prepared for
General Georges F. Doriot
in partial fulfilment
of the requirements of
the manufacturing course
at the
Harvard Business School

Dear General Doriot,

The subject report, Making The Automatic Factory
A Reality, is respectfully submitted as the Automatic
Factory Report, in partial fulfilment of the Manufacturing
Course in the second year.

The subject report has changed considerably
from the ten year industry production which you originally asked us to
prepare. A ten year period was assumed, but it is not the primary
focus of the study. For as industry progressed it became increasingly
clear that a great gap was evident between automatic production and
any significant change because of the pace of industrialization. Most manufacturers
now realize the need to mechanize the way of business production and
automate. They do not yet realize in what terms they must live in order to
effectively apply this technology to industry. It is to this need that we have
responded. It is not that we have added to the
sense of knowledge, it is rather that we have added in a small way toward
the modern most needed stage of automatic factory to indeed become
a reality.

It is to you whom have most helped and encouraged
this study that we can least adequately give proper thanks for making
such a fruitful year possible.

John T. Diebold
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May 13, 1951
General Georges F. Doriot
Morgan Hall
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Boston 63, Mass.

Dear General Doriot:

The attached report, Making The Automatic Factory A Reality, is respectfully submitted by the members of the Automatic Controls Group in partial fulfillment of the requirements of the Manufacturing Course in the second year at the Harvard Business School.

The nature of this report has changed considerably from the ten year industry projection which you originally asked us to prepare. A ten year projection is included but it is not the primary focus of the study. For as our work progressed it became increasingly clear that a great gap must be closed before automatic production can in any significant sense become a reality. That gap is primarily informational. Most manufacturers do not know what is technologically possible in the way of automatic production. Nor do they realize in what terms they must think in order to usefully apply this technology to industry. It is to this need that we have turned. It is not that we have added to the sum of knowledge. It is rather that we have tried in a small way to aid in the manner most needed if the automatic factory is indeed to become a reality.

It is to you who have most helped and encouraged this study that we can least adequately give proper thanks for making such a fruitful year possible.

Respectfully,

John T. Diebold
Group Leader

John Carlin Engleff
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ACKNOWLEDGEMENTS

It would take many pages to list all of the companies which have responded to our requests for information. They have been thanked individually for their very generous aid, and all that we can do here is to state that the interests of American business in new development work is great indeed if the help which we have received is at all typical.

Special thanks are due to certain individuals who throughout our study have been especially helpful and kind in guiding our efforts. Norbert Wiener and Jerry Weisner of MIT, Howard Aiken of the Harvard Computation Laboratory, Julian Bigelow of The Institute For Advanced Study and Gordon Welchman formerly with the “Whirlwind” computer project at MIT and at present a consultant with Engineering Research Associates, are the men who were responsible for providing the primary direction to our study. Gordon Welchman in particular gave us much of his time and good advice. William Rodemann of The General Electric Company made possible a visit to Schenectady and a day of conferences with engineers of the Control Division of his company. John von Neumann of the Institute For Advanced Study, Claude Shannon of Bell Telephone Laboratories, Ralph Risch of Sylvania Electronic Products, Raymond Rausch of Willys-Overland Motors, James Healy and Benjamin Selekman of the Harvard Business School, E. S. Davenport and Thomas Reed of United States Steel Company, T. J. Ess of the Association of Iron and Steel Engineers, R. S. Burns of Armco Steel Corp., James Halley of the Inland Steel Company, J. J. Munns of the Weirton Steel Company, Charles Parker of the American Iron and Steel Institute, Thomas Walsh of Case Institute, and John T. Dunlop of Harvard University have been most kind and helpful.

The design of an automatic piston factory, Section III of our report, benefited not only from the advice, but from many hours of work by a variety of people outside the group. Tom Lilley and G. E. Altmansberger of the Ford Motor Company, B. E. Starr and J. F. Kennedy of the Pontiac Motor Division of the General Motors Corporation, the public relations section of the Buick Motor Division of the General Motors Corporation, the public relations section of the Dodge Division, and the Thompson Products Corporation have all provided us with flow diagrams and work schedules used in the manufacture of automotive pistons. This represented much extra work for these people, and we deeply appreciate
their aid. In addition, the Heald Company and the Norton Company, both of Worster, Mass., very kindly permitted visits to their plants and provided the opportunity to consult with their engineers, furnishing blueprints and plans as well as photographs of the production machines which they manufacture.

Of the photographs used in the report, two were taken for us by Major Irving Koss, U.S. Army; two are from a set dealing with piston manufacture sent to us by the Dodge Motors Division; and one is from a set presented to us by Servomechanisms Inc. We are very thankful to these people both for the photographs and for permission to use them in this report.

Ann Alderfer has helped greatly in the final preparation of the manuscript, for which we extend to her our thanks.
INTRODUCTION

Early in our study Julian Bigelow, of The Institute For Advanced Study, suggested to us that:

"...the distinction between automatic controls which are "conveniences" and automatic controls which are "significant" in releasing otherwise applicable man-power contains the essentials of a proper metric of the economic effect of automatic control, and it is upon this principle I would suggest that a meaningful economic study might be found."

This distinction has remained useful to us throughout our study. But in the early formative days it was appreciation of this distinction which gave primary direction to our efforts. For it led us away from an initial preoccupation with existing control devices and systems, and caused us to look first toward the industrial need for such controls. Only after we had formulated some idea as to what work we felt might profitably be mechanized did we attempt a survey of the existing control devices. Our object was no longer to think up possible industrial uses to which existing controls could be put, but to determine how present technology could help -- and to what extent it would hinder -- in the mechanization of those functions which we felt might be performed automatically.

The approach most popular among those presently seeking automation in industry is that of reducing control mechanisms to their basic elements -- sensory and effector devices, and collation units -- and then rearranging these units into new control systems. This is the method and the terminology of Norbert Wiener's Cybernetics. And it is Wiener's analogy between the control systems of machines and the nerve and muscle systems of animals which has had dominant influence upon recent thinking in the area of industrial automation. However, we feel that there is some question as to whether this is the most fruitful long run approach to the problem of mechanizing industry.
In the first place, "... since this terminology has been developed and popularized, many people working in scientific or engineering fields (and elsewhere) have become aware of a new phenomenon, and go about recognizing new examples upon every hand, frequently where it already existed but was unnamed, and not infrequently where its existence is doubtful. All this tends to make concrete and useful ideas diffuse and emasculated." (A letter from Julian Bigelow)

In the second place, Wiener's exposition throws primary emphasis upon the control systems and communication devices; but typically the greatest handicap to industrial mechanization is not the control function, but the automation of fabricating and materials handling functions which are now performed manually. Fascination with the individual devices can (and often does) quickly lead to speculation as to how such mechanisms could be used industrially. The critical areas of the mechanization problem are thus often side stepped in favor of the simpler problem, "What useful things can we do with these devices which we now have?" We feel it more fruitful to ask, "How can we most easily make these objects which we desire?" This is not to say that the answers to the first question cannot be economically significant. They assuredly can be, for they have often led to cost and labor saving devices. The only limits to an answer are those imposed by the ingenuity of the imagination, for the variety of automatic devices and potential uses is endless. But there is no assurance that in the process of thinking of uses for control devices one will come by solutions to the more crucial problems of mechanization. Even at best such an approach does not guide one in looking for such solutions.

In the third place, although a study of control systems and their component parts is a necessary step in ascertaining what is technologically possible at any one time, we believe that the exclusive use of such an approach can seriously limit the extent of automation which one thinks feasible at any one time. Looking at the devices and their elements keeps one in terms of automatically controlling the same processes which are now controlled manually, and of producing the same products which are now produced manually. We believe that there are many processes which require basic changes before they can be automatized in any workable way. Likewise there are many products which, in their present form, cannot be made economically by automatic machinery. Often simple redesign of the product with automatic production in mind is all that is necessary. Othertimes a more basic product change must be brought about through reassessment of product use and the design of an essentially new product before automatic production is possible. We feel that looking first at the device, and then toward a possible use, has a tendency to keep
one's mind from such reassessment of product or process; and that even at best such a procedure does not foster such reassessment.

In an attempt to evade these shortcomings we have tried to begin our study by asking such as the following:

What are the functions of man in our present manufacturing processes?

Can machines perform these functions more cheaply, more quickly, more accurately, or more continuously than man?

Can the product -- or another product fulfilling the functional requirements of the user -- be manufactured by some different process, perhaps more attainable of automation?

How can such automation be brought about?

We have asked these questions of many industries, but primarily we have asked them of industries in which discrete units of product are handled; for it is here that new thinking can prove most fruitful. The continuous process industries are already very automatic. Study of them is useful and instructive as a guide to the solution of control problems elsewhere, and for this reason we have not omitted them here. But on the whole they do not present as challenging a problem as does automatically processing discrete units of product. It is thus to this latter area that we have primarily directed our questions, and it is in this area in which we have tried hardest for solutions.

But these first questions are in themselves not enough. The innovator cannot stop here. He cannot say, "It is for me to invent and to apply; it is for someone else to consider what this will mean to the men my machines will replace". Regardless of how useful a device, if the invention brings about a revolutionary change, it is the innovator’s responsibility to ask: "What will this mean to society?" Such a question is clearly necessary when one is considering completely automatic production processes. But this question cannot be answered intelligently until one has determined the extent to which fully automatic production is feasible.

Unfortunately much glib writing exists on the subject of automatic controls. The mechanisms, particularly the larger and more spectacular, lend themselves to journalistic fantasy. This in turn begats
social criticism of those who would ‘debase’ man with the machine. But few look at what is really possible -- and most important, probable -- that the criticisms are themselves in the realm of fantasy. We have thus first turned our attention to the questions: “What do men do?” “Can machines do these things better?” and “How can this be brought about?” Only then have we asked, “What will this mean to society?” For it is only then that a meaningful answer can be given.

It is the title of this paper that suggests a higher degree of industrial automation is both desirable and technologically possible. The achievement of such a level of automation does not depend on the formulation of basic technological innovations, for the limiting factor is not technology but the difficulty which men experience in thinking fruitfully in the terms required. But although technology will not form the ultimate limit to the development of automatic machinery the desires of consumers will put an effective limit to the economic functions which machines will perform. The fear of some that machines will become all pervasive -- fears which are today touched in the same manner as the broadsheets and pamphlets of the Luddites -- will prove to be even less valid than were those fears expressed at the beginning of the steam age.

To a large degree man’s function in today’s industry is the tending of machines. He watches to shut them down in the event of an emergency, he places work into them, and removes it from them; he moves the work from machine to machine, and keeps record of it, and in the less automatic machines he controls operations by moving certain devices. Basically the machine performs the desired fabricating operations while the man services or tends the machine. In addition to these functions man keeps record of the operations by writing on slips of paper, filing the paper, and later perhaps referring to the information contained on the paper. We do not feel that the performance of these functions by automatic controls will ‘debase’ the worker. Rather, production could be carried on more quickly, more accurately and most important, more continuously than at present. A higher rate of output can thus be made possible with no increase, and perhaps a decrease in the capital requirements.

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ARGUMENT

It is the thesis of this paper that a much higher degree of industrial automation is both desirable and technologically possible. The achievement of such a level of automation does not require the postulation of basic technological innovations, for the limiting factor is not technology but the difficulty which men experience in thinking fruitfully in the terms required. But although technology will not form the ultimate limit to the development of automatic machinery the desires of consumers will put an effective limit to the economic functions which machines will perform. The fears of some that machines will become all pervasive -- fears which are today couched in the same terms as the broadsheets and pamphlets of the Luddites -- will prove to be even less valid than were those fears expressed at the beginning of the steam age.

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Automatic devices are being used to an ever increasing extent to perform man's industrial tasks. But it is only in the continuous process industries -- from oil refining to the production of fissionable materials -- that individual controls have been organized into systems which permit fully automatic operation.
One of the chief reasons for this is that the first attempts at automatic production of discrete units of product have been in the form of single large automatic machines performing all fabricating functions. Such machines typify the packaging industry but they present only a poor solution to the mechanization of most fabricating processes. Being specialized the machines cannot be mass produced. Little change in product is possible, and can only be attained at great refitting cost. Extremely long runs of nonvarying product are thus required to make such a machine practical. Although this is not the only solution to the problem of mechanization it is the solution which most quickly comes to mind when the problem of automatically processing discrete units is considered. And since this solution is in most cases not practical the idea of automatic production is quickly put aside.

An alternative solution to this problem which we believe to be very practical is the utilization of standard production type machines for the fabricating function, and the linking together of these units with automatic materials handling equipment for the achievement of automation. Individual automatic controls will be used on the production machines while an overall system of control can be provided by use of a small digital computer. This solution permits a very flexible setup -- with machines easily rearranged for the production of another product -- and the use of fabricating units which can be mass produced. The problem of obsolescence is minimized while a high degree of automation is attained.

Technologically such a solution is possible. Recent developments in tool metals permit long continuous runs on the individual automatic machines. Small digital computers suitable for overall programming and control are already available, at useably low cost. The materials handling function -- including the loading of the automatic production machines -- is a far less difficult problem than is generally supposed. As an illustration of this we have developed, and included in this report, plans for a fully automatic piston factory. This exercise not only shows the ease with which many of the technological problems can be overcome -- provided one is determined to think in terms of automatic production -- but it also shows the relatively low capital investment required for such a production line.

Control of the automatic processes at low energy levels is made possible by the vacuum tube. A small energy
input, such as might arise from the micro current of a thermocouple, can be made to control a large flow at high energy levels. Coupled with the phenomenon of feedback this permits the control of machines and processes by their actual performance rather than by their expected performance. Complete automation can thus be attained, for if a turning time of three and one-eighth minutes does not produce the result it is expected to produce the machine will automatically allow more turning time. The system thus observes what it has done and if need be corrects itself. All this is technologically possible at the present time and costs are constantly being reduced by the production of standard control units suitable for use with a variety of machines.

The technology required for industrial automation is thus in large part already here. There are problems to be sure -- and in some areas these problems will limit automation for years -- but the extent of mechanization which is technologically and economically possible at the present time is far in advance of our manufacturing processes as they exist today. It is our belief that the lack of knowledge of what is technologically possible, and the lack of fruitful thinking about the industrial application of this technology is today the greatest single factor holding back the level of automation which is otherwise possible.

Perhaps the most difficult part of thinking in terms of automatic production is recognition of the fact that many times the product or the process, or both, must be redesigned in order to make automation feasible. Applying automatic controls to a process in an attempt to automatically reproduce the action of man, with the process remaining the same as under manual control, is often a fruitless task. But thinking in terms of a new process, or a product variation, is very difficult.

As examples of the kind of ‘rethinking’ that is often required we have included studies of the steel and chemical process industries. A wide variety of automatic controls is used in the production of steel, but with the single exception of continuous casting there has been no basic process rethinking of the kind needed to make automatic production feasible. In the chemical industry, however, processes are developed and plants built with a view to full automatic control. Two specific examples of such plant design are given in some detail in the chemical industry report.
The most important single question which arises when considering the problem of fully automatic production is, "What will be the social effects of automatic factories?" We believe that in order to arrive at a sane answer to this question one must recognize two facts:

1. Automation will find its limits long before it covers the economic functions of our whole society. In the long run these limits will not be technological -- they will be the limits imposed by the desires of the consumers. There are simply things which people do not want mechanized. People still want to eat their meals at home. Automatic vending may increase but to a great extent people still want personal service in retail stores. The service industries as a whole -- which each year have been accounting for an increased portion of GNP -- will be aided by automatic devices, but they will not be automatized. Automation will progress to that point at which people are willing to give up low cost for other qualities such as uniqueness, personal service, and the ability to have something which is 'hand made'. And the skill of the craftsman, a desirable personal quality which enriches our society, will not be killed off in an age of automatic factories, for people who are provided with more and cheaper machine made products will present an increased effective demand for the handiwork of the craftsman.

2. Automation will not come about overnight. It will be gradual and there will be time in which an intelligent population can adjust to more leisure. But all will not be leisure. Much of the increased productivity brought about by automatic factories is needed to provide for the physical well being of our population, for the proportion of the aged to those physically productive is constantly increasing. The needs of this country and of the world are tremendous. The time freed from the repetitive tasks of tending machines can be spent in many worthwhile projects. Reclamation of this country's natural resources alone can take the newly freed time of all its citizens.

It can make possible the development of much that is good in man. As Norbert Wiener has written:

"It is a degradation to a human being to chain him to an oar and use him as a source of power; but it is an almost equal degradation to assign him purely repetitive tasks in a factory, which demand less than a millionth of his brain power. But it is simpler to organize a factory or galley which uses individual
human beings for a trivial fraction of their worth than it is to provide a world in which they can grow to their full stature."

It is indeed hard to provide a society in which the increased leisure can be used to benefit man rather than to cheapen him. But it is not impossible. Strong moral leadership is needed as is a realization of just how far automatic machines will be developed. But the need for such leadership and such foresight is not new.

Clearly a study of this sort cannot attempt to catalogue all the functions performed by man in today's industry. It can only be a survey of the most general functions which he performs. We do not pretend that this is anything more than just that, a survey. But we feel that such a survey does point up the kind of functions that are performed over and over again in all the various forms in which industry assumes. And it is from this reason it is useful as a guide to what machines we must do if production is to be fully automated. For those who seek a generalization and feel that the only terms in which one can meaningfully talk are terms of a specific situation, our chapter on the design of an automatic piston factory is recommended. This exercise of actually designing an automatic production line has proved useful to many ways, not the least of which has been to clarify our own thinking as to what the role of man in industry actually is.

Machinery, Operation

For our purposes industrial machines can be roughly classified as 1) production type machines, and 2) non-production type machines.

Production type machines are the more specialized and typically more complicated devices, economically useful when a series of similar operations are to be performed on a great number of workpieces. The exact nature of each operation can be varied before starting the machine, but once "set up" the machine need only be "fed" new workpieces, for the actual fabrication is performed automatically.
I

THE ROLE OF MAN IN OUR PRESENT PRODUCTION PROCESSES

In considering the role of man in our present production processes our attention has been directed chiefly to those processes which are already partially mechanized, but which still require men to operate the machines. It is here that the greatest immediate strides can be made toward automation, with the least cost and the greatest return. And it is from the study of these processes that much can be learned in the way of solutions to the problems of mechanizing processes which are at present entirely manual.

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An example of such a production type machine is the automatic chucking machine pictured below in operation. This machine performs a series of turning and cutting operations on a workpiece. It holds several -- six or eight -- workpieces at the same time. Each operation is performed in turn and one workpiece is undergoing each of the group of operations at any one time. When the slowest operation is completed all work pieces “index” or move to the next position -- just as the White Rabbit, the Mouse, and the Mad Hatter simultaneously move to their new positions about the tea table.

![Image of a man operating a machine.]

**WHAT IS THE FUNCTION OF THE MAN?**

He places work into and removes it from the machine.

He visually inspects each workpiece as it is removed from the machine.

He watches to shut down the machine in the event of an emergency.

In addition, other men move the finished workpieces from machine to machine; supply fresh workpieces for each operation; set up the machine for changes in workpiece size, etc.; replace worn out tools; keep records and programme operations.
Non-production type machines are the more general purpose machines of the job shop. They are the lathes and the milling machines, the drill presses and grinders which are not built for long continuous runs of the same product, but which are flexible enough to produce a variety of products without excessive "set up" for each. They are essentially the less automatic machines of modern industry, used where only short runs of product are contemplated or where accuracy greater than that attainable with production type machines is desired.

WHAT IS THE FUNCTION OF THE MAN IN THE USE OF NON-PRODUCTION TYPE MACHINES?

He performs all those functions which he performs when using a production type machine.

In addition he moves the tool, or the workpiece, in such a way that the desired machining operation is performed.

He typically has much greater control over the movement of the various parts of the machine.

The same service functions -- moving work from machine to machine, tool set up, etc. -- are necessary as when using a production type machine. In the case of a non-production type machine these functions are usually performed to a greater degree by the operator than they are with production type machines.
Since this report is not concerned exclusively with analysis of the fabricating process, but is also concerned with the office of the automatic factory -- and the term automatic factory can as well be applied to an insurance company, for instance, as to a fabricating firm -- it is well that we look to the role of man in dealing with the paper work of today's business.

![Image of a person writing]

**WHAT IS THE FUNCTION OF THE MAN?**

He gathers information, both from the production processes and from letters, bills, orders and direct contact with those outside his own business.

He puts this information in useful form, and either acts directly on it or files it away.

He constantly changes his files, adds and deletes, manually lifting the bits of paper and rearranges them.

He refers to his bits of paper in the file and arranges the information in usable form at a date after it has entered the material in the file.

He writes letters, bills, and orders to be sent outside his firm.

The proportion of men in offices who act administratively on the information so handled is very small to those who handle it.
Functions Other Than Machine Operation

The functions of man in modern industry, other than the operation of machines, can be roughly classified as follows:

Moving material from machine to machine; seeing to it that machines are constantly supplied with enough work, and the floor about them cleared of finished work.

Keeping record of the work that is in progress, programming operations, and gathering information necessary for costing and quality control, etc.

Inspecting work in various states of completion.

Performing fabricating functions in the less mechanized industries.

Watching gages and other instruments and starting and stopping otherwise automatic processes in the continuous flow industries.

Changing tools, setting up machines and equipment.

Maintenance work.

The functions of man in modern industry can thus be considered as being on various levels -- not levels of skill, but merely categories. In the actual operation of machines his function is chiefly that of tending the machine, of providing work and watching for difficulties, but on the whole letting the machine perform the crucial part of the fabrication function while he makes sure all runs smoothly. In the less mechanized industries man performs more of the fabricating functions himself, in some cases guiding the machine, in others working with tools rather than machines. Even in the highly mechanized industries man often moves the workpieces between machines, gathers information for records, files bits of paper with information on it, and looks for these bits of paper when he again needs the information. And on still another level of operations he programmes work.

This is admittedly the most general kind of list of functions. He who looks for omissions will assuredly find them. But this brief survey serves as a better jumping off spot for an investigation of industrial mechanization than merely asking, "What automatic controls can we build?" We now know something of what we need.
II

APPROACHES TO MECHANIZATION

Can the industrial functions now performed by man be mechanized? Is there any advantage to mechanizing them? These are the questions which most naturally arise at this point in our study, and it is to these questions which we now turn.

Clearly there are many groups of manufacturing functions which can be performed by single automatic machines. The packaging industry presents numerous examples of this type of mechanization. The local Coca Cola bottling plant is in many ways the closest approach to an automatic factory handling discrete units of product which we have. But for most manufacturing processes this presents but a poor solution to the problem of automation. Being specialized, the machines can not be mass produced. Little change in product is possible, and can be obtained only at great refitting cost. Extremely long runs of a nonvarying product are thus required to make such a machine practical. It is for this perfectly sound reason that such machines have not been built to turn out anything like the number of products which it is technologically feasible to produce in this manner. Unfortunately the disadvantages of this approach have hindered mechanization generally, for it can easily seem that the only logical answer to automatic production is an automatic machine. And if the investment in an automatic machine requires longer runs of product than are feasible, then (to follow through with this reasoning) automatic production, however desirable, is not economical. But is the single product automatic machine the only answer?

Several years ago two Canadian radar men, Eric W. Leaver and John J. Brown, proposed an alternative solution in the form of machines which are designed to perform certain basic functions rather than produce predetermined end products. Their proposal ran like this:

"The new machine is made up of many small units plugged together. Each unit is capable of performing one function and several plugged together will be capable of doing all the operations required to build a given part."

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The direction of their thinking is very helpful in that it looks toward greater automation through a means other than larger and more specialized machines. But we do not feel that their solution, of basic functionally oriented units which can be "plugged together" is the answer to our problem. A machine which turns, if it is not to be a machine which turns all sizes of work pieces -- clearly impractical, for watch parts as well as pistons are turned -- must be a machine which turns work pieces of a certain range of size, and such a device can not be simply "plugged" into a device which drills (as Mr. Leaver's and Mr. Brown's radar circuits can be plugged together). It must be equipped with materials handling machinery which will be capable of handling a range of different sized work pieces to any of the other "basic" machine units. If certain combinations of these "basic" functional machines are used repeatedly it becomes a waste of investment to keep them universally adaptable. One then arrives at a series of machines each of which is capable of handling a certain range of work pieces and of performing a certain "bundle" of functions on these work pieces. This is not the "basic" functionally oriented machine unit of Messrs. Leaver and Brown; but it is the production machine of modern industry. And it is the use of these machines which we propose as the solution to the automation problem.

Our Proposed Solution

The solution which we propose to the problem of industrial mechanization is that of using production type machines for the fabricating functions, and of providing automatic materials handling, inspection, and programming in such a way that the machine units can be built into an automatically controlled and automatically producing whole. The idea of tying automatically producing units together with an overall control system is not new. But the usual emphasis is upon the control system, with the casual comment that although the effectors, the fabricating machines, are not too well developed in many cases these problems will undoubtedly be solved. The result is usually that a manufacturer reads such an account; wonders at the marvels of present day science; and wishes that his industry would lend itself to such automatic production; But he is sure that it does not. By dwelling for some length upon the problem of the machines we hope to make it clear that automation is possible in cases where production runs are no longer than those required for the economical use of normal production type machinery. (later we will show that automatic production is also possible in some cases of very short production runs)

The great advantage of using standard production type
machines is that the resulting automatic factory is very flexible. For, when another product is to be produced, or a major variation made in the product that is presently produced, the production machines can be freely rearranged, with additions or deletions as may be necessary. The individual machines can be mass produced, and will have a much longer useful life than a single specialized "automatic machine". For clearly an automatic chucking machine that has been used to machine automotive pistons can be used equally well to machine bearing rings for a gas turbine which has replaced the engine using the piston.

But all of this depends upon the ability to cheaply and effectively overcome the materials handling, tool wear and tool change, and control problems. Unless these problems can be overcome in such a way that production machines can be joined together economically, and then moved apart and rearranged, our solution is clearly of little interest industrially. We have turned to these problems in two ways. Our attempt at the design of an automatic piston factory has been mentioned earlier. The problems we met, and the solutions we have presented represent one approach to economical serving of production type machines by other machines. In addition we have tried to survey some of the problems which we did not meet with in design of the piston factory, but which are nevertheless present in industry. But first let us turn our attention to an important but seldom recognized distinction, the difference between using automatic controls and automatically controlling a process.

The Difference Between A Process Using Automatic Controls And An Automatically Controlled Process

The solution to the problem of industrial mechanization that we have proposed above is basically a solution which says, "Tie together automatic machines; provide the necessary fasteners; and introduce some kind of overall control." From this it would seem that the first step in producing an automatically controlled production process is to secure individual automatic machines to perform the functions which are now performed manually or semi-automatically. This may be a first step toward complete mechanization, but there is no assurance that it will lead to mechanization. Often a process, although it may use many individual automatic controls, is simply not suitable for effective overall automatic control. Such a process can benefit from the utilization of automatic control mechanisms and still remain a long ways from a state in which one could say it is "an automatically controlled process". Thus the mechanization of what is presently done manually, although economically significant in that it reduces costs and saves labor, is often not at all a
step toward the development of an automatic process. In such cases basic reassessment of the process, or perhaps the product, is necessary before any real progress can be made toward complete automation.

It is difficult to describe what such basic "rethinking" consists of. It starts with an ability to look at the functions performed by the end product and of asking the question, "Can some other product, made by a process more suited to automatic control, perform the functions which the user now expects of this product?" Perhaps a simple redesign in the product is all that is needed. In the case of consumer goods this is very simple. In the case of industrial parts it is very much more difficult, but often not altogether insolvable. For example, to look again to our automatic piston factory, a simple casting of two reference points in the head of the piston makes it possible to position the casting prior to loading it into an automatic chucking machine in a predetermined relation with the chuck.

When the product cannot be redesigned, and another product cannot be used, it is necessary to try to reassess the process by which the product is made. Perhaps the best way of approaching this problem is to look at the desired product and say, "How could this product be made?" The process by which one knows the object is made will be the first answer to come to mind. But if it is possible to continue thinking in terms of, "How could this object be made?" one is not tied to the original process and the possibility of developing a process economically suitable to automatic control is greatly increased.

As difficult as it is to describe "rethinking" of a process, the actual "rethinking" is far more difficult. And it is precisely because of this that much of our present industry is far from a state of mechanization. It is thus important to make clear the distinction between automatic controls and automatically controlled production. For thinking in terms of applying individual automatic controls to present processes can keep one far afield of the critical problems of making a process automatically controllable.

In order to make this distinction clear, and also for the purpose of showing the variety of controls which can be used in one industry -- and industry as it happens which is far from the state of being automatically controlled, we have prepared an analysis of the steel industry from the automatic controls standpoint. The full report is attached in the
form of Appendix A. A brief statement of our conclusions is presented below. The steel industry is perhaps the prime example in our economy of an industry utilizing a bewildering variety of automatic controls yet—except for the single example of continuous casting—being far away from a process which could be termed “automatically controlled”.

Automatic Controls In The Steel Industry

The industry that supplies the most basic necessity of the present-day world is indeed marvellous. Yet from the standpoint of automatic control, this steel industry, for all of its accomplishments, has in it an enormous flaw. That flaw is its basic technology. For years and years the steel industry has smelted its ore and turned out its ingots by the same means and with the same instruments—the blast furnace and the open hearth. These huge vessels have always worked, and few people in the industry looked at them with a questioning eye. No one felt the need for any large scale modernization.

Fundamental changes in an industry as big as steel and with its huge capital investment cannot be brought about easily. One does not go around obsoleting millions of dollars worth of equipment overnight. Thus we note that steel research is focused primarily on improving the industry’s product rather than its methods. In view of this fact, the automatic control of the steel making process is a long way off.

There are, however, indications that some people are thinking in terms of mechanization. The recent development in the continuous casting of steel, which eliminates several costly steps in the steel making process, suggest that future processes will lend themselves more easily to mechanization. The present combination of batch and continuous processes in the different stages of production hinders the establishment of an automatic factory, but future developments along the lines similar to the work on continuous castings could make the automatic factory a reality.

Although the industry has been slow to change its basic technology, it has adopted numerous uses for electronic control devices. This acceptance has grown out of the fact that the industry was interested in any developments which would increase the quality and
decrease the cost of the product. More and more automatic control mechanisms will be installed on many more of the processes and machinery as future study and developments will show the way and justify the change. We are not, however, approaching a push button era in the next ten years in which the operator will push the button, ‘on’, and electronics will do the rest. There is a definite place in the steel industry for electronic controls, but in many applications rotating or static electrical controls are still more useful.

Automatic Controls in The Chemical Process Industries

In contrast to the steel industry, the chemical process industry presents a much more advanced picture from the standpoint of the automatic control of production. In fact, when speaking of automatic production the chemical process industries are always brought in as the most advanced industrial application of automatic control -- and many times the inference is that this is where automation in industry will stop, because, "You can use automatic controls with continuous processes, but you can't apply them to other manufacturing processes." Now, the chemical process industries have a great advantage, from the control standpoint, in that the material lends itself to continuous handling more readily than the products of many industries. But chemical processes are not naturally continuous any more than are any other processes. To make them continuous, and thus more adaptable to automatic control, it was necessary to think in terms of such control. That this is somewhat easier in the case of chemicals has led to much more extensive use of automatically controlled plants in such industries as oil refining than we have in other fields of manufacturing. But the need of rethinking is still there. And to show how such rethinking has resulted in profitable changes in means of manufacture we have made a study of the chemical process industries from the standpoint of automatic control, just as we did in the case of steel. This study is included as Appendix B. At the end of the chemical study we have also included two case examples of how plants have been built around the concept of easy and complete automatic control of the process.

The Means Of Mechanization

Thus far we have dwelt upon the need for automation, and approaches to mechanization. We have tried to explain in a general way what we believe to be useful ways of looking at the problem of automatic production. Our next step is to explore a specific manufacturing problem -- the fabrication of automotive pistons -- and to show how we feel such a process could be made fully automatic.
The project of designing an automatic production line for the machining of automotive pistons was taken up for several reasons. For one, such an exercise provides an excellent illustration of what we were trying to talk about in general terms in the last section. That is, the connecting together of production type machine tools, and the overall control of a digital computer. Also, the project provides some idea of the cost, however rough, of actually building such a production line. And, although we did not fully realize this at the beginning, the clarification which the undertaking provided to our thinking about the problems of automation was in a very real sense, the major advantage to come out of the design process.

Machining Problem

Automotive pistons are received in the form of castings by the piston fabricators. The castings are generally similar to the drawing on the following page. The piston manufacturer must turn this casting into something similar to the second drawing. This involves a series of machining steps. The casting is too rough to be used in an engine without overall machining, and in addition the piston ring slots must be cut, and the lower portion of the piston skirt must be machined into an ellipse -- inorder to allow for the unequal expansion of the unevenly thick portions of the casting when the piston is in operation. The final step is to tin plate the entire piston for better wearing characteristics.

The manner in which various manufacturers go about this process differs greatly from company to company. We surveyed the methods of several manufacturers, and then sat down with a finished piston before us, and tried to work out our own method. The results seemed simpler than the process we had seen, and the automatic loading which we designed was, "Clearly an over simplification." we were told by a graduate engineer. Nevertheless, somewhat after this we received a very complete manufacturing schedule from the Ford Division of the Ford Motor Company, and found their process essentially the same, and also that the earlier stages of the process utilized automatic loading.
Initial and Final Stages of Piston - AUTOMATIC PISTON FACTORY

Wrist Pin Hole Cast into Piston before machining operations.

Cast Piston as delivered from Foundry to be Processed

Lock Ring Groove

HALF PLAN

Chamfered Wrist Pin Hole not shown

SIDE VIEW

Elliptical Skirt

Fully machined Piston to be delivered to Motor Assembly Lines.
similar, although hardly identical, to that which we proposed. We felt much relieved since this indicated that our very unsophisticated approach was not entirely unrealistic. This experience did, however, make us feel that we were really contributing somewhat less than a revolutionary idea to manufacturing. Even the Ford plant -- which from what we have seen appears to be far ahead of rest of the industry from the standpoint of automation -- however, utilizes much less automation than we have proposed in our designs.

Machining Process

The following operation sheets show the machining processes which we propose. As can easily be seen, the majority of operations are carried out on standard machines, with automatic loading. There are cases, however, of automatic machines being specified. These are in reality not as ‘special’ as the tag would indicate. To begin with, they represent simpler functions by far than do the more complicated automatic lathes for instance. They can to great extent be fashioned from the standard tools which presently exist for performing their function, and we do not feel it all out of the way or premature to specify them. We have not gone into their construction, however, since we feel that they do not present the major problem to automation -- automatic machines, as we saw in the previous section, can readily be produced -- it is rather the way in which single standard production machines can be combined into flexible systems which is the major problem of automation, and for this reason we have dwelt primarily upon the materials handling and machine loading problems, and upon the problems of overall control of the system.
## Operations Sheet - Piston line.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Unload rough castings from crates. Load on belt conveyor. (automatic load)</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Rough and semi-finish turn O.D. Rough and finish face head end. Rough and finish turn ring dia. and widths. Chamfer O.D. at head end. -- .03 x 45° Chamfer #3 ring groove .015 x 30° --skirt side. (automatic unload) (automatic load)</td>
<td>Std. 6-Spindle Horiz. Indexing lathe.</td>
</tr>
<tr>
<td>30</td>
<td>Chamfer 5.804 radius .015 x 45° .025 (automatic unload) (automatic load)</td>
<td>Std. 3-head Rotary Indexing Deburring mach.</td>
</tr>
<tr>
<td>40</td>
<td>Machine piston to weight (amount to be removed determined automatically by machine-- light and heavy pistons rejected.) (automatic unload) (automatic load)</td>
<td>Special automatic weight milling machine.</td>
</tr>
<tr>
<td>50</td>
<td>Rough grind O.D. --feed thru on locating rollers. (automatic unload) (automatic load)</td>
<td>Std. Thru-feed centerless grinder.</td>
</tr>
<tr>
<td>60</td>
<td>Finish bore wrist pin hole.</td>
<td>Special Single-end boring machine.</td>
</tr>
</tbody>
</table>
70  Finish grind ring land dia.  
    (automatic unload)  
    (automatic load)  

    Special 4-wheel  
    automatic grinder

80  Chamfer outer ends of wrist pin  
    hole - .04 x 45°. Machine locking  
    ring groove at both ends & burr.  
    (automatic unload)  
    (automatic load)  

    Special vertical 4-position  
    straight-in-line machine.

90  Finish cam grind O. D. - (dummy  
    wrist pin automatically inserted  
    in piston before machining to  
    locate work in yoke of drive shaft)  
    (automatic unload)  

    End of machining operations  
    (automatic load)  
    (on conveyor )

100  Tin plate piston  
    (automatic unload)  
    (automatic load)  

    Automatic tin-plating  
    operation--conveyor  
    and dipping tanks.

110  Clean wrist pin and burr.  

120  Inspection  

130  Weighing and packaging for delivery  
    to stock or further assembly.  

    End of production process  

- 24 -
Machine "Loading"

To make the process automatic it is necessary to connect each of the automatic machines with automatic materials handling equipment -- devices which will place the pistons in and remove them from each of the machines. In addition it is necessary to provide some sort of overall control which will replace both the worker's functions -- turning the machine on and off, stopping the machine if something occurs to delay production, etc. -- and the functions of the supervisor in providing for overall programming and control. We shall treat these problems in order, beginning with that of automatic loading.

Perhaps the best approach to this problem is to look at the function the man performs -- not the physical motion his hand must go through, but the end function the hand must perform. The picture below is of a man loading a piston into a chucking machine.

What does the man do?

He takes a piston from a conveyor or from a dolly.

He places the piston onto the chuck in such a manner that the chuck can expand inside the piston to hold it firm.
He also removes the finished piston from the machine.

And he places that piston onto a conveyor or dolly.

Thus the function of the man is to move a piston casting onto the machine and remove it from the machine onto a materials handling device.

But why need this be performed manually?

There are countless reasons given. But we believe that it can be accomplished very simply, even to positioning the piston on the chuck in a predetermined relation between chuck and piston. The system which we have designed is one of a number of possible methods which we have considered. Numerous others exist. It is possible to perform most engineering functions in several ways. And it is recognition of this fact which will do much to help automation. For example, it is perfectly possible to exactly duplicate the motions of the man's hands in the photograph on the preceding page. But it would be very expensive. If one forgets about this duplication of motion it is possible to design a very low cost device, similar to the device we use for this particular operation.

To see our solution to automatically duplicating the function, not the motions, of the man in loading the piston casting into the automatic chucking machine, turn to the drawing on the following page. Remember that this represents the solution to only one loading problem. We have considered, and worked out solutions to the others in the line, but none are more complicated, and none more costly to reproduce automatically what the man presently does. We thus feel justified in presenting merely this one.
Wrist Pin Hole Cast into Piston before machining operations.

Cast Piston as delivered from Foundry to be Processed

Lock Ring Groove

HALF PLAN

Chamfered Wrist
Pin Hole not shown

Elliptical Skirt

SIDE VIEW

Fully machined Piston to be delivered to Motor Assembly Lines.

Initial and Final Stages of Piston - AUTOMATIC PISTON FACTORY
Control

The problem of control in the type of automatic factory which we outlined in the preceding section (II) is the problem of overall control and programming. The individual machines are fully automatic, once the pistons have been unloaded and new ones loaded. The control that is needed is thus a checking device which determines when something has gone wrong in the system.

To perform this function we propose a series of “sensory” devices and a small digital computer. A “sensory” device is a mechanism which in some fashion duplicates the function of human sensory organs. The devices and the theory are explained in detail in Section V. Here it is only necessary to state that there are devices which can count the number of pistons which move past a certain point (photoelectric cells); and there are devices which can automatically tell whether a machine is going, etc.

A digital computer is a machine which makes a logical choice between two alternatives, the choice being based upon a “memory” which is predetermined and can be altered. As with the sensory devices, a much more complete description of computers and their components is presented in Section VI. Here the fact that such a machine can be built, and more important can be mass produced, is all that it is necessary to know.

With these devices, sensory mechanisms, and a digital computer, we plan to control the automatic production line. What the computer does is to “ask questions” of the sensory devices. For example, the computer will electronically “ask” a counter whether a predetermined number of pistons have passed a certain point. The question must be of the “yes” or “no” type, because the computer can only make a decision between two alternatives. In the above example, if the desired quantity have passed the spot the computer moves on to ask questions of another device. If the desired number have not passed the spot, if the answer is “no”, the computer asks another question of the photoelectric counter, or of another sensory device. Always the question is of the “yes” or “no” type. And always there are memory schedules of questions to ask if something is not as planned.
The computer schedule -- the list of questions and alternatives -- is put into the machine in a mathematical form explained in Section VI. But before this schedule can be turned into binary numbers (two digit numbers corresponding to "yes" and "no") it must be written in the form of "yes" or "no" questions. The elaborateness of the alternatives, the amount of material that the "memory" of the machine must contain, the speed with which the machine must be able to draw upon this memory and the speed with which the machine must be able to ask all questions in order and return again to the first question for another cycle of questions, determine the characteristics of the computer that is needed to perform any given function.

On the following pages can be found the schedule of computer questions and alternatives which we believe necessary for the automatic operation of a piston production line.
II. Computer Schedule - Piston Line

Note: To be used in conjunction with the Operations Sheet (I).

Oper. No. | Logical binary questions asked by computer of sensory devices | Additional questions and action indicated if questions are answered in the negative
--- | --- | ---
10 | Are pistons fed to belt at proper rate? Is conveyor at proper speed? | Notify manual loader by alarm to fill hopper. Automatic adjustment of belt speed.
20 | Did 1st station index with piston on chuck? Did piston unload at 6th station? | Belt stopped automatically--castings not fed to belt from hopper. Check power on Mach. #1. If negative continuously, autoshift to standby line--notify reg. maint. for routine overhaul and inspection. Same as above. All partially machined parts returned to hopper which then feeds standby machines.
30 | Did 1st station index with piston in pot-chuck? Did piston leave pot chuck when 3rd station indexed? | Same as #20-- Check power to Mach. #2 Shift all after Mach #1 to standby mach. Notify maintenance. Same as above. Parts semi-finished returned to line feeding #2 standby.
40 | Did piston load at weight mill. ? Is piston correct weight? Did piston unload after mach.? | Same as above. Shift to #3 standby. Reject light and heavy pistons. Count reject rate. Note incidence of lights. Record rejection rate - specifying failure. Were failures due to original condition of rough castings? Recording affirmative answers serve notice to mgt. Same as #20--Shift to #4 standby mach. Notify. No power check--if previous answer affirmative.
50 | Did piston pass to rollers? (sense mechanism under rollers) Did piston leave grinder? | Check power on belt conveyor to Mach. #4. Shift to alternate machine. Check power to grinder. Shift to alt.#4.
60 | Did piston load? Did piston unload? | Same as #20--shift to # standby grinder. Same as above. shift to # alt. Notify.
Computer Schedule (cont.)

Oper. No. | Logical questions asked by computer of sensory devices.
--- | ---
70 | Did four (4) pistons pass counter prior to loading? Did indexing of work-holder occur? Did pistons unload?
80 | Did piston load? Did piston unload?
90 | Did piston load? Did piston unload?
100 | Conveyor to tin-plate-- Did hook pick up two pistons for dipping? All conditions correct?--temp., liquid level, analysis of plating solution, ? Did pistons unload after plating?
110 | Did pistons locate properly? Did pistons unload?
120 | Inspection-- Did pistons pass inspection? Did piston unload?

Additional questions and action indicated if questions are answered in negative.

Shift to alternate selector-counter. Check power on belt to machine #6. Shift to alternate machine #6. Check power on #6--notify. Check power. Shift to alt. #6. Notify.

Shift to alt. #7 mach. Notify. Power check on machine.


Same as above--shift to alt. #8. Same as above--shift to alt. #8.

Were two pistons on rollers for pick-up? Is conveyor travelling at proper speed? Shift to other conveyor-speed up and switch in alternate path of travel thru tank. Continuous control of these variables should insure constant affirmative answers, however if negative, shut down line--notify immediately for correction. Stop conveyor--shift to other belt track. notify.

Check power, shift to alt. cleaning mach. Notify. Check power only...feed is straight thru. If stopped, start automatically--otherwise shift to alt. machine.

If not, individual sensory mechanisms will indicate which dimensions are faulty, therefore will automatically indicate which machines need to be taken off the line. Check rejects for reclamation--return for proper correction. Shift machines to eliminate faulty machining operations. Shift to alt. mach. check power, notify.
## Computer Schedule (concl.)

<table>
<thead>
<tr>
<th>Oper. No.</th>
<th>Logical binary questions asked by computer of sensory devices</th>
<th>Additional questions and action indicated if questions are answered negatively.</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>Packing—Are proper number of pistons moving off inspection?</td>
<td>Is inspection line functioning? Do previous counters indicate normal conditions? Slow belt loading of containers. Check possible hold-up and vary speed of line. Signal to loading line. Check power to belt. Stop piston flow off inspection—vary speed.</td>
</tr>
<tr>
<td></td>
<td>Are cartons in position?</td>
<td>Check hopper feed to belt. Alter speed if flow is behind belt. Slow hopper if ahead. Check controls operating sealing device—vary speed of flow. —check power. Notify. alternate flow to hopper storage till affirmative answers appear.</td>
</tr>
<tr>
<td></td>
<td>Are cartons full?</td>
<td>Check power. Vary conveyor speed. Check packaging machine? See if answer to #130 is negative—if so, stop line till affirmative. Notify.</td>
</tr>
<tr>
<td></td>
<td>Packaging machine functioning properly?—sealing? flow?</td>
<td>(End of manufacturing process)</td>
</tr>
</tbody>
</table>

**Note:** Action involving a shift to alternate machines or stand-bys should not be interpreted as requiring an infrequently used, duplicate line. These machines are part of similar lines being used for piston production. When shifts are indicated, the speed of flow to these lines is varied to prevent choking lines which are already operating properly. Delays and returns to storage hoppers may be indicated depending upon the rate of speed at which the line is traveling; in this case, the flow would not be interrupted—rather, the flow would be directed to storage hoppers which would provide stand-by parts as needed. The fact that machine stops seem to be frequently indicated if negative answers appear should not be taken to mean that the line would be constantly starting and stopping. The infrequency of negative answers depends more upon the proper functioning of the mechanical devices rather than upon the controls governing their operation. Therefore, the line should function at optimum levels when mechanical "bugs" have been largely eliminated. The questions asked in actual operation will go beyond the scope of those outlined here; the answers, too, will be more detailed as far as indicated action is concerned. The prime reason for this computer schedule is to indicate the type of questions and the type of indicated action resulting from the receipt of negative answers.
The Automatic Production Line

A drawing of the automatic piston factory which we have designed appears on the following sheet. Basically it is exactly the system which we proposed in Section II as the solution to many of the industrial situations in which product variations exclude a single "automatic machine." It is a series of standard, or slightly modified production type machines connected together by conveyors and automatic loading and unloading devices, and controlled by a small digital computer. We believe that this project shows that it is not only possible, but economically practical to build such a factory. Our opinions as to cost have varied greatly as the study has progressed, but the loading devices are relatively cheap -- a few hundred dollars per several thousand dollar machine. The computer schedule, although rough, shows that the order of magnitude of the control problem is certainly within that possible with even the small IBM units which now rent for $650 per month. The conveyors are already in use in many places, and are certainly adaptable to other uses, as are the storage hoppers used at various points throughout the system.

We think that the project, although it is in no sense as complete in detail as we would like it, clearly shows that what are generally thought to be serious obstacles to automation, are in reality engineering problems far less difficult than many that are given by the businessman to the engineer in the normal course of production. The difficulty in this case is that these problems are not given to the engineer -- for the businessman assumes they cannot be solved.

We believe that the project also brings up a very interesting question to which we do not pretend to know the answer, but which might well be the subject of some profitable research. We have seen no other references to it in the literature or in industry. And that is, could a central computer perform the control functions for machine operation -- for indexing and movement of cutting tools, etc. -- as well as the overall control? At present a substantial portion of the cost of a production machine is the control system. The relays and other electrical devices are used only intermittently, being idle the rest of the time. Could a computer -- the slow ones ask and answer their questions in hundreds of thousands of seconds -- not perform the control functions for all the automatic machines in a plant as well as the overall control? Would this not substantially reduce the cost of automatic machinery? We feel that this is perhaps one of the important things to come out of the time we spent on the automatic piston factory problem. For although it is only a question, it might well have an answer which could mean far lower costs and better use of resources for industry.
SUPPLEMENT TO FLOW CHARTS

This supplement contains drawings and schematics of certain important operations depicted in the Flow Charts. Their purpose is to help explain how the Automaticity of Production is achieved. Only certain representative operations have been chosen. They are:

<table>
<thead>
<tr>
<th>OPERATION</th>
<th>MACHINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>No 20</td>
<td>Std six spindle Horizontal indexing lathe</td>
</tr>
<tr>
<td>No 30</td>
<td>Std. three head rotary indexing and deburring machine</td>
</tr>
<tr>
<td>No 50</td>
<td>Std Thru-Feed Centerless Grinder</td>
</tr>
<tr>
<td>No 60</td>
<td>Special Single End Boring Machine</td>
</tr>
<tr>
<td>No 100</td>
<td>Tin Plating Solutions</td>
</tr>
</tbody>
</table>

In addition a schematic representation of the Hopper Arrangements is included. Finally an explanation of the other operations not illustrated is given.
MACHINE USED: Standard Six Spindle Horizontal Indexing Lathe

Station No. 1
Automatic Load

Station No. 6
Automatic Load

Station No. 2
Face Skirt End
Rough Turn Ring
Groove Diameters and widths

Station No. 5
Finish Turn Ring
Groove Diameters and Widths.

Station No. 3
Rough Turn Q.D
Rough Face
Head End

Station No. 4
Semi-Finish Turn
Ring and Land D.
Semi-Finish Turn
Skirt Diameter
Chamfer Both Side
#1 and #2 Ring
Grooves.
Chamfer Both Side
#3 Ring Groove
Chamfer Head
Finish Face Head
to Length.

OPERATION #20
Explanation of Operations and Schematic Drawings
Operation No. 30
Chamfer Bottom Radius.
Operation is carried out on
Standard 3 Head Rotary Indexing and Deburring Machine.
MACHINE USED: Special Single End Boring Machine

OPERATION # 60

FINISH BORE WRIST PIN HOLE

Explanation of Operations:

1. Piston is automatically delivered and placed in single end Boring Machine. (See Flow Diagram)

2. Piston is rotated and located by retracting pin

3. Automatically clamped in Chuck

4. Boring Tool is then fed in from Right to Left Automatically. Wrist pin hole is finish bored to .9122 - .9125 Automatically.

5. Piston is automatically unloaded onto conveyor.

Note: Explanation of this operation was carried out for it is typical of the "type" of production operations that take place automatically. Operation #90 in which the wrist pin hole is chamfered and the lock ring groove is machined is similar but for the fact that it is a four station operation. Operation #90 is broken down by stations:
Station #1 - Automatic Load, Locate on Pins, Clamp;
Station #2 - Chamfer outer Ends of Wrist Pin Hole (.04 x 45°);
Station #3 - Machine Lock Ring Groove at Both Ends and Burr;
Station #4 - Automatically Unload.

Thus, in effect, an understanding of operation #60 which is typical of all boring and chamfering operations, would enable us to carry out all other boring operations. The essential components are the rotating mechanism, the locating pins, and the automatic Chuck.
OPERATION # 100
TIN PLATE

Schematic Representation of Tin Plating Operations.
1. Tin Plating.

Pistons to be tin plated are automatically delivered by Conveyor to Hopper. Hopper releases Piston to 'Support' in upright position. Hydraulic Pusher places piston at predetermined position where it is picked up by conveyor arm.
HOPPERS were used in the Piston Line where ever there was a need for an inventory point. The schematic representation presented above operates as follows: (1) Pistons roll into Hopper chute where they are picked up by a section of the moving belt. (2) They are then passed on to the next moving belt in stages depending upon the volume of in Process storage required for a particular operation (3). The pistons are then delivered to the automatic loading mechanism of the particular machine.

Capacity: The Capacity of the Hopper depends upon three variables that are determined by the particular use of the HOPPER in the production process. (1) Length of each Belt (2) Number of Belts (3) Speed of each belt and spacing of Stops.

Delivery: The rate of delivery of pistons to the loading mechanism can be varied by adjusting the distance between stops on the movable belt as well as the velocity of each belt.
OPERATIONS

No 20 - Illustrated

No 30 - Illustrated

No 40 - The special automatic weight milling machine. The piston is located by two "V's" in the central part of the machine. An automatic chuck similar to the one shown in Operation 60 clamps the piece in position. The machine automatically determines the amount of metal to be removed and a cutting tool removes the metal as directed.

No 50 - Illustrated

No 60 - Illustrated

No 70 - Special 4 wheel Automatic Grinder. The operations are similar to those in Operation 20. Four pistons are Finished at the same time. The pistons are held in an Automatic Chuck as in Operation 20.

No 80 - Special vertical 4 position straight in line machine. The methods of locating the piston, of feed and of clamping are identical to those in Operation 60. The difference between the operations lies in the fact that Operation 80 is carried out on a 4 station indexing machine whereas Operation 60 has a single station.

No 90 - Standard infeed centerless Grinder with special cam attachment. The process is similar to that illustrated in Operation 50. The difference is that a special locating mechanism is employed.

No 100 - Illustrated

No 110 - Automatic Cleaning Machine. Its operations are similar to Operations 30 and 40 and the additional use of special attachments.

No 120 - Inspection. This operation is conducted by a series of inspecting devices connected by loading mechanisms and belt conveyors. See the report proper for an explanation of these devices.

No 130 - Special auto weighing and auto packing machine. This machine embodies the principle of Operation 40 in weighing and is also a special loading and packing machine.
THE PROBLEM OF MAKING MACHINES AUTOMATIC

In the second section of this paper we considered various approaches to the problem of mechanization, but we did not go into the problems encountered in making the fully automatic machines. We assumed that such machines could be made, and talked of how they could best be used in combination. Likewise, in the section on the automatic piston factory we started with the automatic machines. In this section we shall talk briefly of the major problems presented by the task of making fully automatic machinery.

Tool Change

One of the tasks which the machine tool operator must perform in the course of his work is to remove and resharpen his tool as work progresses. How can a machine be made to operate automatically if the cutting tool must constantly be removed and replaced by a new or resharpened one? There are two answers to this query: 1) provide for automatic changing of tools, and 2) produce tool metals which wear for long periods. Neither solution excludes the other.

A tool holding device which can 'index', as does the headstock of the automatic chucking machine described in the first section of this report, presents one easy solution to the automatic tool change problem. This is essentially the same kind of device which, on a turret lathe presents new and different tools to the work piece. As with other aspects of the automation problem the solution will probably go much further if one does not attempt to duplicate what one sees on the turret lathe, but rather uses the idea in new forms. The use of hopper fed, automatically aligned tool holding devices could provide for automatic change of soft tool metal cutting tools which only last for a small number of work pieces.

The use of harder and longer life tool metals has been the most widespread answer to the problem of providing tools adequate to high speed automatic machines. A tool material is required to cut a given amount of metal with a minimum of attention for
a maximum period of time. In automatic machines the requirements are simply stepped up a bit. The speeds are generally higher, the runs longer, and the metal of the work pieces has been getting harder and harder as the years go by. Basically, the problem here is that of metalurgy. And from the standpoint of the manufacturer of most goods it has already been solved satisfactorily for a much higher degree of automation to be possible than we now enjoy. The postwar trend to heavier and faster automatic machinery in itself has speeded the developments in metalurgy. The most important postwar innovation is the use of sintered carbide. This cutting material consists of powered carbide of tungsten, tantalum, titanium, and columbium, pressed to shape and then sintered, or thermally bonded. This is usually in the form of a tool tip, which is then brazed or welded to the tip of a tool shank, which has been grooved to accommodate the carbide tip. This type of tool has been able to machine effectively the new highly abrasive and hard, high-temperature alloys used in jet engine manufacture, as no steel tool could.

With these materials properly applied production approaching four times that of steel tools can be hoped for. However, to utilize carbide tools effectively, it is often necessary to redesign and modify, if not replace entirely, present machine tools, in order to incorporate the increased load and speed which carbides can withstand. The material is ideal for fully automatic machines where long tool life and minimum dimensional change are required. As an example of the economies to be gained through the use of high speed tool metals we would like to cite the following case:

An automobile manufacturer designed an entirely new lathe for machining gears from forgings. Operating at 1005 rpm, and fully automatic, it was equipped with multiple carbide tools on three sides operating simultaneously. His heat treatment time has been cut almost 90%, due largely to the ability of carbides to cut harder material. His total cycle time on the lathe is now 21 seconds, and the machine's production is equivalent to that of seven ordinary lathes with high speed steel tools running at 300 rpm. In addition surface finish has been improved along with dimensional accuracy, with resultant saving in subsequent machining operations.

There are, to be sure, operations in which the tool wear problem is an important obstacle to automatic machining, but all in all, a much higher degree of mechanization is possible with the present state of tool design and metalurgy than is presently the case in our industry.
Materials Handling

The problem of materials handling has already been touched upon in earlier parts of this report. Our suggested approach to the solution of this problem were presented in the second section "Approaches to Mechanization" and specific applications of this approach were spelled out in the third section, "An Automatic Piston Factory". It is very hard to talk in terms other than the generalities of our second section lest it be the specific applications of our third -- and there is little more room for detailed examples of specific solutions.

So long as one's thinking is not confined to duplicating motions presently executed by the human hand, and so long as one can think of what a possible variation in product design or process could accomplish, there is every reason to believe that much more can be done automatically in the way of loading and unloading automatic machines, and increasing the tasks which these machines themselves can accomplish.

Control

The problems connected with the control of automatic machines, (that is with the provision of automatic devices to start and stop, and to regulate machines -- the mechanisms which in fact make the machines automatic -- as well as the devices which permit several such machines to be connected together) are treated in the next two sections of this paper.

Machine Design

Clearly one of the major problems in making machines automatic is the problem of combining the potentials of new tool metals, easy automatic loading, control devices, etc., in the actual design of machines. It is very hard to draw a line at this point as to where machine design (which we do not propose to cover in this paper) begins and where other aspects of automation end. But the problem of automation is not chiefly the problem of our not having skillful enough machine designers, it is the problem (as stated in section two) of where the design of one large machine becomes uneconomical--and the problem of an alternative solution to fully automatic production. We do not believe that that problem will be served by more detailed analysis of machine design at this point.
V

AUTOMATIC CONTROLS

Thus far we have dwelt upon the problem of automatic machinery for performance of the fabricating and materials handling functions in the manufacturing industries. The next step in full mechanization is the provision of control devices for the automatic operation of this machinery. It is this problem with which we are concerned in this and the following sections.

The Concept of Control

Fundamentally control is the sending of messages which effectively change the behavior of the recipient. When dealing with control mechanisms, (or communication machines) we can classify these messages into two broad categories, 1) the messages which direct the machine to initiate its operation, state what that operation is to be, and determine the extent of the operation -- these are messages originating with man or another machine -- and, 2) the messages which inform the control device of the extent and direction of its own action. The first type of messages is called the taping (derived from the frequent use of paper or metal tape, with punched holes or magnetic areas acting as a coded form of input message) and the second type is called feedback.

There are, generally speaking, two classes of automatic control, based upon the two types of control messages. These classes are commonly called 1) open loop systems, and 2) closed loop systems. In the former the control acts in accordance with the dictates of some arbitrary quantity and the fidelity of action depends upon the linearity of the mechanism or on the calibration. In the latter the control acts in accordance with the dictates of an arbitrary quantity and in accordance with what happened as a result of the control operation. Linearity of the mechanism and calibration occupy a secondary role.

Time operated traffic lights are one example of open loop controls, since what the lights do or even what the traffic
does, cannot affect the time mechanism that operates the lights. Recently Denver installed a new mechanism whereby the traffic is counted every six minutes and the number of cars moving actuates the lighting schedule. This is a closed loop system. Another example of the open loop control is an automatic home laundry, for the degree of dirtiness does not affect the time the clothes remain in the washer. On the other hand, when mother washes the clothes she functions as a closed loop system because the time she takes at the task and the vigor of her actions are functions of the effectiveness of the washing operation.

The Open Loop System

It is often desired to control a force or motion, a hydraulic pressure or some physical quantity in accordance with another physical quantity. For example, a light flux may be used to control voltage or the weight of an object to control the intensity of sound. The agreement between the responding or controlled quantity and the signalling quantity may here be accomplished by means of an open loop or open ended control system as shown in the figure below. This class of controls is termed open loop because there is nothing in the mechanism that actually measures the result in the controlled operation and does something about it if the result is not what is desired.

The Closed Loop System

The essential requirements of a closed loop system are that the error between the state desired and the state existing is constantly measured, and if there is an error, something is done about it. A closed loop system is thus an error sensitive system. An
example of such a system is shown below.

Early examples of a closed loop control system are encountered in the control of temperature, speed, position, and the like. Many of these systems are now called servomechanisms, others are called regulators.

Servomechanisms

Servomechanisms were first successfully applied to industry and science for the automatic control of machines and processes several decades ago. Basically their sole function is to control automatically a given quantity or process in accordance with a given command. They have three predominant features:

1) They are a closed loop system.
2) They can establish control over a wide range of command.
3) They permit control of high power operations at a remote point from lower power operations at a local point.

In other words the servomechanism is an error sensitive, follow up amplifying system, permitting a wide range of input command, remotely located from the element being controlled.
PARTS OF A SERVOMECHANISM

1. A remotely located command or input station designated as ‘A’ in the figure. This is the INPUT.
2. An output or process designated as ‘B’ in the figure.
3. An error measuring means capable of measuring the difference between command and output. Designated as ‘C’.
4. An amplifier or controller, designated as ‘D’. It actuates a servomotor with some function of the error.
5. A servomotor designated as ‘E’. It operates the controlled member or OUTPUT.

Clarification of “Parts”

1. Command Station -- can be the pointing of a compass needle or gyroscope, for indicating the desired position or direction of a ship or an aircraft, of a delicate roller, or index in an industrial process; or the pressure of a force exerted by a spring for indicating the position or speed desired of a controlled member; the directive property of a radio wave reflected from a body moving in space (The command here calls for direction); a light flux whose magnitude is a measure of an integration or multiplication as in a calculating machine; a voltage or a current from a thermocouple used to measure temperature or any one of several physical quantities.
2. **Controlled Quantity** -- can be position or speed of a member such as a ship, airplane, automobile, gun turret, roller in a printing operation, cutting tool, or drum in an industrial operation, conveyor in a plant. In these examples the controlled quantity may be either position, speed or the like and the controlled member is the body whose position or speed is controlled in accordance with the command. For example, the controlled quantity may be temperature of a house or process, the element controlled may be either a valve regulating flow of heat or the fuel consumption necessary to establish the temperature desired by the command, a volume or quantity encountered in the process industries or the dairy industry. The element controlled would be the valve regulating the flow of fluid necessary to establish the volume or rate of flow desired by the command. In the case of an electromotive force of a power supply the element controlled would be the exciter furnishing the excitation necessary to give the voltage desired by the command.

3. **Error Measuring Means** -- has no standard form. It is difficult to distinguish it from the data transmission equipment that interconnects the input or controlled quantity with the controlled quantity. It constantly monitors the controlled quantity. It is made to indicate the difference between the input and output and to give an error signal as a function of time by appropriate design. It is sometimes called a summing device.

4. **Amplifier Controller** -- receives the error signal and supplies the necessary quantities or signals to the servomotor or controlled member. This unit serves as the brain of the system and if considered as a human being, takes the error signal and decides what the servomotor should do with it in order to establish the desired state of output. The amplifier portion usually converts from a power level encountered in the measuring process of -10 to the -15 power watts to a few watts.

5. **Servomotor** -- where used, is generally the element that operates the controlled member, quantity or process. It is often an electric motor, frequently a hydraulic motor or piston, but it may be a regulating valve, rheostat or clutch. It is generally energized by the amplifier controller and its response determines the future state of the controlled quantity. It may be required to overcome friction or inertia load as in gun drives or industrial machine controls. Frequently it must work against hydrodynamic pressure as in automatic pilots or flow control. Often it may actuate a valve or a rheostat or clutch to control power flow to a furnace or vat.

Frequently a servomotor does not exist. The fact remains that it is not easy to identify a member as a servomotor for the control element may be a generator which furnishes the control power as heat, or as current to output member.
Industrial Availability of Servomechanisms

Because of the uniqueness of function of the various servo systems it might be felt that these systems must be custom built, at high cost, for each job. This has been the case many times, but it need not be. And here we do not have to predict what can and might be done, for Servomechanisms, Inc., offers a line of packaged plug-in servo components which may be used as the building blocks for a complete servo system. A photograph of one of these units is shown below.

In effect, by use of these units, a new tool is offered to the industrial designer. Its successful application to automatic control problems does not demand that the personnel using it have extensive training in the servo component art itself. It enables the industrial designer to approach his control problem with a number of packaged components at his disposal with which to construct a servo loop. His task then becomes a system function, or one of combining these packaged units into servo loops that will meet his requirements, thus leaving the details of circuit design, servo stabilization, matching of components, etc., to specialists in the field.

This is but one case in which control devices are beginning to be put on the market in the form of standardized components. But it is a good one, for servo systems are highly complex, and ten years ago the predictions that servo systems could be made cheaply enough for everyday industrial use was looked upon as something of a dream. In our later section on computing devices we make a similar prediction as to mass production of computer circuit components. Such a development is today laughed at by many.
Norbert Wiener’s Cybernetics

Before proceeding to a description of how these control systems are used in specific industrial applications it may be well to explain something of Norbert Wiener’s recently introduced theory of Cybernetics. The word itself is the latinized Greek word for steersman, and Wiener applies it to the study of communication in man and animal. The communication concept of control was mentioned at the beginning of this section. Wiener’s primary thesis is that the control process in machines is very similar to that in the human and animal nerve and muscle system. The analogy is a good one for explanatory purposes, and for this reason we have quoted a summary passage from Wiener’s second volume on the subject, The Human Use Of Human Beings. In actual development use the value of the concept is doubtful, for at times Wiener seems almost obsessed with the similarity between animal and machine systems, to the exclusion of some facts. And the psychological basis of his work is strictly behavioristic, stemming from Watson’s physiological and psychological teachings, which are felt by many to present but a limited concept as to the workings of the animal nervous system. Nevertheless, the analogy is a good one for explanatory purposes, particularly before presenting examples of the industrial application of controls. In reading the following passage it should be remembered that ‘communication machines’ and ‘control mechanisms’ can be used interchangeably in Wiener’s writings.

“It is my thesis that the operation of the living individual and the operation of some of the newer communication machines are precisely parallel. Both of them have sensory receptors as one stage in their cycle of operations; that is, in both of them there exists a special apparatus for collecting information from the outer world at low energy levels and for making it available in the operation of the individual or of the machine. In both cases these external messages are not taken neat, but through the internal transforming powers of the apparatus, whether it be alive or dead. The information is then turned into a new form available for further stages of performance. In both the animal and the machine this performance is made to be effective on the outer world. In both of them, their performed action on the outer world and not merely their intended action, is reported back to the central regulatory apparatus. This complex behavior is ignored by the average man, and in particular does not play the role that it should in our habitual analysis of society.”
The Use Of Controls In Industry

This has been a description, in the broadest possible outline, of the principles of industrial control systems. The specific ways in which control problems have been mechanized are endless. Devices for sensing and measuring the important types of measurable physical quantities have been developed. These quantities include light, speed (linear and angular), hydrogen ion concentration, temperature, gas pressure, electricity, mechanical movement of solids, gasses and liquids, and liquid levels. In addition to these sensory devices such basic control elements as the vacuum tube and the potentiometer permit the execution of control at low energy levels. They have been combined with the sensory devices and with effector mechanisms -- the machines upon which we have already dwelt -- in an infinite variety of systems. All that we can hope to do here is to give some indication of the general approach to control, which we have tried to do, and of the means at the disposal of those attempting solution of control problems -- which we attempt to do by giving a variety of examples of control problems and solutions already working in industry. These illustrations are in the form of an appendix to this section. It in no way claims to be complete. The illustrations have been selected for the variety of the approach and the diversity of the problems.

APPENDIX TO SECTION V

Photoelectric devices            Color densitometer -- The McBeth-Ansco Company is producing devices to determine color densities through photoelectric measuring using electron multiplier tubes. The primary uses of this type of instrument appear to be: 1) precise determination of textile and paint colors; 2) an accurate measuring of the transmission of color filters; and, 3) the control instrument replacing manual spectrophotometer.

Electronic Counting -- Photoelectric counters can be applied to the counting of any objects which are in motion. They are used to count production moving along a conveyor system, and production coming from the output of automatic machines. A standard photoelectric counter can be applied to the counting of practically any size or shape of object. Use of photoelectric counting equipment is not limited to conveyor systems handling objects so spaced as to allow a beam of light to project across the conveyor. When conditions are such that items to be counted cannot be separated on a conveyor, it is still usually possible to devise methods of installing photoelectric equipment to provide an accurate count. Typical of this is an application in a cannery where it is desired to count the output of cans even though they are in contact with one another. A drawing of this application, showing how the problem of continuous contact of cans was overcome, is shown on the following page.
Tin Cans that have been processed are continued along assembly line where they interrupt a light beam. This 'interruption' is converted to electrical impulse that activates a counter.

USE OF A PHOTOELECTRIC COUNTER WHERE PRODUCT UNITS ARE IN CONTINUOUS CONTACT

Electronic Timing — An example of photoelectric timing exists in a steel strip mill whose management wanted to maintain a running total of sheet steel yardage being processed in connection with more accurate determination of piece rate. Since the velocity of the output conveyors was constant, production could be measured by totaling the time during which conveyors were loaded, thus interrupting a beam of light. A time totalizing chart-type recorder was used to record the amount of time during which the sheet metal was interrupting the beam of light.

Photoelectric Register Control for rotogravure multi-color presses. These control units which are built into the presses at the time of manufacture, provide a means of making certain that the three primary colors to be printed will be placed in the correct positions with reference to each other. An installation such as this was first used at the plant of the Philadelphia Inquirer in 1939. Each printing cylinder is engraved with equally spaced register marks. For high speed presses (1000 ft./min. or more) twelve marks per printing cylinder revolution are recommended. Fewer can be used. The more marks, the less the error can be built up before it is corrected. The first cylinder prints a series
of evenly spaced scarcely visible register marks on a track of the web. The track need not be clear of other printing.

A photoelectric web scanner, located as close to each of the printing cylinders as possible, views these register marks and generates a pulse each time a mark passes under its beam. At the same time the web position indication is taken at each printing unit. The position of the printing cylinder is checked by the unit cylinder scanner or the master cylinder scanner. A cylinder scanner also sends twelve position indicating pulses for each cylinder revolution by means of photo tube head viewing slots accurately cut in a drum in the unit cylinder scanner rotating with fixed speed relationship to the corresponding press cylinder. Web position pulses and cylinder position pulses are fed to the control panel and both sets of pulses are compared in time relationship. Panel provides correction by sending power proportional to the amount of error to the correcting motor and misregister is quickly corrected. No dead zone (which requires a definite amount of misregister before correction occurs) is used in this system. All circuits are electronic and no time is lost by solenoids operating.

Controls for each press unit are provided from an explosion proof push button station. The stations for all units are lined up together at a central point of press operation along with a master control station.

Cut-off Register Control -- Most bag or tube making machines -- for production of candy bar wrappers, etc. -- are fed from large preprinted rolls. It is impossible to maintain register of cut off without a suitable control which will compensate for such factors as draw roll slippage, web stretch, differences in web speed relative to cutter speed, and dimension changes of the web caused by drying in the printing process.

Although the rate of run out may be very small, the error is generally cumulative which causes the amount of misregistration to increase directly with the length of the web consumed. The cutoff register control will automatically correct for all these variables. It is manufactured by the General Electric Co.

The scanning head obtains an indication of web position from the register marks on the edge of the web. At the same time a selector switch provides an indication of the position of the knife. These signals are compared by the electric panel which controls the output voltage of a small generator in such a manner
that the correcting motor speed is increased or decreased as necessary to maintain register. It is thus possible to maintain an accuracy of about 1/64th of an inch.

**Side Register Control** -- A photoelectric scanning head observes the position of the edge of the moving web (or a printed line on the web) and produces a signal voltage. This voltage is indicative of the direction and amount of deviation of the web from the desired position.

The signal from the scanning head is amplified by an electron control panel and is used to control either contactors or the correcting motor directly, or to excite the field of an amperedyne generator.

This type of device has been used on such machines as slitter rewinders, side trimmers, and textile tenter frames.

**Positioning Control System**

A positioning control system is used to adjust the angular position of one rotating shaft or object in accordance with a shift in angular position of another rotating shaft or position indicator.

The master control potentiometer is moved to its desired position. The follow up potentiometer is thus put out of correspondence with the master control potentiometer and an error signal results. The error signal is amplified in two stages by electron tubes in the electronic control panel and energizes the coil of the forward relay. This closes the contacts of the forward relay completing the motor circuit and causing it to run in a forward direction, thus driving the follow up potentiometer into correspondence with the master control potentiometer. The error signal becomes weaker. When the error signal is reduced to a preset value (the dead band adjustment) the forward relay drops out, de-energizing the motor and allowing the motor to coast to a stop at the desired position. A drawing appears on the following page.
Inspection Machines

The Arma Company of Brooklyn, New York, manufactures an automatic electronic inspection system which inspects, counts and classifies metal parts up to 1 and 1/2 inches in diameter. Unskilled or even blind workers can operate this machine, and in several applications inspection speed has been increased by 100% on such items as nuts, bolts, and small stamped parts.

Counters

Counting mechanisms commonly used today are actuated by three types of impulses: electrical current, mechanical movement and photoelectric beam interruptions. A counter based on input through electrical current can be exemplified by a mechanism...
designed by the Potter Instrument Company to be used in precision coil winding.

PRECISION COIL WINDING

In this application, the electromagnetic pickup coil is used for detecting shaft revolutions. The desired number of turns is selected by means of preselection by an operator. For each shaft rotation or turn applied to the coil, a count is injected into the counter. At the completion of the predetermined count, the output relay closes and there by actuates the brake or motor control to stop the rotation of the coil after the proper number of turns has been wound.

Mechanical movement of a stylus is the initiating impuls of an electronic counting mechanism which is used to count paper sheets which have been fanned or riffed to provide a step-like edge. The stylus is run down the stepped edge, generating a count as it drops from sheet to sheet. This method of counting may also be adapted to thicker material than paper such as cardboard, plywood, tinfoil, provided ofcourse that a stepped edge is available to be counted. It can also be used to count serrated edges such as presented by stacked can ends, gear teeth and other materials which have distinct edge.

A drawing of one application of this method of counting appears on the next page.
PAPER SHEET COUNTERS

Another method by which mechanical movement can be utilized as the initiating impulse for a counting mechanism is one in which objects are counted electro-magnetically by being dropped one at a time on an inclined plate where a pulse is generated for each impact. Since this type of detector responds to the impact, the part may be of any shape or material. Photoelectric beam interruption as a means of providing input to a counter has previously been covered in the section on photoelectric applications, particularly those used on conveyor belts.

The result of the counting action by each of these three types of counting mechanisms is either recorded in some manner as an indicating dial, or it may be used to activate some effector mechanism when a preset value is attained.

Liquid Level Control

Two types of liquid level controls are generally used today. The most common of the two consists of a float attached to an arm whose lever action serves to mechanically operate a switch or valve controlling the activation of a power source when a specified level is attained. This power source usually supplies the liquid which permits renewed reaching of the preset level.
A second type of liquid level control is accomplished through the use of two probe rods which can be suspended into a tank. The probe rods project into the tank to the levels corresponding to the low point at which pumping is to start and the high point at which pumping stops. When the liquid in the tank falls below the lower probe, the level control closes the electrical circuit controlling the pump and the tank fills. When the liquid rises to the level of the upper probe, the fluid itself acts as conductor of the minute current required for the operation of the liquid level control. This opens the electrical circuit operating the pump and the pumping operation stops. For pumping out control, these are reversed.

An example of this second type of liquid level control exists in the automobile industry where the filling of automobile radiators on completed cars has been speeded up with a considerable saving in labor costs. Special nozzles incorporating a liquid level probe mounting in the cap of the hose are used. A 24 volt solenoid valve is mounted immediately above the filler spout and is operated by the level control. As soon as water in the radiator rises to the point of contact with the liquid level probe tip, the level control deenergizes the solenoid valve which turns off the water.
Variable speed drives

The General Electric Company has developed a control mechanism which can vary the working speeds of AC and DC motors from 1/4 to 30 horsepower in such a manner that sufficient power is available for normal work loads at slow speeds. Speed ranges of up to 250 to 1 are possible under certain conditions. When equipped with a tachometer feedback device this equipment, called Thy-mo-trol, can hold the predetermined speed to an accuracy of less than 5%. Any number of motors can be operated using this device.

Simplified Schematic of A typical THY-MO-TROL Drive (General Electric Co)

Four situations in which Thy-mo-trol equipment has been adapted with success include: 1) a wire drawing machine on which the speed of the motor can vary from 60 to 1380 rpm depending on the size of the wire being produced; 2) over 1200 units in service in full fashioned hosiery knitting mills where 100 speed variations are required during the course of the production cycle, 3) a chemical manufacturer who was able to put production of phthalic anhydride on a continuous basis by maintaining the correct flow ratio between molten naphthalene and air, 4) a tire manufacturing company which matched the speed of an output conveyor system with the speed of an extrusion machine producing tire treads.
Hydrogen Ion Content Control

The direct electrical measurement of pH consists of measuring the potential difference between suitable electrodes immersed in a solution under test. Modern technique uses a glass electrode having a thin membrane of high conductivity glass as a barrier between the test solution and a half cell of constant electro-magnetic force. The potential difference between this half cell and a suitably made connection to be sampled is directly proportional to the hydrogen ion concentration. This kind of control equipment is used extensively in the paper, textile, chemical, distilling, steel making, and water filtration plants.

A steel plant utilizes this process to properly neutralize the river water which it needs for plant operation. In this system, changes in temperature as well as measured pH have to be taken into consideration in controlling the acidity of the water. The electromotive force of the controller’s potentiometer circuits is balanced against the voltage of the control instrument’s slide wire. Because the voltage is modified by the action of the temperature compensator, the balancing operation is influenced by the pH change and by temperature change so that the resulting value is in terms of actual pH at the operating temperature. Should the pH of the water begin to deviate, the resulting change in emf generated by the electrodes is promptly measured by the controller. Acting through its unit control mechanism, the controller immediately begins to increase or decrease reagent flow. The amount of this increase or decrease is proportional 1) to the extent of pH deviation from the control value, and 2) to the length of time the deviation exists. By means of a dial operated by hand, the flow can be corrected.

Combustion controls

The purposes of combustion controls, when applied to steam boilers for instance, is to: 1) regulate the flow of fuel needed to produce the required amount of steam, and 2) to regulate the air flow with respect to the highest combustion efficiency. While the maintenance of a reasonably constant steam pressure is of varying importance to the nature of the plant process and power equipment, the most important function is the proper control of air flow, since that alone determines the relative cost of operation of the plant.

Simplicity of design is possible because only two variables are being measured and controlled, that is, steam pressure and the visual density of the boiler exit gases.
A system in operation consists of 1) a master regulator (fuel oil valve, master pressure selection station, and remote control stations), 2) photoelectric air flow control (analyser consisting of energized lamp assembly and photoelectric cell assembly), 3) controller and haze indicator, and 4) electric power unit and remote control station.

When the steam pressure declines, the master regulator operates to increase the oil flow until the desired steam pressure is restored. Simultaneously through an electrical connection, it causes the air flow power unit to change at approximately the same rate as the air flow. The photoelectric cell analyzes the visual density or haze of the gases in the breeching and causes the damper power unit to reposition the damper to correct any error in the air flow, thereby maintaining the proper fuel to air ratio.

Temperature and Pressure Controls

Through the use of either spring wire thermometers or Bourdon tubes (for pressure measurement), the commonly used temperature and pressure controls operate to trip a switch upon the accomplishment of a preset temperature or pressure. There appears, however, to be little industrial application of temperature or pressure controls. As has been shown earlier, such controls are built into systems which are usually sensitive to more than one measurable quantity.

3) Special control systems are possible which incorporate several types of sensory devices, but which are attended by an operator. An example of this type of control exists in the mental system manufactured by the Leeds and Northrup Company for the control of rotary kiln operation. Bicycles are used to measure the temperature of the kiln lining, a thermocouple measures the temperature of the feed of preheated air, the speed of the rotary motion is measured by a tachometer, and the draft of air flowing through the kiln is regulated by an air pressure regulator. Each of these variables, namely temperature, air draft, and speed of rotation, is recorded automatically on a paper chart, and is automatically controlled through valves, dampers, and variac speed drives on the power source. The operator's function is that of preserving the control instruments in order to indicate the desired performance from the kiln.

3) Coordinating devices exist which need no human attention. Numerous examples of such single function devices exist. They are most numerous in the areas of photoelectric controls, combustion controls, and servomechanisms. Here the control system itself is complete, acting upon sensory information, and in closed loop systems correcting its action.

Appendix to Section V
VI

COMPUTING DEVICES

It is the object of this section to explore what is done with the information which the "sensory" devices gather; to tell something of the use of computers in handling such information; and to give a brief description of the construction and operation of computers suitable for handling industrial problems.

How is the information supplied by industrial sensory devices used?

At the present time there are three methods being used in reading and acting upon the impulses emitted by the sensory devices of industry. There three methods are:

1) A man can visually attend a series of sensory mechanisms and take action based on what he sees. An example of this occurs in a textile mill when an operator watches the yardage output of a series of looms through the use of individual yardage counters attached to each loom and connected to a central control board which indicates what each loom has produced during the shift.

2) Special purpose systems are possible which incorporate two or more types of sensory devices, but which are attended by an operator. An example of this type of coordination exists in the control system manufactured by the Leeds and Northrup Company for the control of rotary kiln operation. Rayotubes are used to measure the temperature of the kiln lining, a thermocouple measures the temperature of the input of preheated air, the speed of the rotary motion is measured by a tachometer, and the draft of air flowing in is regulated by an air pressure regulator. Each of these variables, namely temperature, air draft, and speed of rotation, is recorded automatically on a paper chart, and is automatically controlled through valves, dampers, and variable speed drives on the power source. The operator's function is that of presetting the control instruments in order to indicate the desired performance from the kiln.

3) Coordinating devices exist which need no human attention. Numerous examples of such single function devices exist. They are most numerous in the areas of photoelectric controls, combustion controls, and servomechanisms. Here the control system itself is complete, acting upon sensory information, and in closed loop systems correcting its action.

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Perhaps the most fully automatic control systems being used today are in the electric power generation, chemical, and steel industries. As an example, at the Sunbury Station of the Pennsylvania Power and Light Company, operations have been placed under automatic control to the extent that eight boilers producing steam for electric power generators are operated by a work force of six men per shift. These generators produced 274,811,000 kilowatt hours of electricity in 1949.

What are the limits to automatically using sensory information?

Simple closed loop systems provide completely automatic operation. Therefore, cannot the automatic factory be built around such control systems? The answer is both 'yes' and 'no.' Simple closed loop systems -- control systems in which feedback is used as well as original taping in control -- can be used to control a small number of variables, such as occur in the operation of a device or simple process. But where one is talking of automating an entire factory, or any large, many-variable system, something more than the devices mentioned above is needed. It is here that computers come into use industrially.

A computing machine is a device which handles a number of variables, manipulating them in a predetermined and variable manner, and producing answers, or output, logical according to the rules built into the machine. Computing machines are classified as either digital or analog. A digital device, as the name implies, is one which performs mathematical operations with numbers expressed in the form of digits which can assume only discrete values. The results yielded by such a device are expressed in digits. The precision of such a machine is determined by the number of digits which can be handled. An analog computer is one in which numbers are converted for purposes of calculation into physically measurable quantities such as lengths, voltages, or angles of displacement. Computed results are obtained by the interaction of moving parts or electrical signals. The precision of results, as contrasted with a digital device, depends upon the precision with which the machine is fabricated, the skill with which it is operated, and the precision with which the answer can be read.

At the present time neither of these types of computers has come into wide industrial use. Analog computers will be used to an increasing extent in the control of machine tools, in the operation of certain processes, etc. But for overall factory control, for the programming of production, and for the coordination of the fabricating and materials handling machines of an automatic production line, it is the digital computer to which we must turn.
Digital computers provide the accuracy which is needed for the overall control of an automatic factory, and they serve as a check to the possibility of a cumulative error which might occur if analog computers were used. A digital computer is actually slower in operation than an analog machine, however, slow in this business is no hindrance industrially. Early in our study Professor Howard Aiken, Director of the Harvard Computation Laboratory, laughingly told us, "The units one uses in the computer business are micro-seconds and mega-bucks." And it is the need for micro-seconds in the very complicated mathematical work for which these machines were first built, that produces the cost in mega-bucks. The greatest cost of computers -- and the magnitude at present is two to three million dollars for a full scale machine -- is the cost of making them react in micro-seconds. For industrial process control, even for control of a large plant, reactions in a tenth of a second could be fully adequate. In addition, the cost of computers at present is very much a function of the custom building. An order for a small number of similar machines could substantially lower this cost, since a great number of repetitive circuits are used in each machine, thus leading to mass production of the circuits, even though the total number of complete machines demanded was small. Added to this is the fact that present computers are used for solving a great variety of mathematical problems, thus they must be fully flexible. A machine designed specifically for use in an industrial plant can be much simpler, and less flexible, consequently much cheaper.

But how, specifically, can a computer be used industrially? One example is the coordination of a number of production and assembly lines. The great number of variables now handled by the production planning and expediting people could be easily and automatically handled by a computer. The great headache in developing such a system is of course the problem of taping, or building in the "memory" necessary for the machine to act in the manner desired, and the development of input taping, so that changes in production rate, etc. make sense to the machine. It is very difficult to talk about these machines without going further into the details of their construction. For those not desiring to do this it is enough to know that a computer makes logical choices between a series of two alternatives, going from one to the next. The machine can be applied to any task requiring logic. The chief problem in applying them industrially is the problem of determining all the many alternatives to a particular set of conditions -- alternatives which human operators carry about in their heads, and which do not occur to one until the task of drawing up a computer schedule is faced.

We turn now to a discussion of computer machines, their construction, theory, and operation. Such knowledge, in the general manner presented here, is necessary before one can intelligently consider their industrial possibilities.
Basic Theory, Construction, and Operation of Computing Machines

The basic components required for general purpose computing machines are: (1) the input system, (2) arithmetic techniques, (3) a system of operations (including arithmetic elements, storage, and control), and (4) the output system. The input system more nearly defines the use to which a machine can be put than does any other component. There is no universally applicable input system. Some computers use manually operated keyboards, others punched cards, and still others utilize perforated tapes. Arithmetic techniques must be used in the solution of problems introduced through the input system. The solution must be evolved from a utilization of mathematical processes and engineering processes working together. Systems of operation consist of a programming of successive arithmetic steps, together with storage functions. If the computer is not to control a process, and the process continues during the calculation, then the output may be some sort of on-line device including facilities for transmitting a digital output to continuously variable control signals. If the output is a printing device, it is important to avoid letting the printer retard the speed of the computer.

Counters

Counters are essential in computing machines. Ordinary desk calculators utilize a ten position adding machine wheel. This mechanical counter can be transformed into an electromechanical counter by the addition of ten position contacts and pickup wipers. With this modification, the stable state of the wheel is determined electromechanically, and the influence of the wheel on the other components is completely electrical. An example of such a device is the counter developed for card tabulating purposes. Among the few large-scale computing machines, there is at least one, the IBM Automatic Sequence Controlled Calculator (Harvard Mark I), the entire action of which is based on the use of such electromechanical devices.

The vacuum tube's characteristic "flip-flop" configuration allows the tube to be used as a counter. As each electrical impulse enters the tube, a two position switch is thrown to its opposite position. If the original position of the switch is known, it is possible to determine whether the number of impulses entering the tube has been odd or even. This principle is readily adaptable to counting in a binary number system, described below. A single tube acting in this manner is known as a modulo 2 counter. Two such tubes connected together are known as a radix 2 counter.
(2) The binary number system admits the marks 0 and 1 at each digital position, and no others. This system is used frequently in automatic computers, for many of the basic circuits, such as the flip-flop, naturally assume two stable states and are therefore convenient to use with binary numbers. The following table best illustrates the equivalence between decimal, binary, and the octal numbering system described in the following paragraph.

<table>
<thead>
<tr>
<th>Decimal</th>
<th>Binary</th>
<th>Octal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>2</td>
<td>10</td>
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<td>3</td>
<td>11</td>
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<td>4</td>
<td>100</td>
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<tr>
<td>5</td>
<td>101</td>
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<td>7</td>
<td>111</td>
<td>7</td>
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<td>8</td>
<td>1000</td>
<td>10</td>
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<tr>
<td>9</td>
<td>1001</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>1010</td>
<td>12</td>
</tr>
</tbody>
</table>

(3) The octal numbering system will allow 8 admissible marks in each position. This system is of interest because of the easy transformation with which binary numbers can be changed to octal numbers. The ease of transformation stems from the fact that new digital positions are necessary as each new exponential power of the decimal number "8" is accomplished, while the binary system requires new digital positions each time a new power of the decimal number "2" is accomplished.

(4) The biquinary-numbering system is used as a convenient equivalent to the decimal system in the machines produced by the Bell Telephone Laboratories. This system is one in which the decimal system is factored. The sum of a pair of successive marks can be considered in the place of the decimal mark itself, there being 10 such pairs. For example, the decimal numbers "4" and "8" would be represented by the biquinary notation 04 and 53 respectively.

Numerical Analysis

Types of numerical analysis performed by current
transmission to some other part of the equipment, such as another ring. A large number of gates are used for the purpose of signal preservation and actually have nothing to do with arithmetic operations. They are required solely for signal preservation and pulse shaping. A gate may be used to allow a standard master pulse which is continuously generated and available throughout the computer to be combined with the distorted signal in such a way that a properly timed and shaped portion of the distorted signal is selected by the master signal. This selected portion is then passed on to the rest of the equipment. This type of signal preservation or pulse standardization is required in all machines using pulses spaced at 10 micro seconds or less.

There are four primary types of switches used in computers. Manually operated non-automatic switches are often used for the programming of operations; and the insertion of constants. Electromechanical relays, energized by an electric current, are relatively slow in operation, but are quite cheap costwise and introduce very few errors. Vacuum tube gating circuits operated in such a manner that the output is activated only when two input circuits are operative. Resistor matrices have been used in electronic gating. Their chief disadvantage lies in the small amount of power which they are capable of handling, amplifier tubes being necessary at intermediate stages of the unit.

Most commonly used gates and switches operate in such a manner that the electrical current will pass through the gate upon activation. A group of switches and gates known as inverse gates or buffers are used in many electronic circuits applied to computing machines. They differ from the commonly used switches only in that the inverse gate or buffer will shut off the current when activated.

Arithmetic Systems

Descriptions of four basic arithmetic systems which are currently applicable to computing machines will follow.

(1) The decimal system is universally understood. Its chief significance to its adaptation to computers is that the 10 admissible marks in any one digital position are not dependent on the marks made in any other digital position.
Counters known as R-triode counters and 2R triode counters - modulo R represent developments of the flip-flop principle which enable greatly increased speeds of computation. Such tubes are now being used at the Aberdeen Proving Grounds in ENIAC.

These tubes consist of decade rings making use of successive flip flops. This permits a modulus of 10, which is usually the highest modulus possible with ordinary sources of power. A carry over effect between each decade ring permits use of a decimal numbering system. ENIAC can thus handle up to 20 digits at a time.

To date, the major considerations effecting the cost of elementary computing components (such as counters) has been in developmental charges and in military adaptations. Cost figures for currently manufactured desk computers ($600 to $800) can be taken as representative of what mechanical counters are likely to cost in the future. Regarding elementary "flip flops" or decade rings, the costs have not been closely governed by the operating speeds involved. Labor, rather than materials, have been the largest item of expense. The introduction of printed circuits should serve to bring down substantially the costs of computers in the future.

Switches and Gates

One of the principal differences between a series of ordinary desk computers and a high speed electronic computer is the ability of the latter to switch numbers. These numbers can represent either intermediate solutions or coded instructions from one arithmetic or control unit to another, between arithmetic and control units and storage, or between the storage and input or output equipment. Such switches are known as gates, and consist of an off-on switch in which the passage of one electrical signal is controlled by the presence of one or more other signals which hold the switch on or off.

Switches and gates are used for data switching, data conversion, and signal preservation. In switching data, a number transfer bus is used to connect the output of one component to the input of the next desired component. ENIAC provides a good example of data conversion. Data is sometimes stored statically in vacuum tube circuits and transmitted serially in trains of pulses. The conversion which takes place is one in which a given number represented on the ring counter (the digit 7 represented by the seventh flip flop in the ring, for example) is transformed into a train of seven pulses for
large scale digital computers include linear interpolation, interpolation of periodic functions, numerical integration, solution of algebraic and transcendental equations, solution of simultaneous linear equations, numerical differentiation, and the solution of differential equations.

Types of Calculators

Three general types of digital computing systems have important possible industrial applications. The three types to be so discussed are desk calculators, punched-card computing systems, and large scale digital computing systems.

(1) Desk Calculators-- Desk calculators are capable of performing simple arithmetic operations quickly and simply. They are not intended to compete with electronic computers of large capacity and high speed. Of the five different types manufactured, three (the Friden, Monroe, and Marchant) are most widely used. They are comparable in cost and speed of operation with the exception of the Marchant which has the advantage in speed of addition and subtraction. A competent operator can handle 400 full-length (10-digit) products or 1000 sums during an 8-hour day. For computations of this magnitude, the desk calculator is most economical. Its speed is low enough to permit continuous exercise of judgement by the operator.

(2) Punched-Card computing systems-- Punched card computing systems operate with greater speed and accuracy than desk computers. Three main features make this possible: (1) Automatic transcriptions of output data, (2) Automatic programming of operations possible through the use of wired control panels, and (3) Automatic checking devices built into the mechanism eliminate errors.

There are two primary manufacturers of punched-card computing equipment: The International Business Machines Co., and the Remington-Rand Corporation. IBM equipment is most prevalently used for scientific work. Devices are manufactured by each of these companies for transcribing the cards of the other into cards usable by their own machines.

All punched-card computing equipment handles cards with holes punched in them. Some IBM equipment recently
developed will handle cards with the data arranged in the form of graphite deposits left in a pre-determined pattern. The cost of cards for either purpose is about one dollar per thousand.

The main difference between the IBM and the Remington-Rand cards is that the IBM cards makes use of a field containing 80 vertical columns and 12 horizontal rows, while the Remington-Rand card utilizes an upper and lower field each containing 45 vertical columns of 6 positions each. Alphabetical material can be entered on either of these cards through combination punching in any one vertical column.

Input mechanisms to the IBM and Remington-Rand machines are very similar. Both can utilize punched cards or perforated tapes. Output mechanisms from devices such as wind tunnels and precision measuring equipment (such as comparators) have been electrically connected to key punch mechanisms which in turn automatically punch the cards.

Specific operations performed by punch card computing systems include counting, sorting, consulting tables, addition, multiplication, division, and the printing of results.

There are six different machines manufactured by the IBM Company which perform all the operations necessary in the computing currently possible. These machines are the sorter, the collator, the tabulator, the electronic multiplier, the calculating punch, and the electronic calculating punch.

The sorting machine is a device which separates cards into 15 pockets depending upon the position punched in a specified column. Counting may be done with sorting equipment if desired. Sorting can be performed at a rate of 450 cards per column per minute. The newest machines sort at a rate of 650 cards per minute.

The collator will perform more complicated re-arrangements of cards than the sorter. The machine has two feeds and four output pockets. It is particularly useful in the consultation of tables, or in the inter-filing of two decks of cards. The collator works at a speed of about 240 cards per minute.
The tabulator will perform the functions of addition, subtraction and counting. The output of this machine is released either through a printing mechanism or through a summary punching of the input cards or possibly a new card.

The electric multiplier will multiply up to two 8 digit numbers and produce products up to 16 digits. One of the numbers to be multiplied has to be in the input card. The other number can either also be on the input card, or can be contained on a separate master card held in the machine. Two 12 digit numbers and one 8 digit number can be added or subtracted on any one card. The speed of this machine ranges between 730 and 1000 cards per hour.

The calculating punch will add, subtract, multiply and divide. The output, of course, is not printed, but is punched in the card. The speed of this machine is largely controlled by the time required for punching.

The electronic calculating punch can use all arithmetic methods and can program up to 60 successive steps. Calculation and storage components are electronically operated. Approximate speed of operation is 80 milliseconds per card.

The Remington-Rand equipment available is generally comparable to IBM's for general calculating purposes. However, Remington-Rand does not presently manufacture any machine of the capability of the IBM electronic calculating punch. The outstanding mechanical difference between the two makes of machines is that the Remington-Rand equipment operates entirely on mechanical contacts, while IBM's contacts are largely electromechanical.

IBM equipment is available on lease only. Remington-Rand equipment can either be purchased or leased.

The IBM Company has recently introduced a new calculator which combines several IBM units in a sequence controlled machine. The master unit consists of an Accounting Machine which controls and tabulates the output. Each card inserted in the input carries 8 digits of instructions specifying the location of the
components to be activated in the computation. The counters on each of the 80 columns of the control unit are utilized for internal storage. Punch cards are used for external storage, but can be supplemented by a storage unit capable of handling 16 ten digit numbers which have been relayed to it from a component similar to the electronic calculating punch previously described. This calculator will accomplish 2000 additions or subtractions per second and will multiply and divide 86 times per second.

(3) Large scale digital computing systems - Four large scale digital computing systems using electromechanical relays as primary elements in the arithmetic, storage, transfer, and input-output units are in operation. These four large scale digital computing systems are Harvard Mark I, Harvard Mark II, the Bell Telephone Laboratory's Relay Computing Systems, and the IBM Pluggable Sequence Relay Calculator.

Harvard Mark I - Howard Aiken of Harvard University, T. J. Watson of IBM, and three others developed this machine, starting in 1939. The relays, counters, cam contacts, typewriters, card feeders and card punches employed in this calculator are all standard parts of the tabulating machinery manufactured by IBM.

The external outline of Mark I consists of a 51 foot panel, 8 feet in height, and 6 feet in depth. Along the 51 foot panel are mounted: (d) the sequence control which directs the programming with punched tape, (2) three interpolators which are tape fed units for selecting data required in the interpolation process, (3) functional counters for controlling the interpolation of functions, as well as controlling the printing mechanism, (4) a multiplying-dividing unit for 23 digit accuracy, (5) 72 storage counters for the intermediate storage of results up to 23 digits capacity, and (6) a storage unit with a capacity of 60 23 digit numbers which can be introduced to the machine by manually setting dial switches. The mechanical drive for this computer is a 4 horsepower electric motor. The total assembly weighs approximately five tons.

The machine operations are controlled by orders introduced on a coded 24 hole punched tape which consists of three columns of eight holes each. This input tapes also controls the time which is required for the tape to add two numbers, since it is that time which is required for the tape to move one step forward. The control tape can be advanced at the rate of about 200 units per minute.
Mark I can perform arithmetic operations on numbers up to 23 digits in length. Addition and subtraction are performed with a set of 72 electromechanical adding-storage registers which can store 23 digit numbers and can combine numbers which are generated by the machine in the course of its operation.

The 72 registers used in the arithmetic operations provide intermediate storage. Numbers are transferred from one part of the machine to another by timed electrical pulses of 50 volts amplitude on a single transfer bus. It is not therefore possible to transfer simultaneously more than one number.

Harvard Mark II - This calculator was designed by Harvard University for the Naval Proving Ground at Dahlgren, Maryland.

Mark II uses electromechanical relays for the internal storage of numbers, for the transfer of numbers, for performing basic arithmetical operations, and for sequence control of these processes. This machine handles 10 digit decimal numbers. The addition of 2 ten digit figures consumes 125 milliseconds, while the multiplication of 2 ten digit figures requires 250 milliseconds. About 100 ten digit numbers can be stored in the machine. Additional internal or intermediate storage may be supplied by punching data on tapes for introduction to the machine at a later time. The machine registers its results on punched tape.

This calculator has 12 input mechanisms for introducing commands and numbers to the machine. All of these input mechanisms employ a punched paper tape. Commands are introduced to the machine on one group of four input tapes. Another group of four input tapes introduces numbers to the machine in any prearranged order. The remaining group of four input tapes is used for supplying the calculator with coded tables mathematical functions. 800 functional values can be introduced on these punched tapes.

Results are recorded through the use of four page printers, or can be punched in paper tape for future use, if needed.
Six algebraic and transcendental functions are stored permanently within the machine. These functions are the reciprocal, the reciprocal square root, the logarithm, the exponential, the cosine, and the arc tangent. These functions can be calculated for any problem to 8 or 9 significant figures during a time period of 5 to 12 seconds.

Bell Telephone Laboratory's Relay Computing Systems - The Bell Laboratory began to design its computing system in 1938, using the apparatus and circuit design techniques used generally in the dial telephones. Six types of computers, designated Models I to VI have been built. Models V and VI are in the large scale computing machine class.

The input mechanism of Model V is similar to that of other digital machines. It introduces both numbers and orders to the machine on a perforated paper tape. About 2 seconds are required for the machine to read and transfer in a seven digit number of average length. Addition can be carried out in 0.3 second, multiplication in about 1.0 second. Input speed of the numbers is therefore slightly lower than the unit time of operations for the machine.

The essential difference between Bell's system and the other electromechanical calculators is the biqinary number system which it employs as contrasted to the binary system generally used.

The machine can store 30 seven digit decimal numbers. A unit of 62 relays, required to store one seven digit number, is called a register. The BTL machine has 44 such registers, 30 for storage, and 14 for performing other operations.

BTL's recently developed machine, Model VI has been constructed in similar fashion to Model V. Its chief feature distinguishing it from Model V is that the input and output mechanisms are attached to the machine through remote control.

IBM Pluggable Sequence Relay Calculator - This relay calculator operates on numbers read from punched cards, undertakes a sequence of operations activated by relay networks, and punches the results of these calculations on cards. The machine has
a total of 36 storage and computing registers. The normal capacity of the machine is 8 digit decimal numbers, although higher capacity than this can be obtained with sequence operation. In comparison with the standard IBM calculating punch, this calculator has a very high operating speed. It is approximately 10 times faster on all operations than the calculating punch.

Electronic Computing Systems in Operation

In order that more complicated physical and mathematical problems may be solved in an economical time interval, the operating time for automatic computing systems must be decreased wherever possible. By using electronic vacuum tubes for switching, storage, and arithmetic functions, a saving of time on these functions is effected over devices using electromechanical relays. It is probable that for some time to come, input and output mechanisms using data punched on cards, paper tape, registered as dots on film, or as marks on a magnetic medium will be employed along with the vacuum tubes in the most advanced large scale digital computers.

The Industrial Use of Computers

In contrast to the great speed and other elaborate requirements of the complicated large scale computing systems just described, the requirements for an industrial programming and overall control system are very simple indeed. As was mentioned at the beginning of this section, the speed of such a machine can be much lower than that required in solving very complex mathematical problems, and the memory schedules are far simpler, as is seen by the schedule drawn up for the automatic piston factory (section III). The principles are the same, but machines themselves can be far simpler than the all-purpose devices.
VII

AUTOMATIC PRODUCTION FOR SHORT RUNS OF PRODUCT

In Section II we explained the disadvantages of single large, fully automatic machines for the complete production of a product. The runs of product required to make such a machine economically feasible are in most cases too long to permit this form of automation. Our alternative of connecting standard production machines, although requiring much shorter product runs to cover set up and special equipmen costs, nevertheless presuppose rather large orders for a single product. Does this mean that although the order of magnitude of the run has been decreased, automation is still not possible without mass production? For the type of factory we have proposed it does. But the Control division of the General Electric Corporation has just developed a system of machine control which permits automatic production of very small runs of product.

The system is called "record playback control", and operates as follows. As the machine operations are carried out through a work cycle in the usual manner, the various motions are translated into electric signals, usually by selsyns or synchros geared to the motion. The electrical signals for each desired motion are recorded concurrently on a magnetic tape, or similar medium. This is the record action. During playback the magnetic tape is run through an electronic amplifier and the recreated electrical signals are checked against those from selsyns actuated by the corresponding machine motions. Electronic servomechanism control compares these two signals and drives the feeds (or other motions) to cause the selsyns to stay in step with the recorded signals. In this way the machine is made to repeat its previous motion.

With this system attached it is possible to have automatically operated job shop machinery. An order of ten or twenty units could be made automatically just as economically as an order for many more -- provided of course that the shop receives numerous orders for more than one unit of product. The cost of such an installation is at present $10,000 per machine. This greatly exceeds the 10:1 ratio that is the usual rule of thumb in machine tool design of machine cost to control cost. But the savings are obviously the deciding factor, and in the
proper kinds of instalation they can be great indeed with this system.

Manner of construction

The accuracy and speed of operation which may be obtained depend on three factors. These are:

1. The precision with which the original selsyn motion duplicates the machine motion.

2. The faithfulness with which the record-playback system reproduces the electrical signals from the selsyn.

3. The ability of the servo system to make the final selsyn and driven member follow this played-back signal.

1. The record may be made by any means which actuates the machine motions and connected selsyns. This may be manual or automatic such as by contour following or cam operation on machine tools. This is particularly important when duplicate records are made for operations in a number of machines. The precision of this portion of the operation is a function of both the machine and input servomechanism equipment (if any).

2. The magnetic recording and playback are highly developed and are usually the most precise portion of the sequence.

3. The operation of the servo-controls to drive the output motions and hold the monitor selsyns in step with the playback signal references is quite similar to that of any servo such as used for contour tracing, computer, gun laying, etc. Precision here is the result of close cooperation between the electrical design of the control and the mechanical design of the machine, since inertias, friction backlash, etc., are as important as motor torque and the electrical circuit characteristics in determining accuracy, speed and stability.

For many applications, the same machine may be used for both recording and the playback operation. This has advantages in cancelling out some mechanical errors. However, as this description of principles indicates, the field for record-playback control covers a much wider range than this.

A schematic drawing of the system follows.
VIII

SOCIAL IMPLICATIONS OF THE AUTOMATIC FACTORY

Before one can intelligently discuss the social implications of automatic factories, two conditioning factors which tend to limit the extent and importance of these social problems must be taken into account. These factors are: (1) the limited portion of our economy in which automatic production will be used and (2) automatization will take place gradually in those industries which it affects.

1.) Automatization will not pervade all the economic functions of our society. Any process which can be geared for mass production will be ready for automatic production. In other words, any process where the set-up or taping is properly related costwise to the size of the run of the particular product will serve as a possible field for automatization. This, we believe, largely limits completely automatic processes to the field of manufacturing industries and miscellaneous accounting functions of other industries.

Manufacturing industries employed 14,142,000 people or 24.2% of the total number of people employed excluding the armed forces in 1949 as shown in the Statistical Abstract of the U.S. 1950. Within manufacturing, however, only a small part of all the processes will be automatized because of both cost considerations and the fact that consumers desires dictate that certain work be done by hand.

In other fields of economic endeavor we feel that automatic systems will be largely limited to accounting systems. In particular we believe that systems will hardly be used at all in the following industry groupings: agriculture, trade, service, construction, mining, and a miscellaneous grouping including proprietors, self-employed and professional men, etc. In 1949 these industries employed respectively 18.3%, 16.1%, 8.1%, 3.7%, 1.6%, and 8.4% or a total of 56.2% of the total employed workforce excluding the armed forces. By contrast to these six industry groupings we believe that government and finance, which employed respectively 9.9% and 3.0% of the 1949 workforce and where accounting is a relatively important part of the work, may have a considerable amount of automatization. The remaining industry grouping, transportation, with 6.8% of the total employment
in 1949 could be automatized extensively, but as long as trains and trucks continue to be used for moving most of our freight, automatization will not affect the number of people employed in this field very much.

If only manufacturing, government, and finance will be substantially affected by automatization, then 37.1% of the working people or about 21,700,000 of our present-day population would be affected by these changes. The number probably will be much smaller since automatization will actually occur in only a fraction of all the companies or government offices in these fields of activity. Even where it does occur, men will be needed to maintain the plants and technicians will be needed to plan the system and repair any breakdowns.

From the above discussion, only a relatively small portion of the working population will be affected. While this factor limits the magnitude of the problem, our ever-increasing population which will require more jobs may prove troublesome. The employment increase from 6,750,000 to 14,215,000 or from 16.4% to 24.2% of the total population by the service and trade industry grouping in the last 30 years suggests that they could take up some of this slack.

2.) The second conditioning factor which must be kept in mind while considering the social implications of automatic production is that the change to automatization will be gradual. This idea has been discussed in other sections of this report and will not be repeated here. However, it is significant to note that a gradual introduction will tend to decrease the severity of the problems which must be faced.

The stage is now set for a consideration of the social implications of automatization. The main problem areas which will be considered are: (1) the displacement of the workers, (2) the adaptation of the workers to a new kind of work situation, (3) the problem of leisure time.

The Displacement Of Workers

There will be a great difference in the reaction of the interested parties, namely workers, unions, and the community, depending upon whether an entirely new plant is built for the automatic process or whether an old plant is remodeled for this purpose. The new plant will cause no direct labor displacement and is, therefore, much less likely to cause any trouble.
Changing over a plant currently in operation, however, will bring about labor displacement which will be felt by everyone in the plant and the community. Since this second example presents a problem for society, we will confine our discussion to it.

Union attitude towards changing to completely automatic processes may include some obstructionism, but it is likely to be one of acceptance provided the union membership shares in the benefits of the change. To do this the unions will strive to keep more than the required number of people on the job by shortening the work day and/or demanding higher take-home pay for those people retained on the job. Such demands will decrease the savings gained from installing a completely automatic system and will probably tend to slow down the speed with which they are introduced. How much the unions can do against this and other technological changes depends largely upon their bargaining strength.

Moreover, we believe that the manner in which automatization is introduced will strongly temper one way or another the immediate reaction of the workers, the union, and the community. If carelessly managed, the union and the community at large will strongly object to it. The immediate furor will probably die down after a year or two, but what happens during this transition period may cause the demands for and the enactment of legislation and the imposition of controls which may leave lasting harmful effects -- that is, if the introduction is not handled intelligently.

Every worker in a plant which is to be automatized will not be able to keep his job. Will other employment be available to these workers? We expect that the increased productivity from automatization and other technical developments will cause increased demands for all types of goods and services which will open new jobs just as it has in the past. The recent increase in the service and trade industry groupings are encouraging. We feel that the effects of completely automatic production will not be substantially different from those of technological developments in the past. That is, although severe temporary dislocations may occur, they can be worked out within a relatively short period through newly added employment opportunities elsewhere. Although the population and the proportion of older people will be increasing, we do not think that the automatic factory will aggravate this potentially serious problem.

Adaptation Of Workers To A New Kind Of Work Situation

Automatization will no longer allow workers to handle their work but will confine them to "button-pushing" and...
routine maintenance jobs around the factory. We feel that this work is no more and, perhaps, less degrading than doing the work manually. Is it not better to regiment machines than men?

It is true that this type of job may be very boring for some people and, therefore, very undesirable. Nevertheless, some people are well-suited for this kind of work. To discover who these people are will require a careful personnel screening. In attempting to get the best-adapted people to work in the automatic production lines, companies may run into trouble with union seniority rules.

The Problem Of Leisure Time

The introduction of automatization could lead to more leisure time for those working in the affected companies since union pressure will probably demand shorter shifts in order to provide more jobs for the work to be done. In addition, organized labor is continuously driving for shorter hours on its own -- a movement completely independent of the results of automatization.

What will people do with this additional leisure time? We must recognize that many workers would now prefer a 30 hour or less week provided that they could earn enough in that time to provide them with enough money to buy the things they want and need. For this reason, we believe that many of the problems which numerous people impute to the existence of additional leisure time do not exist.

Leisure time can be initially utilized by doing odd jobs around the home. Besides these tasks, there are countless other things that people can do with their time. It will give them the opportunity to spend more time with their families. Some may just want to enjoy themselves in sports, travel, or other types of recreation. Many people have hobbies upon which unlimited time could be spent. Still others may want to devote their free time to the pursuit of culture, whether it be through additional formalized education or informal activity of their own.

The existence of this leisure time gives a great opportunity to engage in many worthwhile projects which the fast pace of our industrial civilization has been passing by. Billions of man-hours could be well spent on such projects as soil conservations, reforestation, purifying our polluted water resources, and numerous other reclamation projects which will replenish our rapidly consumed natural resources. To get the average man
interested in these projects will require an enlightened leadership. We feel that this leadership must be generated by the government since it is such an immense undertaking.

We conclude, therefore, that people will not encounter any substantial trouble in utilizing leisure time. There are always things to do; in fact, we often complain that we never have nearly enough time to do what we would like to do. Moreover, an enlightened leadership can help to channel some of the leisure time into worthwhile projects long neglected which will increase our overall well-being. Rather than confronting us as a problem, the utilization of leisure time will serve as a challenge for leading a more useful life.

Types of companies:

There are three types of companies currently producing automatic control mechanisms and measuring devices:

1. Large and highly diversified companies in the electrical manufacturing industry like General Electric are doing considerable development work on such mechanisms as contact utilizing equipment, variable speed drives, and record playback equipment. There are two reasons for this type of work being carried on by a company such as General Electric: First of all, funds are available in such companies to carry on the extremely expensive development work necessary. Secondly, such companies have the incentive of developing control mechanisms for use in the manufacture of their other products. In addition, these companies manufacture equipment similar to the equipment manufactured in the group of companies making the more advanced types of control mechanisms.
SIZE OF THE INDUSTRY WHICH MANUFACTURES

AUTOMATIC CONTROL DEVICES

The field of automatic controls is not recognized as an industry as such at present. Hence a definite determination of its size in terms of volume of output or number of firms in the industry is not possible with any degree of accuracy. We know that a major part of the industry exists within the electrical manufacturing industry as we know it today. However, many other types of companies, as well as educational institutions and government agencies, are also known to be engaged in either the manufacture of or research on automatic control mechanisms. The difficulty of accurately forecasting the size of this so-called industry was very well expressed by Julian H. Bigelow of The Institute for Advanced Study when he stated that

"...any phenomenon which grows from practically zero to a full blown rage in so few years is representable by a very wild (and probably capricious) curve, difficult to extrapolate for ten years even if accurately defined and known for the past and present."

Types of companies

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1. Large and highly diversified companies in the electrical manufacturing industry like General Electric are doing considerable development work on such mechanisms as contour milling equipment, variable speed drives, and record playback equipment. There are two reasons for this type of work being carried on by a company such as General Electric. First of all, funds are available in such companies to carry on the extremely expensive development work necessary. Secondly, such companies have the incentive of developing control mechanisms for use in the manufacture of their other products. In addition, these companies manufacture equipment similar to the equipment manufactured in the group of companies making the more advanced types of control mechanisms.
(2) Old and well established instrument manufacturing companies produce the greatest part of the output of sensory devices. This is the feeling of the group and is based on the contacts which have been made with all types of companies producing sensory mechanisms. Included in this category are companies such as Leeds and Northrup, the Foxboro Manufacturing Company, the Taylor Instrument Company, the Bristol Company, and Minneapolis-Honeywell. By and large, these companies are unable to put the large amounts of money into research and development that a company such as General Electric can afford. Because of this, these companies are somewhat slower in the development of new control devices. A policy of waiting until sufficient demand exists to justify the development of products for volume production has been adapted by a greater part of these companies. As an example of this type of thinking, Veeder-Root Counters Inc. of Hartford, Connecticut, producers of a full line of electrically and mechanically activated mechanical counters, is not contemplating commercial development and production of electronic counters. They realize, however, that such electronic counters exceed their own in performance, but they are not prepared to take the risk of developing an improved counter until their customers should demand such an improved counter.

(3) The greatest proportion of the more advanced types of automatic control mechanisms are manufactured by comparatively young companies which had their origin during the Second World War. It should be noted at this point that the types of devices produced by these young companies differ from the sensory devices described in the preceding paragraph in that they consist of a "package" of devices designed to accomplish a specified task. The sensory devices described can only pick up information and are not capable of taking action thereon.

The advanced nature of this work is possible because of the fact that many of these companies were founded specifically for the purpose of developing mechanisms for military applications on government contracts. Servomechanisms Inc. of Mineola, New York, the Airborne Instruments Laboratory, of the same city, the Ultrasonic Corporation of Cambridge, Massachusetts, and the Control Engineering Company of Canton, Massachusetts are examples of this type of company. At present these companies are operating almost exclusively on either prime or sub-contracts for the Federal government.
Growth of the Industry

A rough approximation of the growth of the industry can be obtained from the enclosed chart which shows the increase in the number of companies and the number of new instruments listed in the magazine "Instruments" from 1935 to 1950. During this period, the number of new instruments listed has increased from 310 to 1065 and the number of companies producing the instruments has increased from 684 to 1363.

Future of the Industry

In the near future, progress will be made in coordinating the sensory devices already developed, rather than in the creation of additional sensory devices to measure physical forces not now being measured and controlled. The lone exception to this development is that as radioactive isotopes come into common industrial usage, control devices utilizing the Geiger counter as a sensory mechanism will be developed. The first applications of such devices can be expected in processes similar to the one now employed in making paper.

The development of more coordinated systems during the next ten years, at least, will be subject to several limitations, the most significant of which are:

1. A policy on the part of most companies of developing and manufacturing control mechanisms only after they are demanded by the potential users of such devices.

2. Since many potential users do not understand how vacuum-tubes and other electronic devices operate, they fear that electronic control equipment may not be fully reliable and thus will go slow in accepting it for general use. A major part of their distrust stems the easily understandable suspicion that people have of devices which they cannot see or hear in operation. Moreover, vacuum tubes (and other circuit components) will burn out without warning from time to time unless preventative maintenance is instituted.

There have been many instances of extremely reliable performance by vacuum tubes. The Bell Telephone System is reported to have installed several special-purpose tubes in inaccessible underground installations. These tubes are expected to last as long as the companion equipment--probably 20 to 30 years.
During the first seven years of use, these tubes have given no trouble whatsoever.

It is expected that increasing amounts of consumer education through advertising and sales contacts by manufacturers of electronic equipment can and will overcome a substantial part of this suspicion of electronic equipment during the coming ten years. In spite of this, however, the companies installing such equipment will have a continuing need for technicians to maintain and service the installations.

(3) The threat of an all-out war is having a very strong effect upon the rate of development of automatic control mechanisms to be available for use in the manufacture of civilian products. There is no question that development of some devices such as servo-mechanisms (which have direct military application for gun directors) is being carried out at a very rapid rate during the present emergency. As to pure research and development activity, it can be expected to continue on regardless of whether or not an all-out war comes about.

However, manufacturers using control mechanisms during the present mobilization, and more particularly in the event of an all-out war, will want to use any control mechanisms which will help them to increase their production, raise or maintain quality, and possibly lower their costs. The time necessary for adapting new devices to specific production situations and the high costs involved probably would be such that the users of the control devices would be forced to use devices already developed.

A vivid illustration of this is that the Arma Corp. of Brooklyn, New York abandoned their development work on an automatically controlled lathe because of the pressure of military work thrust on them after the outbreak of the Korean War.

The general conclusion to be made as to the effect of a war upon the development and use of automatic control systems is that the necessity of finding applications for the military effort will maintain or even accelerate the research effort being made, but that adaptation to specific industrial situations will be slowed considerably.

(4) The costs of developing coordinated systems will be extremely high. Except for cases where the Federal Government is subsidizing companies making control devices to help the mobilization effort, installations of automatic controls must be made
on a basis which will lower the cost per unit of the product and at least maintain the quality of the product.

The manufacturing cost savings available from employing automatic controls result from a combination of three factors:

(1) Displacement of labor -- as in the case of the automatic combustion controls on the boilers of the Sunbury Station of the Pennsylvania Power and Light Company.

(2) Increasing the volume of production as in the case of the variable speed drives attached to the looms in the stocking knitting mill.

(3) Improving the product -- as in the case of General Electric's multicolor register control.

Until now the purchase of only very few systems using two or more sensory devices has been justified through the types of savings outlined above. This can be explained by the fact that the investment required to obtain these savings is so large as to make the payback period unduly long.

What makes the cost of these devices so large? The major cost factor is not the labor or the materials that are involved but rather the expense of research and development engineering. Obviously, this large engineering expense can be spread over more units thereby lowering the cost as more of these devices are sold.

The cost of computing units are tremendous but are slowly decreasing. Large sized, high speed digital computers such as the Whirlwind are proving to cost about three and one half million dollars. IBM's newest selective sequence calculator will rent for about $8,000 per month. Remington Rand's newest high speed digital computer will sell for approximately $300,000. The cheapest digital computer recently applied to industrial use is being rented by the Buick Division of General Motors from IBM for $650 per month.

In the more distant future, these limiting factors will be gradually eliminated. This will allow the size and output of the industry to increase tremendously over its present size.
CONCLUSIONS AS TO FUTURE GROWTH
OF THE AUTOMATIC CONTROLS INDUSTRY

The chief point which we wish to make in connection with the future of this industry is that the greatest single determinant of the rate of automation is the extent to which people in business understand what is technologically possible, and the degree to which they can rethink their production in terms of automation.

There are many logical arguments concerning reduction in cost that comes with mass production, and future technological developments, which relate to forces determining industry growth. We have tried to cover these in Section IX. But when all is said and done, the degree to which business men understand what is possible, and the extent to which they can learn to rethink their processes, where that is necessary, will be the deciding factor in determining just what the automatic controls industry will be like in 1960.

Rather than make assumptions as to how fast, or how slowly, business men will make use of automatically controlled processes; and rather than extrapolate any curves on the subject we have decided to try ourselves, in a very small way, to make some of this knowledge available to the businessman -- or at least to let him know that something very useful is available to him if he wishes to use it.
APPENDICES

The U. S. industry that supplies the most basic necessity of the present day world is a marvel. Yet this steel industry, for all of its accomplishments, has in it an enormous flaw. That flaw is its basic technology. For years and years the steel industry has operated on area and turned out its ingots by the same means and with the same instruments - the blast furnace and the open hearth. These huge vessels have always worked, and few people in the industry looked at them with a questioning eye. No one felt the need for any large-scale modernization.

Minimizing Research

Although steel has some top-notch scientific minds, its climate has never been friendly toward broad-gauge research. It is too busy for science in boom times and feels itself too brusque for such a luxury in depressions. And so says chemical engineer Warren Kendall Lewis of M. I. T. "Our most basic industry has never submitted itself to a thoroughgoing scientific analysis, everything about it has remained empirical for a hundred years. The industry's attitude toward fundamental research can be sum- med up in a four-word sentence: Let George do it!"

Current Problems

Come war or peace, the next 10 years for the U. S. steel industry will be the most critical it has ever known. If the industry doesn't want to change, there is a convergence of forces likely to make it change just the same. Its costs are running out by running thin. A much more serious stringency is its coal. The wonderful coal deposits of the Connellsville district in Pennsylvania which fed the industry for 75 years are almost gone, and coals that are poorer, although more expensive, will have to serve the steel industry in the future. Its capital costs have increased five-fold since the 1930's, and the high cost of scrap will go on for a long time because as estimated 150 million tons of material that might have been scrap is today lying at the bottom of the oceans or pulverized over the continents of Europe and Asia as the partial
APPENDIX A

Automatic Controls in the Steel Industry

The U. S. industry that supplies the most basic necessity of the present day world is a marvel. Yet this steel industry, for all of its accomplishments, has in it an enormous flaw. That flaw is its basic technology. For years and years the steel industry has smelted its ores and turned out its ingots by the same means and with the same instruments -- the blast furnace and the open hearth. These huge vessels have always worked, and few people in the industry looked at them with a questioning eye. No one felt the need for any large-scale modernization.

Minimum of Research

Although steel has some top-notch scientific minds, its climate has never been friendly toward broad-gauge research. It is too busy for science in boom times and feels itself too broke for such a luxury in depressions. And so says chemical engineer Warren Kendall Lewis of M. I. T., "Our most basic industry has never submitted itself to a thoroughgoing scientific analysis; everything about it has remained empirical for a hundred years. The industry's attitude toward fundamental research can be summed up in a four-word sentence: Let George do it."

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price of World War II.

Thus every line in the economy of steel -- the thinning ores, the poorer quality of the coal, the higher prices of scrap, the soaring freight rates, the increasing capital and operating costs, and the enormous consumer demands of today -- converge at a single point: the blast furnace, producer of the world’s pig iron.

Present Methods

The blast furnace is not only the steel industry’s prime converter; it is the most important single-product converter in the industrial world. In the value of its product it outranks everything else there is. This being so, one might expect to find the blast furnace an ultra-modern instrument. But it is not. Anyone who wants to see the present difference between the fundamental technology of steel and the fundamental technology of oil should visit the modern blast furnace that steel can show him and then visit one of the modern catalytic crackers of the oil industry. The former would be familiar to William McKinley; the latter might even surprise Thomas E. Dewey.

Opposition To Changes

Wide-scale acceptance of new steel production methods will come slowly. Fundamental changes in an industry as big as steel and with its heavy capital investments cannot come any other way. It is not just a question of changing jigs and dies and rearranging the assembly line as an automobile plant does when it shifts from one model to another. It is a question of obsoleting many millions of dollars worth of equipment. It is a question of spending many new millions for new equipment. The cost of a single blast furnace with auxiliary coke ovens and blowers may run to $35 million. These funds are not easily secured today.

Consequently the expansion of steel capacity now under way cannot be credited to any improvement in steel’s century-old technology. Steel research is still focused primarily on improving the industry’s product rather than improving its methods. Yet there are important innovations on the steel horizon. These deal with the beneficiation of iron ore, the pressurization of blast furnaces, the use of oxygen in the open hearth, and the direct casting of molten steel into continuous castings. Only the latter process, which eliminates ingot pouring and the need for expensive soaking pits and blooming mills, is an application toward more mechanization with a view toward automatic or continuous processes.
Automatic Processes

Therefore no one in the steel industry is thinking in terms of complete automatic operations; the pouring in of raw materials at one end of the hopper and the flowing out of a finished product at the other end. The present operations are too big to be automatic; the processes involved are too complex to lend themselves to complete mechanization. Present executives feel that there are too many unknown variables and intangibles to allow the control of the process to automatic control mechanisms alone. They feel that the experience and skill of the operators cannot presently be replaced by automatic machines or equipment.

The present production of steel involves different types of processes which hinder the establishment of an automatic factory. The blast furnace by itself is almost a continuous process. The next step, or the open hearth, is a batch process. This type of operation does not lend itself to continuous flow processes, and consequently the first bottleneck in designing an automatic factory for steel making is encountered right here. Until this process can be eliminated or made continuous, any plans for future mechanization of the total operation will have to be abandoned.

In view of this problem the mechanization of the various processes has been piecemeal. In fact, the development of automatic production has started at the other end of the steel-making process -- the finishing departments. The automatic and continuous processing of steel pipe and sheets has been going on for about 20 years. The production and finishing operations in the manufacture of butt-weld and seamless pipe are almost completely automatic. Consequently this suggests that if the steel industry will ever modernize its production processes into continuous, automatic operations, it will accomplish this end by working backwards -- from the finishing operations to the basic operations.

But the concentration of future research in the steel industry will stress product development and improvement in present processes instead of experimenting with new process developments. The steel companies are continuously trying to improve the quality of their existing products or are developing new products in anticipation of future needs. In addition, they are trying to make the basic processes more efficient; for example, the use of pressure or oxygen in blast furnaces. None of the present large-scale research and development is aimed at automatic processes per se. The only indication that we have of any effort in mechanization is the recent development in the continuous casting of steel ingots.
CONTINUOUS CASTING OF STEEL

There has been little change since the dawn of history in the process of casting metals into forms as the first step toward a finished product. Primitive man made his mold, poured in the metal, then took out the casting to be reheated and hammered into shape. Steel plants today follow the same basic principle. But for the last century metallurgists have been dreaming of continuous steel casting -- of putting hot metal into a cooled mold and getting a steel shape out of the other end.

Recent Success

About 10 years ago continuous casting did become practical for nonferrous metals. The process requires a relatively low capital investment; only a few men are needed to run each unit. The product of nonferrous continuous casting is said to be better than that cast by the older methods.

So far the most successful application of the continuous casting process has been at Scovill Manufacturing Company, a founder and prefabricator of brass. At Scovill, molten brass is fed into a continuous casting machine and comes out in continuous strips 24 inches wide, 2 1/2 inches thick. The strip, which travels at the rate of about 16 inches per minute, is finally cut into 2,000 pound bars about 10 feet long.

Continuous casting with brass, a nonferrous metal, is one thing, but doing the same thing with steel is another. Brass and most of the nonferrous metals have low melting points. So it isn't too difficult a job for an engineer to design a cooling assembly that converts brass from a molten state to a solid state as it rolls through the casting machine. High melting point steel, on the other hand, has a high melting temperature. The cooling device must do a faster job to cast steel continuously at a speed that is practical and economical. In addition, some method must protect the surface of the cast strip from the time it is molten until it chills to a cold state to prevent scale formations on the alloys and carbons which are sensitive to air.

Republic Steel Corporation and Babcock & Wilcox Tube Company, who announced in August, 1948, that they had succeeded in casting steel continuously, used large amounts of fast-flowing water to cool their molds. To prevent a reaction between the atmosphere and the molten metal, steel casting uses an additional device, a blanket of argon, an inert gas. Argon isolates the red-hot steel from the air and cuts down the formation of scale on the surface of the steel.
Advantages and Savings

Continuous casting is of dollar-and-cents interest because it cuts out several very costly steps in the steel making process. (See diagramatic sketches No. 1 and No. 2.) At present, molten steel tapped from the open hearth furnace, electric furnace, or bessemer converter is poured into ingot molds. After the metal has solidified, the molds are stripped off, and the ingots are shipped hot to the blooming mill. There they must be held in pit furnaces, called soaking pits, to be reheated until the proper rolling temperature exists throughout the whole mass. The blooming mill rolls the ingot into blooms or billets -- chunks of steel in sizes easier to handle than the big ingots.

This process requires massive equipment and lots of manpower. But the casting tower makes all these steps unnecessary. It saves time and money. It opens up the possibility of small-scale, decentralized production by nonintegrated mills.

Future Use

Republic and B & W say that the steel produced by continuous casting is better than that produced by the conventional method. The surface of the billet is said to be freer of imperfections than ingots usually are, and the interior of the billet is freer from slag.

A mold producing billets with a cross-section of about 27 square inches has been used so far, and billets can be produced by the pilot unit at the rate of 12 tons an hour. Future experiments will discover whether there are limits on the size of shapes that can be cast. The latest word is that the 27 square inch mold used by B & W has been replaced with a new mold with an area of 48 square inches. So far, it seems that ovals of special proportions are the most practical for these can easily be rolled in a mill into flats or rounds.

However, continuous casting is still in the experimental stage. More developments will be necessary before full scale units can be set up. In order to do this, controls will have to be designed so that bigger units can be operated to the best advantage.

THE USE OF ELECTRONIC CONTROLS

Although the steel industry has been slow to change its basic technology, it has rapidly adopted numerous uses of electronic control devices. The industry presently uses many automatic control devices.
The continuous casting of steel would eliminate Parts B, C, D, and E of the steel making process.
A - Molten Steel is poured into mold through which straings out slag.

B - Pinch Rolls control speed of descending steel

C - Acetylene Torch cuts billets into desired lengths

Materials Handling equipment to move steel out into mill.
mechanisms for heating and cooling processes, various types of gauging, inspecting, counting, marking, machining, welding, plating, burning, and handling. Numerous applications of automatic motor controls are used to regulate some function of steel processing. In the laboratory chemical analyses and coating thicknesses are being done and will be extended by the use of spectrometers and x-ray equipment, which are automatic but under the control of an operator. More automatic control mechanisms will be installed on many more of the processes and machinery as future study and development will show the way and justify the economics of the change.

There are four major fields where electronics has been largely applied in the industry. They are (1) power electronics used primarily for power conversion; (2) electronic control; (3) high frequency electronic heating; and (4) electronic measurements. The steel industry has taken advantage of electronics in all four fields. New additional fields will be, undoubtedly, opened up as the art advances.

Electronic equipment has been available for industrial use for the past 20 years. The steel industry has been interested in new developments and devices which increase the quality or decrease the cost of the product. It is not surprising, therefore, that in the recent past many varied and useful electronic devices have been installed in the mills. Some of these, the larger electronic equipment, including rectifiers, frequency changers, and high frequency heating, are well known as electronic in their own right. There are many others in which the electronic device is a small part of the machine and is used to regulate, control, or indicate some function highly important to proper operation of the main device.

Phototube

The phototube is perhaps the best known, as well as the most publicizes, of the electronic tubes. It is used in commercial establishments for operating doors, controlling the flow of water at drinking fountains, switching on billboard lights, etc.

In the steel industry the phototube is used for a variety of purposes. In the boiler house the phototube measures stack density. This data enables the operator to maintain proper combustion control. In the steel works the phototube is used on the bessemer converter. In this application it is focused on the flame through filters and indicates the temperature and condition of the steel during the heat. It also accurately indicates the end point of the heat. In the tin mill the phototube is utilized as a switch in conjunction with a sheet counting device and as a pinhole detector for eliminating defective sheets.
In addition to its use as a switch, the phototube is used to control the flow of steel strip through the processing lines. It is desirable at times to have loops form ahead of and back of trimmers and shears. The amount of this loop can be controlled by the phototube. It is also desirable to control the winding of the coil on the tension reel so that the edges are even. Both of these operations can be controlled by phototube electronic circuits.

**X-Ray Equipment**

The mechanical contact type of steel gage does not lend itself to the continuous high accuracy the trade demands on the high speed tandem cold reducing mill or on other high speed mills. On the hot mills also, the temperature of the steel requires the non-contact type gage, unless this gage is located far down the cooling tables from the last stand on the mill. It is, therefore, possible to run through several tons of off-gage steel before the finishing stand screwdowns could be corrected by the mill operators. With this hot mill service in mind, the electrical manufacturing companies developed an X-ray gage for the measurement of steel thickness. With the advent of high speed cold mills, this gage has been redesigned for cold mill rolling service.

The X-ray tube was discovered by Roentgen in 1895. It is considered the forerunner of electronic devices. However, it has been adapted to steel mill use only recently. X-ray gages have been installed to measure the thickness of hot rolled strip and cold rolled strip. These gages are essentially an instrument of comparison wherein the X-ray penetration through a test sample is compared with the penetration through a known calibrated sample. The two penetrations are compared electrically and this comparison is indicated on the meter. It is possible to differentiate directly on the instrument in ten-thousandths of an inch above or below the standard sample.

**Electronic Regulator**

Electronic control as a voltage or speed regulator can be made adjustable over a high range of response and is used quite extensively. A typical example of this type of control is in the speed regulation on wire drawing machines. On this machine the wire is reduced in size by being pulled through successive dies, the wire being wrapped several times around a motor-driven draw drum between each set of dies and finally wound on a spool. Each draw drum motor must successively travel faster due to the elongated wire, and the final spooler motor must also have speed compensation for the wire buildup.
In order to adjust these speeds, a tension arm is placed after each draw drum unit to regulate the speed of the following unit. This arm is a spring actuated device for return to a normal position. This spring maintains a tension on the wire. Should any motor on the machine not be driving the connected draw drum fast enough to maintain the proper tension on the preceding arm, the arm will move radially. This arm is connected to an electrical device which alters the field voltage to bring the draw motor up to the proper speed. The electrical device activated by the arm commonly used until recently has been a field rheostat. Because of the dusty atmosphere and the frequent movement of the arm, this rheostat was a continual source of trouble. In recent installations, this rheostat has been replaced with a variable core transformer and electronic control which have proven very satisfactory.

Electronic Speed Control For Flying Shear Drive

As a considerable amount of hot rolled strip is sold in the form of hot rolled sheets, a flying shear is required immediately following the hot strip mill finishing train. This shear is used to cut the continuous strip into desired sheet lengths, and often to crop the front end or the rear end of the strip or both, without making any cuts in the body of the strip. In the past, the flying shear was driven and synchronized to the last stand drive through a complex mechanical or hydraulic system, with separate electrical motors to accelerate the shear. These units were cumbersome, maintenance was high, and they were not easily adjustable for different cut lengths. An improved all-electric flying shear drive controlled by a very accurate electronic regulator is paying its way by simplifying the drive equipment, reducing the maintenance, and cutting sheets to lengths more accurately than with the older forms of drive.

When the accuracy required of a flying shear is studied, it is not surprising that initially there was some skepticism as to whether or not an all electric drive would give successful operation. For instance, if the length of cut is 25 feet and the allowable variation is 1 inch, the maximum error which can be tolerated is 1/3 of one percent. The duty on the regulating system is further complicated because of the necessity of bringing the shear from rest to full speed as quickly as possible without perceptible overshoot. The high accuracy and quick response features of electronics and the ease with which damping and anticipation circuits can be utilized made it a natural selection for the flying shear regulating system.
Electrolytic Tin Plating Line

The modern, high speed electrolytic tin plating line probably utilizes more different types of electronic apparatus than any single application in the steel industry. Such lines may have the following electronic control and power devices:
1. A plating current-speed regulator to assure that the proper coating of tin is applied to the strip at all line speeds.
2. High speed frequency induction heating to reflow the tin.
3. Photoelectric scanner system to control the flow line.
4. Photoelectric loop regulators. Depending on the layout of the line several of these may be used.

Plating Current-Speed Regulator

An interesting application of electronics on the tinning line is the plating current-speed regulator. (See diagramatic sketch No. 3) If a uniform coating of tin is to be deposited, it is necessary to control the plating current proportional to speed, as it is impossible to operate these lines at constant speeds all times. This is accomplished by an electronic regulator which compares the totalized plating current with the speed of the line. The regulator automatically adjusts power supply so as to maintain the plating current proportional to the line speed. The equipment can be used with either motor-generator sets or rectox units as a plating supply. In the case of the motor-generator sets, the regulator automatically adjusts the excitation of the generators to get the necessary variation in the current. With a rectox power supply, a saturable reactor is used ahead of the rectifiers to vary their voltage and consequently the plating current. With this system it has been possible to operate tinning lines over a speed range as great as 50 to 1300 fpm and to maintain the thickness of the tin coating deposited within commercial tolerances.

Tin Reflow

One of the outstanding wartime accomplishments of radio frequency heating was its use to reflow the tin on electrolytic tinning lines. (See diagramatic sketch No. 4) A Total of 9800 kw of radio frequency generators, more than twice the kw employed in all radio broadcasts in the U. S., has been supplied for this application. In fact, the first trial installation of induction heating for reflowing tin was made with an obsolete broadcasting set.
Block Diagram of the elements of an electronic regulating system for matching plating current to line speed on continuous electrolytic tinning lines.

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Block Diagram of high frequency induction heating system for reflowing electrolytically deposited tin. The photoelectric scanner system for automatically maintaining the flow line is also shown.
The tin plate produced on an electrolytic line has a gray matte surface. If the tin is heated to the flow point, the strip surface changes from a matte to a bright, shiny appearance and results in a coating which has minimum porosity, maximum corrosion resistance and which is better bonded to the steel strip. The high frequency generator consists of a power plate transformer, rectifier, oscillators, and tank circuits and are much the same as standard radio broadcasting sets, except that the components are designed for heavy industrial service. The output of these oscillators is fed into the induction coils. The high frequency field caused by these coils generates electrical currents in the moving strip which heats it to the desired temperature to flow the tin coating. This method requires no physical contact between the heating coils and the strip and therefore cannot harm the surface.

Flow Line Scanner System

In order to assure power reflow of the tin coating at all line speeds and with varying widths and thicknesses of strip, a unique electronic photoelectric scanner system was developed. One set of photoelectric equipment scans the strip passing through the inductor coil just before the tin is hot enough to flow and while it still has a dull surface. A second set of photoelectric equipment scans the strip after it has been flowed and a bright surface established. The intelligence from both of these units is fed into an electronic regulator which in turn controls the saturable reactor or induction voltage regulator to vary the power supplied to the induction heating coils. The action is such as to automatically maintain the flow line between the two sets of photoelectric scanners. With this system it is possible to vary the tinning speeds over a range of from 50 to 1300 fpm and to properly flow all of the strip passing through the inductor coils. This is an application which would have been extremely difficult, if not impossible, without the use of electronic control means.

Loop Control

Probably one of the best known and more common uses of photoelectric devices in the steel industry is for loop control regulators. (See diagramatic sketch No. 5) In the early applications when line speeds were relatively slow, these regulators consisted of one or more photoelectric relays operating in the overall control circuit as limited switches. The system is designed to keep the loop between the two photoelectricals. If the loop gets above unit 1, the motor driving the pinch rolls will be slowed down by relay action. If the loop falls below unit 2, the motor will be speeded up by relay action. The photoelectrical consists of a photosensitive tube and an amplifier to furnish...
Block Diagram of photoelectric loop control systems. “A” shows the limit switch type in which no correction is made until the loop leaves the area between the phototrollers. “B” shows the ‘photo-thyratron’ type in which smooth continuous correction is made.
power to operate the relay equipment.

As line speeds increased, the problem of loop control became more difficult. This was due to the higher rates of correction required, larger inertia of the rotating equipment, and the wider operating speed ranges of the drives involved, all of which increased the problem of correction and stability. The modern phototyatron loop regulator installed on many of the high-speed processing lines today helped to overcome this problem. The light source consists of a long fluorescent tube. Two phot cells are employed to measure the amount of light not blocked off by the loop. The total output from the phototubes is fed to an electronic regulator which combines the necessary degrees of forcing and damping to assure fast response and stable operation. The electronic regulator varies the field of the direct current motor or booster generator as is often used to keep the loop at the proper length. This type of regulator gives continuous smooth correction as compared to on-off limit switch type operation and is a decided improvement over the older forms of loop regulators.

Maintenance

The maintenance problem of keeping electronic equipment in operation is very similar to that of any other electrical equipment. Checks and tests must be made periodically and a log book showing the actual history of each device should be kept. To the average maintenance man, especially the older one, this type of control is radically different from the clapper type controls with which he has been working all his life, and he must, therefore, be educated in its use. Many classes have been set up for the mill men which will teach him the fundamental circuits, but in the end, he will have to learn the know-how on electronic control in the mill itself.

Conclusion

A few of the electronic controls have been covered. There are many other applications in the steel mills. Because of the great field of electronics opened during the war, many people have been under the impression that we are coming into a push button era wherein the operator touched the button and electronics would do the rest. This is not the case. There is a definite place in the steel industry for electronic controls, but in many applications, due to its high initial or maintenance costs, rotating or static electrical controls should be installed. However, numerous automatic control mechanisms will be installed on many more of the processes and machinery in the steel industry as future study and development will show the way especially in justifying the change on the basis of the economics involved.
APPENDIX B

Automatic Controls in the Chemical Process Industries

Introduction

In the group’s study of the Automatic Factory, it might seem only natural that the wide-spread industry would merit especial attention. For it was here that the first industrial application of controls took place. The beginnings were with simple control mechanisms such as liquid-level controls. And of more recent origin such devices as thermostats and steam pressure regulators.

At that time the character of the chemical industry differed from what it is today. Labor was plentiful. Today the reverse is true. Consequently, the chemical engineer, who formerly designed a plant for batch operation has been pressed to discover new engineering methods and techniques to operate his plant more economically. The end result is the continuous process of today.

Labor, however, was not the only motivating force behind this sharp change in chemical production methods. The growing scale of operations had its impact as well. For it is generally more economical, where long runs are possible, to employ continuous rather than batch operations.

From the increasing emphasis on labor costs came the need for more effective automatic control instruments to run plants with as few workmen as possible. Reliable instruments were then developed to record automatically temperatures, pressures, specific gravities, and other indices of operating conditions. The results were gratifying to the chemical industry. Operating costs dropped. But one cloud hung over this rosy prospect. Maintenance costs edged upwards, though hardly enough to offset the savings arising from reduced labor costs. For in order to maintain a plant properly, skilled maintenance was now required to keep the controls running smoothly and to repair any that broke down.

From the foregoing, it must not be assumed that the choice of a batch sequence of operations must always be submerged to that of a continuous process. In some cases, as in the manufacture of paints, the batch process is more economically desirable. This arises
from the small-run characteristic of the batch process and the
differences inherent in each run. Unlike operations adaptable to
continuous processing, standardization is seldom possible. For instance,
in the case of paints, the manufacturer may wish to make 30 or 40
different shades of a particular color. Each shade would require different
ingredients and different operating conditions. A workman must be present
to make these changes and to keep checking to be sure that the right
ingredients enter into the making of the shade desired. Each change in
the end-product desired means different operating conditions; tempera-
tures and pressures necessarily vary from one product to the next.
No controls have yet been developed to supplant the mental process
which decides when one color is called for, when another, and under what
conditions.

The preceding discussion may impart something
of the flavor of the increasingly important role controls have taken on
in the chemical industry. Their importance was emphasized by Dr.
Norris Shreve, professor of chemical engineering at Purdue University,
who said: "Instrumentation for the indicating, recording, and control
of process variables is an almost outstanding characteristic of modern
chemical manufacture."

What functions do controls perform in plant
procedures? Basically, controls are employed in:

1. The analysis of incoming raw materials.
2. The analysis of the reaction products during processing.
3. The analysis of the end-product.

In the first function, it is a foregone conclusion
that the chemical manufacturer would establish stringent specifications
regarding his raw materials to preclude the possibility of undesirable
impurities contaminating his end-product. Moreover, it is the usual
practice in the chemical industry to purchase raw materials on the basis
of chemical analysis.

The second function, that of analyzing reaction
products during processing, is of surpassing importance. Many in-
process tests are necessary to make certain that reactions do not get
out of hand with attendant losses of time and materials. At first
glance, it may appear as though an extensive laboratory might have
to be provided to tie-in product tests taken at every unit operation.
This is not the case. Today the plant engineer, in cooperation with the instrumentation engineer, can frequently devise simplified tests and controls to depict the progress of a given reaction. These are reliable enough to enable the non-chemical workman to work with them. By way of improvement—and symbolizing automatic controls carried to the ultimate—a robotized plant has been designed in the past year which reduces the need for workmen to a minimum, approaching the much-discussed, but frequently scoffed-at, notion of an Automatic Factory.

The third function of controls turns on the analysis of the end-product. To ensure that the customer receives the product he wants or asks for, a complete analysis is often called for to pass on its purity and composition. This function is taking on increasing importance in the minds of chemical engineers and instrumentation engineers. They are presently considering the end-product analysis as the base upon which automatic controls can be more fully extended. At the present, control is based on such variables as temperature and pressure. For example, the measurement of refractive index was formerly confined to manual determination by visual means. But with the development of a means for continuously measuring the refractive index, a solution to many difficult distillation control problems manifested itself. An example may clarify this: In the separation of styrene from its parent material by distillation, separation by conventional temperature control is hard to achieve and frequently unreliable because of the proximity of boiling points between the parent and product materials. But inasmuch as the refractive indices of the materials are widely divergent, control by this means is highly reliable.

The remainder of this section will be devoted to specific applications of controls in chemical plants. In the next section will appear a general discussion of the economic implications of an Automatic Factory, as applied to the chemical industry. Here an attempt is made to justify automation on the basis of savings to be gained from reduced labor costs as well as from less tangible factors such as the diminution of the incidence of human error.

Automation

As mentioned earlier, the chemical industry, in its most recent past has become more and more enmeshed in the web of problems spun by high labor costs and the thickening complexity of
of processing methods. The end solution, it appears, would be the automation of a chemical process, in which the process is designed to be performed automatically, using a central nerve center or a computer which relieves human beings of the responsibility for overseeing the operation of a process.

The key to automation consists of the proper application of automatic controls to all necessary portions of a chemical process; and, equally important, of the integration of the various controls, to the end that all operations normally run by workmen are now automatically geared to a prearranged pattern. Integration, then, is the difference between automatic controls as they are applied today, and automation, which is the application of controls extended to its ultimate--the Automatic Factory.

It can readily be seen that integration would discharge all of the routine duties of the workmen, among them:

1. Control of process variables.
2. Sequencing of unit operations and their coordination within the processing cycle.
3. Checking on the processing and on the proper running of the controls.

Integration of the last two functions, by some system of interlocking electrical and mechanical devices, employing switches and relays, would enable automation, as will be described later on when a specific application is described.

Before discussing more fully the cost and economic aspects of automation in the chemical industry, it may be advisable to first discuss the need for such a development. How does automation fit into the pattern of chemical production? What does it do? What can it do?

Inasmuch as occasionally the proper functioning of a control cannot easily be checked, automation in which checks are linked to every control from a central point is a clear advantage. For instance, alarms, in showing the exact point of disturbance, would enable positive steps to be taken to stop the process. In this fashion, the development of hazardous conditions would largely be
eliminated. In a sense, this may serve to refute the skepticism of those who regard automation with something less than enthusiasm. Their chant: "No one knows when a gadget gives out." Or: "It takes just one electron-tube to die out to disrupt the whole works." The answer is, of course, that most tube failures occur in starting or stopping the control, and at these times, people are present.

In addition to cutting down on direct labor costs, automation whittles down indirect labor costs. For the costs created by human error, which inevitably accompanies human control, fade to insignificance. If a chemical plant is correctly designed, with all the elements of automation properly harmonized, it is a foregone conclusion that a classic uniformity of conditions and sequence of operations will be achieved.

It is conceivable that with human operators there may arise such production blocks such as incorrect batching, improper rate of feeding materials, faulty judgement of end-points of processing cycles, or errors in reading instruments. A further point of note is that during an emergency, a race develops between the response of the operator and the speed with which the emergency gathers force. Automation, however, prevents the race from even starting. In summary, automation would trim down the excess service costs, raw material wastes, and the inevitable breakdown of chemical apparatus and equipment. It would also deflate maintenance and amortization costs as well as prevent the incidence of hazardous conditions.

Professor Thomas Walsh of Case Institute of Technology posed this question: "What effect might variable conditions have on a completely automatic process, if those conditions did not depend on human error?" It is quite possible, as Professor Walsh suggested, that there may well be some indeterminable or unavoidable variations in the composition of the materials entering into the process. On the other hand, it does seem reasonable to say that, armed with full advance knowledge of all possible material variations, anticipation of such variations are not beyond the realm of possibility. The required correction can be built into the automation of the process to dispose of them.

So far, discussion has focused largely on the savings harvested from production costs. Further savings may be gained by
paring down necessary capital investment. Some instances may be
conjured up where they are not only possible but probable. For example,
it may be less costly for a chemical concern to design and build a large
plant to operate on a one-shift basis rather than on a three-shift basis.
Keeping in mind that the premium wages paid to skilled workmen on
irregular schedules would be eliminated. Continuing in the same vein,
it is also conceivable that automation may lessen the need for equipment
which must often be incorporated in a chemical plant to neutralize the
effects of human error. For example: equipment to rerun poor batches
or to mix below-standard materials with above-par materials.
Throwing in the added labor, which may be needed to perform these
operations, it can be seen that sizeable savings may result from automation.

Cost Estimates

Among the question-marks that curl themselves
up in the minds of chemical executives are: What are the costs?
How much would it cost us to put our plants on an automation basis?
Can we economically mold our plant layouts and sequences of operations
to conform to this basis? How long would it be before we recover our
investment? These and similar questions are uppermost in their minds.

Labor pains are being felt all over the country
as the chemical industry is preparing to give birth to improved products
as well as new ones to meet the demands of both the military and
civilian economy. But material costs are sky-high. So are labor costs.
The chemical executive is therefore saddled with the nagging responsibility
of being continuously and sedulously alert to cost-cutting opportunities,
the better to combat competition.

In running a plant under automation, the costs can
be broken down as follows:

1. Maintenance costs.
2. Amortization costs.
3. Operating costs (power, air, etc.)

The first-named is large compared to the other two,
inasmuch as it hinges largely on the initial outlay made, the utility of
the automation system, and the plant capacity.
The amount of capital investment necessary pivots on the type and complexity of the process, as well as on the precision of control necessary and the instrumentation needed over that ordinarily employed. But since all chemical plants now use automatic controls to a great degree, additional costs would embrace, for the most part, only those needed to cover the integration of existing controls; that is, the interlocking of one control with another such that each functions according to a pre-determined pattern of operation.

To cite one example, a company installed a plant which cost $187,550, of which $18,450, of 9.8% of the total plant cost, was spent on instrumentation and the integration required for the plant's automation. But the $18,450 is remarkable more for what it conceals than for what it shows. For only $1,500 or 0.8% of the total cost went into the installation of the integration system. In other words, more than 90% of the $18,450 was for the instruments themselves, a cost which would have been incurred anyway, automation notwithstanding.

An interesting sidelight to this specific example, was the effect of automation on labor needs. This company normally employed 14 men to carry on its plant operations. With automation, however, the company now employs one man as the attendant for the nerve center, to which all controls are linked, and another serving as the attendants' assistant and maintenance man. A conservative estimate of the labor savings would reveal that about $40,000 per year might be saved with automation. With these savings alone, therefore, the total plant investment of $187,500 could be redeemed in less than five years. Should profits and savings other than those assignable to reduced labor costs be included in the calculations, the pay-back period would be considerably less than five years.

The foregoing example relates to the cost implications in the application of automation to a continuous process industry. But, is it likely that automation would enable savings of similar magnitudes for batch processes? As alluded to in the early portions of this appendix, the batch sequence of operations has been gradually nudged into the background through the economies inherent in continuous processing. At the same time, it was also recognized that some chemical reactions cannot be tailored to fit the requirements of continuity. The manufacture of paints was cited as one example. Another is the production of ethical drugs—cortisone, terramycin, and ACTH. However, with automation, it may now be possible to not only boost the efficiency of those operations economically adaptable to the batch process, but also revitalize many of the smaller
chemical plants which have been unable to keep pace with their financially superior competitors.

A second example may be cited in which a chemical plant had been shut down for three years, because the selling price of its product was almost equivalent to its production cost of 42¢ per lb. The corrosive combination of hazardous working conditions, varying yields, and high labor costs had undermined the company's ability to turn out a profitable product. Last year, under the impetus of a bursting need for more chemical products to satisfy the appetites of both the military and the civilian economy, the plant was infused with new blood. About $11,000 was poured into new instruments, $3,000 into automatic valves, and $2,000 into electric relays and the nerve center which enables automation. The results were electric. Labor costs dropped sharply. Yields improved. Product uniformity was realized. The incidence of hazardous conditions was minimized. And of surpassing importance to the manufacturer was his glowing financial picture which reflected profits approaching 17¢ per lb.

A question which looms large in the mind of the chemical producer relates to the utility of automation. What is its useful life? Normally the life of a control will depend on the relative severity of operating conditions among various processes. Some reactions, for instance, are more corrosive than others. Inasmuch as the nerve center with its electrical relays and switching mechanisms is physically apart from the process itself, it is not exposed to the same operating conditions as are the instruments themselves or the process equipment which the latter control. Generally then, the automation system will outlast both the instrumentation and the plant equipment. Amortization costs for the system may therefore run well above that of the equipment. A conservative estimate might be 10 to 15 years. At best a guess, this range is built on sand. No automation system has been in operation for more than a year, and no reasonable estimates have been advanced as to the utility of such a system.

The tenor of discussion thus far has been that the additional costs required to install automation are relatively moderate. Automation can be super-imposed upon existing plant without much additional instrumentation. Conversion, therefore, rarely involves more than the cost of the nerve center or central panel and the interlocking relays and mechanisms between the instruments and the nerve center.
To emphasize the cost-saving opportunities a bit more, one last example of savings through automation will be presented. A medium-sized, continuous process plant, upon automation, was able to retrieve in nine month’s time its total investment on the installation of an automation system. As in a prior example, only savings in labor costs were considered.

In this case, automation amounted to about 8% of the total initial plant cost. If the system is amortized over a five-year period, its cost would be $.003 per pound of product. Before automation, labor costs were $.055 per lb. Adding in $.0003 per lb. as the cost of maintenance, power and service, the cost of automation reached $.0033 per lb. And in striking contrast to the former labor cost of $.055 per lb., it can be seen that sizeable savings of $.40 per lb. are realized. Nor does the $.40 reflect savings incident to the elimination of human error factors and to the improvement of quality variations enabled by automation.

The chemical industry, as most other industries, is presently riding the crest of a growing wave of business prosperity. No recession is in sight. Nevertheless, it may be provocative to soberly pose the question; What happens when a plant under automation is thrust into a period of low business activity, to the extent that idle capacity materializes? Would the plant’s cost position be better off with or without automation under such shadowy circumstances?

In view of the fact that a chemical plant normally requires skilled labor to keep it in smooth operating condition, reduced production may seldom justify the release of a proportionate number of men. In other words, labor costs take on increasing significance as production falls off. As production costs rise, the chemical producer has the choice of either raising his selling price or of accepting a lower profit margin. What his competitor does ow what the market will bear, largely determines the choice he makes. In contrast, with automation lessening the emphasis on skilled labor, the impact of a recession in operations would be much lighter on the company. It is true that amortization costs persist in the teeth of reduced operations, but the costs are of such small magnitude that they would hardly cause more than a ripple in the company’s rising production costs in relation to units of output.
Design Considerations

Following in the wake of consideration of cost, discussion will now be focused on the scope of problems growing out of the engineering involved in bringing automation to fruition. Different problems spring up between one process and another, between a batch and a continuous process. Can these technical problems be broken down into manageable, well-ordered parts to enable full-blown automation in the chemical industry?

No process, whether it be batch or continuous in character, is so complex or intricate, but that it can be reduced into elementary unit operations -- filtration, distillation, etc., which are controllable by one or more instruments. And, as mentioned earlier, most chemical plants have such mechanisms already incorporated in their production lines. The over-riding problem therefore breaks down into one of fitting all severally controlled steps -- filtration, distillation, etc. -- into a pre-determined pattern of operations or processing. Without automation, this pattern of control is in the hands of the plant operator and his subordinates. With automation, however, he and his assistants are largely removed from the picture, and in their stead, is substituted a mechanical or electronic "brain" to which all controls are channeled.

Automation would entail the integration of three types of functions:

1. Coordination among the different unit operations.
2. Time sequencing between these operations.
3. Automatic checking on the operation of the controls to prevent hazardous conditions.

An extreme case in which much ingenuity would be required to effect automation would be a plant that produces paint. Here the batch is used alternately for many different paint products. For each shade of paint, the processing conditions vary, and some steps may in fact be cut or added. Such a situation may require intricate switching arrangements among the various unit steps--mixing, drying, etc. - to differentiate conditions for each paint product. Costs may be high, but automation would still be practicable. Realizing that this last statement cannot be buttressed by factual evidence, it would be reasonable to say that the scope of automation is relatively fixed by the units which
constitute the process system. To achieve automation, therefore, it would only be necessary to design a network of switching arrangements among the various relays leading from the nerve center to the controls, by means of which controls serving each unit are set into alternative coordination and sequence operations.

With a continuous process, however, the problem of automation takes on a more receptive air. Only one product is manufactured. All that needs to be done is to design an automatically controlled system in which each step would be brought into proper relationship and time sequence with other continuously operating steps.

Implicit in the foregoing discussion is the pooling of different skills and knowledge needed to develop automation in a given plant. The chemical engineer is incapable of doing it himself. He must draw upon the services of the electronics and instrumentation engineers as well. Automation is in actuality the distillation of their ideas put to practice.

**Instrumentation**

Another question that comes into the picture is whether automation would alter the type of controls to be employed on the production line. Inasmuch as automation generally connotes the absence of workmen or of human manipulation, it would seem reasonable to conclude that the plant manager would demand for his plant those instruments which meet the most severe conditions. Basis for this conclusion is the difference in factors bearing on the choice of instruments between an automation-designed plant and one which normally uses instruments for isolated control applications. In the former, controls are designed to relieve the workmen of the need for determining such variables as temperature and pressure and for adjusting the process to conform with the values desired. In the latter, however, controls are not designed to relieve the workman of responsibility for the accurate handling of the instruments. It would therefore seem likely that the plant manager would base his choice of controls on rather more stringent considerations than those normally employed. Consequently, it is important that the plant manager consider carefully what the exact requirements to be fulfilled are and which controls best fit them. For example, he must know what type of instrument response is required the accuracy of the response, and the degree to which the instrument action must be rectified for process lags.

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The backbone of automation, the characteristic which distinguishes it from the conventional chemical plant, is the system of electric relays and mechanisms which make up the nerve center. These mechanisms do not themselves respond to or control any variables. They serve as links between various controls. They introduce the required time sequencing. They supply the needed checking of process conditions and of the response of the controls themselves. They interweave the functions of groups of controls. It is clear, therefore, that since their function is important, their selection is as important as that of the controls themselves. These mechanisms must be positive and must operate with piston-precision accuracy. Otherwise, serious waste may occur. For example, a timer whose contacts do not open at the preset time may lead to damaging errors in feed or processing and result in a poor end-product.

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Section II

Case Studies

How has chemical management gone about building plants around instrumentation, rather than fitting instrumentation to the already constructed plant?

Two case studies are presented in this section to bring out in some detail the growing awareness of the chemical industry to the possibility of fully automatic control. Both the Cit-Con Corporation and Dan River Mills, Inc. seemingly conceived of their plant expansions as being a joint product to which were neatly dove-tailed the technical elements of both chemical and instrumentation engineering. This is significant in that a hurdle has been taken in the struggle to overcome the difficulties which come from the inability of the chemical engineer to fully understand instrumentation and therefore proper design, unless an instrumentation engineer be consulted to help him design his plant more efficiently.

Although neither company has taken the step of full automation, there are signs of important strides in this direction. It is a goal, as mentioned in Section I, to which the whole industry may ultimately aspire.
The Cit-Con Oil Corporation

Last year the Cit-Con Oil Corporation built a $42 million refinery at Lake Charles, Louisiana. Having a daily operating capacity of 6,000 barrels, the refinery, according to Mr. J. P. Dorsey, instrumentation engineer with Cit-Con, reflects the latest advances in instrumentation and process equipment for the production of lubricating oil. Other products include paraffin and non-crystalline waxes.

Placing a premium on high quality and uniformity of control, the company obtained the latest available equipment. Its investment in instrumentation--including 783 instruments, instrument piping and panels, electrical service to the instruments, and material and labor -- was about 4 1/2 % of the investment in the operating units.

The refinery may be broken down into the five principal processing units:

1. Twin vacuumStill's -- where the feed stock is separated into five lube oil cuts.

2. Solventextractors -- one a Duo-Sol unit, where the two heavier lube oil cuts are extracted; the other, a Furfural extractor for the three lighter grades.

3. Two MEK (methyl-ethyl-ketone) dewaxers -- one for processing the lighter grades of oil and the other for processing the two heavier grades.

4. Twin clay contact units -- where the oil is finished.

5. Wax treating and filtering plant -- where fully-refined waxes are produced.

Exhibit I depicts graphically and in greatly simplified form the flow of materials between the processing units. The following discussion will pivot on the utilization of instruments in each unit. Beginning with the twin-vacuum unit, a flow recording controller regulates the amount of reduced crude fed to the vacuum unit furnaces. By regulating a diaphragm motor valve on the
fuel gas supply to the vacuum unit furnaces, an Electronik recording controller maintains at the desired level the temperature of the oil spilling from the furnaces. Similarly, a recording controller, by regulating the volume of water through vacuum ejectors, controls the pressure of the vacuum flash tower.

Five sidestreams branch off the vacuum tower, as shown in Exhibit I. The gas oil from the top sidestream is refluxed in order to control the top tower temperature. A flow controller automatically governs the volume of reflux, while a liquid-level controller in the stripper controls the flow of each of the other sidestreams.

In the Duo-Sol unit, the residue and bottom sidestreams from the vacuum unit are solvent extracted in drums, as depicted in Exhibit I. A flow recorder-controller holds constant the flow of oil to this unit. In addition, controllers pre-determine and automatically control the ratio of solvent flows (Selecto and Propane) during the operation, and regulate the flow of raffinate in Propane solution from the last drum to a flash tower. Once the Propane is flashed off, steam is stripped from the stream to eliminate final traces of Selecto and Propane. The temperature of the oil leaving the raffinate heater is measured by an Electronik recorder, which also regulates the fuel supply to the heater. In order to maintain the proper levels, flow from all towers is regulated by liquid-level controllers. In the next step, the extract and Selecto mix from the bottom of the first drum is split. Part of the mix passes to a heat exchanger and part to a furnace. The extract steam is then steam-stripped. Control of the temperature and liquid levels are effected as in the raffinate heating and stripping.

In the Furfural unit, the three lighter streams from the twin vacuum unit are solvent extracted by the Furfural process. Recording controllers adjust the rates of oil and Furfural flow to the extraction tower. A temperature recorder controls the temperature gradient in the tower by actuating a three-way valve that regulates the portion of intercooler streams going through or by-passing coolers. In order to maintain the extract interface at a constant level, a liquid-level controller positions a diaphragm motor valve in the bottom outlet of the extraction tower, thereby regulating the extract mix flow. Before going to recovery units for Furfural removal, the extract mix and the raffinate mix travel to separate accumulators. These recovery units consist of a heater and a vacuum flash tower. The temperature of
the mix going to the flash tower is regulated by an Electronik instrument, while the flow of mix to the heater is controlled by a flow recorder-controller.

A combination level indicator and flow recorder maintains the levels in the flash towers by automatically regulating the stream flow leading from the towers. The vacuum is enabled by a vacuum pump taking suction through a liquid trap.

In the MEK de-waxing units, a flow recorder ratio controller adjusts the ratio of solvent to waxy oil charge to these units. Once the solvent and oil streams converge, the resulting mix is divided into two streams before being charged to propane chillers and to double-pipe heat exchangers. At this point, the entire flow is regulated by a flow recorder-controller on each stream; a flow recorder ratio controller records the total flow through the heat exchangers.

A temperature recorder-controller adjusts the temperature of oil and solvent mix from the chillers by positioning a Propane expansion valve on the chillers. The solvent and oil are then passed to a filter feed tank, and from here to rotary filters. To cool the waxy oil and solvent charge, the pressed oil from the filters is passed to a filtrate receiver, through double-pipe heat exchangers, finally to a solvent recovery surge tank. Both the rotary filter and the filtrate receiver are regulated by means of liquid-level controllers.

In the next step, the filtrate is pumped to a low-pressure flash tower. Here a liquid-level controller-recorder positions the index on a flow recorder-controller for the filtrate mix stream to the tower. A high pressure flash tower then receives the filtrate mix from the bottom of the low pressure flash tower after it has passed through a heater.

A temperature controller, by actuating a valve on the fuel gas line to the heater, maintains the temperature of the outgoing stream from the heaters. The flow of the condensed MEK vapors leaving the high pressure flash tower is automatically adjusted by a pressure recorder-controller. The oil flowing from the bottom of the tower is automatically set by a liquid-level controller. The oil then passes to a stripper, and finally to raw oil storage.
The Dan River Mills, Inc., in a recent expansion of its plant facilities in Danville, Virginia, recognized the need for extensive instrumentation by installing automatic controls “not because of the cost savings afforded but for protection of the company’s reputation for turning out high quality textiles.”

To impart some sense of the utility that automatic controls possess in their application to the processing of textiles, a brief description of the company’s bleachery will be given. Four continuous bleach ranges comprise the production equipment. Three are Becco, one a DuPont. Each range can be reduced to four groups representing process equipment employed and the associated instrumentation. Inasmuch as these groups are similar in each range, a discussion of one range will be a fair reflection of the others.

In Group I, a singer, saturator, and J-Box make up the process equipment. The cloth travels through the singer to the saturator to be shrunken in an enzyme solution. From here, the cloth is pressed through pneumatically loaded squeeze rolls whose pressure is recorded by a Brown pressure gauge. This operation assures the even penetration of the enzyme solution. The cloth then passes to a J-Box, where sizing is broken down in preparation for subsequent processing. A Brown Electronik recording tachometer is employed to make certain that the machine speed dovetails with the other elements of the range. Speed of the tachometer is controlled by a General Electric Thymotrol system.

A washer, saturator, and J-Box constitute Group II. From storage in the J-Box of Group I, the cloth travels through a washer for removal of the solubilized sizing. This particular step is of paramount importance since any slight trace of sizing remaining in the fabric may inhibit adequate bleaching and dyeing. The sizing prevents the penetration of chemicals or dyestuffs. Consequently, much emphasis is placed on temperature control to attain the most desirable wash. To this end, a Minneapolis-Honeywell temperature controller is employed. It throttles the steam input to the washer, keeping water temperature at an optimum level.
Once the sizing is removed, a caustic separator and J-Box are employed to purge the fabric of its remaining impurities which range from natural accumulations to foreign matter. Control of both pieces of process equipment is effected by Minneapolis-Honeywell instruments. The continuous recording of squeeze-roll pressures on both the washer and the caustic saturator is accomplished by using a two-pen pressure gauge.

To maintain narrow temperature limits on the caustic J-Box, an Electronik potentiometric pyrometer with Air-O-Line pneumatic control continuously throttles steam input. A sensitive, special-design Brown thermocouple registers the temperature variations. Among the advantages which the thermocouple offers is its stainless steel construction with adjustable union seat for depth adjustment, and its splash-proof fittings.

A Brown Electronik potentiometric tachometer gauges the Group II drive speed. It records continuously both the synchronization speed of the other range elements and the productive and down times.

In Group III, the equipment and instrumentation are similar to those in Group II. Here, bleaching takes place. The need for adequate instrumentation is underscored in this process phase, as perhaps nowhere else in the process, since the slightest over-bleaching here will wash out the color brilliance. A premium is therefore placed on the precise recording of such critical variables as temperature, pressure, level and speed to assure that the market appeal of the fabric will not be damaged in this process phase.

Group IV is the final phase of the bleach range. The final washer is the only processing equipment at this point. Its temperature is kept constant by a Minneapolis-Honeywell controller. An Electronik tachometer records the speed. Steam flow is both recorded and totalized. A continuous accounting is enabled by the five-figure, direct reading integrator on the steam flow record. In this fashion, departmental as well as individual machinery may be compared and charged for steam use. In addition, it aids in the detection of losses. From the final washer the fabric passes to mercerizing bins in preparation for the finishing range.
This case gives some indication of how and where instrumentation can be applied to the textile manufacturing process. To reiterate the feeling of the management, automatic controls were chosen mainly to protect the quality of the textiles being produced. The management recognized the magnitude of cost savings involved in installing automatic control devices though these savings were not the main consideration. Their decision reflects the ability of automatic controls, when properly integrated, to provide better quality at a lower cost. It will be interesting to observe the extent to which this reasoning will be adopted by other textile manufacturers in the years to come. Improvement of quality through better controlled conditions may provide competitive pressure which will dictate the adoption of such integrated automatic control devices as have been described in this section.

This case material is from an article by T. L. Shealy in the fourth quarterly issue of Instrumentation for 1950.

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