INTRODUCTION

> Once upon a time, a Hindu sage was granted by Heaven the ability to create clay men. When he took earth and water and fashioned little men, they lived and served him. But they grew very quickly, and when they were as large as himself, the sage wrote on their foreheads the word DEAD, and they fell to dust. One day he forgot to write the lethal word on the forehead of a full-grown servant, and when he realized his mistake the servant was too tall: his hand could no longer reach the slave's forehead. . . . This time it was the clay man that killed the sage.

Is there a warning for us today in this ancient fable? Are we in danger of being destroyed by our own creations? The perils of unrestricted 'push-button' warfare are apparent enough, but I also believe that the rapidly increasing part that automatic devices are playing in the peace-time industrial life of all civilized countries will in time influence their economic life in a way that is equally profound. At the same time, our knowledge of these mechanisms, *rightly* applied, could, it seems to me, help us to avoid some economic troubles; and it may also assist in a better understanding of many natural processes that are still obscure.

In industry the use of automatic devices enables us to make more goods more cheaply and, ultimately, with less capital outlay. In the military sphere their application makes possible the design of equipment that could not conceivably be operated otherwise.

And as they are extensively used for both purposes throughout the world, it follows that, with the relative shortage of manpower in the West, our only hope of retaining our position in the world is to install automatic equipment as fast as we can. I know these are rather sweeping assertions to make about the importance of automatic control, but I hope to justify them in this book; they are certainly endorsed by leading authorities.

For example, Major-General Appleyard, speaking as Chairman of a national conference in Margate on 'The Automatic Factory', said that British industry would have to be completely reconstructed in the next few years; and the truth of this statement was generally accepted by those present, who must be in as good a position to judge as anybody.

The basis of this reconstruction is the current movement towards a great extension in the use of automatic devices, to take over the simpler kinds of work previously done by the men in charge of machines. The word 'automation' has been applied to this process and widely adopted. It was first used several years ago by engineers of the Ford Motor Company in the United States to describe their methods for automatically conveying workpieces between successive machines; but since then it has come to have a much wider significance, implying any process in which the lower functions of a human operator—both physical and mental—are taken over by self-acting devices. Interpreted in this way, the word 'automation' clearly means more than mere mechanization, and I think the use of a new term may therefore be justified, though personally I prefer the more clearly defined expression 'automatic production'. In fact, I like to regard 'automation' as a convenient and euphonious portmanteau word, formed by telescoping the phrase above, which is rather cumbersome for constant repetition.

Automation is a new word: but does it stand for a new thing? It is doubtful if a direct answer is possible, but I shall try to give in these pages the main facts on which one might found an opinion. The book is based upon a number of talks given on the Third Programme of the B.B.C. under the titles 'Automatic Control' and 'Automatic Production'. In preparing them for publication, I have radically rearranged the material along the lines of a series of lectures given at the Royal Institution in the autumn of 1955, and have added much that had to be omitted in the first place because of the limited time.

First of all, we must be quite clear about what 'automatic control' means. A convenient way to do this is to refer, in the first chapter, to a few of the historical landmarks in the development of automatic devices. It is remarkable how long some of them have been in use; but even so, we have only recently come to appreciate that a common principle underlies their operation. This is the principle of *negative feedback*, also explained in this chapter. But control is only one component—though a vitally important one—in the process of making a fully automatic plant. We shall show that this is so by tracing, in the second chapter, the evolution of the techniques of automatic production.

The early control systems were relatively crude when compared with the devices used nowadays in industry or for military purposes. When these more sensitive controls were first made it was found that they were apt to misbehave in a most extraordinary way, plunging themselves into a state of violent oscillation. When I deal with this, in the next chapter, we shall, I hope, get some insight into the problems of control system design: naturally we shall be thinking of the basic principles, rather than of mechanical details. In doing this we shall also consider how to take account of the presence of a human operator in an otherwise automatic system.

Having got an idea of what automatic control means and of how automatic production can be achieved, we are ready to consider some of its economic advantages and also the difficulties which its use is liable to entail. Some of these difficulties are likely to be alleviated in the near future by the use of automatic calculating machines—electronic and analogue computers, as they are called—whose main characteristics are accordingly discussed in a separate chapter.

These machines are likely to have an important influence on the future developments of automation, which are considered in the last chapter. After showing there how our knowledge of feedback systems is influencing many branches of science

I shall then make an estimate of the effects that this current tide of automation is likely to have on our economy. I shall also try to guess some of the developments we may expect to witness in the near future. I realize that venturing out of one's own special field of experience in this way is hazardous, but I believe that engineers ought to be alive to the social and economic implications of the machines and processes with whose design and operation they are concerned.

Assembling and organizing this varied material has been a fascinating task and I wish to express my gratitude to Dr Archibald Clow, producer of the original broadcasts, for his willingness to sponsor a newcomer to the medium and for his great help in criticizing the first draft of the scripts: it is not perhaps generally realized how much the final script may owe to the comments of a skilful producer. I am also much indebted to my wife, who patiently listened to the scripts more times than I care to remember and made criticisms that were most useful in giving me a lay point of view. This is the view that matters, I believe, for the attitude that most of us adopt towards automation will determine whether machines are, in fact, to become our friends or our foes.

My hope is that this new branch of technology may eventually enable us to lift the curse of Adam from the shoulders of man, for machines could indeed become men's slaves rather than their masters, now that practical techniques have been devised for controlling them automatically. And in this way only can we make our factories of the future into places fit for men to do work worthy of their capacities. President Reuther, of the American Congress of Industrial Organizations, who must have studied the implications of automation as closely as any man, has reached this same conclusion and expressed it in these words: 'Economic abundance is now within our grasp if we but have the good sense to use our resources and technology, fully and effectively, within a framework of economic policies that are morally right and socially responsible.'

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CHAPTER I

THE DEVELOPMENT OF AUTOMATIC CONTROL

A much wider use of instruments and control equipment has become an essential rather than a desirable feature of process operations. S. W. J. WALLIS
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THE earliest automatic device consciously contrived is probably the pressure control invented by the Frenchman, Denis Papin, who made the first pressure cooker in 1680 by placing a heavy weight on the lid of the pan. He was thus the originator of the steam safety valve, which is one of the simplest and most widely used of all regulators today. He called his apparatus, in a contemporary translation, 'A new digester or engine for softening bones' and claimed that by its use the housewife could 'extract nourishing juices from bones which would otherwise have been abandoned as but poor prey by ye hungry dogs'. Papin is still commemorated by a handsome statue at the summit of a lofty flight of steps in his birthplace, Blois.

During the eighteenth century, various automatic regulators were applied to windmills: the fantail to turn the sails into the wind; a feathering mechanism adjusted the inclination of shutters on the sails, to control the speed; and an apparatus lifted the upper mill wheel automatically when the speed became excessive, so as to prevent overheating the grain. A very similar mechanism, called a 'centrifugal governor', was designed by James Watt in 1788 to control the speed of his steam engine. This was the first regulator to be employed extensively, and it is used, with comparatively minor modifications, on every engine and turbine today.

We also have several examples of regulators in our homes. The speed of a gramophone turntable must be held very steady, or reproduction of the records would be ruined. This is done by means of a small unit, very like Watt's governor, which provides a braking effect, as the speed rises, by pressing a felt pad against the motor shaft. A similar device controls the return speed of the automatic telephone dial. A hinged float measures the level of the cold water in the tank at the top of the house, and keeps it constant by opening the supply tap when the level falls. The same principle was once applied to regulate the flow of water to mill wheels: when the water level became too high a float operated the sluice gate, which allowed a greater quantity of water to by-pass the wheel.

With each of these controls the principle of operation is the same: any deviation of the controlled quantity from the desired value causes the controller to take action in such a way as to reduce the deviation. To obtain the most accurate regulation, the better controllers take progressively more action as the deviation increases, but for many purposes this is a needlessly costly refinement.

We have considered regulators for controlling steam pressure, water level and speed. But any physical quantity can be controlled, provided there is a means of measuring it and a means of adjusting it. One of the most important of these quantities is temperature. Devices for its control are used on the oven, the water heater and the refrigerator. The name 'thermostat' originated with Andrew Ure of Glasgow, who was granted a patent in 1830 entitled 'An apparatus for regulating temperature in vaporization, distillation and other processes'. The crucial points in the design of a thermostat are the device to detect the temperature under control and the method by which it effects control. Ure used the bending of a bimetallic strip, which depends upon the different rates of expansion of metals on heating: the same property is used in the 'rod and tube' type of thermostat frequently employed on gas-heated appliances, and first introduced about 1900. Another type of temperature detector is a metallic bellows filled with a fluid which expands on heating; its use nowadays in refrigerator thermostats was pioneered in 1925 in Britain.

Yet another household thermostat will serve to illustrate an important distinction between two basically different sorts of regulation. The control of a central heating system might work by using a measurement of the temperature of the house to adjust the fuel supply or boiler draught. This is a *closed sequence* of control because the temperature of the house affects the heat supply, which in its turn affects the temperature. On the other hand, the thermostat might use a measurement of the conditions outside the house, increasing the fuel supply when the weather gets colder or windier. This is an *open sequence* of control: the weather affects the heat supply, but the heat does not affect the weather.

The success of open sequence control depends upon just the right properties being built into the controller. If the heating control takes account only of the weather, the house will get cold when a window is left open or if the thermostat is not in perfect adjustment; but the closed sequence system will continue to work satisfactorily in spite of such disturbances, because the heat supply will be increased until the house does reach the temperature desired. A closed sequence control incorporates *feedback*; that is, the results of its own actions are fed back to the regulator and modify its further behaviour.

The controls we have considered so far have all been *regulators*. Another important group are used for *position control*. The earliest of these were steam operated and were used to provide greater forces than a man could apply unaided. The hydraulic valve, which is the essential feature of these early position controls, is said to have originated with young Humphrey Potter. In 1713, he was in charge of one of the steam pumping engines in-