UNIVERSITY OF SOUTHAMPTON

The Integration of Programmable Logic Controllers into a Computer Integrated Manufacturing Cable Making Plant.

by Andrew T. Baldwin

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ABSTRACT

FACULTY OF ENGINEERING AND APPLIED SCIENCE

ELECTRICAL ENGINEERING

Master of Philosophy

THE INTEGRATION OF PROGRAMMABLE LOGIC CONTROLLERS INTO A COMPUTER INTEGRATED MANUFACTURING CABLE MAKING PLANT.

by Andrew Timothy Baldwin

Computer Integrated Manufacture (CIM) is seen as the means of effecting greater plant efficiency and hence of becoming more competitive in the marketplace. For this reason Pirelli General decided to adopt this philosophy at their cable making factory in South Wales. This thesis presents two of the areas that go to make up the overall factory CIM structure - the programmable logic controller (PLC) video specification for the Operator/Machine interface and the integration of PLC's into one particular working area of the factory, namely the packaging section. Using PLC's greatly enhances the operation of any machine by enabling fine-tuned predetermined operating parameters to define the machine performance characteristics and to obtain comprehensive feedback of data regarding product quality and quantity to both Operators and Management. It is also shown that the standardisation of systems, plant and equipment may not always lead to the most cost effective solution.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1. Project Outline - The Teaching Company Scheme

The Teaching Company Scheme is a nationwide, government funded scheme which aims to integrate graduates into areas of new technology and to raise the level of industrial performance by effective use of academic resources. To this end Southampton University and Pirelli General plc set up a scheme which would involve graduates in the Pirelli Aberdare Building Wires project.

The main area of Teaching Company Associate (TCA) involvement has been in the application of PLC's (programmable logic controllers) onto machines for the purposes of monitoring and control. Hence, this thesis concentrates upon the integration of PLC's into the Aberdare factory, but also includes references to the operating systems used within the factory and to the specification and production of PLC video formats used for Operator control of all the machines throughout the factory.

1.2. Pirelli Aberdare Building Wires Factory

There has been a cable producing plant at Aberdare, South Wales, since around the 1930's. Originally known as Aberdare Cables, the factory was bought by Pirelli General and was used to produce 'special' cables to meet specific customer requirements. During the early 1980's, production of special cables was moved to a greenfield site at Eastleigh, Southampton, leaving an antiquated factory at Aberdare standing empty. This was to be replaced by Pirelli with a high technology, fully automated factory producing building wires. (See Section 1.3.).

1.2.1. The Cable Making Process

There are three essential elements in electrical cable manufacture (1) :

a) Forming the electrical conductor
  - METALLURGY.
b) Insulating and sheathing the conductor
  - EXTRUSION.
c) Combining the components into a finished cable
  - LAYING UP and, where necessary, ARMOURING.

At Pirelli, Aberdare, new production processes have been used to reduce the number of different stages involved in cable construction. The three vital stages outlined above each occupy a separate factory zone, as shown on the schematic factory layout in Fig. 1, so arranged as to optimise the flow of materials through the factory.

1.2.1.1. Metallurgy Zone

Electrical conductors produced in the traditional way involve a series of labour intensive, Operator sensitive, separate fixed processes such as single-stage drawing, annealing, bunching, twisting and stranding. This large number of operations has now been drastically reduced by standardising, combining and automating these processes.

1.2.1.2. Extrusion Zone

Conventional extrusion techniques require separate operations for each different colour used for both insulation and sheathing. It also involves high-speed processes, with the risk of poor quality performance.

To ensure total quality control, new extrusion technology has been designed to produce higher yields at lower speeds. Pirelli now has the capability of simultaneously insulating and sheathing different colour cores, the method used for achieving this being known as tandem sheathing. The supply of conductor and of insulating and sheathing materials, the handling of work-in-progress and the automatic in-line final stage testing are all entirely computer integrated and controlled.

1.2.1.3. Laying-up and Armouring Zone

Multicore cables require the component cores to be assembled, sheathed and, where needed, the assembly may be protected with galvanised steel wire armour and re-sheathed. These historically slow processes used to be both separate and labour intensive.

Within this zone, the combination of single-twist input with drum twist take-up provides very high throughput speeds - the quality level being maintained by the degree of automation, by the overall microprocessor control and by the reduced number of operations.

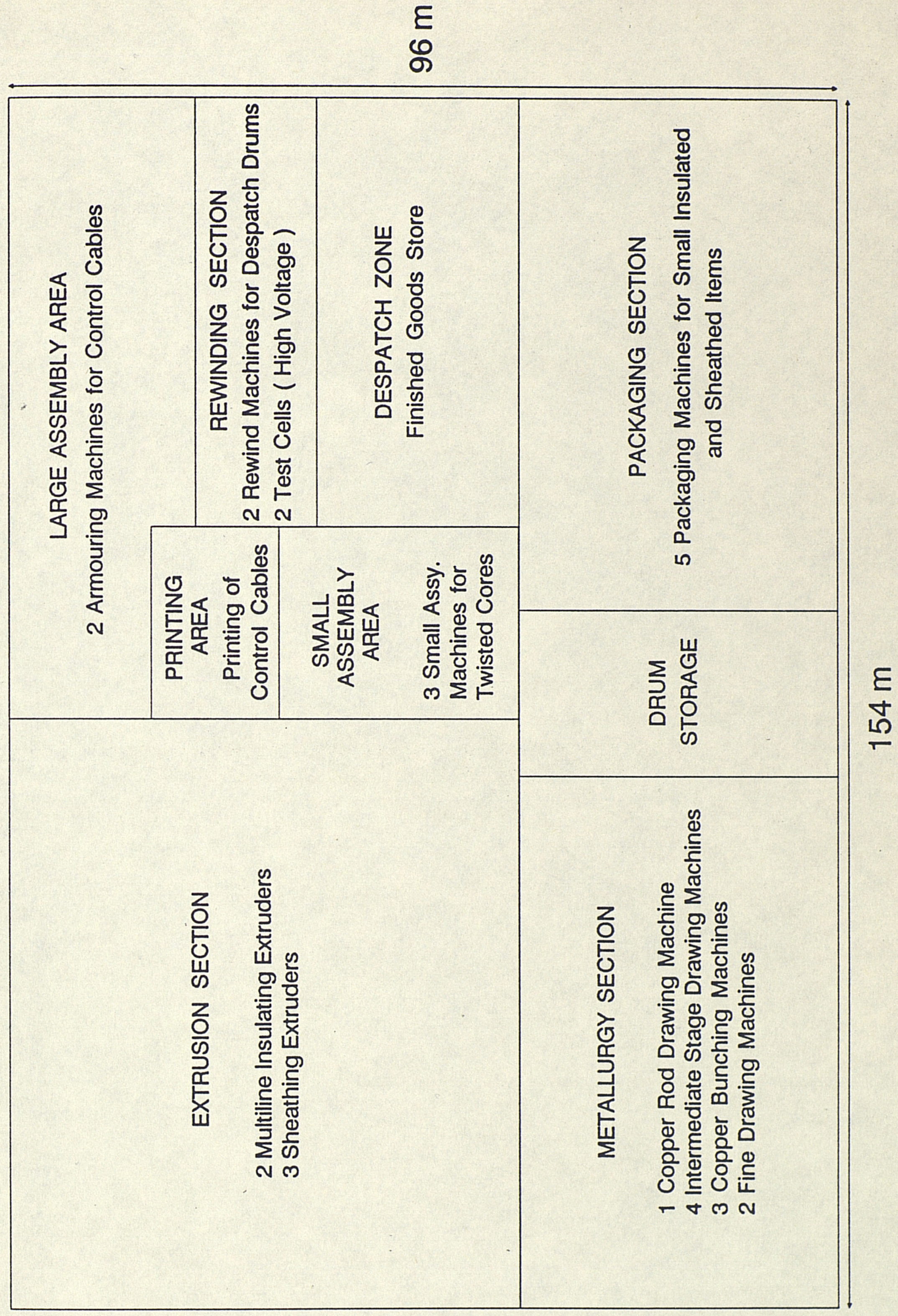

Fig. 1 : Aberdare Cable Making Plant
- Schematic Layout

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1.3. C.I.M. Philosophy

It was during the 1970's that advanced manufacturing technology began to be introduced into industry. Since that time, computer control of plant has rapidly mushroomed to the computer integrated manufacturing systems that are being implemented today. Along the way, there has been the development of the flexible manufacturing system (4, 5) which is already well established as one of the essential building blocks of computer integrated manufacture.

The existing factory at Southampton, which produced 'building wires', was being held back by restrictive working practices and out-of-date plant and equipment. However, building wires make up the largest sector of the cables market and are used, for example, in house wiring or domestic appliances. They are relatively simple products to manufacture, but because of that the market for them is highly competitive, leaving very small profit margins.

Current markets, technologies and competition are such that only those companies that lead the change towards CIM, or at least have the ability to adapt to it, will increase or retain their competitiveness. In order to maintain this competitiveness in both the national and international markets, Pirelli decided that a new business approach was required to achieve reduced labour content, reduced material wastage and reduced work-in-progress.

It was with this aim in mind that Pirelli General chose to make a clean sweep and to apply computer integrated manufacture to the 'building wires' product in a new fully automated factory at Aberdare.

The philosophy of the Aberdare venture is based on three key principles, each outlined below, the application of which should effect reductions in working capital and production costs.

1.3.1. Computer Integrated Manufacture (CIM)

The primary aim of CIM (3, 9) is to integrate decision processes and procedures throughout a manufacturing organisation with a view to achieving specified business goals. The secondary aim is to employ computers for the automation of certain decision activities and for supplying high quality information to decision makers in order to make the integration more effective. At Pirelli, Aberdare, this means the use of integrated computer systems to plan and direct every phase of the business.

1.3.2. Flexible Manufacturing Systems (FMS)

The FMS is designed to bring flexibility to the manufacturing function so that, ultimately, a product is manufactured only when it is needed by the customer. (4, 5) Within Pirelli it is the application of machine technology that allows all the equipment in one zone of the factory to perform all of that zone's functions in order to achieve the fastest response to the varying business needs.

1.3.3. Just-In-Time (JIT)

The aim of JIT (12) is the production and delivery of the right items at the right time and in the right quantities. Inherent in this philosophy is the need to keep inventories to a minimum and planning very much short term. This philosophy is followed at Pirelli by the use of continuous computerised monitoring to schedule and sequence the supply of raw materials and work-in-progress, thus eliminating expensive stock holding.

1.4. Hierarchy Of Systems

At Pirelli, Aberdare, CIM is achieved by linking the computer systems at all levels. These systems can be viewed as a computer 'pyramid' as shown in Fig. 2. A more detailed overview of the hierarchy can be seen in Fig. 3, with Fig. 7 detailing the factory token ring.

At the top of the 'pyramid' is the Business Management System handling customer orders which enter the system either directly or via an external telephone network. These orders are passed to the Manufacturing Management System which controls product data, scheduling, production control, etc.

These systems are linked, via a gateway PC, to two token ring networks (18, 19), one ring for the offices, i.e. Systems, Accounts, Commercial and Planning, and the other for PC's on the factory shopfloor which are used by the Operators as a POMS interface. (See Section 1.5.)

The PC's in turn communicate with factory floor industrial computers (IC) which supervise the PLC's (11), which are themselves responsible for machine control and monitoring, this being the base of the 'pyramid'.

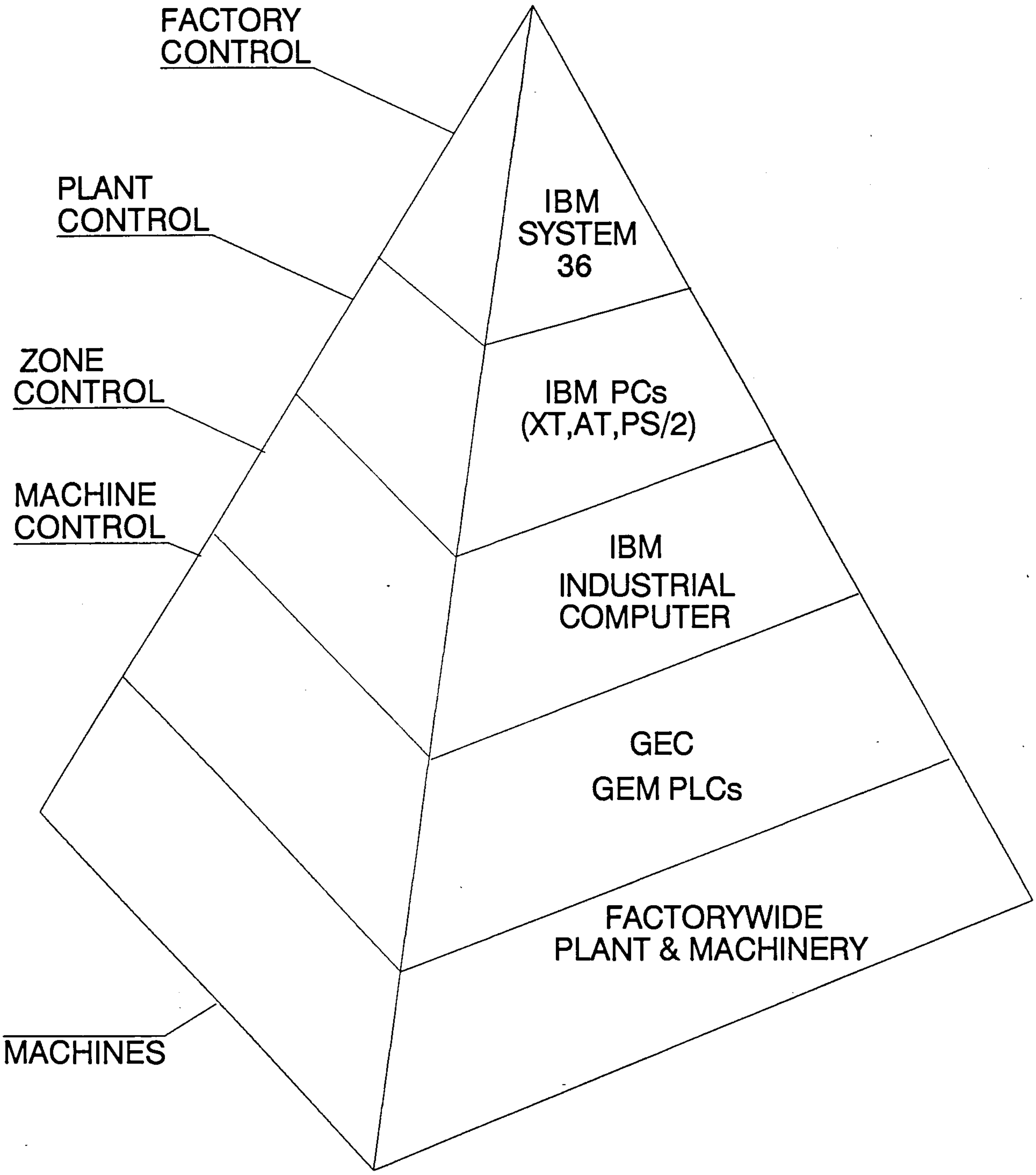


Fig. 2 : Computer Hierarchy at Pirelli - Overview

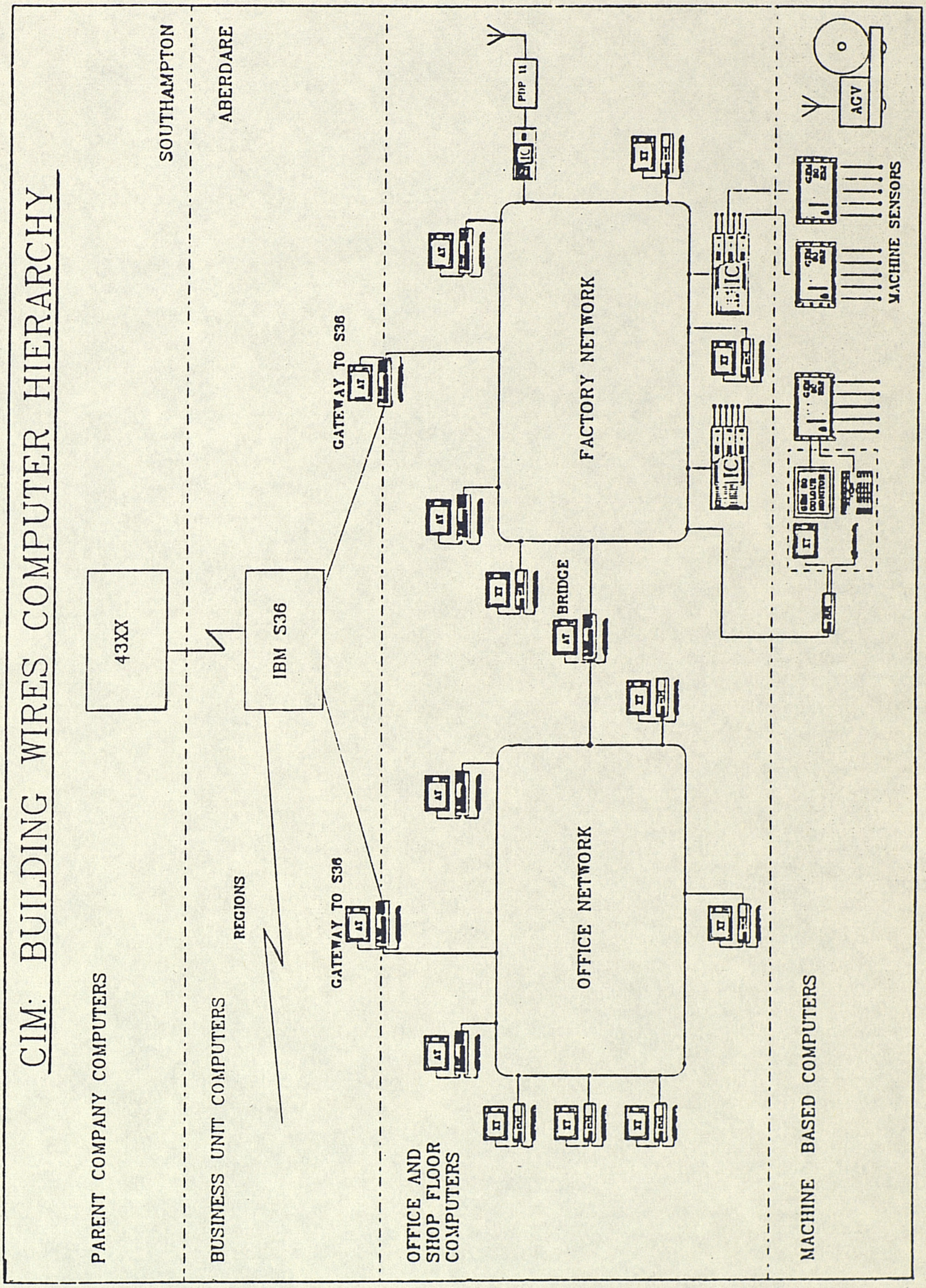


Fig. 3 : Computer Hierarchy at Pirelli
- Detailed

In order to have all the systems communicating and machines running as smoothly as possible, certain philosophies were adopted as standard throughout the factory :

a) machine flexibility
b) rapid changeover times
c) IBM PC's as standard Operator workstations
d) GEM 80 PLC's as standard

These networks, hierarchy of systems and the system hardware architecture, along with standard hardware, should ensure the factory has enough flexibility to cope with future markets.

1.5. Plant Operations Management System

POMS is the system around which the whole concept of the factory and its philosophy is designed and is unique to Pirelli, although the basis of it is applicable to any company embarking on a CIM project. POMS is a fully interactive computer programme written in the 'C' language and is the Operators tool, allowing for the flow of information between the IBM System 36 at the top of the 'pyramid', and the Operator, plant and machinery at its base. (See Fig.2.)

The factory floor PC's receive data from the Manufacturing Management System (MMS) and these data are managed by POMS, which is responsible for machine sequencing, control of the Automated Guided Vehicle System (see Section 1.6.), quality control and so on.

One of the most important reasons for ensuring that all machines within the factory are controlled by PLC's is that it is absolutely paramount that all plant can communicate with POMS via a PLC interface, from the point of view of the downloading of technical data to set up machine operating parameters to the uploading of machine alarms, running speeds and times and any other production data.

1.6. Automated Guided Vehicle System (AGV)

The AGV system is responsible for all bobbin movements within the factory area. It communicates with POMS via a gateway PC enabling any Operator with a POMS terminal to raise a mission to move any bobbin from any one area of the factory to another.

The AGV's themselves are guided about the factory by means of wire tracks laid in the floor. There are three variants capable of handling the three standard bobbin sizes used throughout the plant - DIN800, DIN1250 and DIN1800 (the numbers here refer to the bobbin flange diameter). The DIN1800 AGV is shown in Fig. 4 removing a bobbin from a store location.

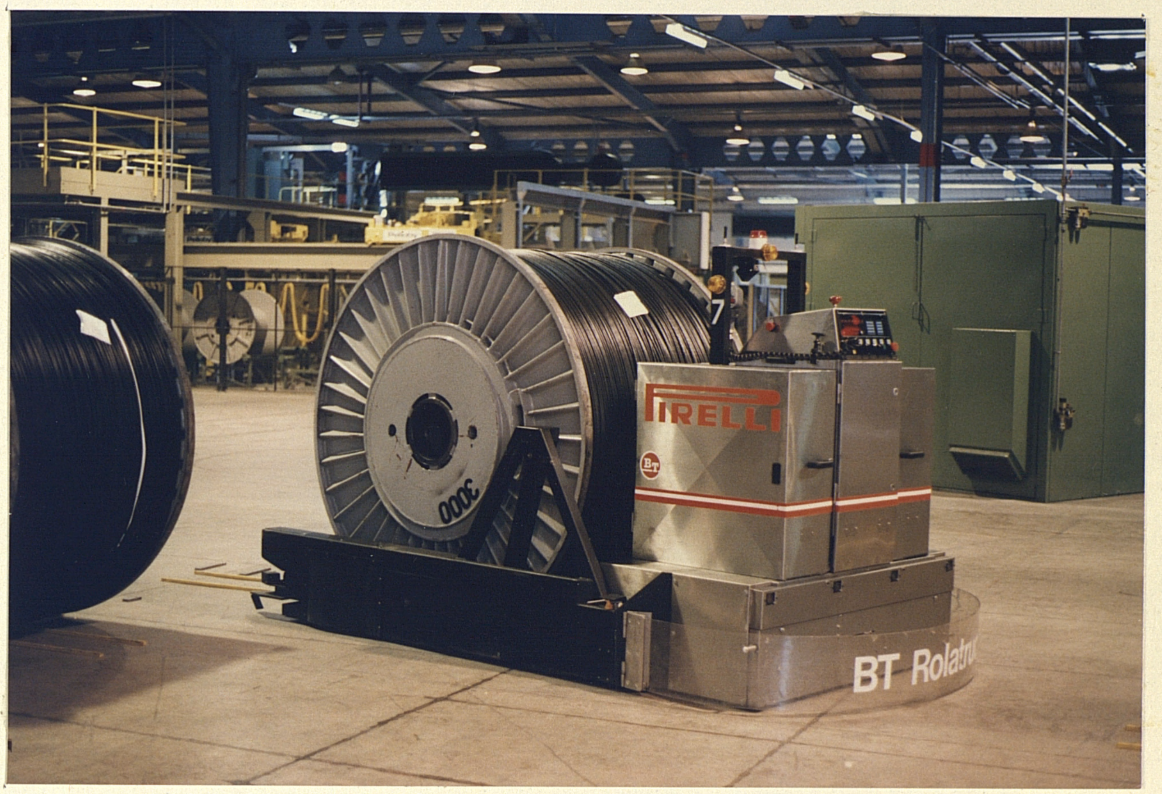


Fig. 4 : DIN1800 AGV moving bobbins

2. VIDEO FORMATS

Each of the lines in the Aberdare factory has a PLC driven video screen associated with it, allowing the Operator to assess the status of the line at a glance.

The Aberdare philosophy with regard to personnel training is that Operators are trained to be multi-skilled and, thus, capable of running any line within the factory. For this reason it was necessary to ensure a standard video format (or video page) throughout the whole of the factory, enabling Operators to change from one production line to another, but to have familiar screen and keyboard layouts.

Having standardised upon GEM PLC's, Pirelli decided to standardise the Operator video interface; the monitor that was chosen was a Microvitec Cub colour monitor for use throughout the factory.

The PLC's use an IMAGEM processor to produce colour graphics using an RGB output to the monitor. A screen can be defined as being of any size between -32767 to 32768 in both the 'x' and 'y' directions. This allows for a comprehensive overview of the line by means of mimicking the status of that line; e.g. valves can be seen turning on and off, machine units moved in and out of line.

Unfortunately, two lines, the cold print and rewind lines, are equipped with GEM 141 PLC's - a small PLC without an IMAGEM facility. The video interface used here was a Volker-Craig monochrome monitor, which turned out to be very fortunate (see Section 4.4.5.). The PLC's on these lines will be upgraded at a future date to give a standard interface throughout.

2.1. Philosophy

As the extrusion section was considered to be the most comprehensive and complex area of the factory, it was only natural that this should be the area from which the philosophy for the video formats should originate. It involves many different machines and statuses upon which it was possible to base the formats for all other areas.

The Operator interfaces with the PLC via a keypad. This keypad, of 8 x 8 keys, had already been defined by Pirelli, as shown in Fig. 5, and was divided up into discrete sections for ease of use. This included 8 sets of function keys which had up and down arrows and START and STOP functions associated with them. Added to this, there was a full 'calculator' pad, dedicated keys to allow the Operator to move easily from one video page to another and keys for acceptance of alarm conditions and cable quality.

The operation of the 8 function keys varies depending upon which video page is currently on display. However, the remaining keys are dedicated and a detailed description of their operation is given in Appendix Section 8.1.

2.2. Video Format Sequence

Having worked out the basic format for extrusion, it was decided to have a sequence of format types which would be standard throughout the factory for those machines with IMAGEM.

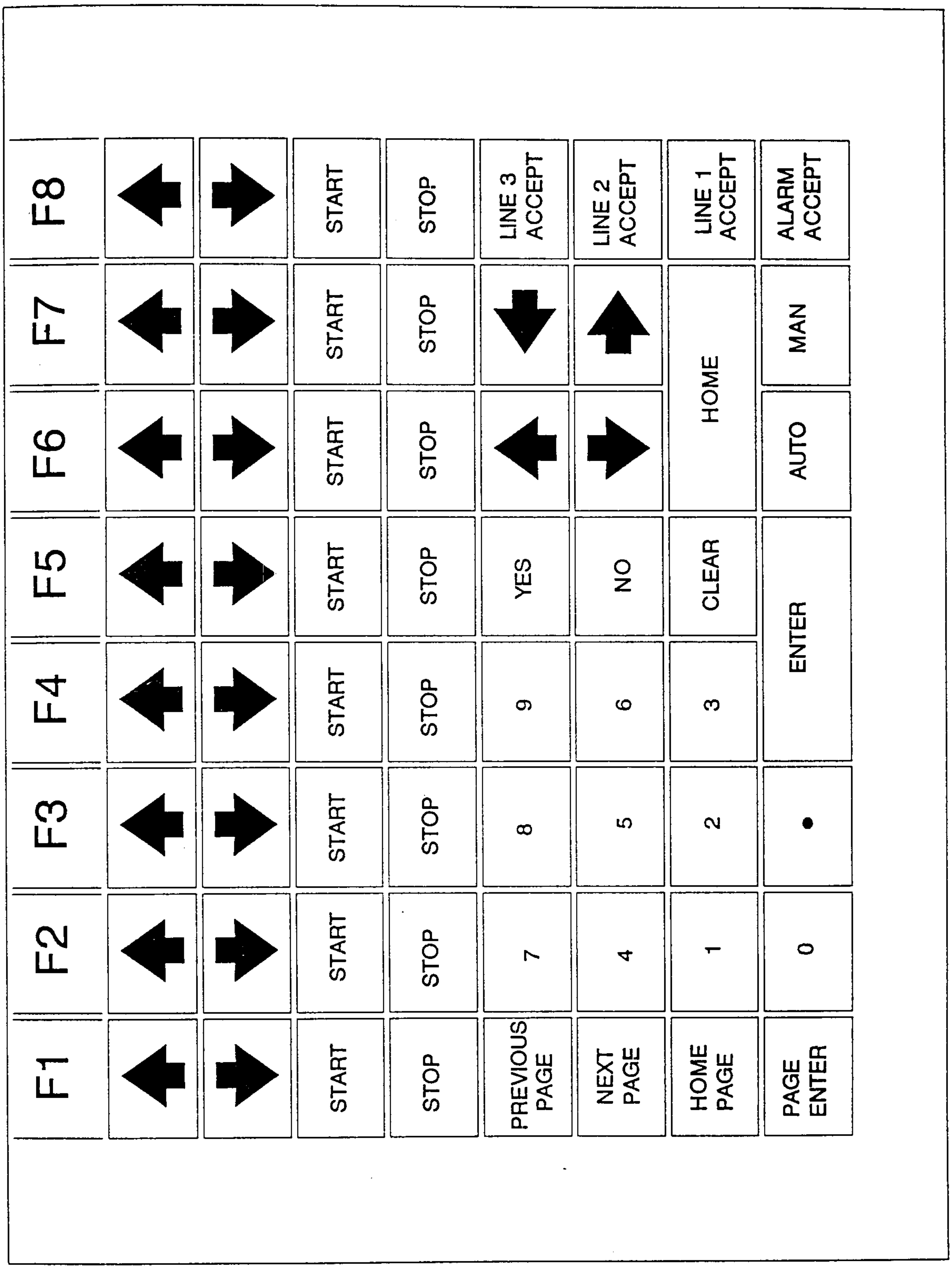


Fig. 5 : PLC Keypad

This sequence would consist of the following:

1. MENU PAGE

2. PREVIOUS BATCH SET-UP PAGE

3. CURRENT BATCH SET-UP PAGE

4. ALARMS PAGE

5. LINE Emergency stop

6. LINE Configuration

7. LINE Overview / Main control (Home Page)

8..... Detail formats of line components

Depending upon which line is being represented by video, certain formats may be omitted on some lines where they are not required, e.g. where the line configuration cannot be changed. Format numbers, however, remain unchanged and the absent formats are indicated by the colour of the text on the menu page. If one of these is called up, the format appears as a blank screen containing the text :

'Format type selected is unavailable on this line'

This page will still display the standard meterage, auto/man, alarm and message information.

In the case of format types 1 to 4, the amount of data on the page may be much larger than the actual viewing area and a scrolling facility may be required to allow viewing of the entire format. To indicate that the full format is not currently being displayed, a 'format continued' message will appear on the screen.

Some individual line components may require more than one page to show both the complex detail of the unit and to facilitate the desired keypad control. Such pages should be separately numbered.

The previous batch set-up page, the configuration page and the emergency stop page are not scrolled using the NEXT/PREVIOUS PAGE keys, but must be called up individually by entering their respective format numbers. This is because during the general operation of a line, the Operator should not require access to these pages.

2.3. Operating Modes

The line is run in one of two possible operating modes, AUTO or MANUAL.

AUTO is the normal running mode for the line in production. Operator intervention is normally limited to on-line trimming of operating set values such as speeds, temperatures and voltages and to key/pushbutton presses during a sequence of operations.

MANUAL mode allows a greater degree of Operator intervention and is used for setting up and testing the line, or for resetting the line following a fault condition.

To ensure safe working practice, AUTO/MANUAL mode selection is permitted only when the line is stopped and MANUAL mode is automatically selected by the PLC whenever the line is stopped.

The mode of operation may be selected whilst viewing any format by using the dedicated AUTO/MANUAL keys, and is then displayed on all formats, as shown on the general layout in Fig. 6.

The mode (along with software interlocks depending on the running/stopped state of the line) determines the enabled/disabled status of the function keys for each page. Keys are enabled only if their operation is consistent with the safe and efficient running of the line, whilst in that particular operating mode.

Function key indication blocks and key-label background blocks are coloured according to the enabled/disabled status of the respective keys in the current operating mode. Thus an enabled key is CYAN, a disabled one, RED.

If a key-label groups two or more function keys together, some enabled, some disabled, then the label itself, is CYAN.

Key indication blocks and labels associated with enabled keys colour up GREEN on a key press for a timed period before reverting to CYAN. Those associated with keys which inch a process colour up GREEN, only whilst the key is pressed.

Function keys which have no operation associated with them are displayed in GREY.

2.4. <u>General Format Layout</u>

Each IMAGEM video format conforms to the basic layout specified in this section, as shown in Fig. 6. More detailed formats as drawn up for the extrusion section may be seen in Appendix Section 8.2.

All formats display the following :

1. Format number indicating scroll sequence position.

2. Format title.

3. AUTO/MANUAL operating status.

4. Meterage on current take-up bobbin(s).

5. Flashing RED alarm band when appropriate.

6. Message texts on a CYAN band when appropriate.

7. Function key indication blocks.

2.4.1. Key messages

Each function key, F1 to F8, may be used to implement a number of options. The various options associated with a key are shown as scrolled key-messages above the relevant key-label block or key indication block. Scrolling is effected by using the dedicated arrow keys on the keypad. Key message texts may include status indications (ON/OFF), line element selections (PUMP1/PUMP2) and line element settings (POSITION1/POSITION2).

The key-message text appears on a background block, coloured according to the current machine status. So for :

a) Key disabled - text is on GREY
b) Key enabled (option not selected) - text is on CYAN
c) Key enabled (option selected) - text is on GREEN

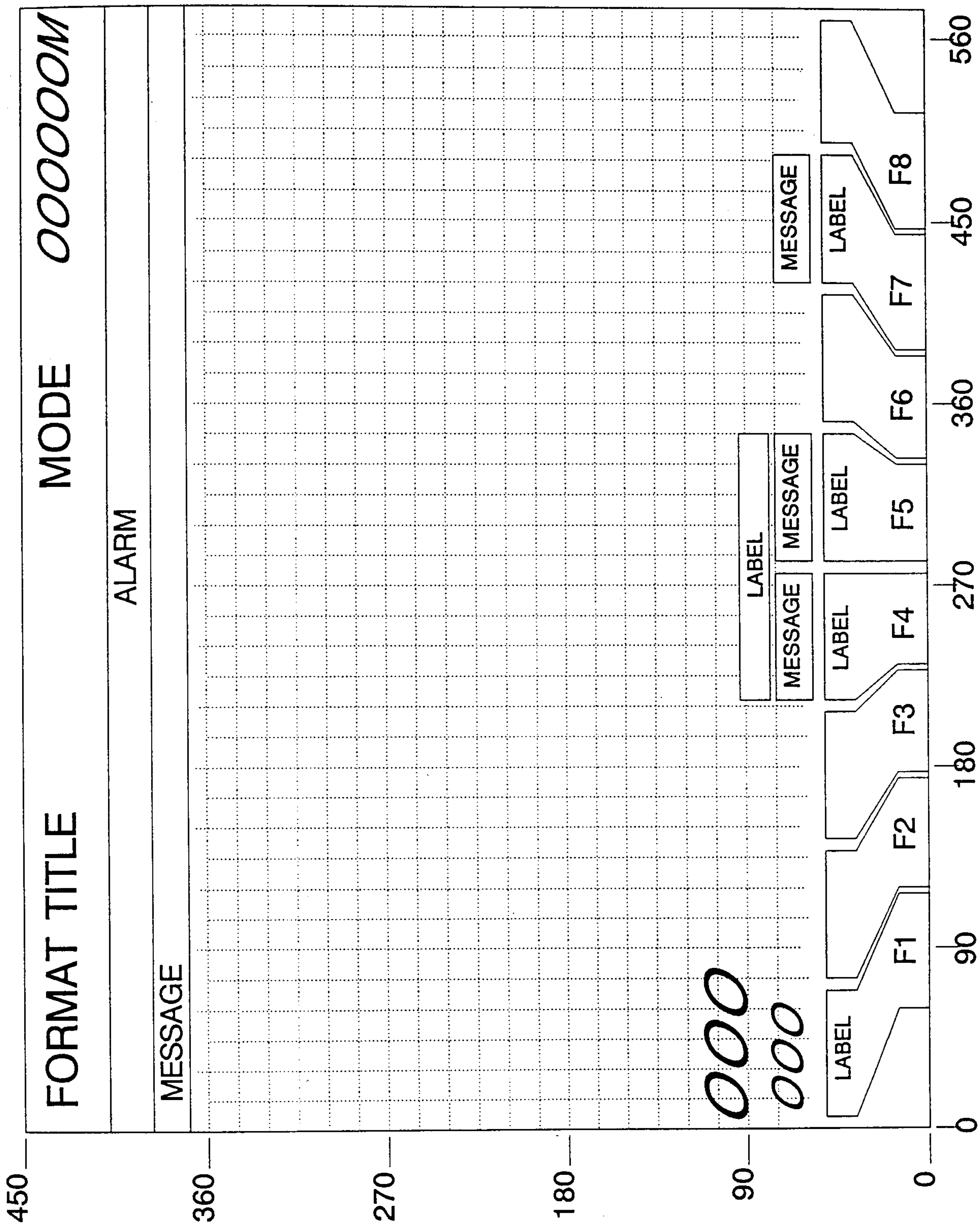


Fig. 6 : General Video Layout

An option is selected by scrolling to the required key-message and pressing the START button. If the option is permitted, the key-message block colours GREEN.

Key-message blocks associated with a function key used for inching a line process colour GREENFLASH while the key is pressed. If the movement is between constraining limits, then, once the next limit is made, the message text changes to indicate the limit position and the background block becomes GREEN. If the key is released before the limit is made (e.g. a tilter stopped at 45°), then the key-message block is BLUEFLASH. If the inching process is not constrained by limits then the block reverts to CYAN on key release.

2.4.2. Numeric Display

Set values are displayed in CYAN size 1 characters above the relevant function key indication blocks. Achieved current values are monitored in size 2 characters directly above the set values. The colour of these characters indicates whether the achieved value is inside or outside the acceptable limits about the set value for the current operating mode. If it is inside the limits, then this colour is GREEN, if outside, it is RED.

The limits normally set for these values are ± 10% of the POMS set value in AUTO mode and up to the safe machine limits in MANUAL mode. (See Section 2.6.2.2.)

Numeric displays elsewhere on the screen (i.e. those not associated with function keys and bar graph indications), follow the same colour code.

2.4.3. Messages

Any information which is necessary for the operation of the line, but is not an alarm condition, is displayed for the Operator as a message. Message text appears in a CYAN band beneath the RED alarm band on all screens and when no message is required, the band does not appear on the screen.

The message text is cleared using the CLEAR key (except on the alarms page) and, if no further message is currently being signalled, the band is also cleared. If a further message is being signalled then this will replace the cleared text. This means that the old messages must be cleared to reveal more recent ones.

2.5. Colour Scheme for Video Formats

In order to have the same machine and bobbin status indications throughout the factory, it was necessary to devise a colour scheme which would immediately show the Operator the overall status of the line. (See Table 1.) Thus, colourfill is used in two distinct areas to indicate status :

a) Bobbins for pay-in and take-up stands.

b) Machines and wire for line components other than pay-in and take-up stands.

STATUS	COLOUR
Not configured	(*)Not on screen
Present but not currently selected	Outline only
Neutral, inactive	GREY
M/c out of position/switched off Bobbin in initial state e.g. take-up empty.	BLUE
M/c out of position + bobbin in final state e.g. take-up full.	BLUEFLASH
POMS signalled, waiting for AGV, or being serviced by AGV.	YELLOWFLASH
M/c in working position (but not 'ready' if this condition exists) or m/c stopped without alarm condition.	CYAN
M/c ready to run or stopped without alarm condition (alternative to CYAN)	ORANGE
M/c running	GREEN
M/c running but ready to stop/change or bobbin in final state (full/empty) but in working position.	GREENFLASH
M/c running with alarm signalled	REDFLASH
M/c stopped because of alarm condition	RED

Table 1 : Machine Statuses and Associated Colours

* This does not apply to the configuration page.

The machine status may also be indicated by the position or shape of symbols on the screen and by screen messages. N.B. - Line configuration, emergency stop and overview formats all have simplified but consistent colour schemes.

2.6. General Video Specification

2.6.1. Page 1 - Menu Page

Each individual line has a menu page which contains a list of all the formats on that particular line along with their page numbers.

The first seven formats for each line are numbered on every production line in exactly the same standard sequence. The following line component detail formats are ordered according to their page numbers which reflect the order of line processes.

2.6.2. Job Set-up Pages

Associated with all the parameters referring to the line, there are two types of set-up data; command data and technical data.

Command data refers to required meterages and cutting lengths of produced cable.

Technical data refers to those parameters that affect the running of the line, such as tensions and temperatures.

These data are sent down from POMS for each job that is to take place on the line and are sent in the form of a matrix of values. This is known as the J table and is a series of addresses received by the PLC for processing and are stored internally within RAM. Command data is held in addresses J0 to J7; technical data in addresses J8 to J31. As each new J table is sent, the previous data is overwritten. The data is presented to the Operator through the use of the job set-up pages.

2.6.2.1. Page 2 - Previous Job Set-up Page

Once a job has been completed, the set-up parameters are transferred to the previous job set-up page, allowing the current job set-up page to accept further data from POMS. These values are held in the memory of the PLC and are displayed for Operator information on this set-up page.

The previous job page has an identical layout to the current job set-up page (see Section 2.6.2.2.), but without the POMS values, only the Operator set values.

The data on this page cannot be changed by the Operator.

2.6.2.2. Page 3 - Current Batch Set-up Page

Data is downloaded from POMS for each job that is to take place on the line upon completion of the previous job. With POMS on-line, a job is signalled as being complete when the required job length has been achieved. Jobs are grouped together in batches, these being relevant to colours, types, sizes, etc.

Upon the completion of a batch or a job, the Operator receives new command data and new technical data.

The POMS set values such as speeds and temperatures are displayed as CYAN characters in a column for reference throughout the batch. These values cannot be changed at the PLC level. However, values derived from POMS values or automatically retrieved from PLC memory are displayed as YELLOW characters.

The current operating set values which are output from the PLC to the various line components are displayed as GREEN characters in a column alongside the POMS values in order to give the Operator a direct comparison.

The current set values may be altered either from individual detail pages by using the dedicated arrow keys associated with function keys, or by inputting exact values on the set-up page.

In either the MANUAL or AUTO modes the range of permitted inputs on both set-up page and detail pages is determined by the availability of set-up data downloaded from POMS. If POMS data is available, the limits can be set to ± 10% of the POMS value in AUTO and to the machine's own limits in the MANUAL mode. If POMS data is not available, the limits are the machine limits in both operating modes.

Trimmed set values that are input from detail format pages are also continuously updated on the set-up page.

Current set values and general set-up conditions may be changed on the set-up page by first addressing each value individually, using a background block screen cursor. The cursor is moved across the set-up page using the keypad arrow keys. HOME takes the cursor to the top left value on the page.

All values and conditions appearing on the screen as current operating set-up parameters are those that have been output from the PLC to the machines. Thus, for safe operating procedure, any default values must operate between being keyed in and being loaded into the set-up table.

The ENTER key must be used only as a confirmation default when preceded by no numeric or other keyed input. If a value on the table is addressed by the cursor and ENTER pressed, then the current table data is retained and the cursor moves on to the next data location in the table. Zero may be input only by pressing a 0 key prior to ENTER.

A new value is put into an addressed table location as :

number + ENTER

The cursor moves automatically to the next table location when ENTER is pressed.

If the input value is either too high or too low, then the existing value is retained and a screen message 'Input too high/low' appears.

Numeric inputs which include decimal places after a point may be input from the keypad and are displayed in the input location on the screen exactly as entered. It must not be necessary to type in the 'correct' number of significant figures.

Conditions such as set/not set are addressed in the same way as numeric inputs by the screen cursor. YES is used to confirm that the present status is correct; alternatively ENTER will give a default confirmation. In either case, the cursor moves on automatically to the next table location. NO will change the set-up state and also moves the cursor on to the next location.

2.6.3. Page 4 - Alarms Page

If any alarm condition is signalled to the PLC, a flashing RED band will appear at the top of every format to indicate such a condition. This band is not removed until the alarm condition is accepted (if allowed) or rectified.

On a new alarm signal, the PLC displays the alarms page automatically on the screen. The Operator, however, may then scroll up other formats as desired in the normal way.

All non-rectified/unaccepted alarm faults are displayed on the alarms page on a RED background along with the meterage at which they occurred.

ALARM ACCEPT and CLEAR keys act on all the alarms displayed on the alarms page.

If an alarm does not require the line to be stopped or the fault to be remedied immediately, then the Operator may press the ALARM ACCEPT, and if this is the only alarm being currently signalled, the flashing band will be removed from all the other formats. All alarms however are retained on the alarms page until the fault condition is rectified.

On rectifying the alarm condition, the alarm may be cleared from the screen using the CLEAR key.

POMS will retain a long term record of all alarms for feedback on the performance of individual lines.

2.6.4. Page 5 - Line : Emergency Stop Page

Following an emergency stop condition, the PLC automatically calls up the 'line - emergency stop' format in order to reset the line.

The format shows the line as it is currently configured and indicates the source of an emergency stop (pushbutton location) in REDFLASH. All other pushbuttons are shown in outline.

The meterage at which the emergency stop occurred is recorded on this page.

The line cannot be run from this page and may only be restarted after reference has been made to this page and line reset has been effected. The Operator must then call up a relevant detail format or overview to restart the line.

F1 LINE RESET START Resets all emergency stop relays ready for line to be restarted from the overview page.

If the emergency condition persists, then F1 is disabled along with the start-up key on the other formats.

2.6.5. Page 6 - Line : Configuration Page

The line may be configured either by POMS or by the Operator. During normal running, POMS downloads set-up data for machines to be used. The line configuration format shows configured machines in colourfill, non-configured machines in outline. The configuration page has the same basic screen layout as the overview format but includes all the possible line components. The Operator may configure or reconfigure the line using the configuration video page when the line is not running and is in MANUAL operating mode. When the line is in AUTO, or when the line is running, the configuration page may be viewed but the keypad is disabled.

N.B. - The configuration page is used only for configuration of the line and does not facilitate monitoring or control of any line parameters.

Once the appropriate conditions are met, changes in configuration are initiated by pressing function key F1 START. This brings up the question, 'Is this the required configuration ?'

If changes are required, the Operator answers NO - this puts the system in a lock-out mode such that the line cannot be started until the key press sequence F1 STOP + YES has been followed.

On NO, the configuration query is removed and the first line component is highlighted in YELLOW. This is asking the Operator 'Is this machine to be configured?'.

The Operator responds with YES or NO and the cursor block moves on automatically to the next component. As on the set-up page, ENTER also acts as a default confirmation leaving the current configuration state unchanged and moving the cursor on.

If NO is pressed, the component is displayed in outline. For YES, the component is in solid colour. The arrow keys may be used to move the cursor block around the screen without changing the configuration status of components.

Once the desired configuration is represented on the screen, the Operator presses F1 STOP and the question 'Is this the required configuration ?' reappears. The Operator now responds YES. This key press downloads the configuration shown on the screen to the relevant drive enable/disable level. This means that machines not configured will be completely disabled through software interlocks.

The configuration is also downloaded at this point to the line overview and emergency stop pages which will display only the configured line elements.

The line may now be started.

The configuration page and emergency stop page are special formats which do not require constant reference during normal running. Therefore, they will not be scrolled to using NEXT/PREVIOUS PAGE keys but may be called up individually by :

PAGE ENTER + format no. + ENTER

2.6.6. Page 7 - Line : Overview Page

Each line will have an overview format representing, schematically, all the configured process functions for the whole of the line.

The overview page provides a master control page for starting and running the line as a whole with all major production parameters being monitored. The format will also retain a record of the last bobbin meterage produced. It can be accessed at any time by pressing the HOME PAGE key.

The general health of the line will be indicated by the colour of the line components on the video :

GREEN	All OK and Running
CYAN	OK but not running
YELLOWFLASH	Being serviced by AGV

RED	Stopped due to fault condition
REDFLASH	Running with some fault condition

The overview format will display only configured line components.

2.7. Video Format Overview

Overall, the use of a video and keypad to replace the standard pushbuttons used to run a machine has been successful. It has allowed the Operator to see exactly how the machine is running, how much cable has been produced and all of the parameters associated with that cable. It also means that once the line is set up to run at it's optimum performance level, it can always be repeated by recording the set-up data, storing it in POMS and then downloading the data at the touch of a button.

A standard specification for the video interface across all the machines in the factory has meant that Operators can go to any machine, and still be able to run the line and interpret fully the information displayed for them on the screen.

The only problem is that, due to the sheer volume of data available, it is not possible to show the Operator all of this data on a single screen, but requires several screens. However, it has been possible to extract the most pertinent and useful data, combine it with a mimic of the machines that make up the line and to produce the overview format, enabling the Operator to see at a glance how the line is running.

3. PLC INTEGRATION INTO THE PACKAGING AREA

The packaging and despatch areas consist of several different sections, each of which has a discrete function to perform.

These can be broken down into three distinct areas :

1. Core printing and rewinding
   - single core insulated

2. Packaging of small non-returnable reels
   - twin and earth, small flexibles

3. Winding large wooden returnable drums
   - control cables, armoured cables

These are so arranged within the factory structure (see Fig. 1), that the general trend for the flow of materials is from one end of the factory building to the other.

Each of the different lines has to be PLC controlled for the purposes of reporting line conditions and product output data back to POMS and receiving machine set-up data back from POMS. The whole factory systems hierarchy (see Fig. 2) is based around PLC's at machine control level. To conform and standardise with all other plant in the factory, Pirelli set about integrating PLC's into the packaging and despatch area. An overview of the token ring network for the factory, through which all communications for POMS purposes between the computers takes place, can be seen in Fig. 7.

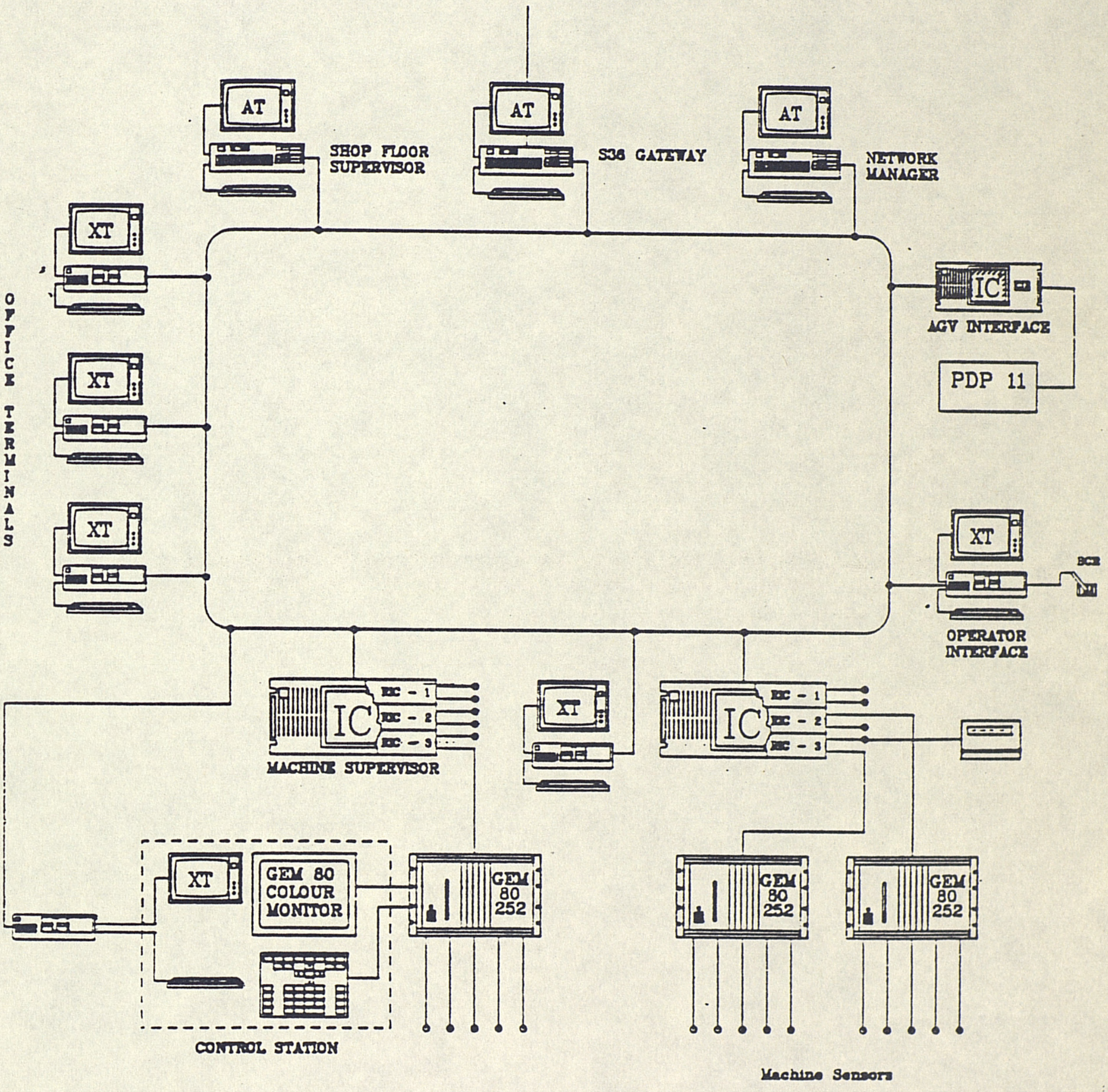


Fig. 7 : Building Wires Token Ring Network

4. COLD PRINT AND REWIND LINES

For this section, it was Pirelli who had the responsibility to tie all the individual machines together into a coherent, working line. This was breaking new ground for Pirelli as it involved not only coordinating the operations of each machine, but completely replacing both hardwired control systems and Siemens PLC logic with GEM PLC software. (Metallurgy and extrusion lines had been supplied complete with GEM PLC.)

4.1. Line Configuration

The line configuration for the cold print line consists of :

1. Pay-off - horizontal DIN1250 flyer
2. Length counter
3. Test equipment
    - spark tester
    - diameter gauge
    - eccentricity monitor
4. Ink-jet printer
5. Take-up - Bongard drum pack machine
    - Skaltek rolling take-up

This configuration is the same for the rewind line, except for the ink-jet printer and the Bongard drum pack machine.

4.2. Line Usage

These two lines may be used for the same purpose, that is as a rewind line.

The primary function of the cold print line is to number the cores which are used to make up control cables; i.e. the number of the core (from 1 to 47) is marked on the core in both figures and words. The cable is strung up through the units and, if the cores are to be numbered, through the Bongard drum pack machine. Otherwise the line is being used for a rewinding purpose and so the cable is taken up on the Skaltek unit. (For different line configurations, see Fig. 8).

The function of the rewind line is to act as a rewind and verification line, checking for and rectifying any faults on the cable using the test equipment mounted on the line. If there are faults on a cable which were registered during the extrusion phase, but which were not important enough to warrant halting production at the time, then the cable is rewound to the position where the fault occurred and either a repair is made, or the fault is removed from the cable.

4.3. Line Specification

Firstly a specification had to be drawn up on how it was envisaged that the line would operate. To have the line functioning as desired, it was necessary to consider all the interested parties; Operators, shift managers, plant development, systems engineers.

As elsewhere, a standard programme approach was adopted, which meant that the same programme could be used on either line, the code relevant to each line being accessed by a machine1/machine2 identifier. This was to be in line with all the other PLC software, ensuring consistent use of addresses, data tables, etc.

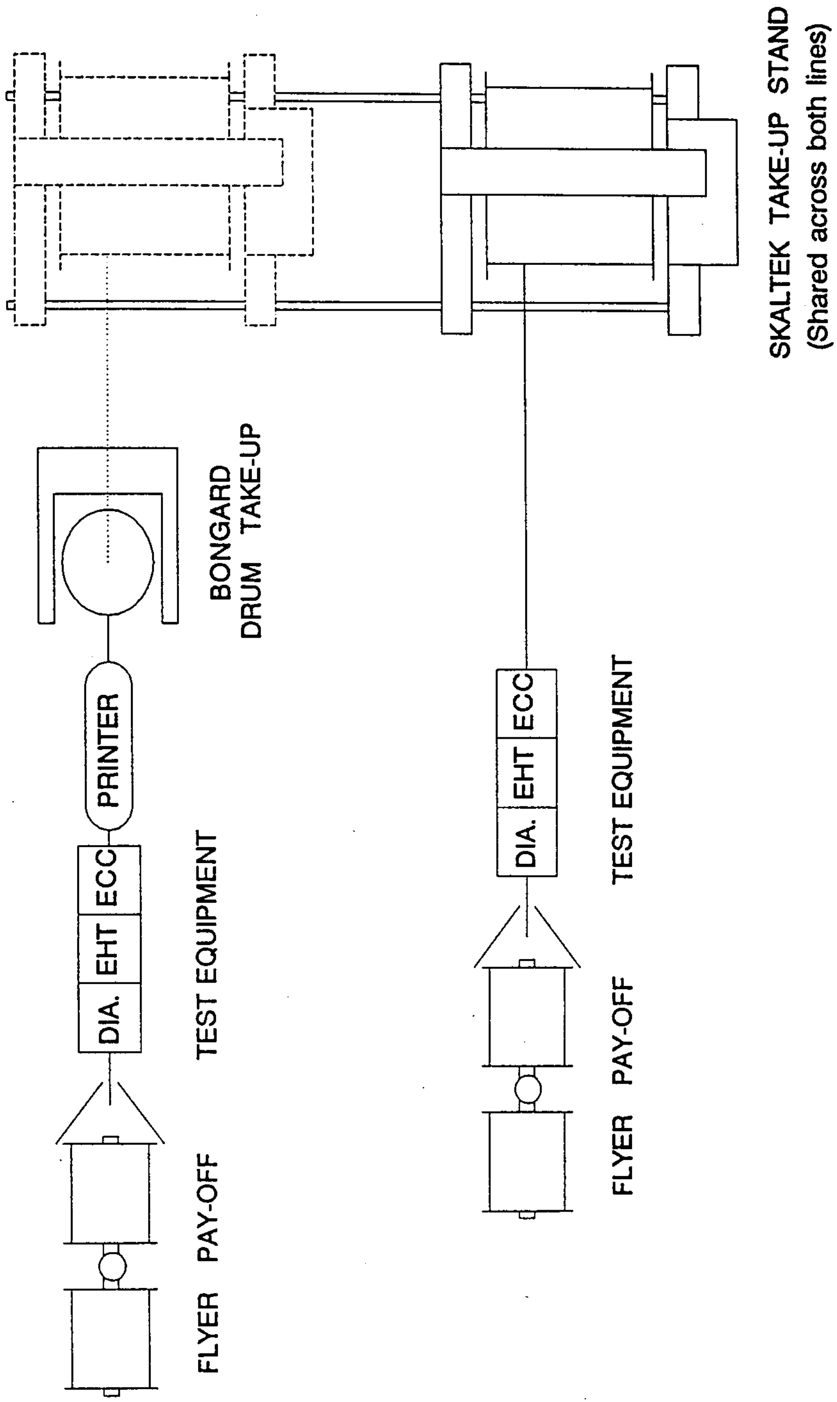


Fig. 8 : Cold Print and Rewind line Configuration
- Schematic

The functioning of the cold print line was the main concern and so individual units were considered one at a time. To appreciate the problems involved, a description of the line units is needed.

4.3.1. Pay-in

These are of the horizontal flyer type, whereby the full bobbin is loaded horizontally onto a carousel and swung around to have the pay-in end covered by a cone (see Fig. 9). The cable is pulled off the bobbin and through the cone, in this case by the take-up at the other end of the line. Attached to the flyer is a backtension unit which has an electromagnetic brake on it. This regulates the amount of tension on the cable during winding by means of belt tension on the braking wheel. The complete unit is supplied as stand-alone, with a small control box containing relays and contactors wired up to pushbuttons, with a potentiometer for brake value setting (between 0 and 100%).

4.3.2. Test Equipment

4.3.2.1. Zumbach Spark Tester

The spark tester is a self contained unit through which the cable passes. A very high voltage (0-15kV) is passed around the sheathed cable and if there is a fault, this immediately goes to ground through the core of the cable, burning the P.V.C., and registering a fault.

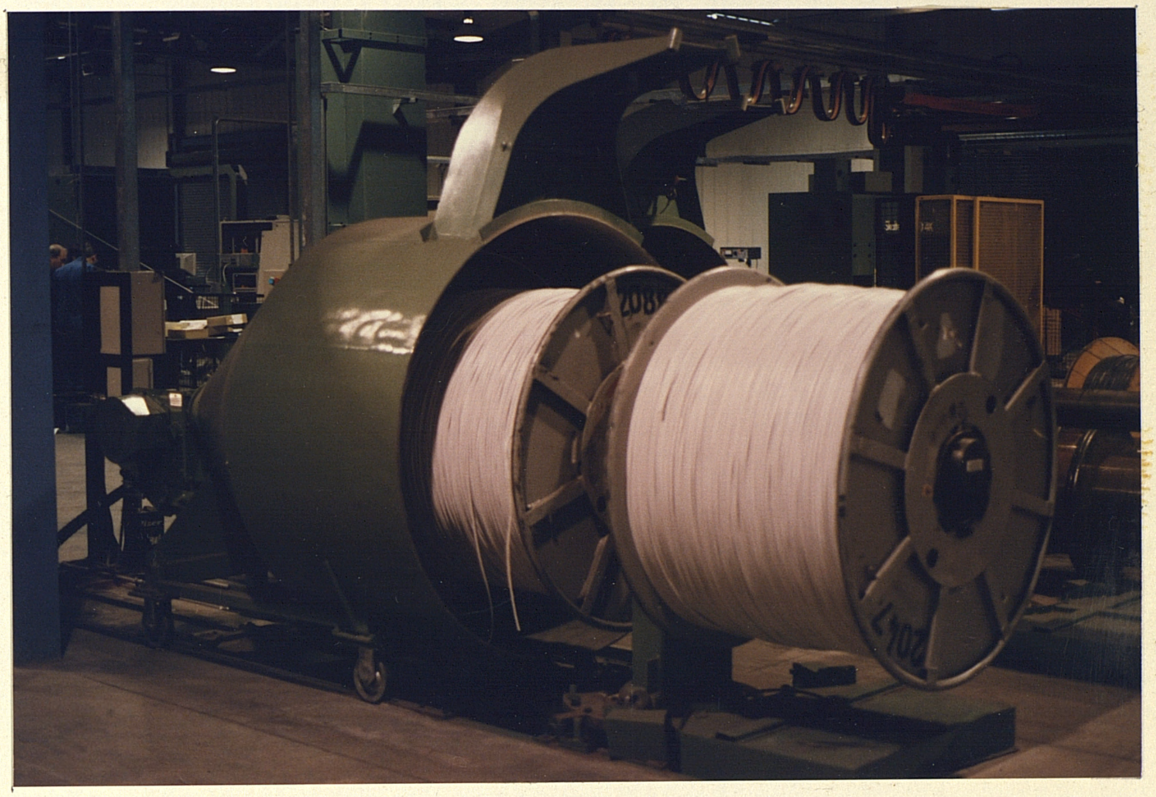


Fig. 9 : N.M.C. Flyer Pay-in

4.3.2.2. Zumbach Diameter Gauge

The diameter gauge uses a laser measurement system to ascertain the diameter of a cable. The laser is scanned across the cable in two planes in order to give 'x' and 'y' values.

4.3.2.3. Uster Metrex Eccentricity Monitor

The eccentricity monitor is used to pinpoint the position of the centre of the copper conductor relative to the centre of the cable.

4.3.3. Weidenbach Ink-Jet Printer

The ink-jet printer (see Fig. 10) uses charged droplets of ink to mark on a cable. The ink is pulsed through a nozzle to produce a fine spray of droplets. Those which are needed for marking the product are electrically charged and deflected on to the cable as they pass between two deflecting plates; the printed characters are made up of a 7 x 5 matrix of droplets. The remainder of the droplets, those which aren't deflected, are collected in a gutter and recycled so that no ink is wasted. (See Appendix Section 8.5).

4.3.4. Bongard Take-Up

The Bongard unit is used, as previously described, to take up cable and to deposit it into a drum. The cable is pulled off the pay-off by a rotating belt which winds the cable and drops it into the drum packs. (See Fig. 11). These packs are then

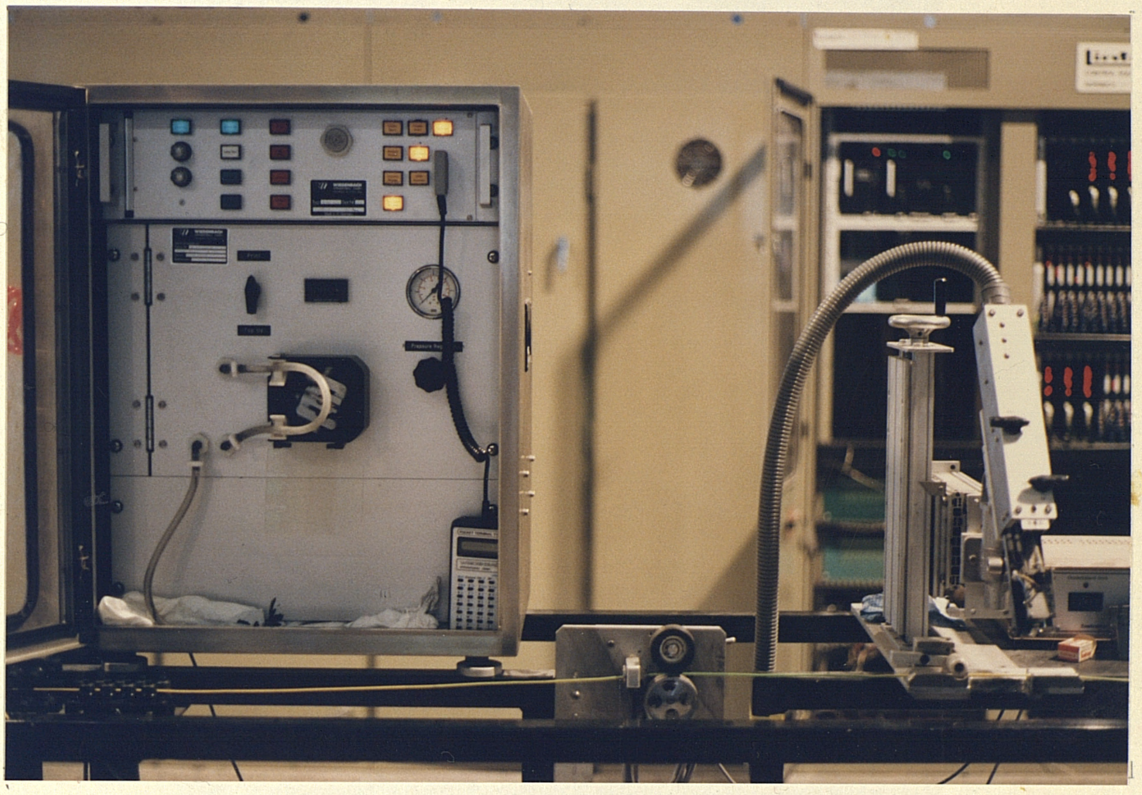


Fig. 10 : Weidenbach Ink-jet Printer

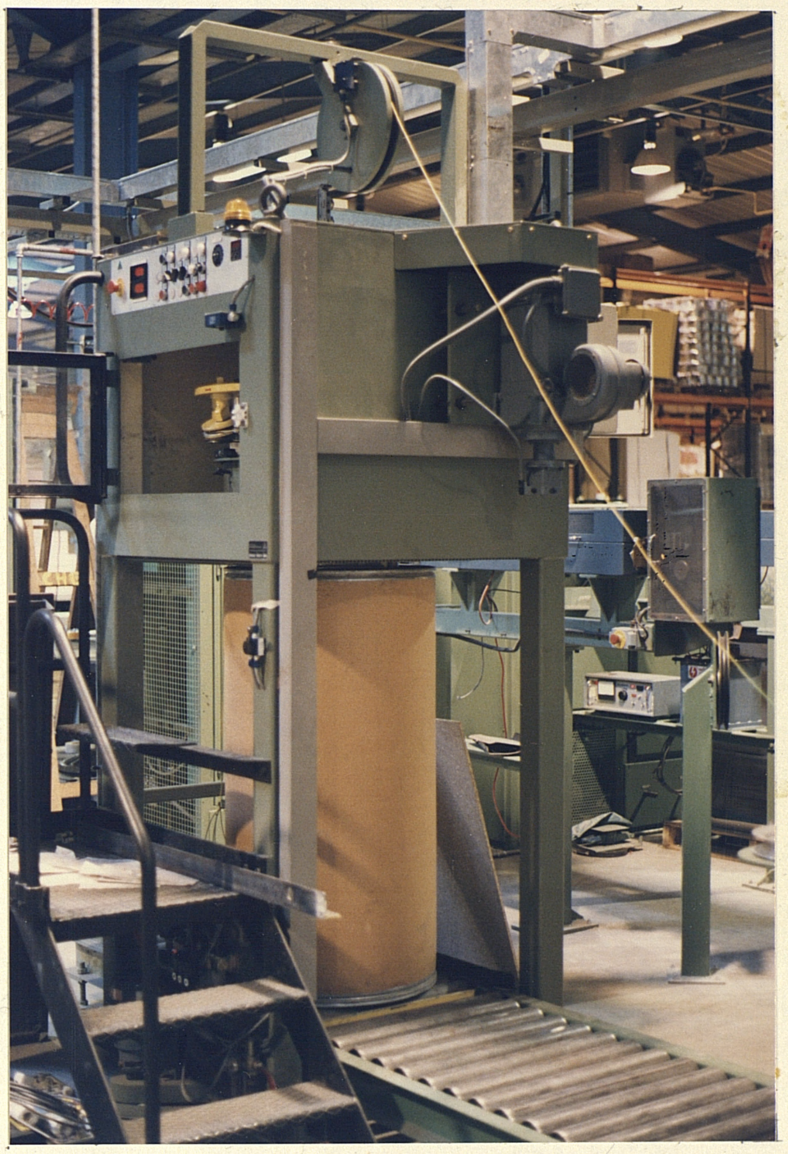


Fig. 11 : Bongard Drum Take-up Unit

transported to a laying up machine where the cable is pulled out of the drums and laid up to make control cables.

4.3.5. Skaltek Take-Up

The Skaltek take-up is a portal stand type unit used widely throughout the cable industry. The take-up can be adjusted to hold any size of bobbin and takes up cable by rolling the bobbin. (See Fig. 12).

4.4. PLC Integration

4.4.1. Pay-in

Problems had been encountered with the use of these flyer pay-ins elsewhere in the factory - certain proximity switches could be made by the steel toe-cap of a safety shoe accidentally firing relays and being very dangerous to factory personnel. Thus it was decided to incorporate the control of the flyer into the PLC software and not just to monitor signals coming from it as had previously been thought. This involved removing the control box relays, replacing them with terminal bars and running the control wiring from the PLC cabinet. The pushbutton signals were wired directly into the PLC digital inputs and the brake potentiometer was removed altogether and replaced with software control from the PLC interface keypad, via an analogue output card.

PLC operation of the flyer means much greater control; it is now possible to lockout the movement of the carousel during AGV bobbin removal and delivery. The brake backtension setting has been

Fig. 12 : Skaltek Take-up Unit

made simpler and can be changed from the keypad whilst still operating the line.

4.4.2. Spark Tester

The back panel of the spark tester has terminals which allow it to be driven by remote means, in this case by the PLC. The PLC provides signals that allow the spark tester and the E.H.T. to be turned on and off and for the actual value of the E.H.T. to be set by a 0-10V signal. This means that any set-up data downloaded from POMS will automatically set the spark tester to the right operating parameters.

4.4.3. Diameter Gauge

The PLC interprets the signals sent from the diameter gauge and uses them to determine whether a cable is under or over size when compared to the diameter defined in the set-up data.

4.4.4. Eccentricity Monitor

The eccentricity monitor sends data to the PLC and these are used to determine the wall thickness variations about the cable. An alarm is registered if the wall thickness is less than the minimum set value at any point.

4.4.5. Ink-Jet Printer

This is the most important area of the PLC integration for the reason that this type of ink-jet printer has never before been driven by a PLC.

The ink-jet printer is equipped with its own CPU, which is programmed with the basic functions necessary for the operation of the printer. Pirelli's requirement was for chimney and mirror printing using a 7 x 5 dot matrix. (See Appendix Section 8.3.)

Communication with the printer is possible via two RS232 serial interface ports. One of these is connected to the PLC and the other allows the Operator to interface directly by means of a portable hand-held programmer.

In order to set up the printer, the CPU is programmed to accept certain escape sequences and the standard ASCII characters. An example of such a transfer protocol is shown below :

<u>HOST</u>		<u>PRINTER</u>	
<STX>	----------->		Start of transfer
	<-----------	<ACK>	Acknowledge <STX>
<CLR>	----------->		Clear text buffer
Mode	----------->		Escape sequence
Text	----------->		ASCII characters
<ETX>	----------->		End of transfer
	<-----------	<ACK>	Acknowledge <ETX>

Once the printer has been programmed, it will continue to print until a new <STX> is received.

Several problems have been encountered whilst trying to drive the printer from the PLC.

At the moment, the line is run by a GEM 141 PLC. This only has the capacity for two RS232 serial links, one of which is used for download and upload of data to POMS, and the other for uploading commands from the keypad and downloading data to the Operators video monitor (see Fig. 14). Consequently, there was not a spare serial link port with which to interface with the printer.

Two other problems arose and were due to the PLC processor. Firstly, the PLC uses the <ETX> code for its own internal purposes and cannot send this code down a serial link to any other peripheral device, such as a printer. Hence, the printer would be left waiting for more text to be sent as there was no means of sending an 'end of transfer' signal.

Secondly, the PLC can only send two stop bits, and the CPU requirement of the printer was for one stop bit. The effect of this would be that having received the first stop bit, the printer would continue in the set-up mode and the extra stop bit from the PLC would throw the programme out of sequence.

However, because the PLC's are 141's, a monochrome Volker-Craig monitor was used for the video display. This monitor comes complete with its own CPU board that has an auxiliary RS232 serial link, through which it can download data to a printer. The monitor is not a dumb terminal, but can be set up to different communications and printer data transfer protocols. Thus it was possible to set the monitor to receive and understand data from the PLC and to interpret this for downloading to the Weidenbach unit.

The PLC sends the data to the Volker-Craig in 8 bit form, with 2 stop bits. The <ETX>, which in ASCII code is @03, or 00000011 in binary, cannot be sent by the PLC. It can, however, send an @83 code, or 10000011. The monitor is set to receive 7 bits, (no check, ignore parity) and 2 stop bits. Thus, when the monitor receives the @83, it doesn't look at the eighth bit, but interprets the code as an @03, or <ETX>.

The monitor is set to download data to the printer in 8 bit form, with 1 stop bit, as the ink-jet printer CPU requires. It also sends the <ETX> (@03) for end of transfer. (See below, Fig. 13).

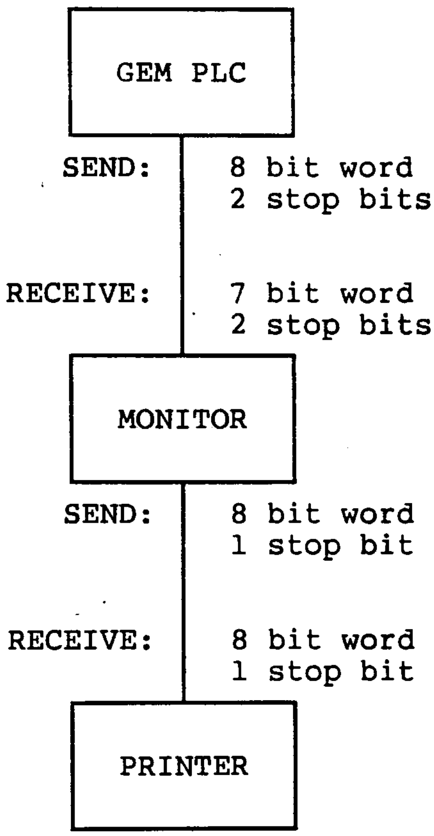


Fig. 13 : Communications protocol

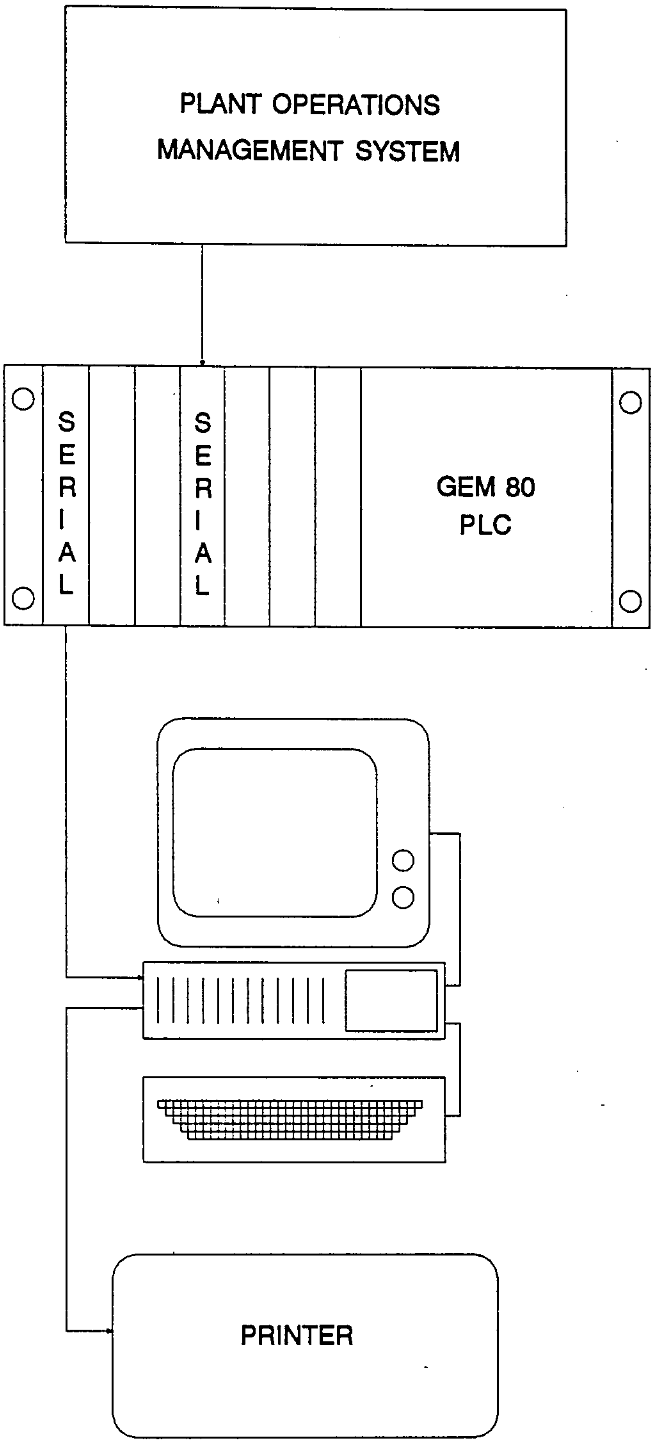


Fig. 14 : POMS to Printer Serial Link Layout

4.4.6. Bongard Take Up

The Bongard machine was supplied to Pirelli complete with a Siemens 100U PLC. For the purposes of full integration and standardisation, the Siemens was replaced with a GEM PLC, the ladder logic code of the Siemens being translated into that of the GEM language. The whole of the machine had to be rewired to the PLC cabinet, the old cabinet becoming defunct. All of the relays, overload switches and the D.C. drive for the winding motor were also re-housed in the cabinet.

Once the machine was placed under the GEM PLC, it enabled greater control of the functions of the drum packer. It was necessary to adjust the D.C. drive to obtain optimum performance with the ramping functions now taking place in the PLC analogue outputs and not from a potentiometer on the machine. A much greater capacity for the drum packs has been achieved by increasing the frequency of the automatic function used to settle the cable in the drum. Other automatic functions include the closing of the accumulator upon reaching the set length, alarm emergency stop if the Operator does not confirm as having cut the cable within a preset meterage after the accumulator has closed and interlocks for doors have been made safer. Also, whereas before all switches to control the drum packing machine were remote from the printing machine, total control is now possible from the PLC keypad, which is adjacent to the printer.

4.4.7. Skaltek Take Up

Very few modifications were made to the operation of the Skaltek take-up. All the ramping of the motor is done by the PLC, the same as for the Bongard, and the traverse pitch, which determines what the lay of the cable on the drum is like, is also now automatically adjusted.

The main problem area here is that the take-up has to be shared across two different lines and the PLC has to know to which line it is connected. This has been achieved by the use of an interlink system. All the signals from and to the PLC pass through a cable harness and if this harness is not connected, the stand is unable to operate. The cable harness which is not being used has a dummy plug on the end with a link to signify that the stand is not connected. Thus, to change the machine configuration so that it will operate on the other line it is necessary to traverse the stand to a mid-point, disconnect the harness from the stand, remove the dummy plug from the other line and swap them over. The PLC now recognises that control of the take-up stand has passed from one line to the other.

5. E40 SKALTEK REWIND MACHINES

Two lines were supplied by Skaltek for the purpose of rewinding the larger armoured cables and control cables onto returnable wooden drums. The lines were standard machines and came with a Siemens 100U PLC control system.

5.1. Line Configuration

The line configuration for the E40 rewind machines is as follows :

1. Pay-off - Skaltek rolling type
2. Test equipment
   - spark tester
   - diameter gauge
   - eccentricity monitor
3. Rewind Carriage
4. Label printer - Off-line
5. Take-up - Skaltek rolling type

5.2. Line Usage

Both of the E40 rewind lines are used for rewinding the same types of product - 2, 3 and 4 core armoured cables up to the largest control cable with 37 cores. This means that the lines must cover a range of diameters, from 8 mm to 35 mm. Equally, the pay-off and take-up have to be able to accept a large range of drums and bobbins, from the smallest returnable wooden drum of 750 mm diameter to the largest DIN1800 bobbin.

5.3. Line Specification

The rewind lines had already been used for production purposes for 10 months using the existing control systems before the time schedule allowed for a GEM PLC control system to replace the Siemens PLC.

The timescales allowed each machine to be taken out of production for a period of four weeks, during which time the Siemens PLC was removed and new wiring installed and terminated, connecting the machine control cabinet with the GEM PLC cubicle.

As before, a standard programme approach was adopted which meant that the same PLC programme could be used on either line. This was to be in line with all the other PLC software in the factory, ensuring consistent use of addresses, data tables, etc.

5.3.1. Pay-in

These are of the rolling type, where the stand can be made wider or narrower depending on the size of bobbin/drum being loaded into the machine. The height of the stand may also be raised or lowered according to drum size. (This is similar to that described in Section 4.3.5.)

The full bobbin is loaded horizontally into the stand and the pintles are pulled together and raised to lift the bobbin off the ground. The stand is supplied complete with its own drives, one for controlling the traverse of the bobbin to ensure as straight a wire line as possible through the machine and the other for controlling the rotation of the drum as it pays off cable.

5.3.2. Test Equipment

The test equipment on the E40 rewind lines is identical to those units on the cold print and rewind lines. (See Section 4.3.2.)

5.3.3. Rewind Carriage

The rewind carriage is the central unit of the rewind line and it is through this that the cable passes as it is taken up by the stand. (See Fig. 15). The rewind carriage acts as a cable guide, but also contains the length measuring wheel and the cutter blades for cutting to a preset length as determined by the Operator.

5.3.4. Zebra Thermal Label Printer

The label printer uses a printhead of 1028 heated elements which transfer thermally sensitive ink from a ribbon and deposit it onto blank label stock. The printed labels are then taken by the Operator and applied to the drum of output material. The printer is driven by the PLC.

5.3.5. Skaltek Take-Up

This Skaltek stand is similar to the pay-off described in Section 5.3.1 except that cable is wound onto this stand.

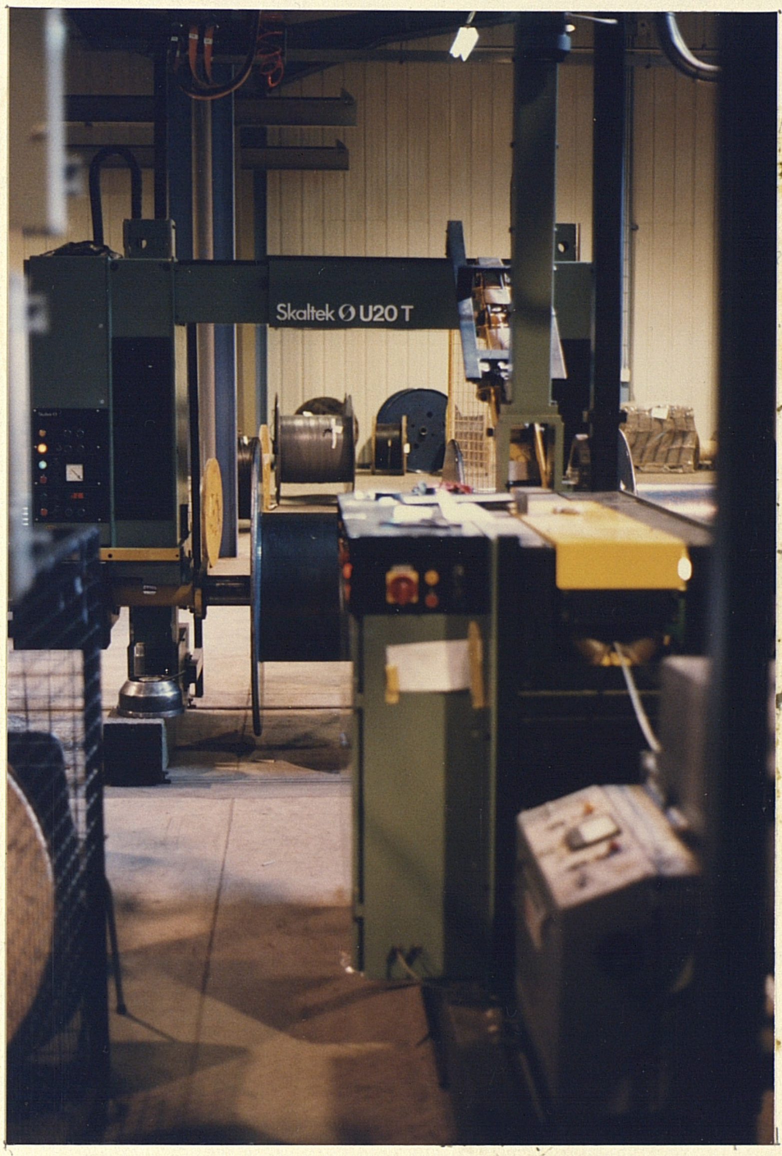


Fig. 15 : Rewind Carriage and Take-up

5.4. PLC Integration

5.4.1. Pay-in

The Skaltek pay-in has its own internal drive control for setting the correct rotation speed which functions well without any PLC control. The only function of the pay-in which it was possible to incorporate in the PLC programme was the traversing of the stand.

As the cable is wound off, the wire line will move off the centre line of the rewind carriage. However, mounted on the carriage are two photocells that sense when the cable passes in front of them. These signals are used by the PLC to traverse the stand in the required direction for a certain period of time, this time being dependant upon the line speed, so ensuring that the cable is guided freely into the rewind carriage.

5.4.2. Spark Tester

(See Section 4.4.2)

5.4.3. Diameter Gauge

(See Section 4.4.3)

5.4.4. Eccentricity Monitor

(See Section 4.4.4)

5.4.5. Zebra Label Printer

The label printing function in this area is driven, as is the printer on the other rewind line, by the PLC. However, the PLC's are of different types, the PLC on this line having the IMAGEM programmed graphics capability as described in Section 2. This means that, whereas before, the PLC was using the Volker-Craig as an interface, here the PLC can be linked directly to the printer using the RS232 interface.

The printer is an intelligent unit equipped with its own on-board CPU that allows user selectable communications, baud rates, hand-shake protocols, parity, data length and stop bits, ensuring that the unit can be configured to talk to any other device. This is particularly useful with the GEM PLC's due to their inflexible nature when it comes to communications.

The method of printing labels is achieved by the printer's own programming language which performs two functions. The first is the handling of all the data communications involved in integrating the printer into the existing computer system and the second is the label design and format processing for the labels themselves.

The commands needed to define the start and end of a label are not as for the ink-jet printer, where there is a problem in sending the ASCII value for <ETX> from the PLC. Here, all commands are given in the form of control characters (a list of which can be found in Appendix Section 8.4.) that specify all the codes necessary to produce any quantity of user defined labels.

The PLC drives the printer by using this programming language, but the codes are sent by the message facility available on the PLC and these messages are made up from hard coded data tables held within the PLC RAM memory that are accessed interactively by the IMAGEM graphics and the Operator's keypad. This is the key to printing the labels automatically, but still allowing the Operator to select the type of label that is required and the quantity. (A general description of how the data tables are arranged are shown in the Appendix Section 8.5.).

5.4.6. Rewind Carriage

In this particular case, the pod is positioned very close to the rewind carriage where all the control pushbuttons for the machine were originally placed. As it is necessary for the Operator to be standing close by the machine when he is starting up, it was decided to leave all the pushbuttons in the rewind carriage and to rewire them back to the PLC for control purposes rather than move them to the keypad. This also saves the Operator from having to scroll through several video pages, as is the case for the extrusion machines, to find the function that he requires.

5.4.6.1. Carriage Laying Arm Positioning

Another crucial area of the setting up of the modified rewind carriage is the automatic positioning of the carriage itself in relation to the height set on the take-up stand. Because the laying arm on the machine is susceptible to being damaged by the drum loaded on the take-up, with a subsequent effect on the quality of the laying, the rewind carriage automatically positions itself so that the arm is the optimum distance away from the drum as the laying arm is lowered ready for winding.

The positioning of the carriage relies on the analogue signal voltage sent by the PLC which is calculated from the take-up stand value. This means that there is an analogue input to the PLC for the 'desired' position which comes from the take-up, and an analogue input to the PLC for the 'actual' position which comes from the arm. The position of the carriage and the height of the arm are then set accordingly, depending upon the voltage from the take-up.

Feedback for correct positioning comes from the two potentiometers, one mounted on the rewind carriage related to a floor mounted datum, the other mounted on the laying arm.

However, during modifications to the rewind carriage, the end limits of the positioning of the carriage were altered. Consequently when the rewind carriage was manually moved to one of the end stops during commissioning, the toothed belt driving the carriage potentiometer snapped and so it was necessary to reset the positioning. Having done so, it was no longer possible to get the carriage to move to the correct position relative to the height set on the stand.

For this reason, the voltages taken from the modified stand and carriage were compared with those of the standard E40 rewind machine. The results can be seen in Table 2 below.

	STANDARD M/C		MODIFIED M/C	
Bobbin Size(mm)	Take-up (V)	Carriage (V)	Take-up (V)	Carriage (V)
DIN 1800	5.20	5.70	5.26	5.37
DIN 1500	4.47	4.84	3.66	3.83
DIN 1250	3.76	3.94	2.67	2.78
DIN 900	3.07	3.02	2.14	2.29

Table 2 : Voltages for Standard and Modified E40 Rewind Machine

A graph of the voltage readings plotted against bobbin size, i.e. against the height to which the take-up stand is set, is shown in Fig. 16. In Fig. 17 the voltages are plotted against one another.

Due to the small number of readings actually taken, it is not possible to draw too many conclusions, but there are enough to be able to compare and show trends.

In Fig. 16, it can be seen that the voltages taken from the non-modified machine follow one another closely, although the increase in them is not linear. However, the values for the modified machine show good linearity, though the correlation between them is poor.

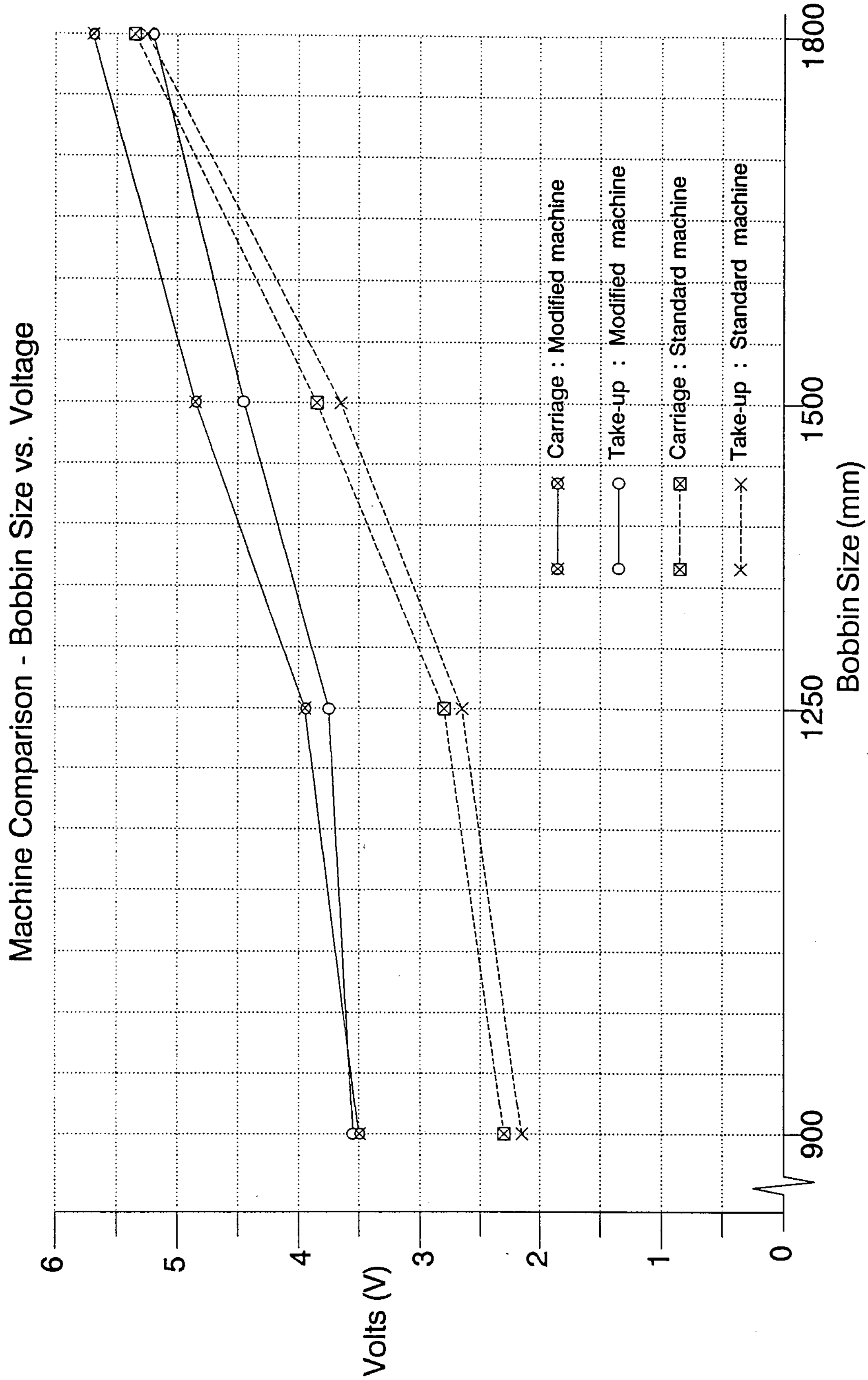


Fig. 16 : Machine comparison - Bobbin Size vs. Voltage

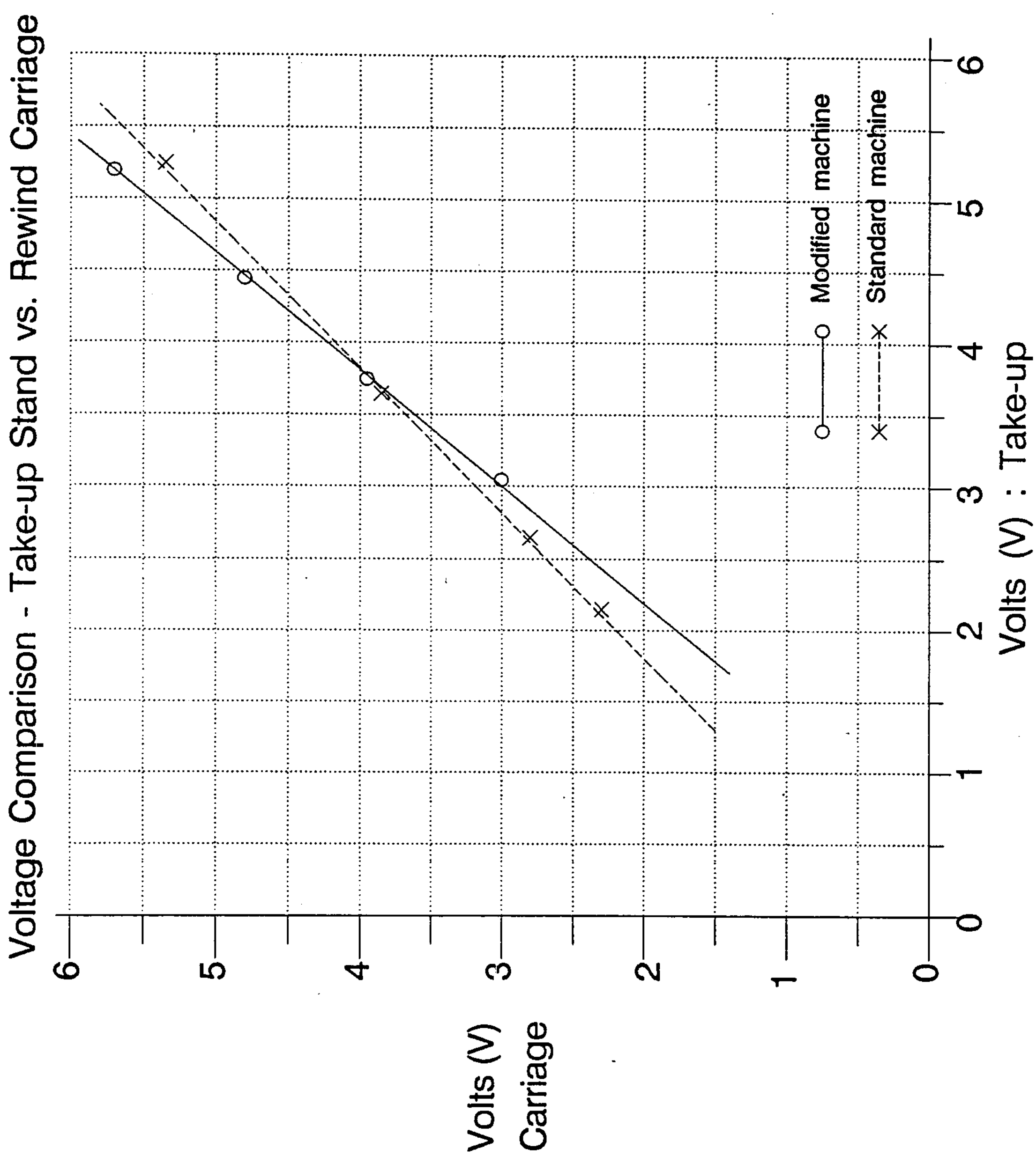


Fig. 17 : Voltage comparison - Take-up Stand vs. Rewind Carriage

Unfortunately, these readings were only taken as the take-up stand height was increased. It must be remembered that there is a certain amount of hysteresis inherent in any such system due to the sensitivity of the components used, such as the potentiometers which regulate the voltages, and this probably accounts for the non-linearity of the voltages measured from the non-modified machine. The reasons for the different set of readings taken from the machine with the GEM PLC are discussed later in this section.

Looking at Fig. 17, and using linear regression methods, it is possible to calculate the gradient, constant value and the correlation between the voltage from the rewind carriage and the voltage from the take-up in both the modified and the standard machine.

The calculations used to determine gradient, constant and correlation are as follows:

Regression formula: $$y = mx + c$$

Gradient: $$m = \frac{n.\Sigma xy - \Sigma x.\Sigma y}{n.\Sigma x^2 - (\Sigma x)^2}$$

Constant: $$c = \frac{\Sigma y - m.\Sigma x}{n}$$

Correlation: $$r = \frac{n.\Sigma xy - \Sigma x.\Sigma y}{\sqrt{[\{n.\Sigma x^2 - (\Sigma x)^2\}\{n.\Sigma y^2 - (\Sigma y)^2\}]}}$$

For the standard E40 machine, the result is :

Gradient	=	0.993
Constant	=	0.158
Correlation	=	0.9998

For the modified E40 machine, the result is :

Gradient	=	1.253
Constant	=	-0.803
Correlation	=	0.9998

Both plots are straight line graphs, as is shown by the correlation figures calculated above being very close to 1.00 .

The difference between the two machines was caused by a combination of factors, an incorrectly set potentiometer on the rewind carriage and the accuracy of the analogue input card of the PLC.

Due to the nature of the system, i.e. the three parameters of the laying arm height, the take-up height and the rewind carriage linear position, a change in any one of the parameters will have a consequent effect on both of the others. The cause of the inconsistency was narrowed down to two deciding factors.

The first was the need to accurately reset the potentiometer on the rewind carriage. This was achieved by using the non-modified machine as a datum and setting the modified machine to give exactly the same voltage reading at the same distance from the take-up stand.

The other factor affecting the correct setting of the rewind carriage position was that the wrong analogue input card had been used by the PLC for reading the voltage from the laying arm.

The cards have a 10 Volt working range, which is interpreted by the PLC on a scale of 0 to 4000. However, the cards are available as both -5V to +5V range and 0 to +10V range. The original card fitted was the former, -5V to +5V, which meant that the effective accuracy of the voltage was only in the range 2000 to 4000. Upon substitution with the correct card, this in effect doubled the accuracy to which the PLC was able to measure the laying arm voltage and ensured that this voltage did not exceed that for which the input card was designed. (It should be noted that the readings for the voltages shown in Table 2 were taken directly from the potentiometer, and not from the PLC analogue input card.)

5.4.7. Skaltek Take Up

5.4.7.1. Bobbin Turnaround Points

The biggest problem area, with the machine functioning in it's original state, was the quality of the winding on the large wooden despatch drums. This was a result of the way that the PLC programme was designed. The turnaround points for the flanges would get increasingly wider for each traverse, leading to a subsequent build up of cable at the flanges.

This build up becomes all the more pronounced when dealing with large diameter control cables and was remedied by using the PLC to store the two readings for the turnaround points in it's memory, these values being the number of pulses, plus and minus, about a fixed central datum point and which are entered manually by the Operator using two pushbuttons, one for each turnaround position. Thus it was possible to always accurately reverse the direction of the traverse at the required point.

Obviously, due to the inertia of a full drum of heavy armoured cable traversing across the wire line, it takes a certain amount of time to decelerate the traverse speed of the stand and bobbin in one direction and to accelerate it in the other. To help prevent a build up of cable at the flanges the D.C. drive controlling the traverse motor was given an extra increase in power at the turnaround to enable a fast deceleration and acceleration in the opposite direction back up to the correct traverse speed.

5.4.7.2. Traverse Pitch Control

The traverse pitch control was the only major function of the Skaltek take-up which needed any modification. The existing potentiometer controlling the D.C. drive speed was disconnected and replaced with an analogue output card on the PLC. This enabled the pitch, (i.e. the distance by which the take-up stand traverses across the wire line for a single revolution of the bobbin), to be automatically set to the diameter of the cable that was being run on the machine. It also allows the Operator to remotely set and adjust the pitch from the video interface without having to be positioned by the take-up stand.

6. CONCLUSIONS

The philosophy adopted by Pirelli for the cable making plant at Aberdare, South Wales, was based on the concept of fully automated manufacture - from the receipt of the initial customer orders, through to the despatch of finished goods to those customers. Associated with this philosophy has been the commitment to the standardisation of all the components which go to make up the system as a whole, from the GEM PLC's at machine level to the IBM mainframe, mini and personal computers at office level.

Standardisation has it's advantages - bulk buying power, familiarity of the Users with the system once it is installed and ease of maintenance, to name but a few. The essence for this policy of standardisation is POMS, the computer system which controls and monitors the machines that manufacture the product. (See Section 1.5.)

However, though it is ideal to have standardised machine control systems, AGV systems, computer software packages and so on, it can cause problems. Indeed, Pirelli's insistence and reliance on standard systems has had it's penalties.

6.1. GEM Programmable Logic Controllers

One example of the above policy was the decision to have one single type of PLC for machine control and a customised communications protocol to allow these PLC's to transfer data to and from POMS. Unfortunately some suppliers are not quite as flexible as others in their attitude to their customers and will only supply their 'standard' machine and will not consider any PLC type other than that which comes with their machine.

Therefore problems have arisen with taking an existing machine that already functions perfectly well. The existing PLC control has been removed and replaced with a GEM PLC, meaning that a considerable additional cost has had to be built into the initial price of the machine to take into account the machine downtime, installation of extra trunking and cabling and the cost of the PLC itself.

6.2. Operator - Machine Video Interface

The IMAGEM video interface has had a great impact on the running of the plant and machinery within the Aberdare factory. All machines have benefited from the installation of the interface. Instead of the Operator being faced with a large array of switches, dials, and pushbuttons, these have been incorporated into the PLC control system and all machine control takes place from a single keypad. (See Fig. 5.)

There is one main video screen which displays the most pertinent data for the Operator and associated with it are the function keys which control the more important line running conditions. This has led to a much greater degree of Operator control and greater awareness of the operation of the machine.

6.3. Packaging and Rewinding Area

The integration of PLC's into the packaging and rewinding areas has allowed for functional improvements to certain machine operating procedures which would otherwise not have been possible with the existing control systems. It has also meant that the

Maintenance department, who are familiar with GEM PLC's, have received feedback of data from the machines, enabling them to readily identify and rectify any machine problems which may occur, leading to a decrease in machine downtime.

Experience at the Aberdare factory has shown that the video interface facility, the ability of the PLC to control and monitor all the machine functions and the familiarity of all the personnel concerned with the PLC's, from Operators to Maintenance and Systems, have proved that the decision to choose PLC control systems was correct in that it has enabled Pirelli to realise the goals which were defined at the outset. This has meant reduced labour content, reduced material wastage and reduced work-in-progress, all of which are factors that affect the profitability of a company and ensure it's competitiveness in the marketplace.

7. GLOSSARY OF TERMS

AGV	- Automated Guided Vehicle
Bongard	- Cable packing equipment manufacturer
CIM	- Computer Integrated Manufacture
CPU	- Central Processing Unit
EHT	- Extra High Tension (0 - 30 kV)
FMS	- Flexible Manufacturing System
GEC	- General Electric Company
GEM 80	- PLC type produced by GEC
IC	- Industrial (ruggedised) Computer
IMAGEM	- Graphics programming language for the GEM 80 PLC
JIT	- Just In Time
Ladder logic	- Standard programming language used for PLC's
MMS	- Manufacturing Management System
Pay in/Pay off	- Means of transferring cable
PC	- Personal Computer
PLC	- Programmable Logic Controller

POMS	- Plant Operations Management System
Siemens	- PLC manufacturer
Skaltek	- Cable packing/winding equipment manufacturer
Tandem	- Simultaneous insulation and sheathing of one cable on two extrusion lines
Take-up	- Means of winding finished cable
TCS	- Teaching Company Scheme
Token ring network	- Standard network communication
Weidenbach	- Ink-jet printer manufacturer
Zumbach	- Cable test equipment manufacturer
<STX>	- Start of data transfer
<ETX>	- End of data transfer
<ACK>	- Acknowledge of data transfer

8. APPENDIX

8.1. Keypad Key Definitions

KEY	DEFINITION
AUTO/ MAN	Used to select the line operating mode when the line is stopped.
HOME PAGE	Brings up the LINE - OVERVIEW page on to the screen.
PREVIOUS/ NEXT PAGE	Brings up the pages adjacent to the current viewed page in the menu.
ENTER	Used to input numbers from the keypad into the PLC. It also acts as a confirmation default key when used in conjunction with screen cursor.
PAGE SELECT	Used to call up formats on to the screen as PAGE SELECT + format no. + ENTER
ARROW KEYS	Used to control a screen cursor. These keys incorporate an auto-repeat facility to allow rapid cursor movement.
HOME	Takes the screen cursor to a predefined position on the screen, e.g. top left.
CLEAR	A general reset key, the operation of which may require a confirmation keypress. On the alarms page, CLEAR removes rectified alarms from the screen. On other pages CLEAR erases the currently displayed text from the CYAN message band.
YES/NO	Used to respond to confirmation requests and screen questions.
LINE #: ACCEPT	Starts length monitoring for individual wire insulation and sheathing operations once the Operator is satisfied with the extrudate colour/quality.
ALARM ACCEPT	Allows some non-critical alarms on the alarms page to be accepted while the line continues to run. Accepted alarms remain on a solid background on the alarms page, whilst unaccepted alarms have a flashing RED background. ALARM ACCEPT is only enabled for the alarms page.

Table 3 : Dedicated Key Nomenclature and Definition

8.2. Detailed Formats - Extrusion Section

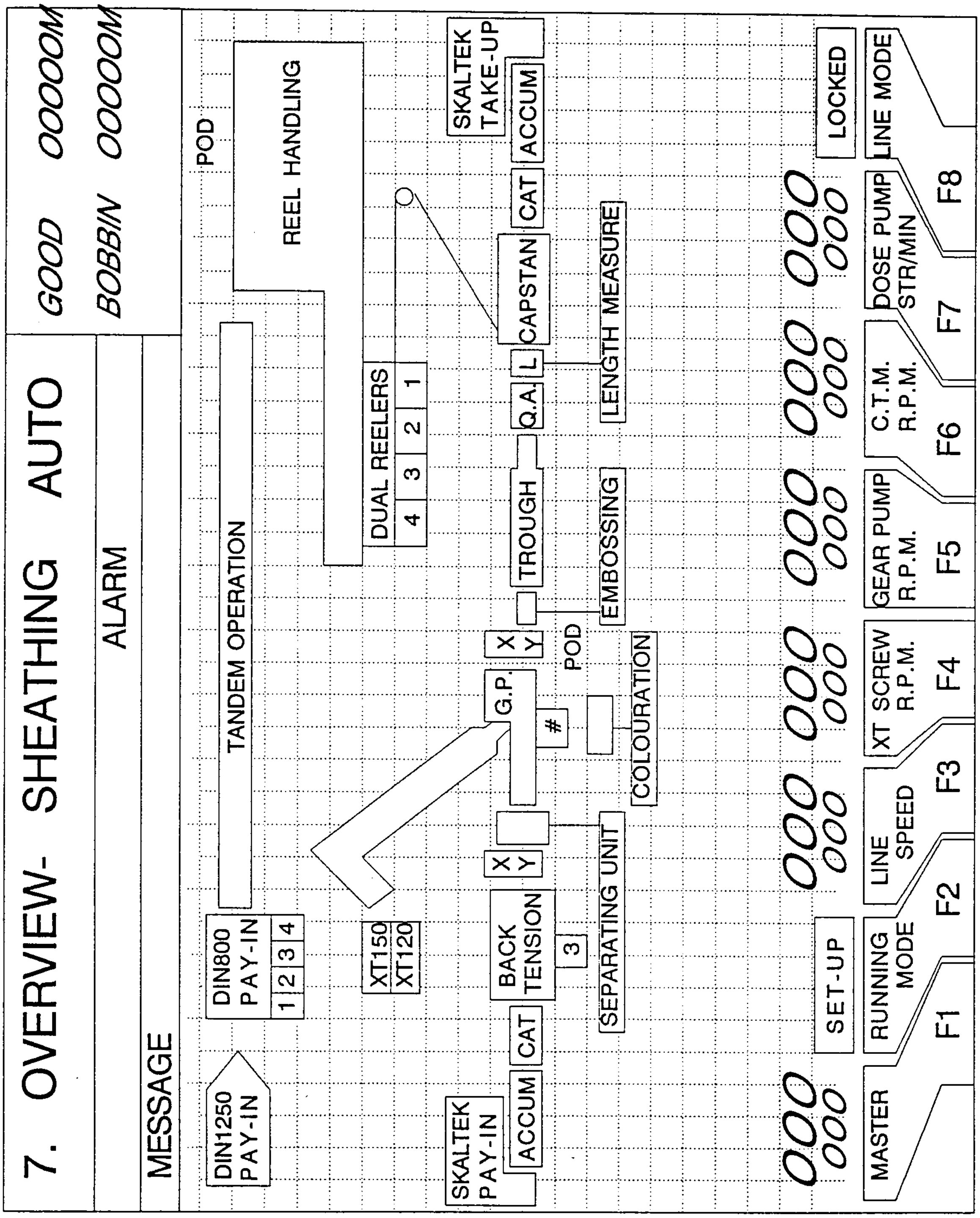


Fig. 18 : Video Format - Sheathing Overview

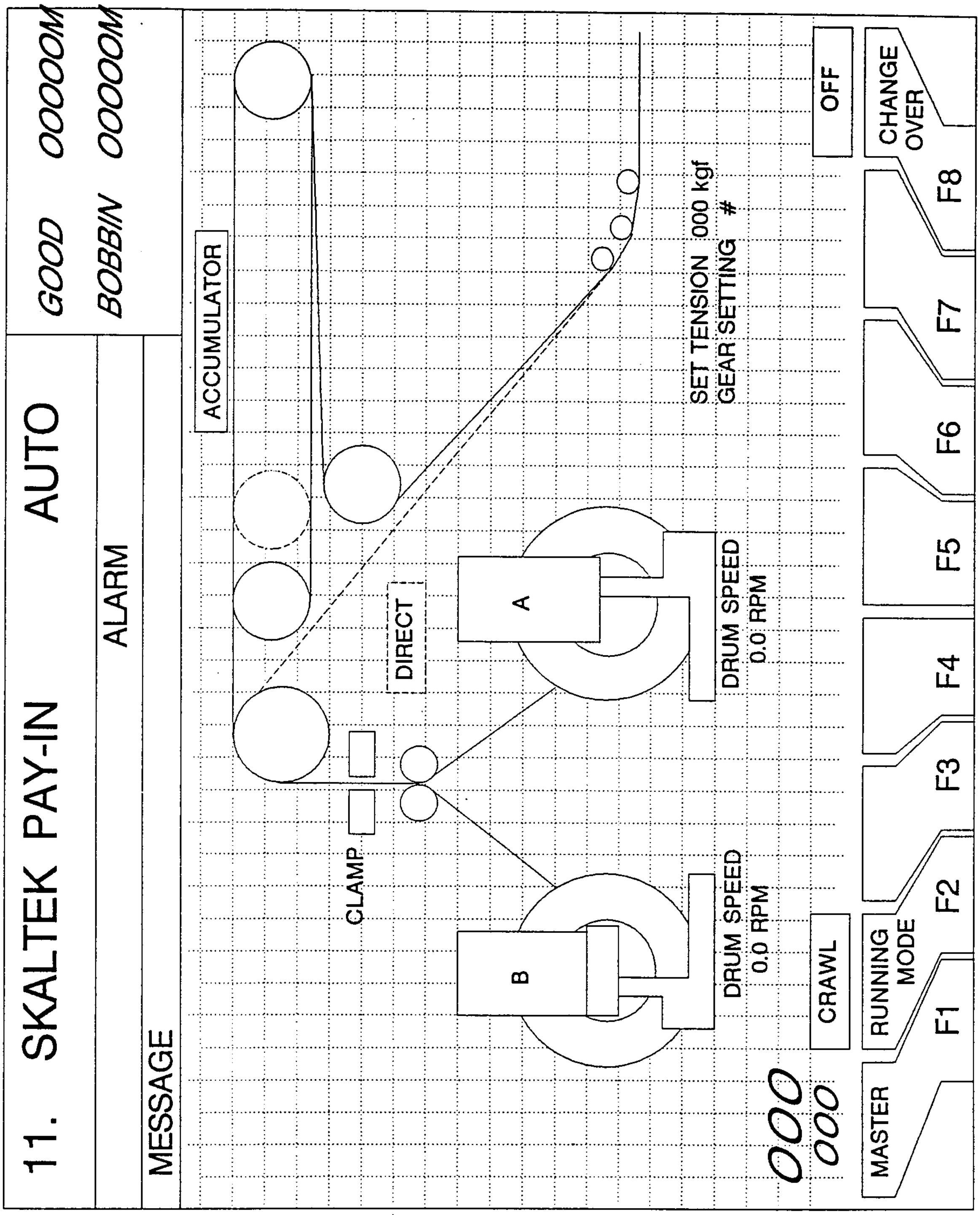


Fig. 19 : Video Format - Skaltek Pay-In

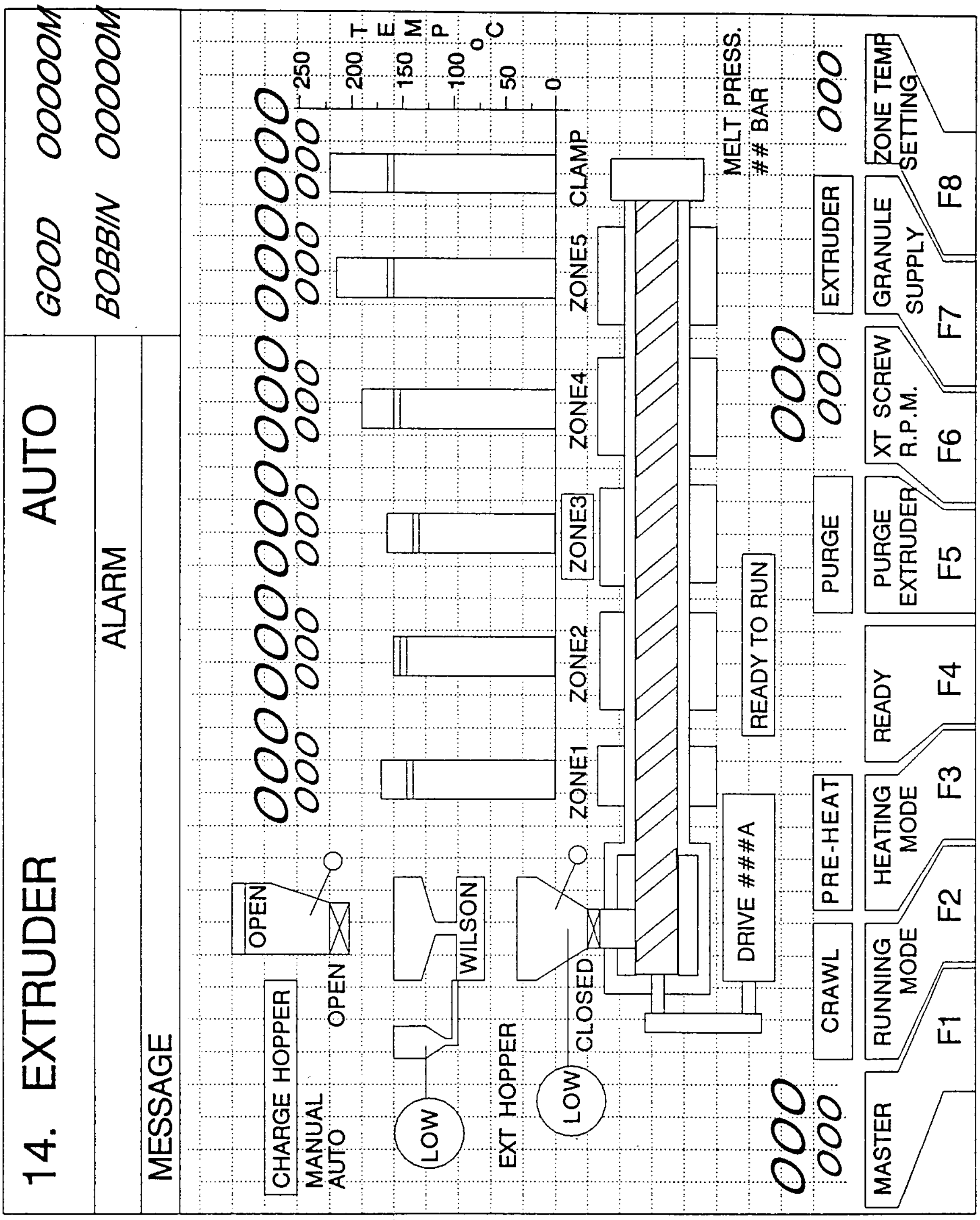


Fig. 20 : Video Format - Extruder

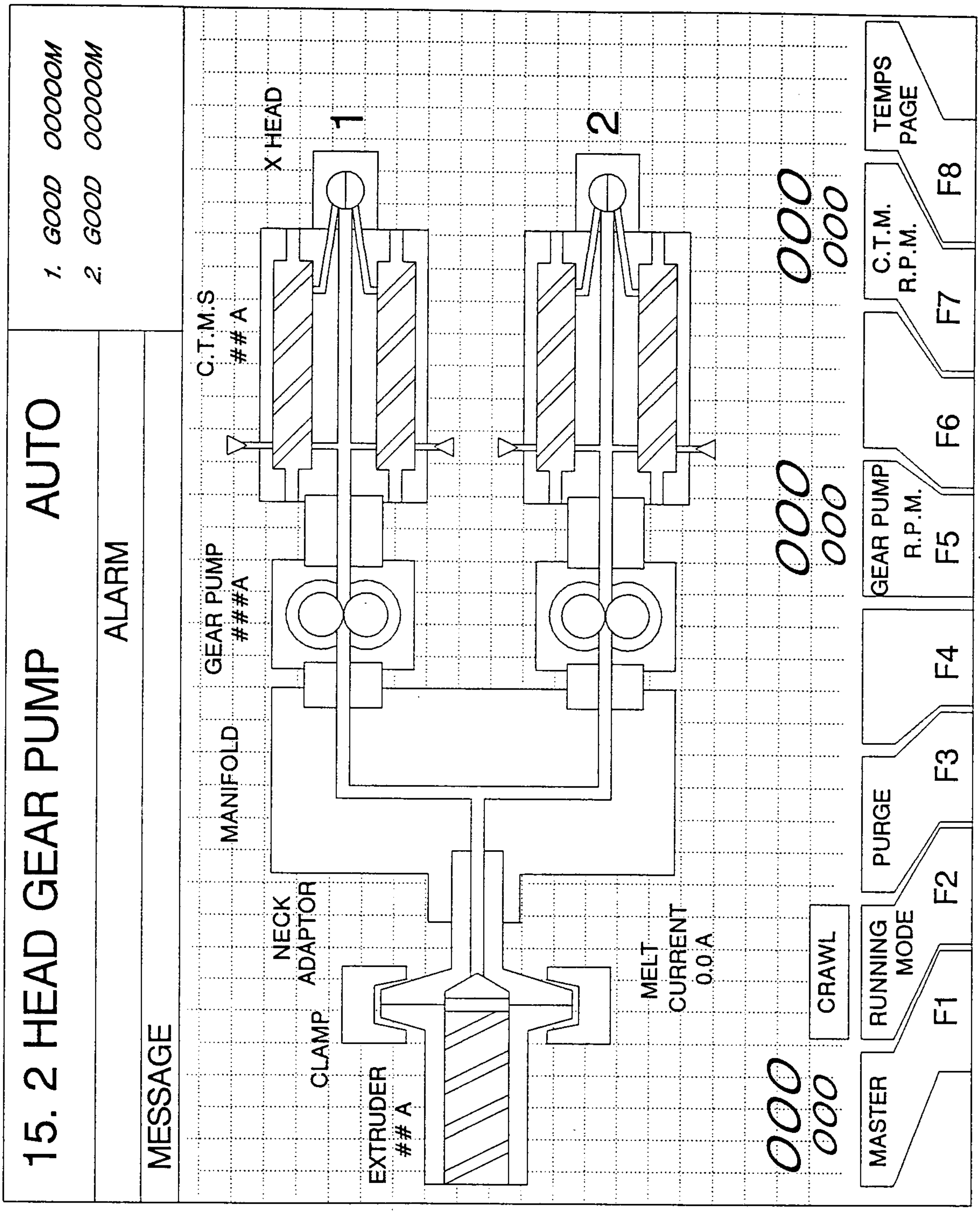


Fig. 21 : Video Format - 2 Head Gear Pump

8.3. Control Cable Cores Marking Specification

1. Printed Material - P.V.C.

2. Diameter of Cable - 2.66 mm (min.)
   - 3.50 mm (max.)

3. Line Speed (Cable throughput) - 200 m/min

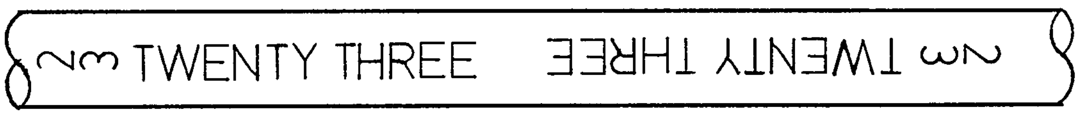
4. Characters - numbers '1' to '48' inclusive
   - words 'ONE' to 'FORTY-EIGHT' inclusive

5. Ink Colour - Black

6. Printing Types - Chimney
   - Mirror

Example of requirement on cable :

ϕ 2.66 mm to 3.5 mm



8.4. Label Printer Format Commands

FORMAT INSTRUCTIONS	
Instruction	Action Taken
^XA	Start of a new label format.
^XZ	End of a label format.
^LH x,y	Defines home position offset. x = no. of dots along x-axis y = no. of dots along y-axis
^LL y	Defines label length when using continuous media. y = no. of dots along y-axis
^FO x,y	Define field origin. x = no. of dots along x-axis y = no. of dots along y-axis
^FD<ASCII data>	ASCII data string for field.
^FS	Field separator.
^AA a,b,c	Alphanumeric print field. a = rotate field 90 clockwise b = character height (in dots) c = character width
^BY i,j,b	Barcode default parameters. i = module width j = ratio b = barcode height
^GB x,y,z	Draw a box. x = width of box y = height of box z = thickness of line
^FW	Change field rotation default
^B3 a,b,c,d,e	Code 39 barcode print field a = rotate field 90° clockwise b = Mod-43 check digit c = barcode height (in dots) d = interpretation line printed e = interpretation line printed above code

Table 4 : Label Printer Format Commands and Description

8.5. PLC Data Configuration - Label Printer

The label printing system can be set up to print six different types of labels. The labels are built up of rectangles given Programmer designed sizes. The following description is for Label 1, with Fig. 22 providing detail of the different data tables used.

8.5.1. Text Configuration

Each label can be configured differently using ten 'P' tables (data tables held within the memory of the PLC), with Label 1 starting at address P2200.

The first table in the group of ten from P2200 onwards denotes the number of rectangles that make up the label. Zero equals no rectangle borders. The 15th. bit of P2200 is turned on if the label is to be printed rotated through 90° .

The next nine P tables set up the format of what is to be printed in each box. P2201 for the first box, P2209 for the last. For example, if only three rectangles are required then P2204 to P2209 will be zero.

The value in the P table is broken down as follows :

i) Bits 0 to 3 contain the numeric value giving the required length of the options list which is displayed when editing the label.

ii) Bit 15 is forced on if a variable is to be printed in the rectangle along with the message chosen from the options list.

iii) Bit 9 is forced on if the required number is to be printed after the message text. This is forced off if the text comes first.

iv) If bit 15 is on and that rectangle is selected for edit, then a number can be entered from the keypad. This number is stored in up to 3 consecutive words in the W600 area. Which three words are used is defined by a number stored in bits 4 to 8. This number starts at 0 and goes up in 3's since there can be three words used to store Manufacturing and Customer Order numbers. A 600 offset is used and so the values for rectangle one are stored in W600 to W602, with bits 4 to 8 in P2201 being equal to 0. The values of the Manufacturing Order number for rectangle six are stored in W615 to W617 with bits 4 to 8 being equal to 15.

v) If a number is to be printed, then the number of decimal places (between 0 and 3) is stored in bits 10 and 11.

vi) If the required number is a three word type, i.e. up to 10 digits, then bit 13 is set 'ON'.

vii) If the number is a two word type, i.e. up to 8 digits, then bit 12 is set 'ON'.

viii) If bit 15 is off, then only a text message will be printed. This text message is selected from the options list and is stored in W500 for rectangle one through to W509 for rectangle nine.

8.5.2. Rectangle Positions

Rectangles are drawn using coordinates for top left and bottom right corners. Hence :

Rectangle 1 -
x1,y1 are in P1400,P1401
x2,y2 are in P1402,P1403

Rectangle 2 -
x1,y1 are in P1404,P1405
x2,y2 are in P1406,P1407

and so on......

8.5.3. Text Positions

The position for printing text is defined by using the coordinates for the start of the first character.

Rectangle 1 -
x,y are in P1800,P1801

Rectangle 2 -
x,y are in P1802,P1803

8.5.4. Options List Message

The list of options which is displayed to the right of the label on the PLC video screen is limited to 20 messages. Thus rectangle one starts at message M600, rectangle two at M620 and so on. The following diagram (Fig. 22) shows the relevant P and W tables of data and the message numbers for the first label.

LABEL ONE : Number of rectangles and orientation - P2200

P1400,P1401
OPTIONS + NUMBER CONFIG = P2201
OPTIONS MESSAGES = M600 - 619
LABEL MESSAGE TABLE = W500
STORED NUMBERS = W600 - 602
TEXT POSITION = P1800,P1801
REC 1
P1402,P1403

P1404,P1405
OPTIONS + NUMBER CONFIG = P2202
OPTIONS MESSAGES = M620 - 639
LABEL MESSAGE TABLE = W501
STORED NUMBERS = W603 - 605
TEXT POSITION = P1804,P1805
REC 2
P1406,P1407

P1408,P1409
OPTIONS + NUMBER CONFIG = P2203
OPTIONS MESSAGES = M640 - 659
LABEL MESSAGE TABLE = W502
STORED NUMBERS = W606 - 608
TEXT POSITION = P1808,P1809
REC 3
P1410,P1411

P1412,P1413
P2204
M660 - 679
W503
W609 - 611
P1812,P1813
REC 4 P1414,P1415

P1416,P1417
P2205
M680 - 699
W504
W612 - 614
P1816,P1817
REC 5 P1418,P1419

P1420,P1421
OPTIONS + NUMBER CONFIG = P2206
OPTIONS MESSAGES = M700 - 719
LABEL MESSAGE TABLE = W505
STORED NUMBERS = W615 - 617
TEXT POSITION = P1820,P1821
REC 6
P1422,P1423

P1424,P1425
P2207
M720 - 739
W506
W618 - 620
P1824,P1825
REC 7 P1426,P1427

P1428,P1429
P2208
M740 - 759
W507
W621 - 623
P1828,P1829
REC 8 P1430,P1431

P1432,P1433
OPTIONS + NUMBER CONFIG = P2209
OPTIONS MESSAGES = M760 - 779
LABEL MESSAGE TABLE = W508
STORED NUMBERS = W624 - 262
TEXT POSITION = P1832,P1833
REC 9
P1434,P1435

Fig. 22 : Label Data Locations in PLC

8.6. Ink-Jet Printing

This is the most recent and flexible printing process to appear on the market. It is one which prints without any direct contact onto very irregular surfaces and on most materials.

The ink is sent under pressure from the main reservoir to the writing head and forced out at high speed. The subsequent jet of ink is broken up by ultrasonics into a stream of droplets. These are then electrically charged for printing purposes and directed towards the surface which is to be printed upon, in this case the cable. To print, the droplets that are required are deflected by two plates on to the product, the remainder which aren't used continue on and are sucked into a collecting tube, pumped to a return tank and sent back to the main reservoir. (See Fig. 23)

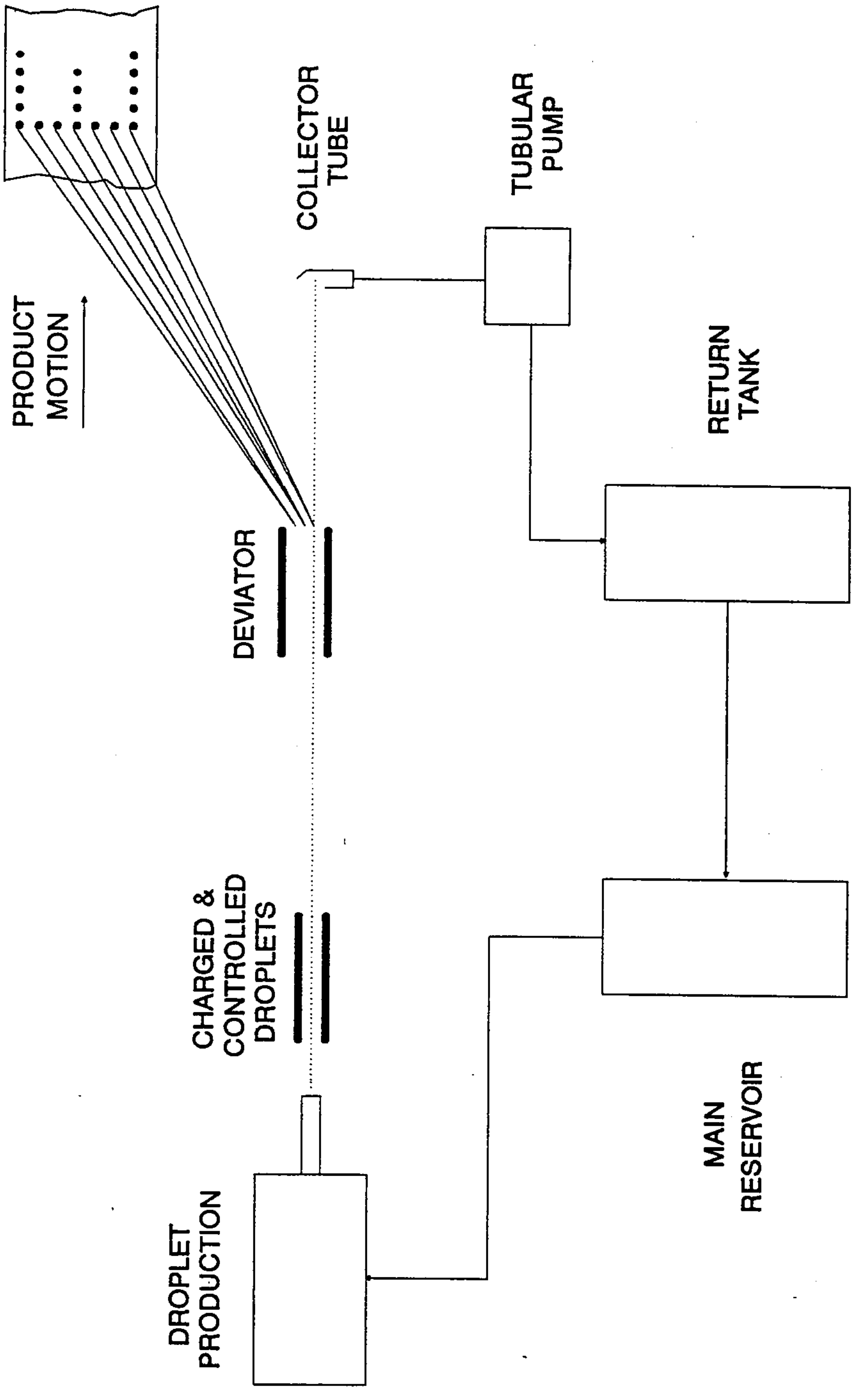


Fig. 23 : Ink-Jet Printer - Schematic

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