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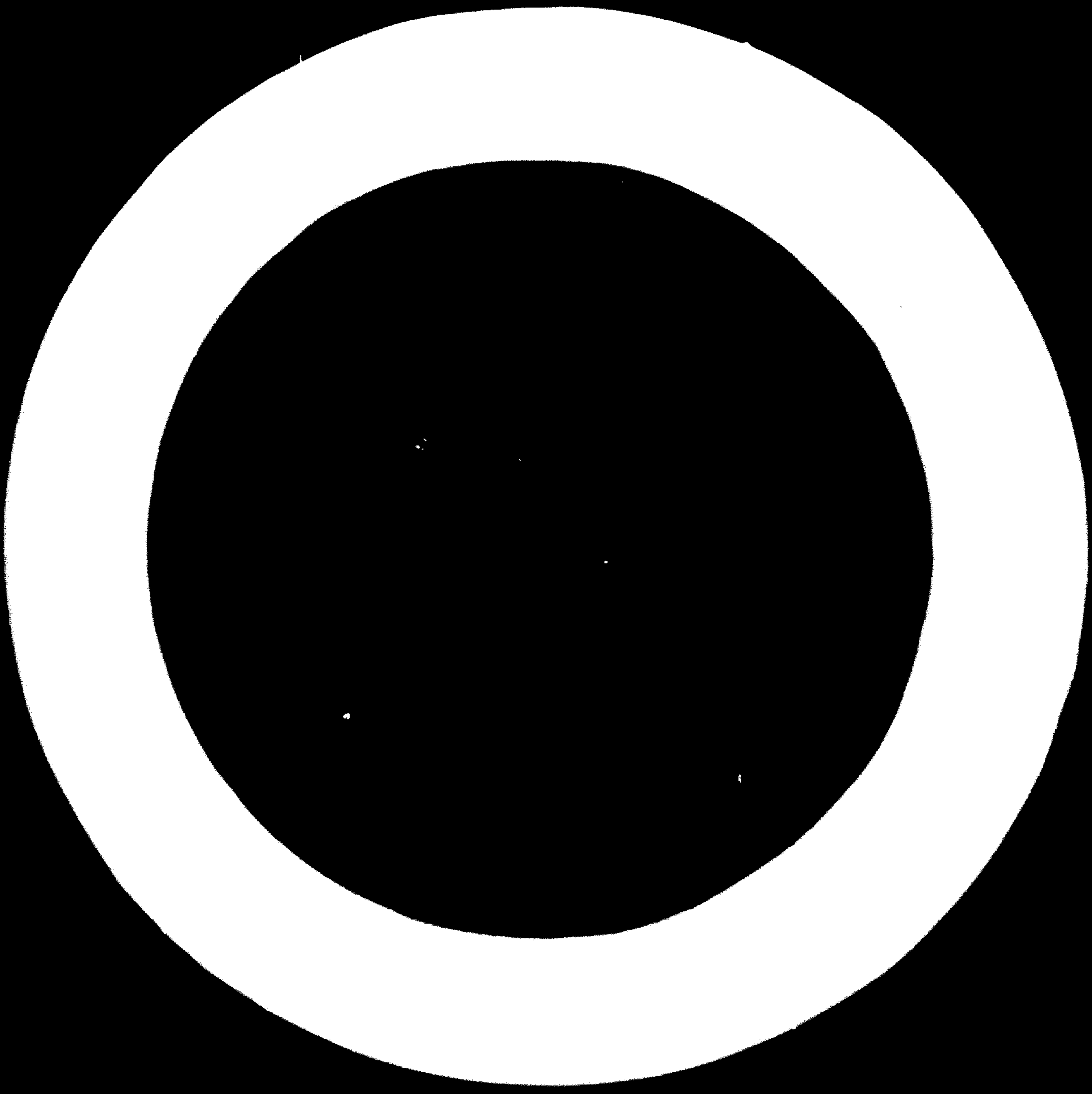

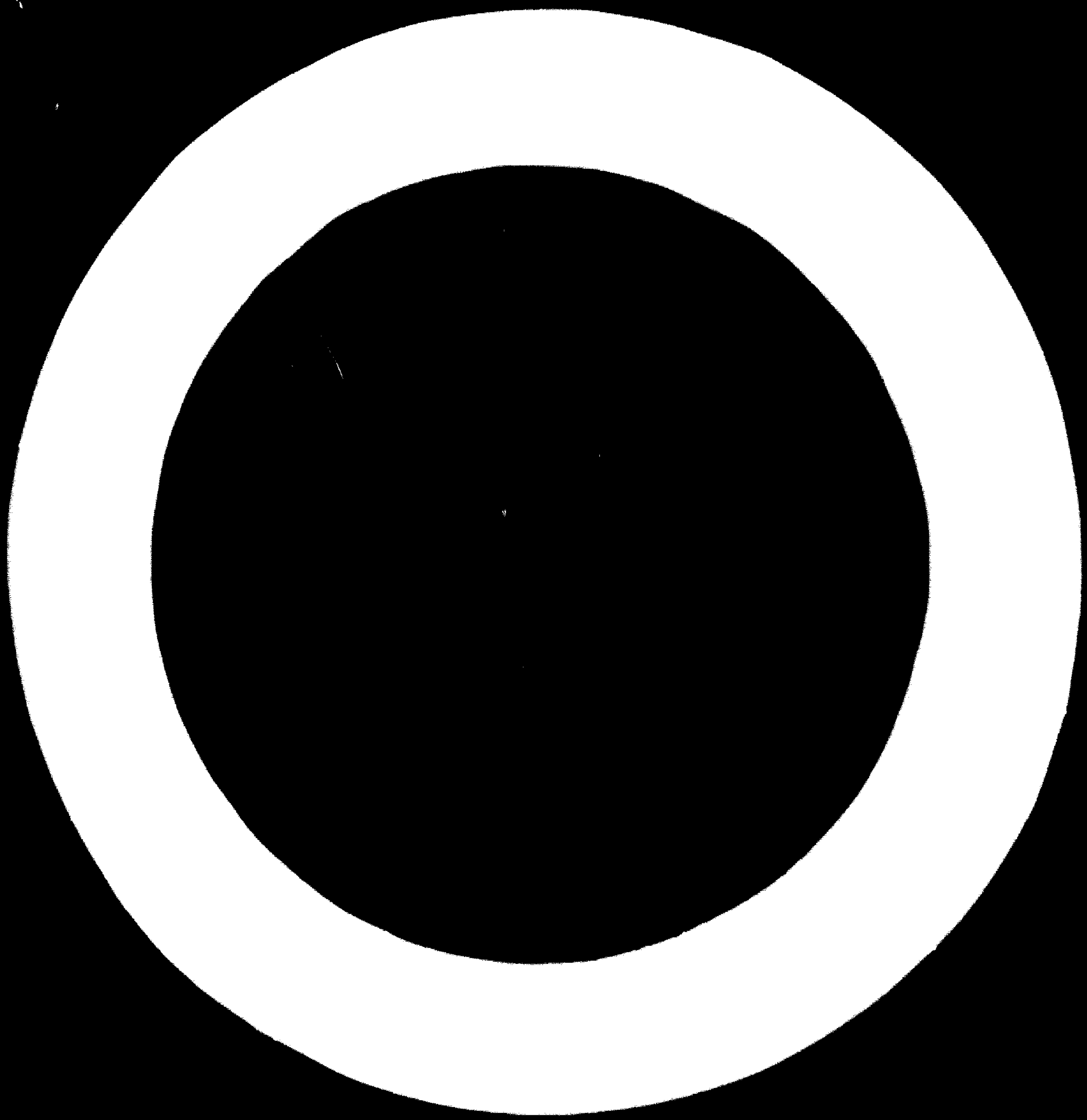

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SOME PROBLEMS IN THE APPLICATION OF RESEARCH IN THE MACHINE-TOOL INDUSTRY

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INTRODUCTION

Today there is great awareness of the problems in the relationship between research and its industrial application. These problems are a constant topic for discussion and there is a good deal of information on the subject—information from which one can draw conclusions as to the methods that should be applied in order to gain useful results. If, however, a particular industry is actually to make use of this information, it must know how to extract those parts which are relevant to that industry.

Before entering fully into the subject of this paper, the author would like to make a few remarks based on his experience as an industrialist. First, it should be borne in mind that economic growth depends upon such factors as the resources which are available, in terms of finance and human skill. It depends also, however, upon a chain of factors which, beginning with basic research, leads to applied research and technological development before culminating in economic growth. It is on this basis that one must study the problems of the relationship between research and its application in industry.

One must remember also that the number of scientists who are working alone is decreasing and that research is becoming more and more a group activity. This opens up all the possibilities inherent in collaboration between different scientific disciplines, but it also opens the way to the dangers of bureaucratization of a human activity which, by its very nature, is refractory to organizational pressure. On this point, it is worth while mentioning the results of the work done by the Organization for Economic Co-operation and Development (OECD), which, at the instigation of the International Institution for Production Engineering Research (CIRP), has worked out methods for promoting joint research between various European laboratories.

Again, one should remember that the incorporation of research into the framework of an organization always results in some upsetting of traditional administrative procedures. Such questions as the following arise. How will the scientific and commercial staffs co-operate? How can the research activity be reconciled with the financial objectives of the organization? At what level will research policy be related to the over-all policy of the organization?

Most persons consider research a positive investment that will eventually pay for itself. There are still, however, those who consider money spent on research as money wasted. Why do these opposing viewpoints exist? In the author's opinion, it is essentially because investment in research entails far greater risks than does investment in more tangible things, such as production equipment. Research does not necessarily produce results that can be commercially exploited and, indeed, the paths taken by research do not necessarily lead to any useful result at all.

If, however, one could know in advance what research paths to take, there could not, in fact, be any research and, as a result, no products better than others.

It is appropriate also to discuss briefly what can be called the "natural industrial pattern" of a region or of a country. In this regard, one must be very careful because one's conclusions can so easily be completely at variance with the facts. Generally, what appears to be a natural state of affairs is merely the result of a particular effort maintained over a number of years. Industrial patterns are the result of the energies, desires, abilities and feelings of social responsibility of those in charge of the industries that go to make up the industrial pattern; this applies as much to centrally planned economies as it does to free-enterprise economies. The continued success of these patterns, however, will depend upon the results of research into the organizational structures required for the attainment of the necessary levels of efficiency.

I. THE ROLE OF INNOVATION

Research cannot be regarded as something which is well defined and which appears the same to all men. The scientist thinks of it as a matter of increasing human knowledge, while for the technologist, it is something which leads to improved processes and new products.

Whatever the research philosophy may be, the results of research will, in time, affect the general economic situation, and the interrelation of research, industry and the general economy should never be overlooked by those who have to plan technological research.

Why is scientific and technological research so important? Frequently, the temptation is to consider that it is unnecessary and that it is sufficient to watch from a distance the evolution of things as brought about by others.

Unfortunately, this is not the case. It is, in fact, only by innovation that one can open new markets and improve the economy. If a firm, or a group of firms, wants not only to maintain its turnover but also to increase it, it is essential that it should innovate in some realm. It must be kept in mind, however, that it is necessary to have more than one string to one's bow, especially if the one fitted is not very strong. Innovation is beneficial not only in design, but also in production, distribution and advertising.

To summarize, innovation is the means for making a product more attractive than its competitors. It creates the difference that convinces the customer he is getting the best value for his money.

Now, it has to be acknowledged that the current rate of progress is much more rapid than it has been in the past, and the more elaborate a product is, the more difficult it is to improve. Moreover, the production facilities required are much greater and the costs much higher.

Consequently, any research organization should attempt to make itself as efficient as possible. Research calls for every kind of knowledge, relating as much to physics as to human behaviour. The efforts exerted by man to master nature compel him to rethink his relationships with his fellow men and to return to the study of the functioning of his mind, the role played by his emotions and the causes of his behaviour and attitude. This is why it is useful to analyse, at the level of working methods, the mental processes of scientists and those whose role it is to develop the results of their research.

II. The various stages in establishing a research programme

The establishment of scientific or technological research programmes—the choice of objectives and of the means for attaining them—require consideration of both the known and the unknown factors. Before reaching any major decisions, one must, as far as possible, attempt to see into the future and systematically to evaluate the various likely possibilities. It is only in this way that one will be able to establish what will, in fact, be useful programmes of research.

How should one go about choosing our research objectives? Here, one should more or less systematically follow what is in itself a research programme—a programme having a number of stages, of which the most essential are the following:

(*a*) The selection by top management, from all the various possibilities, of the general field of research and the broad lines to be followed therein. To do this wisely one must be able to foresee, to some extent, the changes that will come about in the economic situation, for it is necessary, at all costs, to avoid putting outmoded products onto the market. Further, there must be a good knowledge of the current stage of technology so that, from a knowledge of the state of scientific research, one can assess the probable changes that will come about in the technological situation. These two requirements can only be met if a team spirit, with all that it implies in the way of openness, fair play and honesty, exists between the laboratory director and his staff;

(*b*) The second stage is the selection of particular ideas within the general field. It is not sufficient to choose a field of research capable of yielding useful results; one still has to actually obtain results. Therefore, only those ideas which can be clearly expressed should be retained. The research staff themselves should be associated with this second selection and classification so that their own ideas add to those under consideration. At this stage also, specialist help from outside may be useful. It is obvious that although all can contribute to the generation of ideas, only the research staff can give detailed expression to them. It is the author's opinion, however, that a broad knowledge of the general factors involved, in addition to the purely scientific ones, can facilitate their task in this;

(*c*) The last stage consists of fixing relative priorities for the various parts of the programme. This is by no means management's least important task, if all the work is to end together—a necessary condition for efficient research. Unfortunately, planning scientific research is practically impossible because planning means defining not only the aim, the means and the stages, but also the times allowed for them. This can only be achieved for those operations to which known techniques can be applied. Nevertheless, if in applied research the target is clearly defined, it is possible, to some extent, to programme successive experimental stages.

After the initial establishment of a research programme, it is necessary to consider its periodic revision. Steps taken previously should be objectively reconsidered from the points of view of:

(*a*) Changing the tempo of the work, or stopping it temporarily or permanently;

(*b*) Maintenance of the same tempo;

(*c*) Transference to other laboratories for further development;

(*d*) Transference to other undertakings for industrial exploitation.

As was mentioned earlier, research does not necessarily produce results that can be commercially exploited. Is this fact to be regretted? In the author's opinion, it is not—because it is possible to learn in many ways, and failure is not always as fruitless as one imagines, particularly if one is aware of the causes.

III. Working methods used in research and production

Experience has shown that in order to form a link between research and production, it is first useful to analyse the working methods of both the scientist and the production engineer. This is most important if one is to understand their respective points of view.

It enables one to find the proper steps to be taken in order to ensure continuity between laboratory work and manufacture of the finished product.

A. *Similarities between the work of the scientist and that of the production engineer*

Is there, in fact, a similarity between the work of a scientist and that of the production engineer? The author believes that there is, because the engineer must constantly resort to scientific theories, even though he is mainly concerned with practical circumstances.

However, just as improvement in manufacturing techniques can be said to depend upon advances in science, these advances themselves may have been made possible by progress in practical manufacture and there is, in fact, a constant interaction between the progress of science and the improvement of manufactured products.

Both the designer and the scientist use imagination and seek truth, precision and objectivity. The engineer must, as the scientist does, consider that there must be a rational explanation of the discrepancies he observes in the phenomena he predicts on the basis of physical laws: they cannot be simply the result of whimsical construction. Furthermore, in extreme cases, he must check to ascertain whether the laws he has applied are really applicable in the domain explored.

B. *The scientist — mental processes*

How does the scientist go about his work? He generally proceeds in three stages:

(a) *Observing*. This is usually done by examining those phenomena that the research worker himself chooses, consciously or unconsciously, depending upon his curiosity, awareness, patience and experience. At this stage, the role played by instrumentation is by no means negligible, for it enormously widens the scope of the senses and allows one to make exact measurements;

(b) *Hypothesizing*. In the second stage, the scientist formulates hypotheses and makes experiments with a view to verifying them. Hypotheses are the product of creative imagination and of the application of calculations to new phenomena etc.;

(c) *Testing*. Scientific thought accepts only knowledge that can be proved by experiment and observation. The research worker must, consequently, always submit his ideas to experimentation and be ready to modify or change them according to the results of his experiments. Needless to say, this experimentation must be organized on the basis of carefully developed theories and is an intimate fusion of the practical and the theoretical.

C. *Professor Gonseth's point of view*

Dr. Gonseth, late professor of higher mathematics and of the philosophy of science at the École Polytechnique Fédérale, in Zurich, corresponding member of the Institut de France, considered that there are really four stages to the scientific method:

(a) *First stage:* emergence of the problem. The researcher recognizes the general problem. In the case of the experimental sciences, this recognition comes from observation;

(b) *Second stage:* working out of the hypothesis. No research will progress without an inventive mind and a creative imagination;

(c) *Third stage:* proving of the hypothesis. In the experimental sciences, this proof must obviously come from practical experimentation;

(d) *Fourth stage:* recapitulation. The research worker integrates the results from stage three into the general problem.

In the author's opinion, the omission of this fourth stage is often the cause of disappointments and of misunderstanding between scientists and management, and it creates a kind of barrier that is not always easy to cross. When a research worker has isolated a problem, he tends, quite naturally, to solve it for himself alone and rarely concerns himself with the effects that his findings may have on the whole research programme. Indeed, it is questionable whether he can be expected to without a wide knowledge of market demand, production potentials and proposals for future developments.

In view of the above-mentioned problem, it is appropriate to discuss the methods that, in the author's opinion, should be applied in order to exploit profitably the results of research.

IV. Exploiting the results of research

Experience has shown that the transference of research results into the workshop is likely to be the major obstacle to their successful exploitation. Results of work which has been enthusiastically undertaken may never achieve concrete form, leading to discouragement for both research workers and management. On this subject, the report of the First European Regional Symposium on Research Administration and Organization states:

> "In applied research, the transference of results from laboratory to workshop is a constant, delicate and complex problem. We think it advisable to outline the essential features of the proposed solutions for it is at this stage that research work finds its justification. This transference takes place either when the research programme comes to an end or when a coherent set of results has been obtained."

There are two solutions which can be applied either singly or together, i.e. the creation of pilot plants and/or the introduction of "research and production engineers". In the author's opinion, however, it is advisable to add a third solution for the machine-tool industry, namely, the introduction of "research and development engineers". Such engineers form a link between research and manufacture. They play an important part for the reason that a machine, even though manufactured with advanced technical means, will never be worth more than the design principles on which it is based.

A. *Pilot plants*

The above-mentioned Symposium report continues as follows:

> "The question is how to pass from small-batch to quantity production under totally different environmental and processing conditions.
>
> "The technical difficulties of such an extrapolation are too well known to dwell on. Nevertheless, there are some remarks which must be made. It is absolutely necessary that the research worker or research team 'follow' the process under transference in its peregrination from the laboratory to the pilot plant and from the pilot to the main production plant.
>
> "The laboratory engineer must, before any actual manufacturing has begun, form a team with the engi-

neer in charge of the pilot plant. Close co-operation is most important for making a satisfactory start. It can be relaxed as the pilot activity increases. The procedure must also be followed when passing from the pilot to the production plant, and a reverse procedure, if the production schedule is not attained and it is necessary to return to the beginning again.

"Two points deserve attention:

"The advantage of having the pilot plant located within, or as close as possible to the laboratory, because perfecting industrial techniques is more difficult than shifting them from place to place.

"The advantage, equally obvious, of allowing those who carried out the laboratory studies to help run the pilot shop, in order to avoid a 'break in psychological involvement' and the loss of a great part of the benefit of previously established human relationships."

B. *Research and production engineers*

With regard to research and production engineers, the report states:

> "In order to make the transference from the laboratory to the workshop, certain engineers responsible to the production departments may be used to assure a permanent link between the laboratory and the workshop concerned.
>
> "These engineers will preferably be chosen from experienced laboratory staff in order to have the problems clearly revealed. They are, furthermore, propagandists for scientific ideas in the workshop.
>
> "Let us close this chapter by pointing out that the recommendations it contains relate to a major link in a firm's organization that ties the applied research to the use of its results in production."

This may be an astonishing point of view, but it is justified in those instances where a drastic modification of production techniques is called for. The extent to which an organization can profit from research in general depends upon the extent to which it carries out its own research and employs production engineers capable of exploiting it.

C. *Research and development engineers*

It is advisable to stress again that in an industry the role of the university-trained engineer is to form the link between research and that industry. For this reason, it is worth while examining the working methods used by engineers, whether or not they have to deal with the construction or manufacture of machine tools, in order to show the similarities and differences between their work with respect to that of the scientist —using Professor Gonseth's theses (see chapter III, section C).

1. *Emergence of the problem*

A very wide range of problems is encountered in the construction of machine tools. They may result from discussions with customers, from personal observations, from practical tests or, and this is frequently the case, from manufacturing costs which are considered too high. They can concern the operational convenience of the machine and the safety of the operator, as well as improvements in output and accuracy.

The engineer must not neglect one problem in favour of another. He must first observe the phenomena and the environmental conditions in which they arise. Observation is the objective recording of facts without trying to modify them. This observation is not sufficient. Measurement is needed in order to gauge the importance of the problems. Measurements allow one to evaluate the order of magnitudes involved and to decide on the advisability of envisaging new developments.

A point worth noting is that it is the accuracy of the measuring means which limits the detectability of the phenomenon sought. Charles-Eugène Guye rightly says that "it is the scale of the observation which creates the phenomenon", that is to say, the phenomenon changes in accordance with the scale on which it is considered.

2. *Establishment of solutions*

While the scientist tends at this stage to formulate hypotheses, the engineer looks for means to solve the problem in terms of his knowledge. In both cases, however, imagination is the mainspring for their thoughts. The means differ, but the intellectual processes are the same.

The engineer often complements the inventor and the scientist. His mission is to give the most favourable construction to a technical concept. He uses imagination to obtain several solutions, which he then examines for validity. According to the nature of the object to be given a practical form, he will orientate his efforts towards appropriate solutions and, today, engineers have at their disposal widely different techniques for solving the same problem.

Louis Armand, a well-known French engineer, a member of the Académie Française and author of *Plaidoyer pour l'avenir*, says that the engineer of the future will have to change his "knowledge store", on an average, three times during his life. In the present author's opinion, however, the term "change" is too strong; it is, rather, a matter of adding to and extending one's store of knowledge.

It is in choosing from amongst the above-mentioned techniques that the university-trained engineer must show his skill. Because of this, he must, throughout his career, keep abreast of technical developments.

Having a wide choice of techniques at his disposal, the engineer, who uses and masters his imagination, progressively reaches the point where he knows in what manner he will be able to give shape to his initial ideas. Then, his faculty for imagining the material aspect of things comes into play. He must possess the faculty of concentration in order to force his nebulous imaginings to take a form sufficiently concrete and precise for transmission to others.

Owing to the difficulty of obtaining technical perfection and scientific rigour, the solution the engineer selects is often a compromise between contradictory requirements. Indeed, when one considers the range of different techniques available, one sees that the ability to decide between them is not the least of the qualities that an engineer must possess. In this decision-making, sketches, drawings and calculations obviously play an important part in fixing the engineer's thoughts.

3. *Verification of the solution adopted*

In order to be in a position to verify that the proposed design meets the requirement, it is generally necessary to carry out one or more tests, and perhaps to build a prototype; such prototypes are often made in the machine-tool industry. Before reaching this stage, however, the engineer must examine his solution from two different aspects:

(*a*) The technical aspect, so as to see whether the proposed design really is an improvement on the previous design;

(*b*) The commercial aspect, since even the best concept, from the technical point of view, is useless if a market cannot be found for it.

If the engineer concludes, alone or with specialist aid, that the solution he suggests is the right one, the time has come to pass onto manufacture. The engineer must then be able to show managerial ability, as he will, on occasion, be called on to supervise the various personnel in the mechanical, optical, hydraulic, electrical and electronic fields, who are concerned in furthering the solution. He must care about costs and, consequently, about the manufacturing processes and assembly methods.

Then, once the drawings are completed, they are sent to the workshop and, finally, the engineer can see the fruit of his thoughts taking shape. His feelings of paternity with regard to what his imagination has led him to develop grows and he waits confidently for the first trial.

At this stage, the engineer often finds difficulties arising, for he comes up against the engrained habits of the workshops. What seemed to him an improvement turns into a complication, then to a nuisance and, finally, to an obstacle. The prototype is considered by the shops to be something difficult to produce; they consider that they have neither the necessary tooling nor the required information for its manufacture. Consequently, the engineer must be a good psychologist and leader, or enjoy the total support of the management. Nothing is more comforting for the engineer than seeing other people, at all levels, taking an interest in "his" prototype and showing their willingness to aid him in its development.

A real team spirit is essential because many different specialists are now concerned in the development. At this stage also, the production staff must study possible improvements and simplifications of the manufacturing and assembly methods. Operating, testing, dismantling, inspecting and retouching are repeatedly carried out until the machine is ready to be delivered to the customer or is ready for manufacture on a production basis.

4. *Re-examination of the solutions: their incidental effects*

In principle, the incorporation of a new development in a machine tool or an instrument must result in an improvement, but the secondary effects of this incorporation must be considered, for they can, in some instances, prove to be quite disturbing. This re-examination is the analogue, for the research and development engineer, of the scientist's reintegration of his results into the state of knowledge at the beginning of his research—Professor Gonseth's fourth stage.

In spite of all tests, results obtained under production conditions can sometimes be different from those obtained from even the best prototype. All engineers encounter difficulties which did not occur during manufacture and testing of the prototype and which give rise to serious problems as soon as quantity production begins.

At this point, the author would like to make some comments based on his experience as a designer of measuring machines and machine tools. First, improvements in the concept or in the manufacturing methods of a machine tool often result in a price increase. The user wonders whether this increase in price is worth the higher performance. His criteria of judgement are not always the same as those of the engineer. The likelihood of the new concept becoming a commercial success must be examined with the sales department. It may then be necessary to abandon a technical improvement in favour of a lower price, hoping that in future a simplification of the design will allow quantity production to be undertaken economically. Furthermore, the prototype often does not provide enough information as to the life that can be expected from the various separate parts of the machine. Here, one can at least say that the fewer the number of assemblies or components, the safer the functioning, and the lower the specific pressures between the moving parts, the least wear.

Without dwelling too long on reliability of operation, the author would like to point out that the methods used in the development of missiles are possibly applicable. In industry, it is necessary, above all, for a producer to keep an eye on the troubles the customers may encounter with his machine and to make certain that this information is passed back to the engineers concerned. This kind of long-term feedback is indispensable in acquiring the necessary experience and skill required for building better "the next time". In the case of the machine tools, this approach assures the quality and regularity of the production by lessening the down-time required for repair and maintenance.

With regard to more scientific matters, in very high-precision machine tools, one sometimes encounters difficulties which seem quite extraordinary. It is as if the physical laws did not fit one another. One must keep in mind, however, that a physical law aims at describing, in a manner as precise and as quantitative as possible, the relationships between phenomena in a particular system. But it is a formulation which is more or less exact, according to the accuracy of the instruments used in its establishment. A result of this is that one may apply certain laws in optics, forgetting that, ultimately, it is the constitution of the retina that limits the resolving power of the eye; or, further, one may apply Hooke's law, which states that the deformation of material is proportional to the force it is subjected to, forgetting that it is not valid for very small forces, especially if they are torsional.

There is no discussion here of oil films, for all of the author's recent observations have been most perplexing and not open to interpretation at this time. The realm of physical laws is a limited domain, poorer than the real one, and to this domain must be added factors that were neglected when it was established. This is precisely why applied research is necessary. It results from one's inability to fully grasp the problems.

V. Time required for research

It is appropriate to mention some factors which affect both production and research equally. First, management looks forward to receiving positive results from research work at relatively short notice and is often disappointed by the long time spent in working out a new solution. It must, however, be recalled that the more closely a product nears perfection, the more difficult it is to improve it, as the influence of secondary effects becomes more important.

For example, in 1961, the Conférence Générale du Metre decided to change the definition of the Metre. It is now defined in terms of a Krypton 86 wave length instead of being the length between two lines engraved on a platinum-iridium bar. But, if with the latter, it was necessary accurately to know its temperature, the use of the new standard requires one to know the compositions, the temperature and the barometric pressure of the air in order to determine its refractive index. It may be seen, therefore, that the change from the old to the new definition introduces a wider range of dependence upon external physical conditions, and the control of these conditions and the determination of their effects are not always easy and may entail lengthy side studies.

Another point is that the techniques applied in industry are often the result of accumulated experience; they have been progressively developed—sometimes empirically, sometimes on a more scientific basis—but they have seldom been systematically investigated. It is obvious that the change-over from methods founded on empirical knowledge that may be hundreds of years old cannot be effected within a few weeks. The skill and experience of one's predecessors cannot be abruptly replaced by scientific method. It is necessary to decide on the methods of analysis, to determine the problem and to study the effect that a new solution may have on the other factors involved, and for this one requires not only intelligence and knowledge, but also time.

The author has often wondered what factors affect the time for getting something new into production. Obviously, if the newness is only a matter of several detail modifications, it will be easy to predict accurately the required time, but the question is quite different if a complete change is involved. It may be preferable to return to research and completely revise the project rather than to alter a product already in production. It is clear, however, that one must refrain from seeking exaggerated perfection and that one must bear in mind that any object produced today is marked with obsolescence with regard to the future.

Conclusion

Today one must add knowledge of the mental processes of research and production people and a number of methods have been developed for overcoming the obstacles to a satisfactory relationship between them. In the author's opinion, this knowledge must be used to the fullest possible extent if the results of research are to contribute effectively to the economic growth of industry.

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