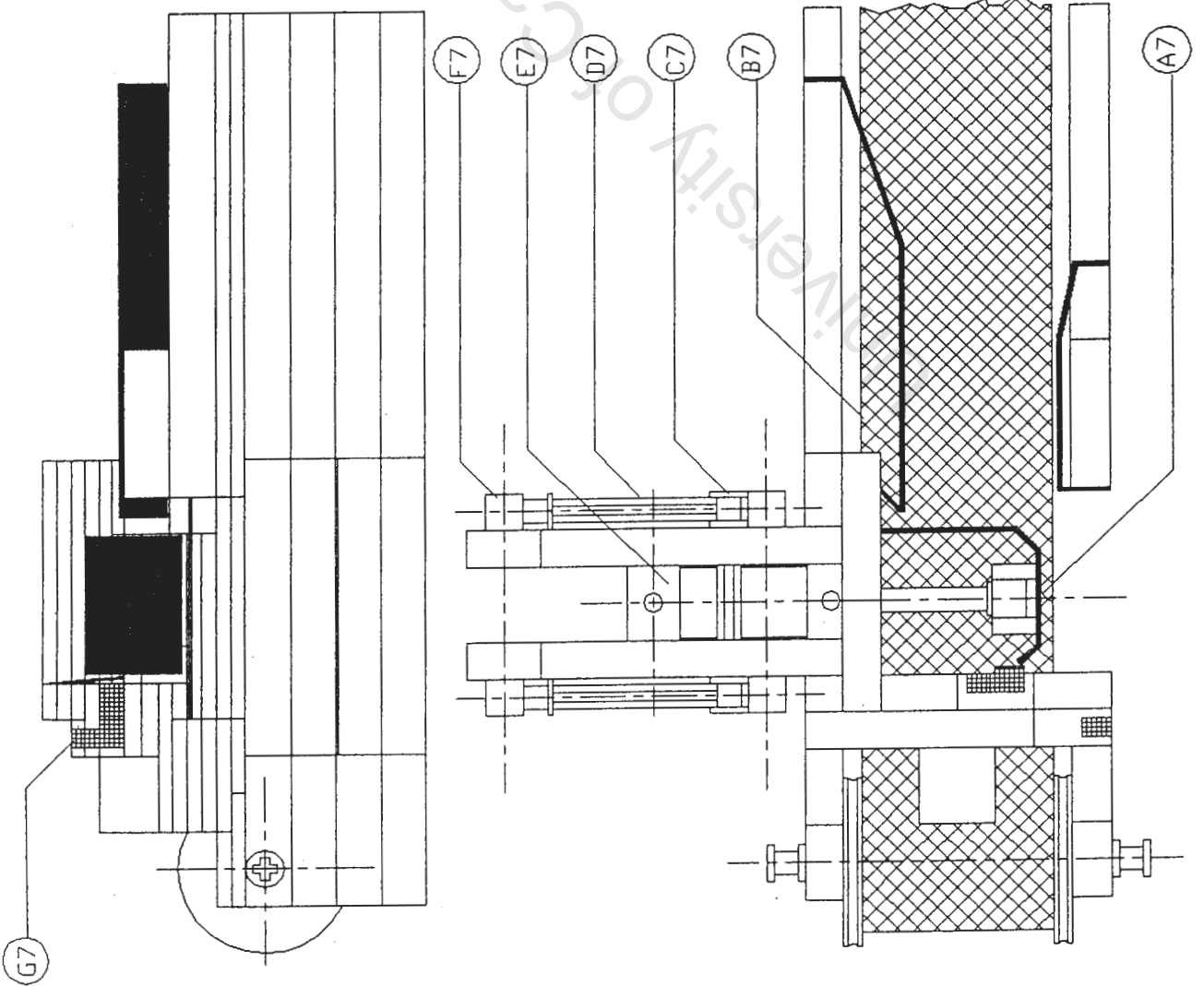
UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT	
Drive Circuit for Sorting Pistons	
Circuit Diagram	
SCALE: 1 None	Sheet 3 of 7
DATE: 30/09/97	BevCap
DRAWN BY: M.E. TOLLNER	



UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT	
Filling Conveyor Light Sensor Circuit	
Circuit Diagram	
SCALE : None	SHEET 4 OF 7
DATE :30/09/97	BevCap
DRAWN BY : M.E. TOLLNER	

UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT	
Power Source AC to DC Circuit	
Circuit Diagram	
SCALE : None	SHEET 5 OF 7
DATE :30/09/97	BevCap
DRAWN BY : M.E. TOLLNER	



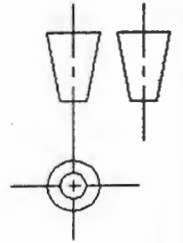
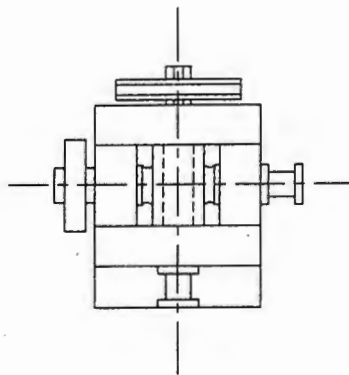
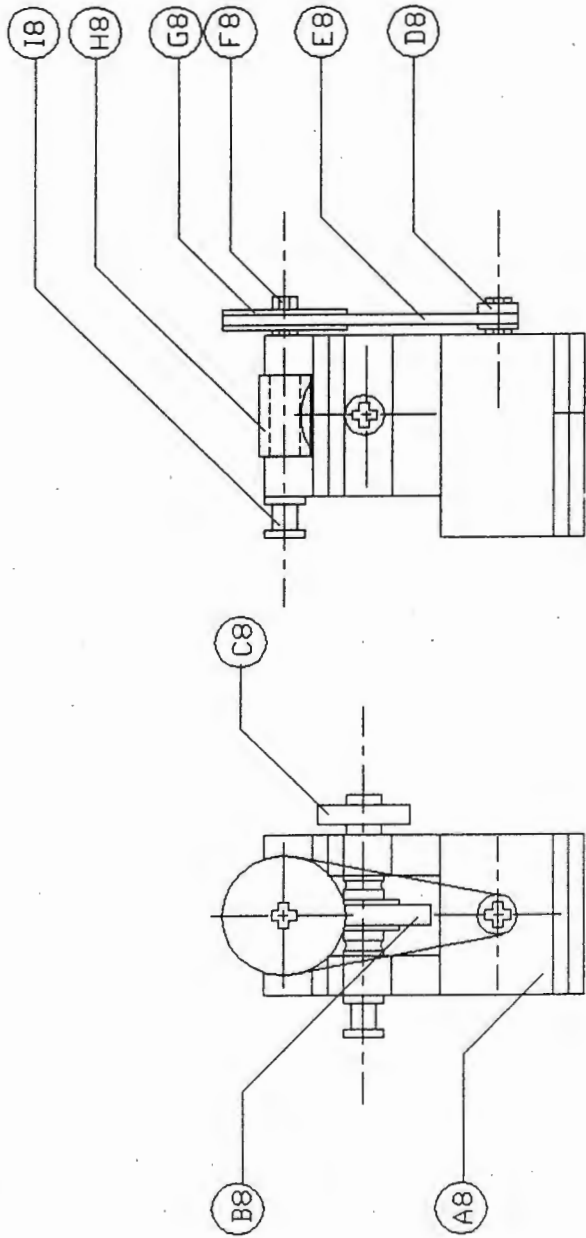


I7	Drum	Plastic	1	d=30mm	
H7	Large Pulley	Plastic	2	N/A	
G7	Switch	Copper	1	N/A	
F7	Shaft Pins	Plastic	4	N/A	
E7	Piston	Plastic	1	l=28mm	
D7	Shaft	Plastic	4	d=5.5mm	
C7	Stopper	Plastic	2	N/A	
B7	Belt	Paper	1	N/A	
A7	Plates	Metal	3	t=1.5mm	
Part No.	Description	Material	No. Df	Remarks	Sheet No.

University of Cape Town
 Dep. of Mechanical Engineering

Bar Code Reader

Scale : 1 : 1.5 Sheet 7 of 14 Sheets
 Date : 30/9/97
 Drawn by : M.E. Tollner BevCap Model

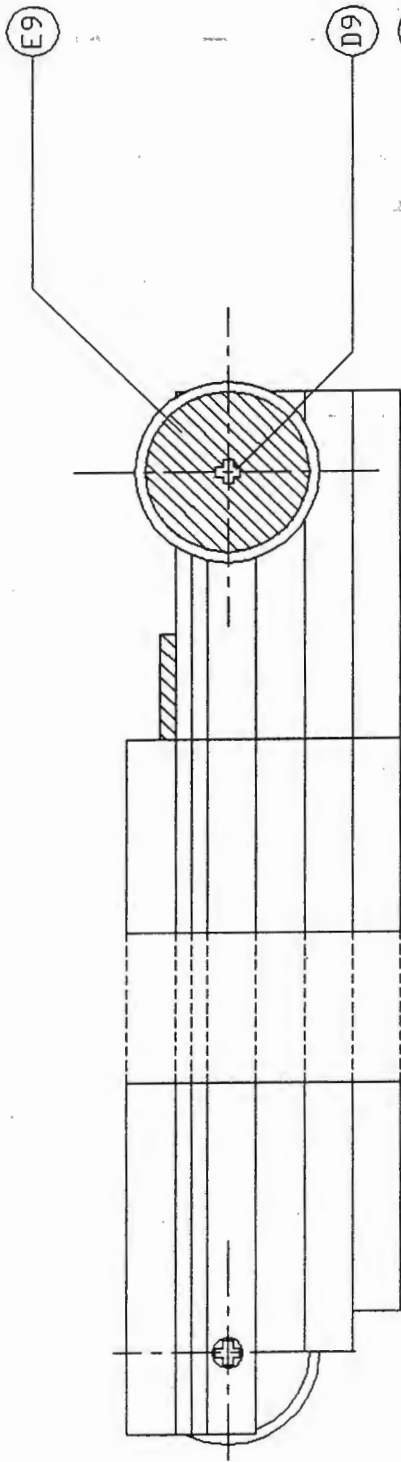


Part No.	Description	Material	No. Of	Remarks	Sheet No.
I8	Stopper	Plastic	2	N/A	
H8	Worm Gear	Plastic	1	d=10mm	
G8	Large Pulley	Plastic	1	d=22mm	
F8	Shaft	Plastic	2	d=5mm	
E8	Belt	Rubber	1	N/A	
D8	Small Pulley	Plastic	1	d=6mm	
C8	Gear	Plastic	1	16 t	
B8	Gear	Plastic	1	24 t	
A8	9V Motor	Various	1	N/A	

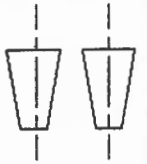
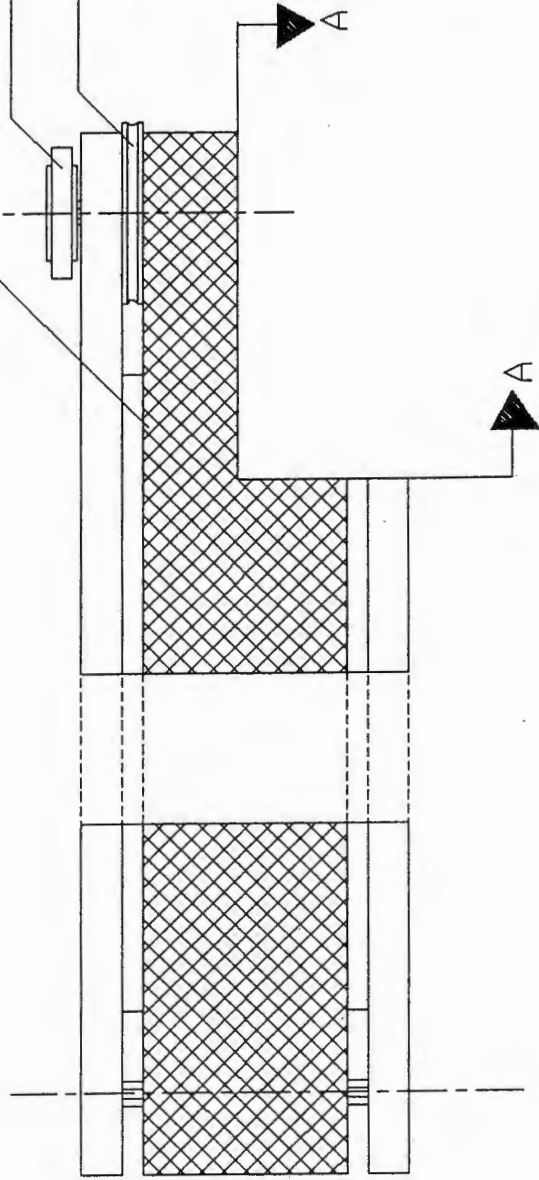
University of Cape Town
 Dep. of Mechanical Engineering
 Main Conveyor Drive System

Scale: 1:1.15
 Date: 30/9/97
 Drawn by: M.E. Tollner

Sheet 8 of 14 Sheets
 BevCap Model



Section A-A

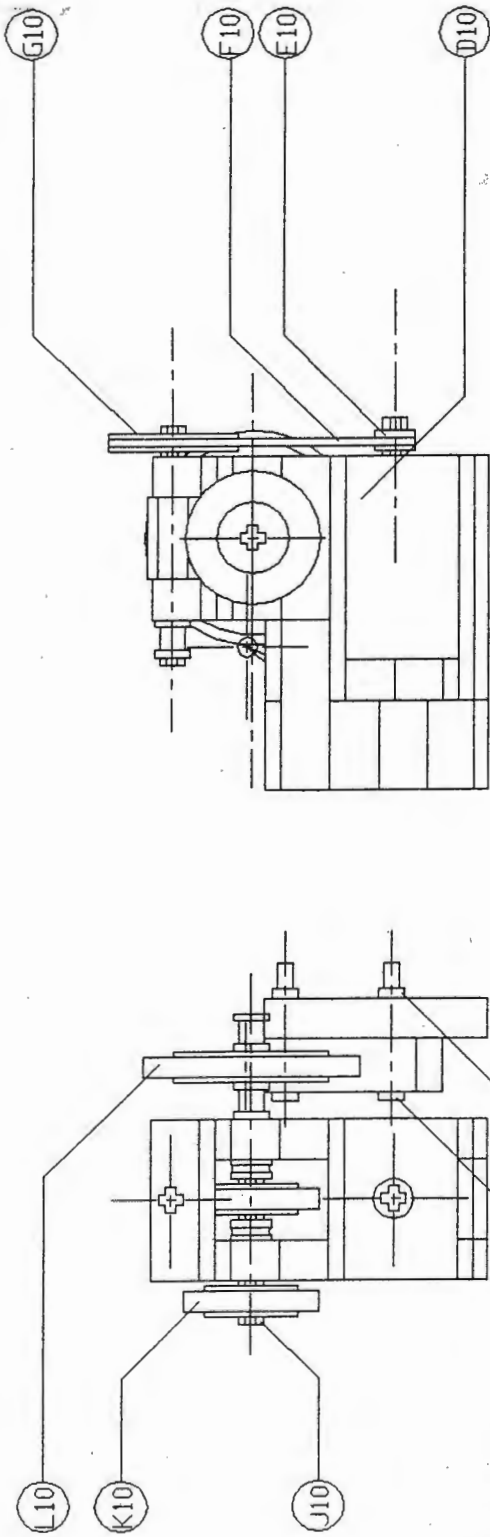


E9	Drum	Plastic	2	d=30mm	
D9	Shaft	Plastic	2	d=5mm	
C9	Belt	Paper	1	N/A	
B9	Gear	Plastic	1	24 t	
A9	Large Pulley	Plastic	4	d=22mm	
Part No.	Description	Material	No. Of	Remarks	Sheet No.

University of Cape Town
 Dep. of Mechanical Engineering

Sorting Conveyor

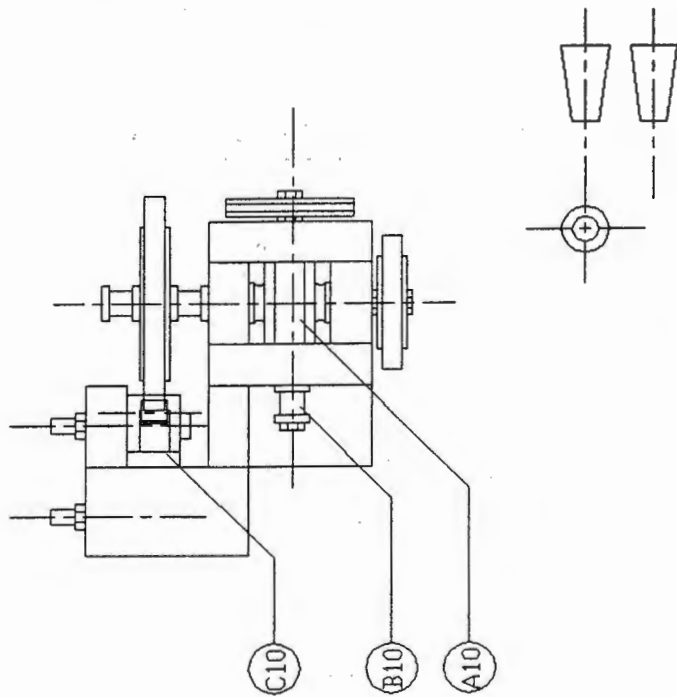
Scale : 1 : 1.5 Sheet 9 of 14 Sheets
 Date : 30/9/97 BevCap Model
 Drawn by : M.E. Tollner

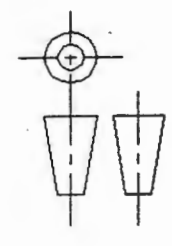
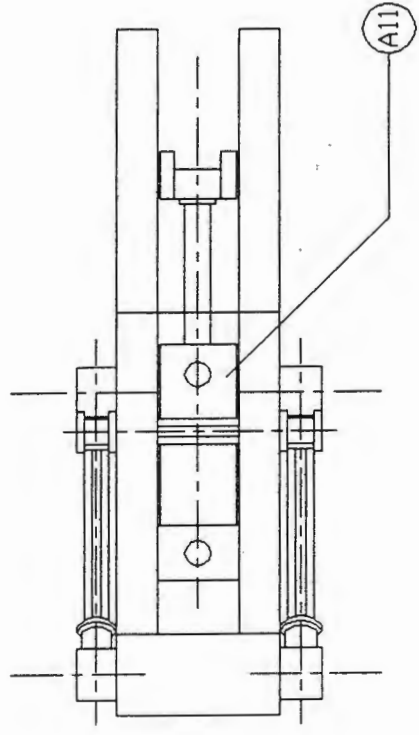
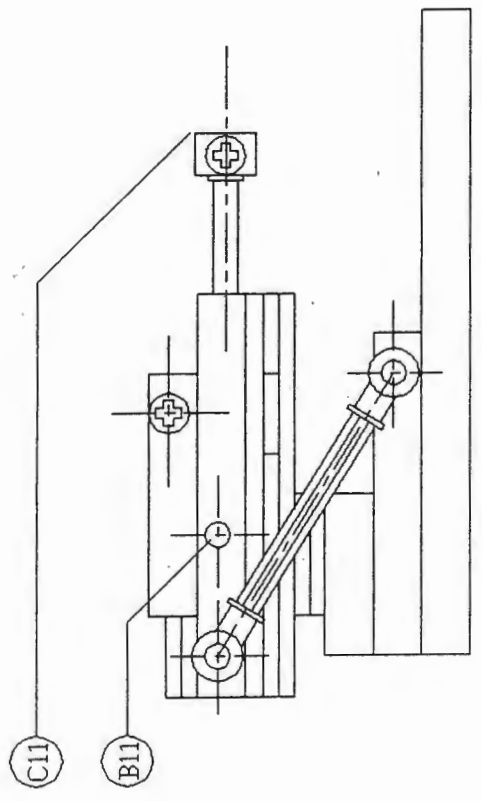
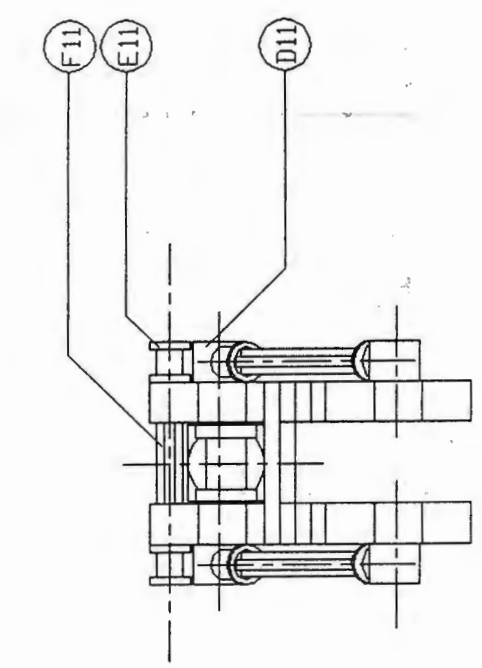


Part No.	Description	Material	No. Of	Remarks	Sheet No.
L10	Gear	Plastic	1	20 t	
K10	Gear	Plastic	2	16 t	
J10	Shaft	Plastic	2	d=5mm	
I10	Bolt	Metal	2	d=3mm	
H10	Nut	Metal	2	d=3mm	
G10	Large Pulley	Plastic	1	d=22mm	
F10	Pulley Belt	Rubber	1	N/A	
E10	Small Pulley	Plastic	3	d=6mm	
D10	9V Motor	Plastic	1	N/A	
C10	Limit Switch	Various	1	N/A	
B10	Stopper	Plastic	2	N/A	
A10	Worm Gear	Plastic	1	d=10mm	

University of Cape Town
 Dep. of Mechanical Engineering
 Sorting Conveyor Drive System

Scale: 1 : 1.5
 Sheet 10 of 14 Sheets
 Date: 30/9/97
 Drawn by: M.E. Tollner
 BevCap Model





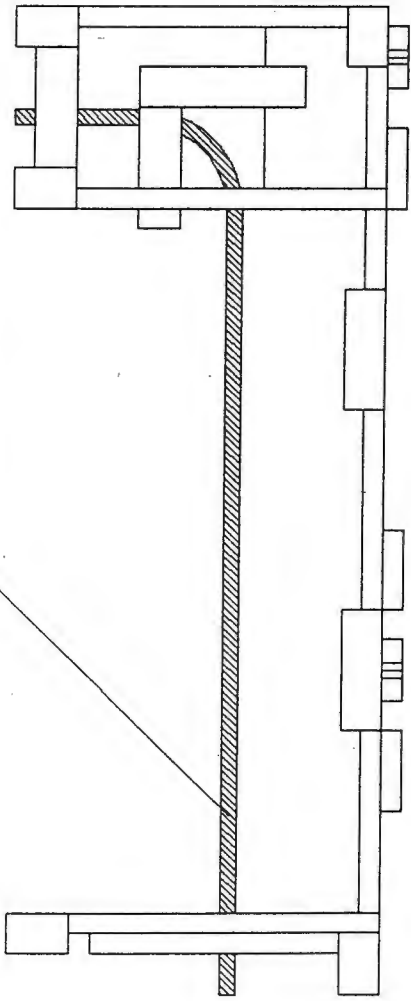
F11	Shaft	Plastic	3	d=5mm
E11	Stopper	Plastic	2	N/A
D11	Shaft Rod	Plastic	4	N/A
C11	Guidler	Steel	1	N/A
B11	Pin	Plastic	6	N/A
A11	Piston	Various	1	d=12mm
Part No.	Description	Material	No. Of	Remarks
				Sheet No.

University of Cape Town
 Dep. of Mechanical Engineering
 Ejection Pistons

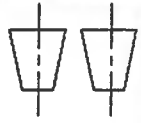
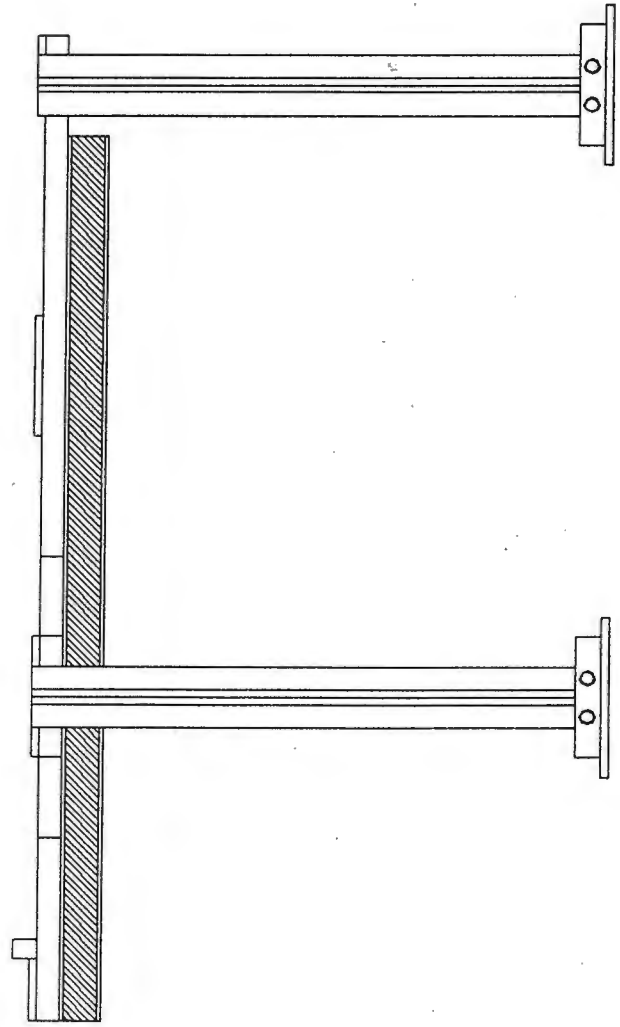
Scale: 1:1.15
 Date: 30/9/97
 Drawn by: M.E. Tollner

Sheet 11 of 14 Sheets
 BevCap Model

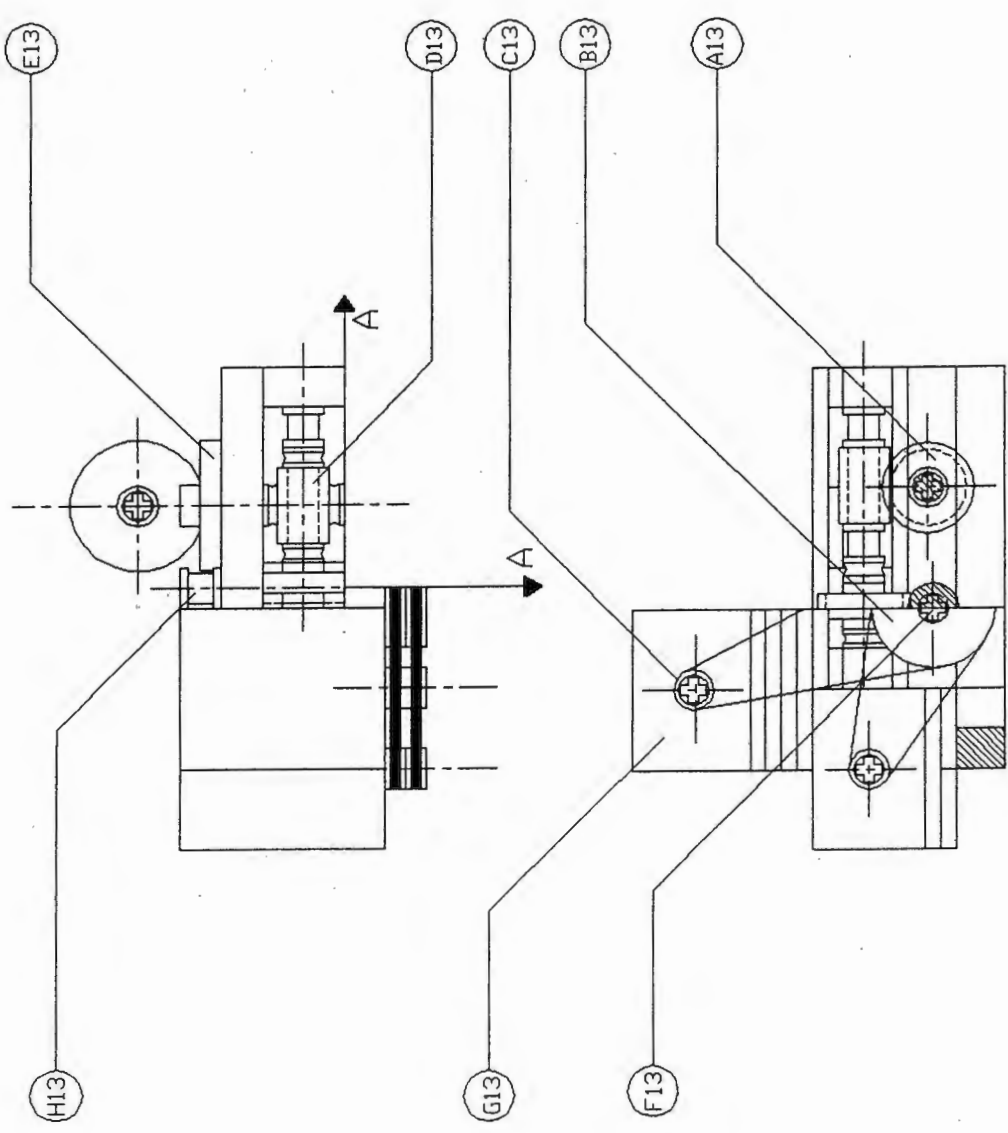
A12



Note : This is only one quarter of the overhead conveyor railing.



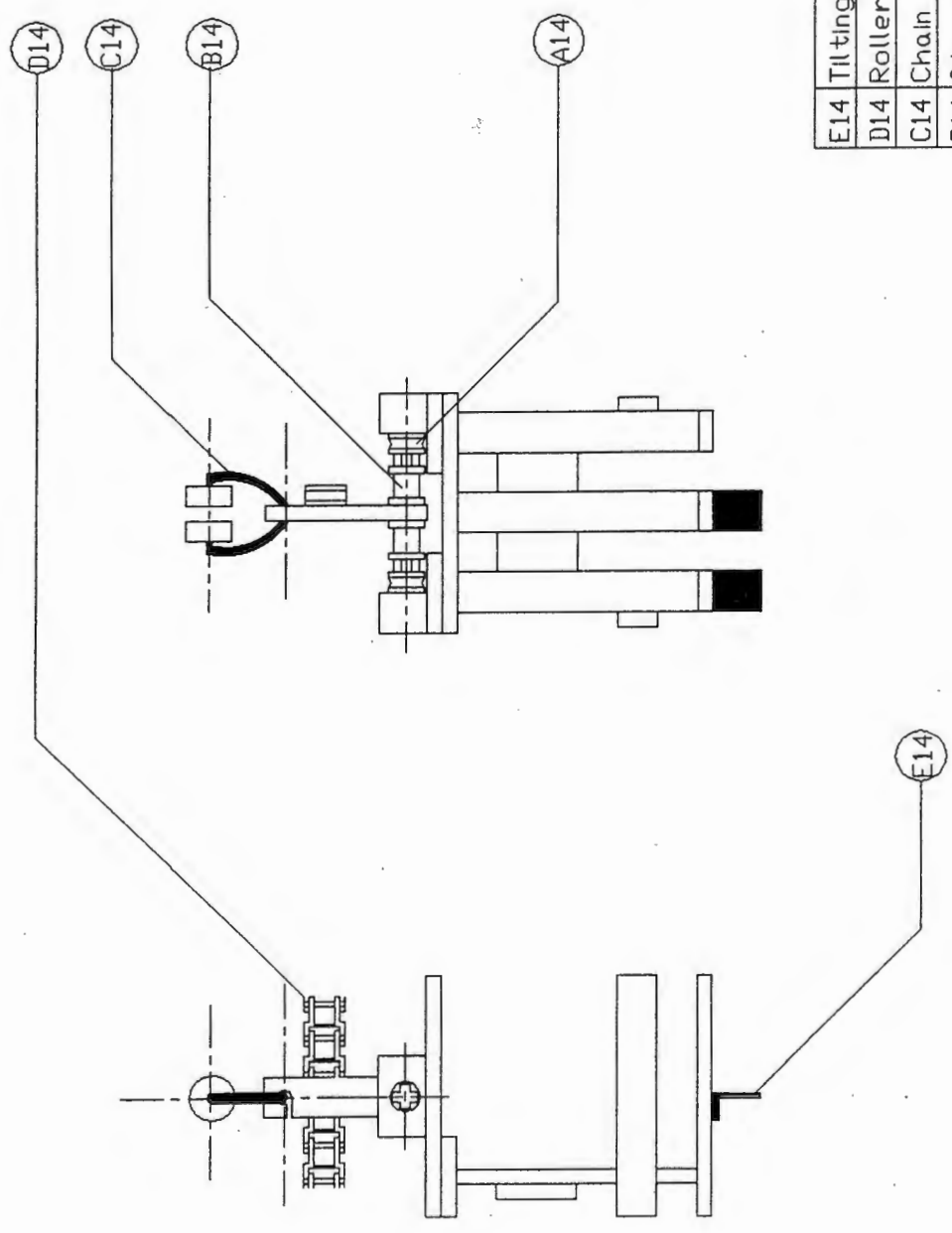
A12	Railing	Al	1	I-Beam	
Part No.	Description	Material	No. of	Remarks	Sheet No.
	University of Cape Town				
	Dep. of Mechanical Engineering				
	Overhead Conveyor Railing				
Scale : 1 : 1 : 3		Sheet 12 of 14 Sheets			
Date : 30/9/97					
Drawn by : M.E. Tollner		BevCap Model			



Section A-A

H13	Stopper	Plastic	4	N/A	
G13	Motor	Various	2	9 Volt	
F13	Shaft	Plastic	3	d=5mm	
E13	Crown Gear	Plastic	2	t=24	
D13	Worm Gear	Plastic	2	d=10mm	
C13	Small Pulley	Plastic	4	d=6mm	
B13	Large Pulley	Plastic	2	d=22mm	
A13	Gear	Plastic	2	t=16	
Part No.	Description	Material	No. Of	Remarks	Sheet No.

University of Cape Town
 Dep. of Mechanical Engineering
 Overhead Conveyor Drive System



E14	Tilting Pin	Metal	2	l=9,5mm	
D14	Roller	Various	1	N/A	
C14	Chain	Plastic	1	N/A	
B14	Stopper	Plastic	2	N/A	
A14	Small Pulley	Plastic	2	d=5mm	
Part No.	Description	Material	No. Of	Remarks	Sheet No.
University of Cape Town					
Dep. of Mechanical Engineering					
Overhead Conveyor Cart					
Scale : 1 : 1.5			Sheet 14 of 14 Sheets		
Date : 30/9/97			Drawn by : M.E. Tollner		
			BevCap Model		

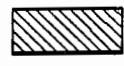
Appendix M

Factory Layout Drawings

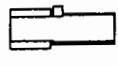
KEY



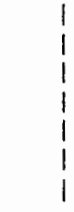
Gravity Conveyor



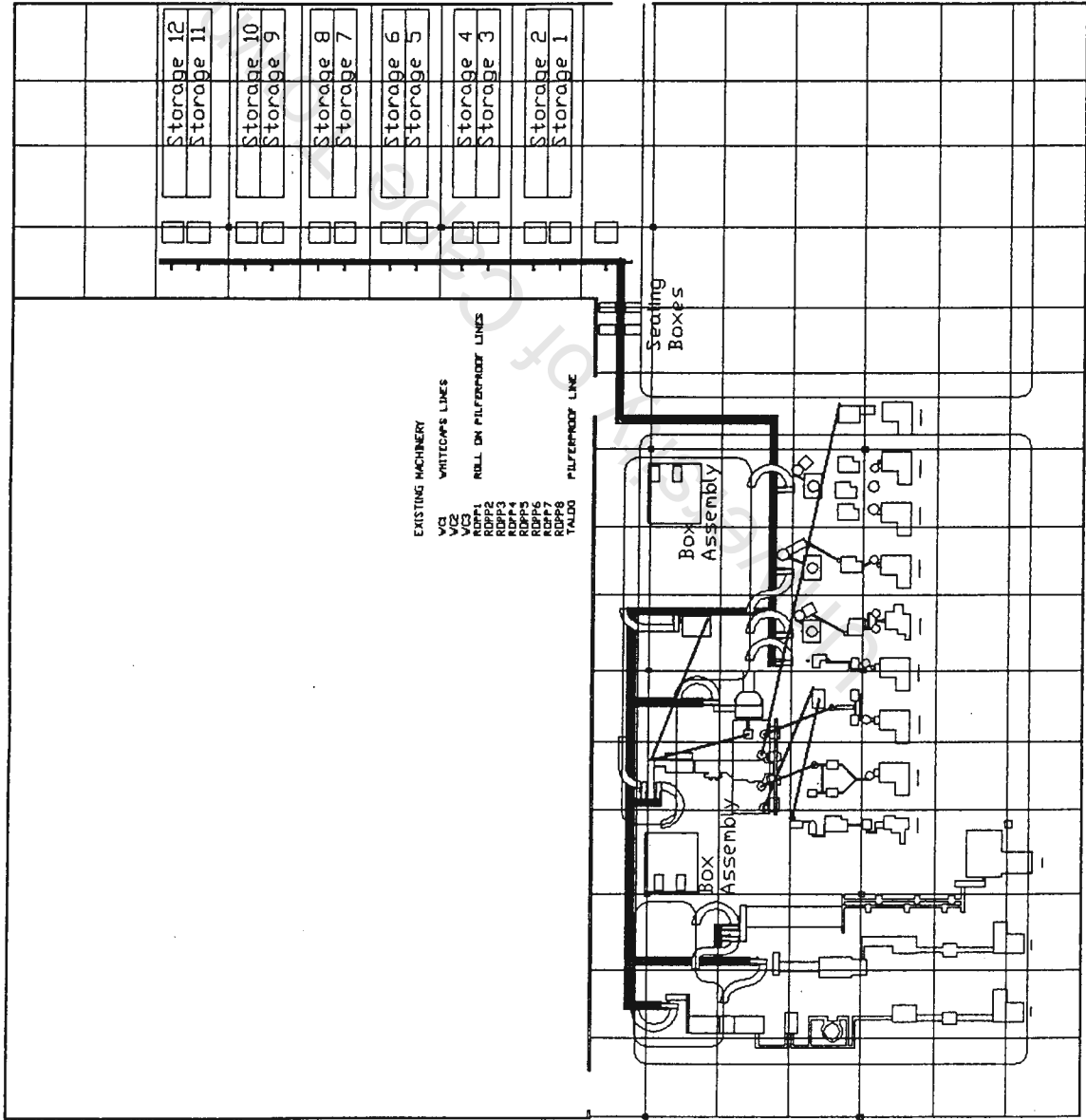
Main Conveyor



Filling Station



Overhead Chain Conveyor



UNIVERSITY OF CAPE TOWN
MECH ENG DEPARTMENT

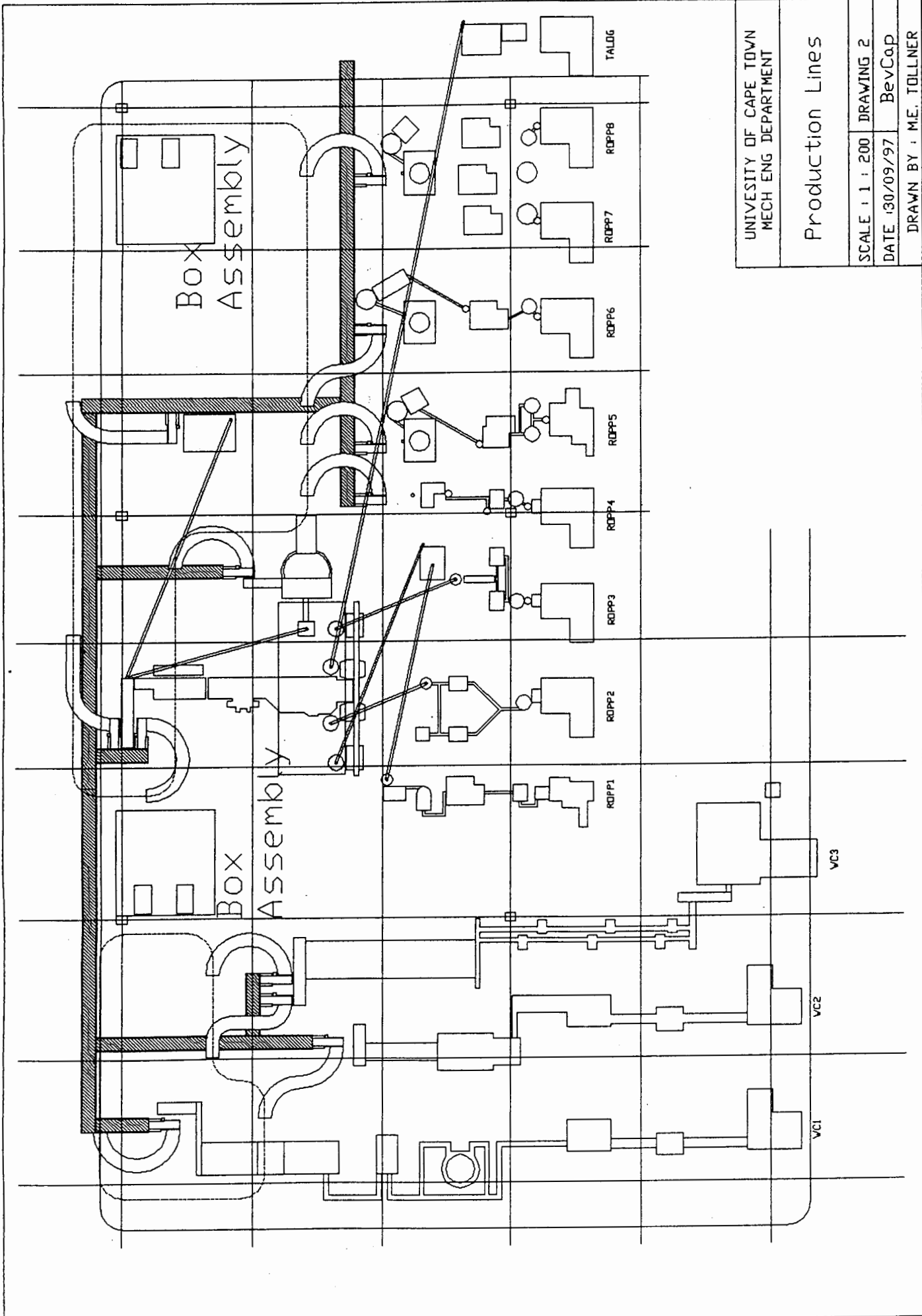
Proposed Factory
Layout

SCALE : 1 : 500 DRAWING 1

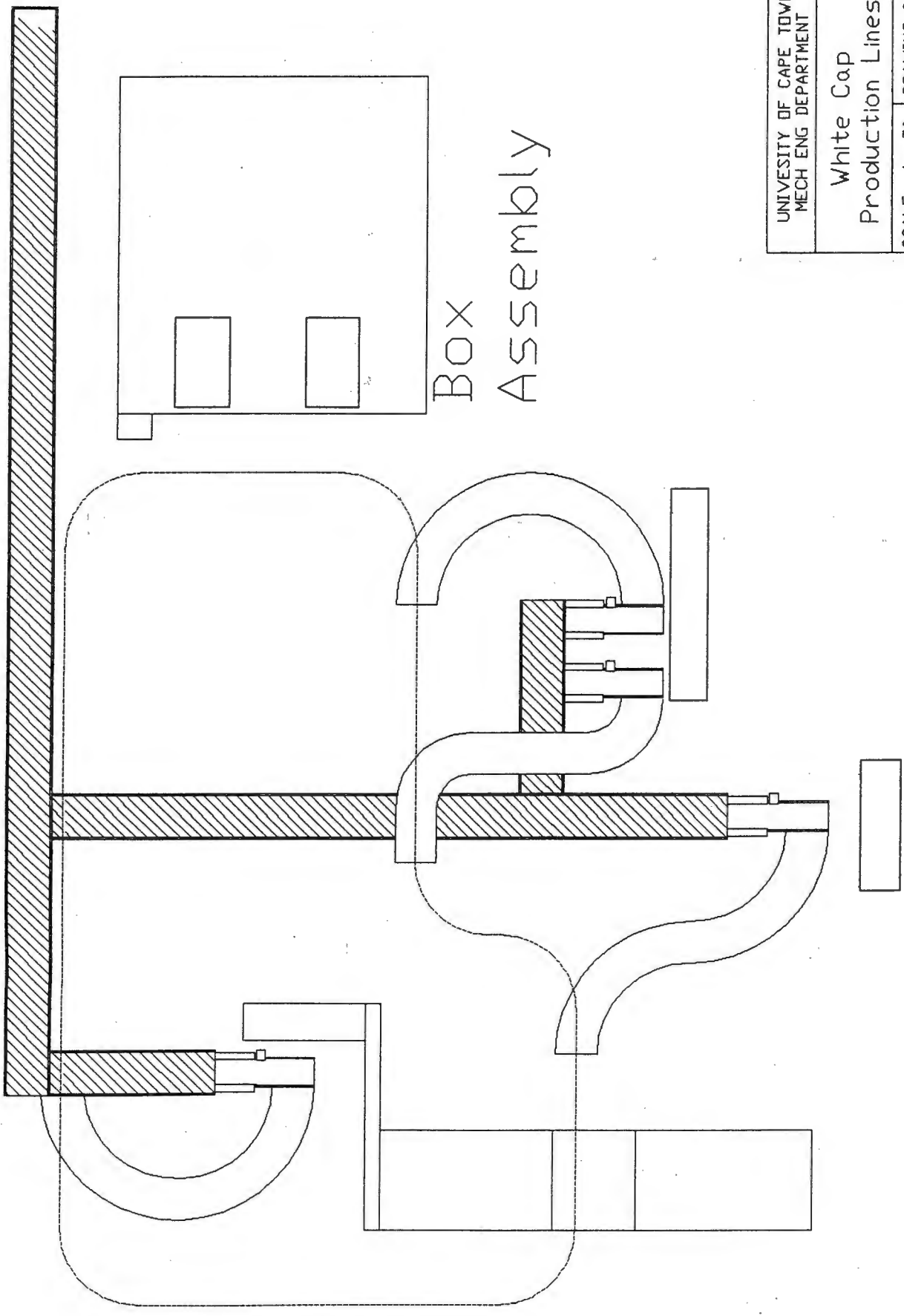
DATE : 30/09/97 BevCap

DRAWN BY : I. ME. TOLLNER



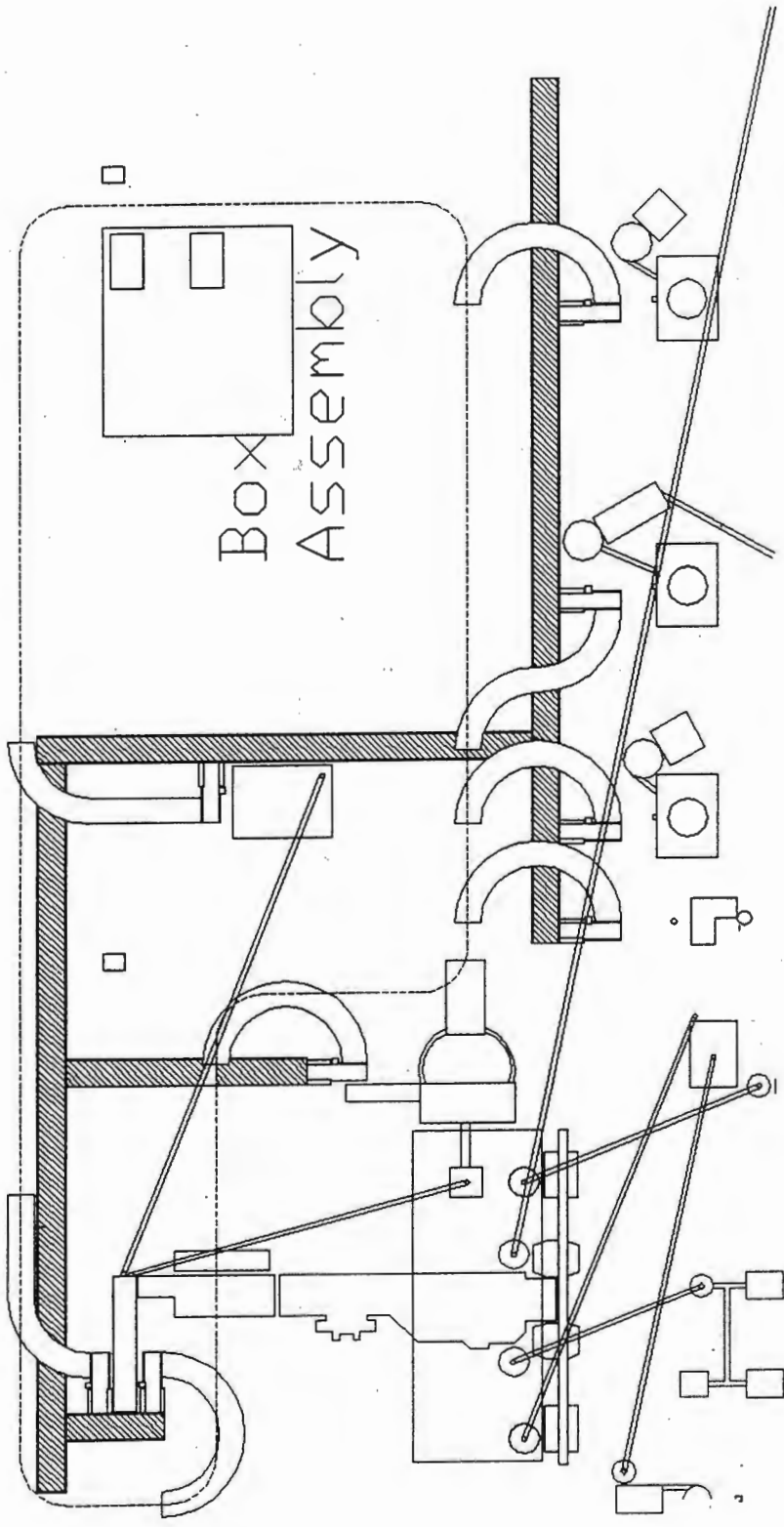


UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT	
Production Lines	
SCALE : 1 : 200	DRAWING 2
DATE : 30/09/97	BevCap
DRAWN BY : M.E. TOLLNER	



BOX
Assembly

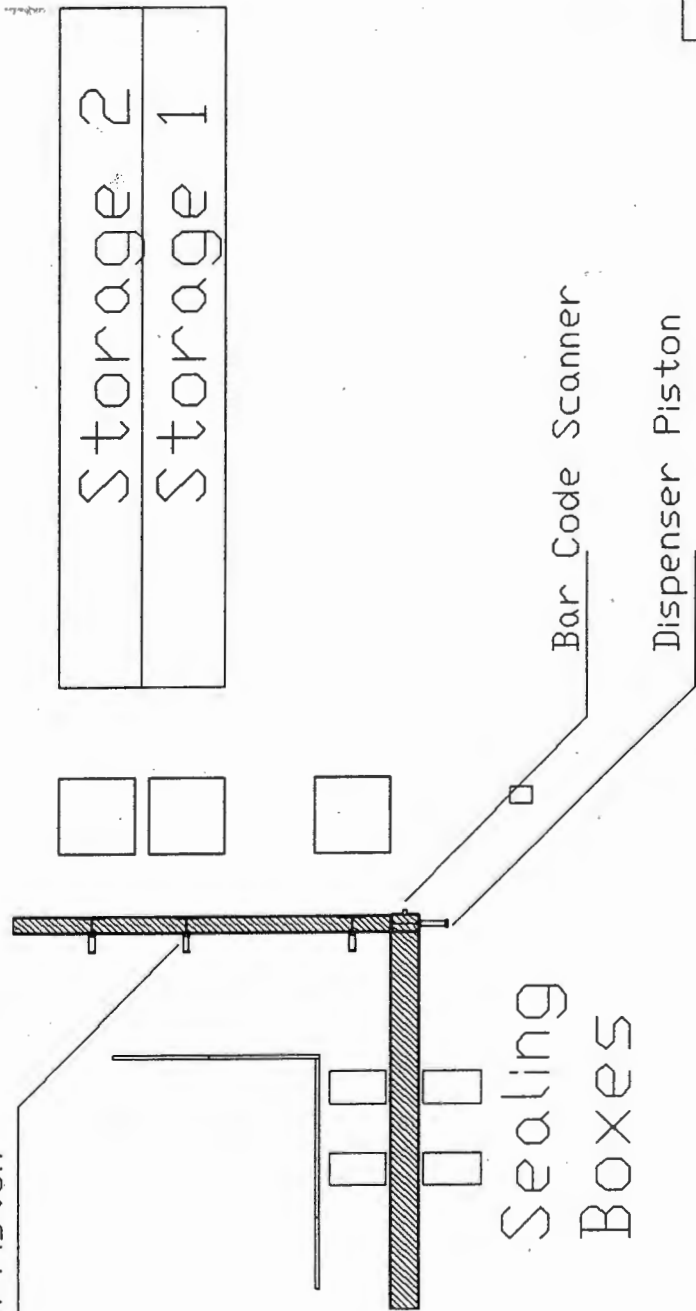
UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT	
White Cap Production Lines	
SCALE 1 : 1 : 70	DRAWING 3
DATE 30/09/97	BevCap
DRAWN BY : M.E. TOLLNER	



BOX
Assembly

UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT	
ROPP Cap Production Lines	
SCALE : 1 : 150	DRAWING 4
DATE : 30/09/97	RevCap
DRAWN BY : M.E. TOLLNER	

Ejection Piston



UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT	
Bar Code Reader And Sorting Pistons	
SCALE : 1 : 150	DRAWING 5
DATE : 30/09/97	RevCap
DRAWN BY : M.E. TOLLNER	

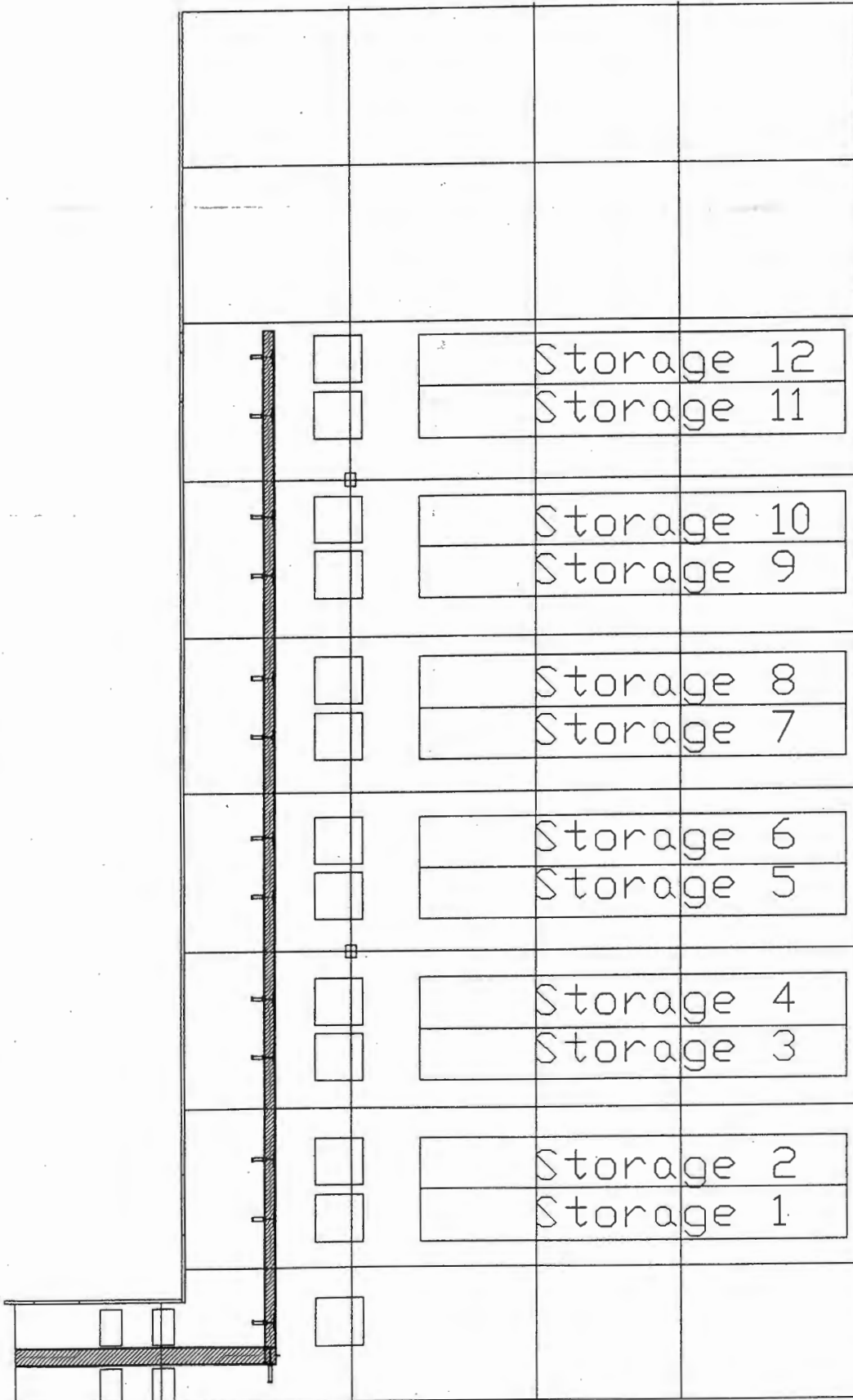
UNIVERSITY OF CAPE TOWN
MECH ENG DEPARTMENT

Sorting Procedure

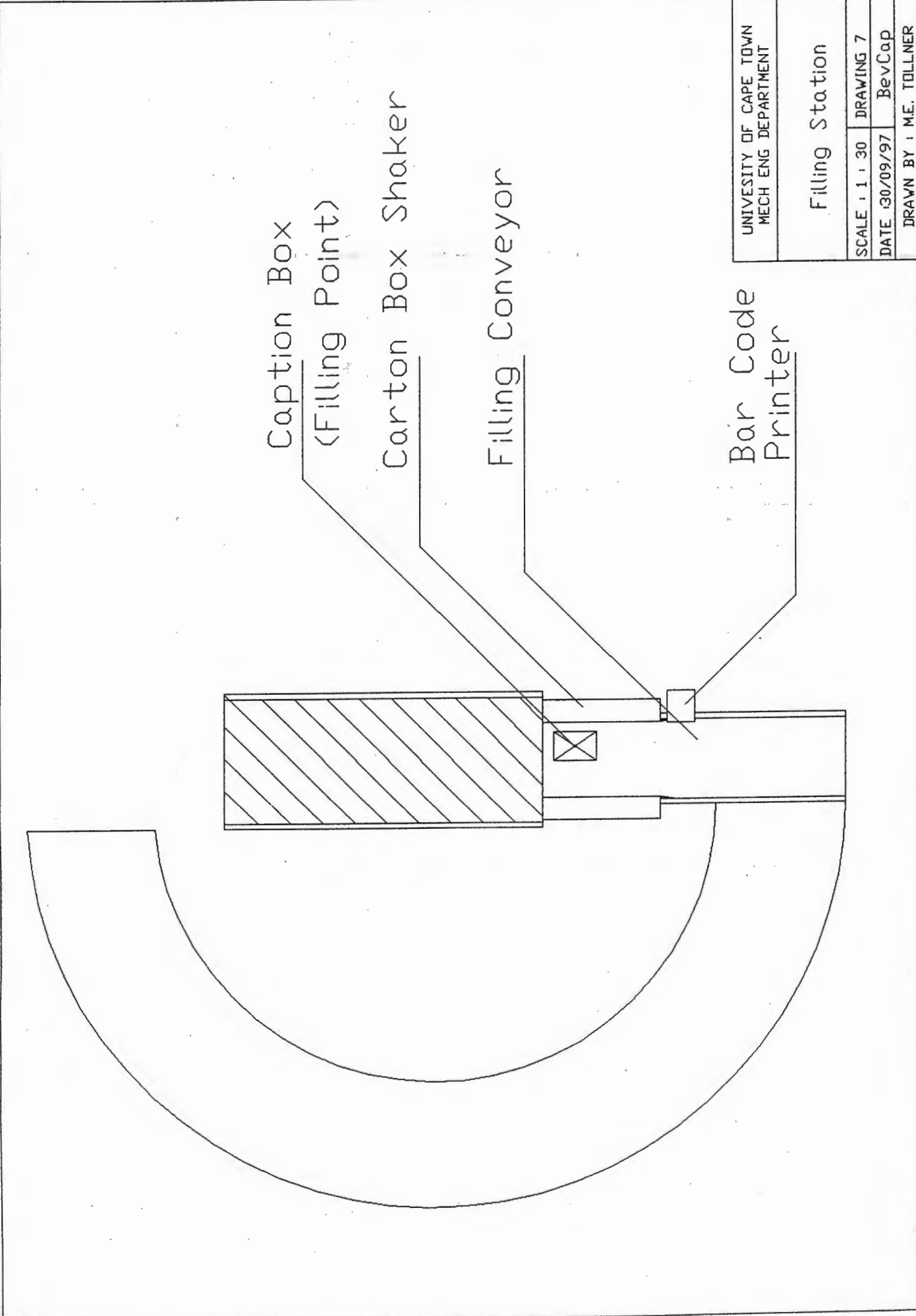
SCALE 1 : 1 : 200 DRAWING 6

DATE 130/09/97 BevCap

DRAWN BY : ME. TOLLNER



Sealing
Boxes



Caption Box
(Filling Point)

Carton Box Shaker

Filling Conveyor

Bar Code
Printer

UNIVERSITY OF CAPE TOWN MECH ENG DEPARTMENT	
Filling Station	
SCALE : 1 : 30	DRAWING 7
DATE : 30/09/97	BevCap
DRAWN BY : ME. TOLLNER	