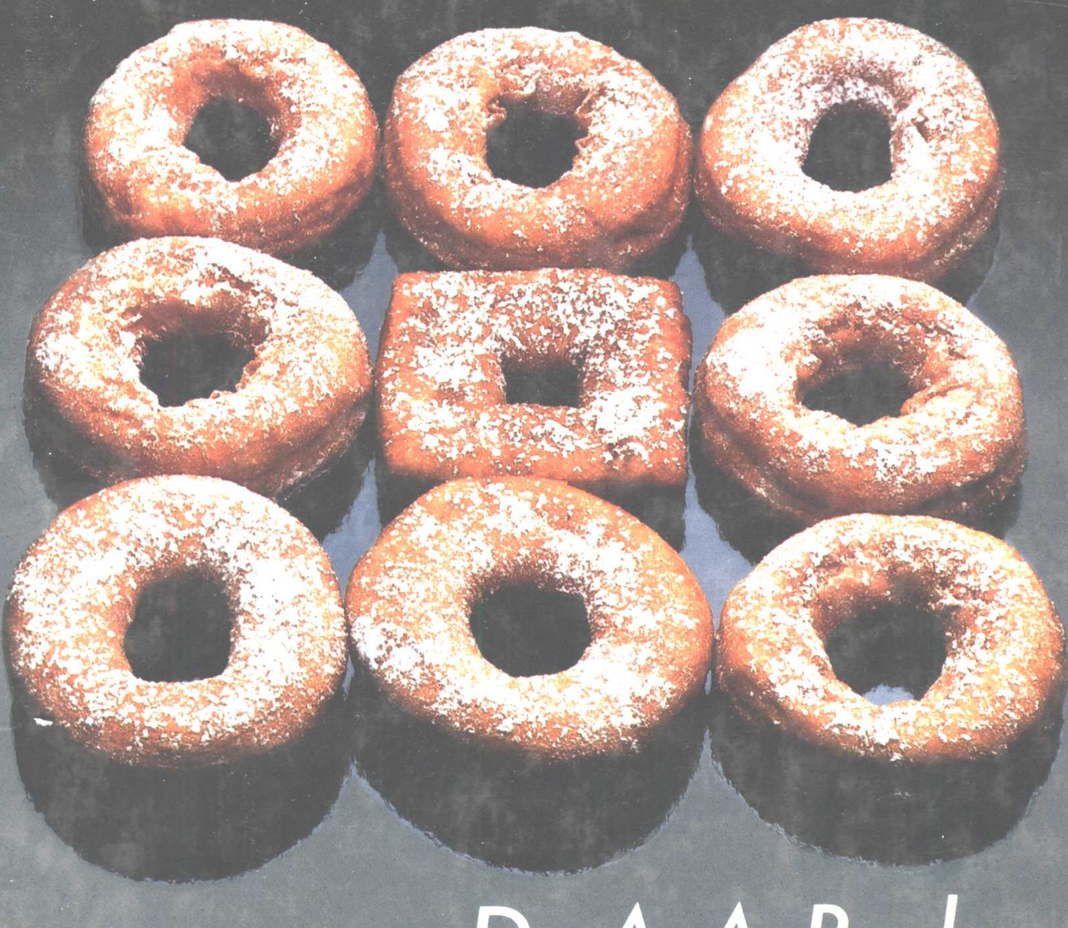
MICROCONTROLLERS IN PROCESS AND PRODUCT CONTROL



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Foreword

There is often a gap between the users of a given technology, and the experts who design and apply it. This is probably more true of the microelectronics field than any other, and it can hamper the adoption of these vital devices even in fields where it is obvious that they are required. This book aims to bridge that gap, and provide a solid background in control devices and their peripherals for anyone who needs to use controllers in a given project. It provides information on the controllers themselves, in terms of the correct level to choose in a given situation. The book also describes common peripherals such as sensors and actuators, and aims to give the reader enough information to perform the initial systems analysis which points the project in the correct direction. The approach is to describe examples of control projects throughout, for use by the reader as templates.

The level of explanation adopted is practical without being too electronically detailed. Design and discussion are taken to the point where an electronic engineer can be brought in to design the system. This gives the non-specialist valuable assistance in dealing with experts in the otherwise mysterious field of control. It also provides ideas and some of the essential background data to consider, perhaps, new ways of viewing the control of products and processes.

The examples used throughout are from my own experience of the ways in which microprocessors and electronics have been used or proposed in manufacturing industries. In many ways the book arises from a need which has become apparent in the personnel with whom I have dealt in those industries. In general, it has been found time and time again that the more knowledgeable those people are, the more efficient is the introduction of microelectronics to their working environment.

The book is suitable for managers and other personnel with a mechanical, electrical or other engineering/technical background who will need to use microelectronics in their industry. It will also be of assistance to programmers who wish to extend their activities into control, but who have worked, until now, in data processing for instance. Though there is a fair amount of technical explanation here, the background material will help them to gain a more low level and hardware-orientated understanding of the technology, which is crucial to the successful programming of controllers.

I should like to thank several people who have helped me considerably. Firstly, my wife and family who have shown their usual interest and understanding during the associated periods of continuous work at all hours. Secondly, to my father who has, as so often in the past, spent many hours reading and commenting upon the material in the text. My thanks are also due to those companies who have supplied photographs for inclusion within the text. Finally, I should like to thank the editorial staff of Collins, whose professionalism has, as always, made the task of preparing the book for publication both pleasurable and rewarding.

Dr. A. A. Berk

Contents

Chapter One

General Control Microelectronics

INTRODUCTION

This chapter introduces a number of aspects of control in processes and products within the manufacturing industry. In general, the book deals with the control (or automation) of both the processes used by the manufacturing industry and the products, where appropriate, being manufactured. As will be seen, the areas encompassed are broad and range across the spectrum of engineering endeavour. For instance, it is not difficult to find a single microelectronic controller which could be used in a plastic moulding plant or a chess playing machine. As will be seen, economics may decide that one of these applications is less efficient than the other. It is also true that the software (programming) within a given piece of computer hardware is the main deciding factor as to the final application – the hardware is often said to be a pawn in the hands of the programmer.

We will start the present chapter by agreeing upon some definitions of the most common terms used in the book. Controllers in manufacturing situations are then described according to a type of classification which will allow control situations and hardware to be seen in context. This inevitably includes a look at simple systems analysis for a process or general control situation. Different types of controller are described in black box form. The internal design of controllers in general is examined in Chapter 2.

There are two appendices which will be of assistance in reading this chapter, as well as the rest of the book. The first gives a roundup of the essentials of binary numbers and associated information. The second appendix gives company names and addresses as contacts in the field of microelectronics and control, along with a short explanation of their products.

SOME SIMPLE DEFINITIONS

The word 'controller' will normally mean any computer circuit which controls the outside world. This is very wide, as it can be argued that a large computer installation (a mainframe, for instance) is controlling the outside world via a screen and keyboard when an operator is using the machine. Similarly, a single integrated circuit will be found within a musical door chime, performing the job of controlling a loudspeaker to produce a noise when someone presses a bell-push. This just about spans the complete gamut of computing devices, and as such means that the word 'controller' can apply in almost any computer situation. In addition, it is possible for non-computer circuits to be controllers too. In general, you will naturally pick up the meaning of the word 'controller' in context as we proceed, but you should remain aware of the complexity of this term.

The word 'computer' is much maligned and over-used. In this book it will have one of several meanings. Since we are concerned here with 'intelligent' electronics, i.e. electronics which can be programmed, our basic hardware will inevitably be based around a microprocessing unit (MPU), or microprocessor. This is an electronic circuit which is capable of executing a set of instructions supplied to it by some external electronics, and written by a programmer.

The word 'computer' will be used to describe a circuit containing an MPU. We will also be concerned, later, with larger computers (known as development systems) which are used, essentially, in the design of MPU-based controllers. As it happens, most of these larger machines will also be based around MPUs.

To place the MPU in its position within the context of engineering, you should consider it as the centre of a network of electronic circuits which are normally devoted to supplying it with a program, fixed data, memory to store its variable data and with interfaces to the outside world. You should further consider such a network to be the most basic and general kind of electronic circuit possible. The general point is that by a change in the program controlling the MPU, the network can be made to emulate any kind of electronic circuit – including analogue circuits, controllers, electronic filters, and so on. It is true that some extra hardware may be needed to complete the system, and that it may be too slow or uneconomic to replace some circuits with an MPU-based device, but this is the art of choosing the correct level of machine for a given application. This book aims to provide the criteria for choice within the engineering field of control – other books are devoted to the use of the MPU in other fields.

Hardware and software are words which are used freely in the industry – most people know the meanings, i.e. that hardware describes the electronics and mechanics of a project while software describes any

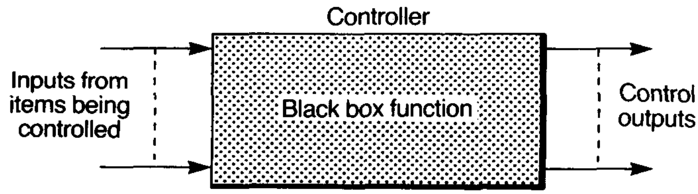

Fig. 1.1 Black box approach.

computer programming which may be involved. As a corruption of these two terms, one may talk of a 'soft solution' to a problem, for instance. This simply means that the solution lies with a standard piece of hardware, and the problem is solved by writing the computer's program in a special manner. There are often two solutions to a given part of a project – hard and soft. A 'hard solution' is normally a solution which depends upon the specific design of a new piece of special hardware.

A black box approach, as in Figure 1.1, will mean an approach which connects a set of inputs and outputs (I/O) to a box and defines how the box acts on these I/O lines. The black box approach does not try to explain the way in which such a box works internally. This is a favourite approach in the analysis of a problem. One can therefore ask the question 'which type of controller (black box) will act in the following way?'. This approach allows the *function* of the problem to be examined and defined without concern for the internal electronics of the black box which solves the problem. It is a good way to approach the setting up of a specification without having to understand microtechnology. In many cases the details of the electronics are standard once the problem is defined.

A certain confusion exists in the use of the word 'microelectronics'. It can be argued that micro circuits which contain many electronic components shrunk to the size of an integrated circuit, or silicon chip, are microelectronic. Others use the term exclusively to mean circuits employing or at least directly related to MPUs. We will tend towards the latter definition in this book, as it is becoming widespread. A microelectronic solution to a problem is fast becoming synonymous with a computer-based solution.

The words 'integrated circuit', 'IC', 'silicon chip', 'chip', and even in some books 'bug' will all be synonymous. These are terms used to describe the type of device where many electronic components are formed onto a small piece of semiconducting material in order to integrate a number of electronic functions into one device.

There are two important comments to bear in mind at this point. The first is that an electronic solution not employing MPUs and programming may be an economic and convenient solution to a control problem and this must be borne in mind throughout. Secondly, the area of the dedicated custom-made integrated circuit for a given job is becoming more and more widespread in the industry. This can lead to integrated circuits of the complexity of an MPU with rather different characteristics. It is fair, in many ways, to use the term microelectronics to include this field too.

'Process control' will generally mean the control of a manufacturing process, and 'product control' will generally apply to the electronics built in to a given manufactured product. For instance a washing machine controller provides an example of product control. The design of a device to control the pressing of steel sheet into side panels for the washing machine, or the moulding of its plastic parts is a problem in process control. A good example of a case where these two definitions overlap is in the case of a controller within the machine which performs the plastic moulding of the lining of a refrigerator. It is process control to the refrigerator manufacturer, but product control to the manufacturer of the moulding machine itself!

Input/output is a term commonly used to describe electronic lines which connect a given black box to devices which someone within the black box might refer to as the outside world. For instance, a door chime controller would have electrical lines connecting to a loudspeaker, to a bell push, and perhaps to a rotary switch which selects the tune to be played. These are referred to as I/O lines for short. In many ways, the key to an analysis of any given control situation is to discover the number and character of all the I/O lines needed.

As a further example, we might consider the control of a washing machine. Choosing a suitable controller depends upon price – it is important in a high volume device to keep the cost of each part to a minimum. The first question is how many I/O lines must the controller have. This is easily estimated as follows. Some lines are needed to read a rotary switch and a couple of special on/off switches on the front panel. Two AC electric motors are to be controlled along with a couple of fluid valves. Four emergency sensors are needed, say, for such parameters as over-temperature, water supply failure, etc. This is shown in Figure 1.2. Of course, in practice there will be more items to be controlled, but this illustrates a first consideration of the problem.

It should be noted that in talking about the number of lines required for a given set of functions, the electrical returns are often not mentioned. Single I/O lines will normally act with respect to a common return which may be the earth or ground of a power supply. Alternatively, twin lines may be needed in some circumstances. Example circuits will be seen later.

Given that a 16-position rotary switch can be read using just four lines (see Appendix 1) the total number of I/O lines required for this washing machine will be around 14, which is below a magic number – 16 – and this can be catered for by a prodigious number of 'single-chip' computers. Such chips contain the MPU itself along with all the peripheral circuits required to turn it into a complete computer, with the program itself formed onto the chip during manufacture. I/O lines are also included – often a minimum of 16. Output lines normally require some external electronic interfacing (I/F

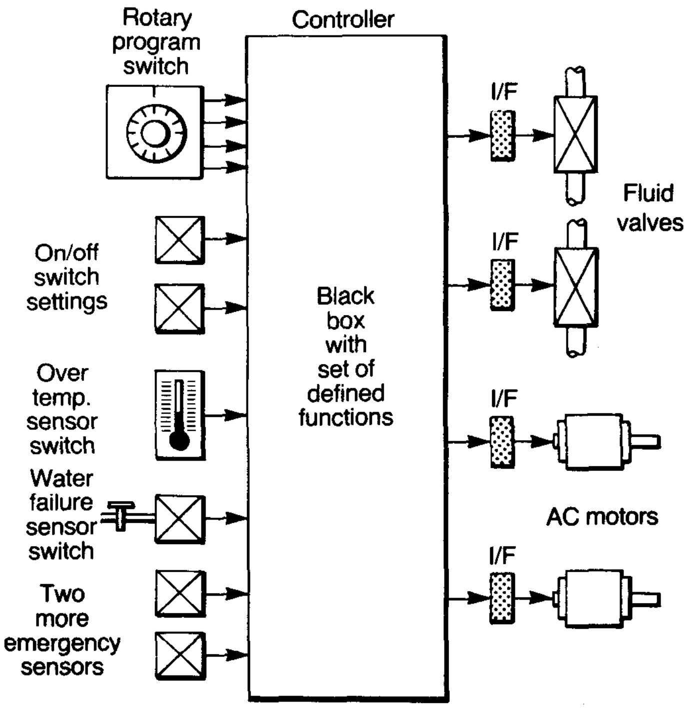

Fig. 1.2 Washing machine controller.

as shown in Figure 1.2) to change their low voltage levels into power switching for mains or other powerful devices, but such electronics is cheap and readily available. In general, the inputs also require some interfacing, as the outside world does not normally run on the same voltages as the computer circuits.

This is an example of a quick, simple view of the systems analysis of a given control situation; it almost always starts with the question 'how much I/O does it need?'. It is generally considered that the way in which that I/O is controlled, i.e. the function of the device – is a straightforward matter of program writing. Of course, this is a simplification as the programming of some types of control situation can be quite complex within the required parameters. Sometimes, the programmer will demand large changes to the electronics in order to make his task easier. This is an important characteristic of control electronics – it is a complete weld of hardware and software.

One of the main differences between hardware and software is that shaving a few components off a given controller will save a lot of money in a product manufactured in high volume. Shaving a few lines off a program, or even doubling the size of a program will often have no effect on the manufacturer's unit cost. However, the amortised development cost may be affected significantly by large changes in software.

The overall system designer has to decide upon the correct direction of the project at the very start by constructing a compromise based on all the factors. For instance, a path which may be cost effective in a given volume manufacturing situation may be inappropriate in a defence contract where reliability and operational effectiveness may be a prime requirement, and cost of less importance.

In conclusion to this section, it should be said that as this field is still emerging, the jargon and definitions are somewhat disparate. Hopefully, the reader will pick up most meanings by the context and normal usage of the commonest terms.

CLASSES OF CONTROLLER

As explained above, a certain amount of data regarding the controller required for a given job can be gleaned from a simple analysis of the problem to discover the number of I/O lines required. However, there are many controllers in existence with a given number of I/O lines, and it is necessary to consider some other characteristics to narrow the choice down, and ensure that the controller chosen is cost effective and efficient. Some of the criteria involved would include, for instance, size and weight where the product to be automated were a child's toy, or if the controller were to be used within a restricted space. The quantity of internal memory storage may be an important criterion in a data logging situation or where the controller is to contain a large 'look-up' table of values for some of its decisions. An important parameter is the cost of the controller versus the number of units required. Some controllers are cheap to buy if ordered in many thousands, but enormously expensive if ordered singly. Indeed some customised units cannot be ordered in quantities of less than 10 000.

We will look, shortly, at the types of controller which may be chosen, and see some typical parameters which are used to distinguish them. However, before continuing, it is important to consider one of the controversies in the industry, which anyone involved in automation will have come up against at some time or other.

There are two types of controller which often compete with each other in the area of machine and process control. These are the PLC (programmable logic controller) and the ordinary MPU-based system. PLCs are complete, fully enclosed units which try to emulate the ideal black box approach, and tend to be somewhat less flexible than the MPU-based systems. PLCs will be described briefly at the end of this chapter, but general MPU-based systems will form the main part of this book, and are described in detail below.

SINGLE BOARD CONTROLLERS

This level of controller is chosen for description first as it is the commonest type of controller to be considered in any typical application. Such devices may be too large or too small for some applications, too expensive for others, and so on, but when considering the development of a given application, a single board controller (SBC) will often be the starting point. Either way, consideration of this level of device produces examples of many of the main types of decision which have to be taken in a project. We will look at two real devices, but it should be borne in mind that they only represent examples of types, and should not be considered as the only examples available. In addition, the manufacturers may well change the characteristics of the devices described, and again the description below should not be taken as necessarily correct for the current state of these manufacturers' products.

As its name implies, the SBC is a single printed circuit board with a number of components soldered to it. It will normally require an external power supply unit (PSU) and some means of connecting it up to a larger computer or screen and keyboard in order to program it for the given application. The board will also have a terminal block or edge-connector through which the outside world devices are connected. There is sometimes some interfacing on the board to allow the low voltages of the MPU system itself to be amplified to drive power into external circuits. We will look a little further into the design of the internals of SBCs in Chapter 2 when we discuss controller design in general.

To illustrate the range of the commonest types of SBC, there are plates of the J.P. Designs SBC and the Arcom ARC40 SBC. Both of these companies produce a range of controllers, and the ones chosen illustrate specific characteristics of typical SBCs.

The J.P. Designs controller (Plate 1) is very simple and low in cost. It is not difficult to design a controller to do the same job, but this SBC is so low in cost that it is simply not worth designing one's own for a given application – it makes more sense to purchase such an SBC already made and concentrate on the application itself.

The board contains nine dual in line (DIL) integrated circuits – flat plastic packages with two parallel rows of pins. There are a few other components shown and a double row of pins standing up from the board onto which an external connector can be plugged. This plug takes I/O lines as well as power to the board.

To identify the integrated circuits, look at the two largest chips which are arranged end to end. One of these is the MPU and the other is used to supply 16 I/O lines to the outside world. Memory, for both the controlling program and general data, resides in the three next largest chips arranged side by side in one corner of the board. Each of these chips can contain a

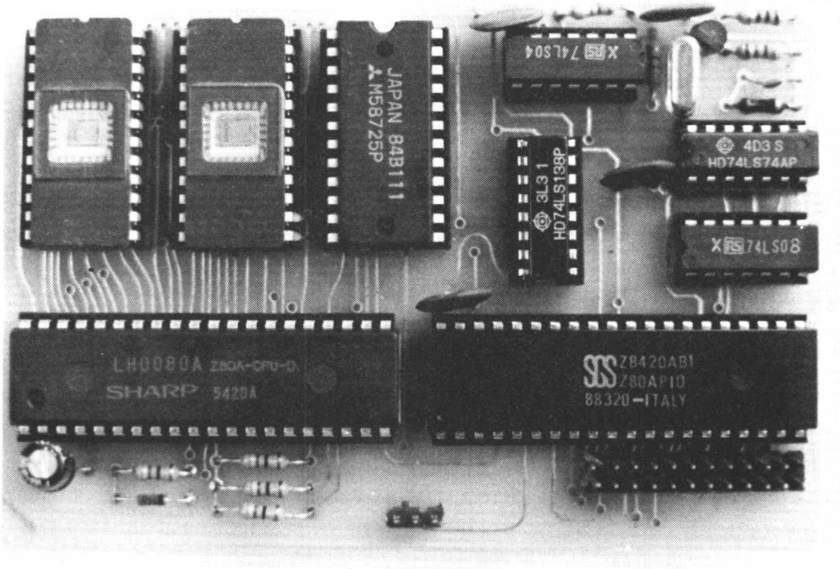

Plate 1 Single board controller (*courtesy of J.P. Designs Ltd, Cambridge*).

total of 8K bytes of program memory and fixed data, and 2K bytes of variable read/write memory. You should refer to Appendix 1 for the meaning of these terms if they are unfamiliar. We will look at the different types and densities of memory in Chapter 2, as this is a crucial attribute of controllers in general.

The Arcom ARC40 board (Plate 2) is essentially the same in concept, but is an example of a more expensive and sophisticated type of SBC which may need to be considered for an application. It has a maximum of 40 I/O lines, and much more internal memory provision. As can be seen from the photograph, the general view is one of a more densely packed board, and this implies many more functions. There are, again, two large DIL chips, and once again they are MPU and I/O chips. However, in this case the MPU itself is an almost complete microcomputer system with internal memory and some of its pins devoted to providing I/O lines directly. The extra I/O chip then provides 20 more I/O lines to give a very comprehensive I/O structure. There are two connectors for the I/O and power, and the board also contains three extra memory chips giving up to 32K of memory in total.

The main difference between these two SBCs is only fully appreciated by considering the way in which programs are developed for them. In the case of the more economic J.P. Designs board, a separate larger computer system is required on which programs may be written to control the

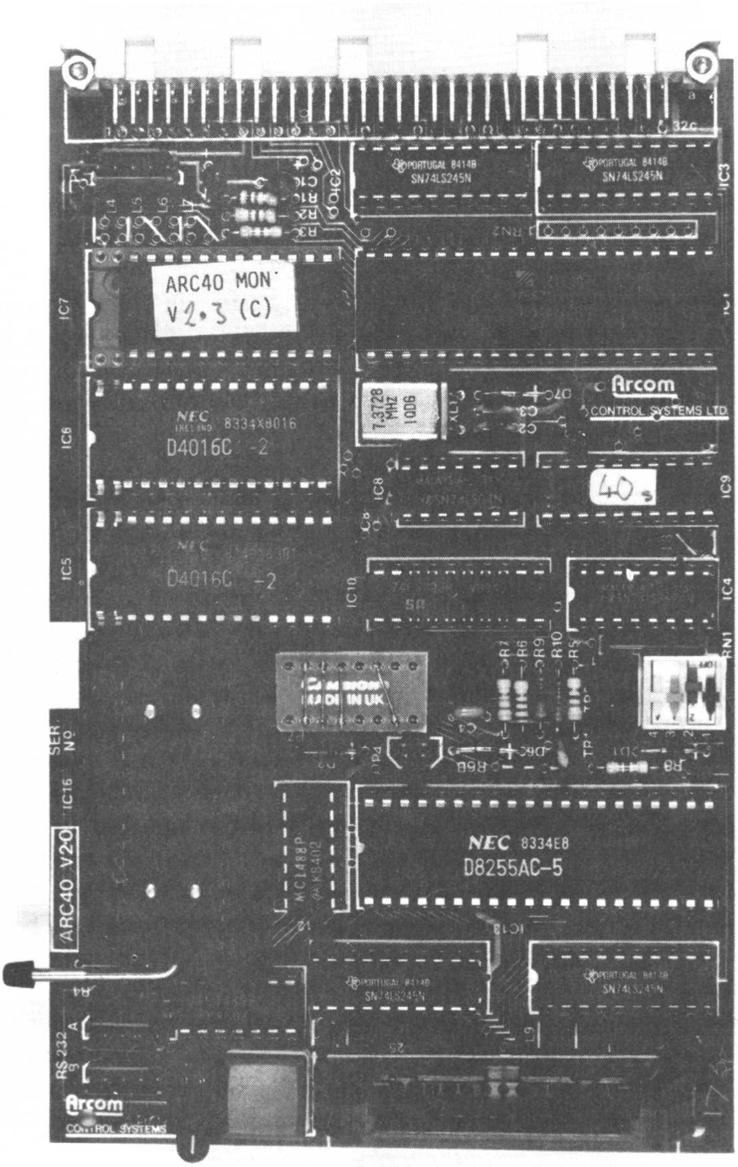

Plate 2 ARC40 Single board controller (*courtesy of Arcom Control Systems Ltd, Cambridge*)

function of the board. Such a system is generally termed a 'development system' when used in this way. Thus, a company using this SBC must have access to a full computer system which is configured in exactly the manner that will interface with the SBC. This is no easy matter, as we shall see later. The Arcom ARC40, however, has the advantage of an on-board development system. The MPU chip, as explained above, is a complete microcomputer on a chip – a so called 'single chip microcomputer' – and even includes a full program for allowing the user of the board to write and store programs for running on the board in the well-known and simple computer language of BASIC.

The version of BASIC offered by the ARC40 is of a rather simple nature compared with that found on even the simplest of home micros. However, it is orientated towards control applications, and allows the system to be used to develop highly sophisticated and efficient programs for the use of the board. These programs can also be used on other, cheaper, SBCs in the Arcom range, and as such allow a complete control environment for experimentation, as well as for the development of low cost control applications.

The ARC40 may, from the above, seem to be an ideal solution to any control situation. However, it should come as no surprise to learn that the decision as to the correct controller for a given application is rather more complex than this suggests.

The two boards described above have been introduced to give the reader a feeling for the type of technology which is common in this area of engineering. We will now look at some simple applications of controllers and see where these two controllers might figure.

Applications for control

Several examples of control applications were mentioned in previous sections, and we shall examine these again in the light of the above information on controllers. One example was that of a large thermoforming machine and another was a washing machine. These are two extremes of the application of controllers to specific manufactured products.

The thermoformer, which is shown in Plate 3, is a machine which takes sheets of plastic, heats them precisely and then forms them around a large heated mould. The model shown is a linear process machine. A stack of flat plastic sheets is placed on the tray shown inside the opening at the end of the machine in the photograph. Each sheet is picked up by vacuum cups and transported into a heating station. There it is heated until soft and then transported to the forming station. Meanwhile, during this indexing, another sheet will have been picked up and transported to the heaters. In this manner, the machine contains several sheets at different stages in the process at any time while production proceeds.

To give some idea of the size of the machine, the viewing windows shown in the side of the machine are too high to be seen directly, and a

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three foot high platform is normally placed by the machine for viewing. The whole assembly weighs nearly ten tons. There are many pneumatically actuated rams within the machine and some of these can be seen extending from the top of the machine.

The electronic computer control system, designed by the author, had to solve two main control problems. The first was the sequencing of the operations, with its careful timing and treatment of several sheets at different stages simultaneously. This was a fairly complex control problem by any standards and used a specially designed dedicated computer controller to achieve it.

The second problem was that of the heater control. In order to vacuum form the sheet around a mould, some parts of the sheet are stretched considerably more than others. The trick is to impress a high-resolution heat pattern into the sheet so that the highly stretched parts are heated somewhat less than the lightly stretched parts. This ensures that the

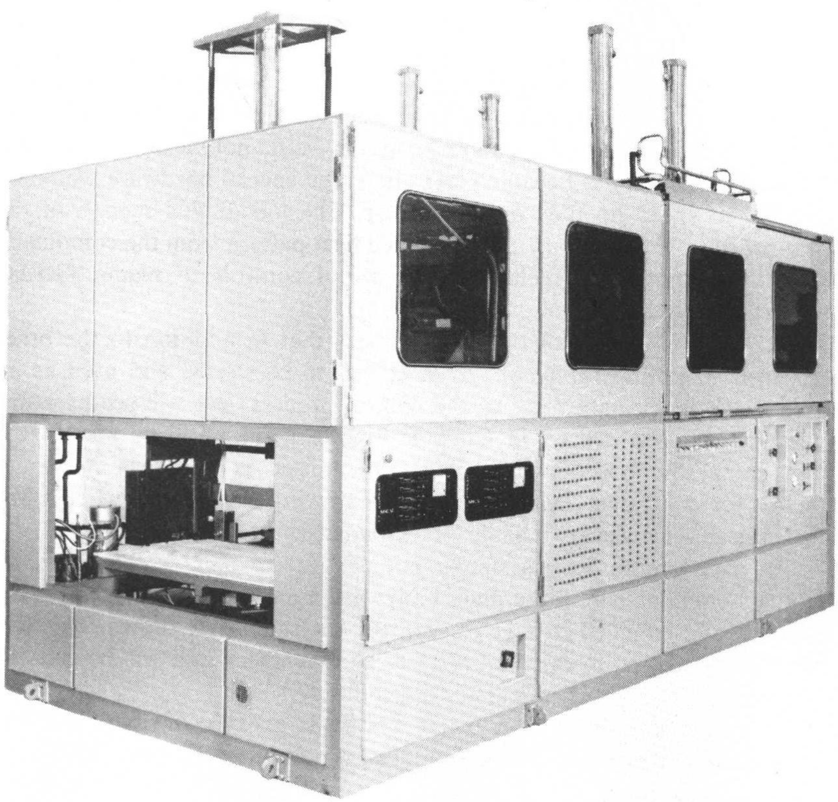

Plate 3 Plastic thermoformer (*courtesy of Shelley Thermoformers International Ltd, Huntingdon*).