PRODUCTION ENGINEERING

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PREFACE

The criticism is often made that too much of the teaching in engineering schools is of the "pigeon-hole" variety; that individual subjects are presented to the students without concerted attempt to make them a coherent whole. The student is expected to recognize their relative position in the general scheme of education and their inter-dependence upon each other when applied to the solution of any specific problem. A few students may achieve this perspective and get a reasonably integrated education, but the majority may not become fully aware of these relationships until after some years of practical experience, when most of the detail of specialized courses has been relegated to the dim recesses of memory.

In the field of production engineering we have all the technical problems related to the product, the manufacturing processes, and the plant. Texts and educational courses which are available cover basic studies such as mathematics, physics, chemistry, theoretical and applied mechanics, and many specialized subjects such as machine design, mechanics of materials, generation and transmission of power, lubrication, mechanical processes, cutting of metals, tool design, standardization, inspection and testing, materials handling. These texts present many of the elements of production engineering.

This volume has been written expressly to point out the relationship of all the above-mentioned details and to emphasize the importance of active cooperation at all times and in all directions for the most effective performance of the multitudinous activities involved. It may be considered as an assembly drawing of the subject. No attempt has been made to treat in detail any part of this work of production engineering except where the existing texts appear to be inadequate or non-existent.

The work of production engineering is here presented as the coordinated efforts of many individuals, each of whom has a specific task to accomplish. These tasks involve not only the obligation of carrying through the work in conformity with the plans of some who have completed the earlier stages, but also the responsibility of reporting back to those collaborators the results of their joint efforts, together with suggestions for present or future improvements. In other words, information and suggestions or constructive criticism must flow constantly in both directions.

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Particular credit must be given to my wife, Nina W. Morgan Buckingham, who "Englished" my original manuscript and has given to this text whatever elements of style it may possess.

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CHAPTER I

INTRODUCTION

The problem of production engineering has three major phases. The first is to prepare for and to start the production of a new product or to make a major change in the design of an existing product. The second is the orderly and effective operation of the plant in the continued production of the product. This involves minor changes in design, generally made to facilitate manufacture, together with changes and improvements in manufacturing processes and the introduction of new manufacturing processes. The problems created by changes in both increased and decreased production are met here. The third includes the continuing and supporting activities that gather information and put it into effective form for its direct application to the two preceding phases.

Modern production today involves an almost infinite number of petty details which must be taken care of by the cooperative effort of many persons. The orderly handling of much detail necessitates setting up a definite routine for most of it. It should be remembered, however, that such routine is established to handle the ordinary, or usual, conditions; unusual cases will always require special consideration. In other words, routine is a tool or method devised to assist us in the control of a mass of detail; but, for more effective handling another method may be employed for any particular detail. Routine should be maintained, however, unless the one suggesting the change can justify the departure from established routine.

The essence of modern production is the breaking down of the productive effort into simple and elementary tasks, so that less skill, or rather a lesser range of skills is required of the machine operator. To attain this end, as much as possible of the skill and technique formerly brought to the work by the craftsman must be supplied by the equipment. The further this substitution is carried, the greater are the skill and technique which must be brought to the problem by the production engineer, the machine maker, the tool maker and the other craftsmen who design, build, and set up this productive equipment.

The many details of production engineering likewise tend to be divided into more and more specialties, so that when a task of any magnitude is to be done, a large group of specialists must be organized to handle it. When time is the important consideration, as is usually the case in preparation, complete cooperation must exist between them, unless chaos and seemingly endless delays are to result. The essentials of effective cooperation are four. First, all persons in authority must have a full realization of the objectives, and the same understanding of them. Second, each one cooperating must have some understanding of the character, responsibilities, difficulties, and limitations of the others' tasks. Third, each responsible person must be a master of his own specialized task. Fourth, and not least by any means, each responsible person must have a definite understanding of his own responsibility and authority.

It seems axiomatic that responsibility and authority are indivisible. No person or organization can justly be held responsible for conditions over which they have no control. On the other hand, any delegation of responsibility carries with it only that authority necessary to carry out the specific task assigned. The form of an organization and the resulting delegation of responsibility is often determined by the aptitude and experience of the individuals forming the group. Of course, certain factors of production engineering logically involve certain responsibilities, and, if responsibilities are to be effectively met, should automatically carry with them certain controls, or authority, regardless of the detailed form of organization. One of the primary purposes of this text is to point out the fundamental lines of responsibility and authority involved in this maze of production engineering activities. No claim is made that this analysis is complete or infallible. Varying combinations of tasks may be assigned to departments and their sections to achieve equivalent results. The attempt will be made, however, to develop a logical analysis of cause and effect.

Let us start the consideration of the subject of production engineering by listing some of the more important factors of the problem, beginning with the initial preparation for production.

Preparation for Production

Functional Design

The first essential of production engineering is to have a product worth making. The initial design of this product will be called the functional design. In its development, the major objective is to make a product that will perform some function or render a definite service. Some thought may be given here to possible methods of manufacture, yet the greatest emphasis is on its ultimate use in the hands of the consumer.

This functional design may be developed in an existing plant, or it may be brought to it from some outside source. It is the responsibility of the management, assisted, of course, by information and advice, wherever they may be found in other parts of the organization, to decide whether or not to accept this new product for production. Certain definite objectives and requirements should be set up at the start: (a) performance requirements of the product, (b) cost of manufacture, (c) quantity, or rate of production, depending upon the size of the potential market, (d) cost of preparation for production, (e) elapsed time required to start production.

Production Design

The production design consists primarily of a critical survey of the details of the functional design. Details should be changed whenever the change will expedite manufacture with the equipment that is, or may be, available. The survey includes the setting of tolerances or of permissible variations in size of the numerous elements of the component parts; the selection of suitable materials; the simplification of the design wherever possible; and the use of as many existing standard parts and elements as possible. Indispensable as is the functional design, it is the effectiveness of the production design that largely determines the commercial success or failure of the new product.

It is, or should be, the responsibility of the production engineering staff—possibly a production design group—to develop this production design. Whatever is left undone on the production design must be completed or corrected after production is under way. Although the major part of the production design should be completed before production is started, it is never finished while production continues. Such changes to facilitate manufacture should never require the approval of the functional designer. The latter should have the veto power only over changes that would impair the performance of the product. Objections may be raised over any proposed change, and the resulting arguments, more often than not, are differences of opinion rather than statements of fact. If questions arise, it is generally possible to make simple experiments, or in extreme cases, to build a model with the proposed changes incorporated, to prove or disprove these differences of opinion.

Estimating

Preliminary estimates are needed to guide the management in its decision regarding the acceptance or rejection of a new product, and also to set up the original objectives and requirements. A more detailed estimate is usually required after the new product has been accepted for production. Such estimates, properly made, serve as a valuable guide to the work of preparation for production which follows, and they also enable an increasingly larger group to work consistently towards the common objective.

All estimating is the responsibility of the preparation group of the production engineering staff. Records and statistics of past performances are an invaluable aid to this work. In general, these estimates give a remarkably accurate forecast of the time and money required for a given project. Too often, however, records of elapsed time, from starting to completion of the preparation, are not kept, and predictions of the actual date when production will be under way, and proceeding smoothly, are much too optimistic.

Operation Layouts and Schedules

The operation layouts are developed from the estimates and specify the various machining operations, their sequence, machines and tools and gages required, and the amount of equipment needed to meet a specified rate of production. This work should also include a schedule, which should take into account the elapsed time needed to design, build, and set up the special equipment. The schedule establishes the order, in point of time, in which each task is started and finished so that the specified date for the beginning of production may be met. At times, notes and sketches of some of the unusual features of a tool or fixture should be included to assist the tool designer in his work. Usually the locating and holding points on the part should be specified.

Operation layouts may also include the making of factory layouts which show the location of the equipment in the plant. The preparation group of the production engineering staff is responsible for the completion of these operation layouts and should retain this responsibility until the equipment is actually producing the parts satisfactorily.

Tool Design

The drafting of the jigs, fixtures, tools, gages, and any other special equipment may be done in the tool design department. This work should be supervised or checked by the process engineer who made up the specific operation layout. Frequently these tool designers are specialists on tools for certain specific processes. They are responsible for the accuracy and adequacy of their drawings, but the process engineer in charge of a specific component part of the product is responsible for the proper selection of holding points and the coherence of the series of tools needed to produce that part.

An increasing number of plants is reducing tool-making and tool-designing facilities to the minimum needed for maintenance of current production, so that both the tool designing and the tool making are done by outside companies. In addition, when new machines are required, the machine tool builder is often required to furnish the machine completely tooled for a specific operation. Here the responsibility of the tool design is delegated to an outside organization. The process engineer in charge of the specific component should then make sure that the correct and necessary information is given to that outside source, since none of his responsibility has been delegated to others.

Requisitions and Schedules for Equipment

It is the responsibility of the process engineer in charge of a given component to see that orders are issued for the design and the construction of the necessary special equipment, and that schedules showing the sequence and dates when each job should be started and finished are prepared. The clerical work involved may be done in a centralized or general clerical section, but it is his responsibility to see that the section receives the necessary information, and to make sure that the clerical work has been actually done. These requisitions are based on the operation layouts. Questions of priority between the several process engineers should be settled by the chief of the section; similar questions between the preparation group and the maintenance or production group should be settled by the general management. This is a problem of interference with routine production by the preparation for a new product, and it is also a question of general policy.

Checking of Tools and Tool-Made Samples

The inspection of new tools, often accomplished by the measurement of work actually produced by the tool, may be done by mechanics and tool inspectors who are responsible only for the accuracy of measurements. The process engineer is responsible for the adequacy of the results. It may be that the same inspectors are used for the checking of tools for new designs and for the routine inspection of replacement tools for the existing production. This, however, does not modify their responsibility.

Initial Production of New Product

The setting-up, adjustment, and operation of the equipment for a new product may be done by the regular production force, but the process engineer who has planned this work should continue to be responsible for its performance until it has definitely proved itself in practice. This means that he must give this part of the work sufficient supervision so that all necessary information is in the hands or minds of the proper persons. Definite cooperation is needed here between the planner and the producer. Similar cooperation is usually needed at the very start of the planning.

Checking the Performance of the Initial Assembled Product

The acid test of the adequacy and completeness of the production design, choice of materials, and all the other preparation activities comes when the first of the tool-made parts are assembled and tested for performance. If the product assembles without difficulty, the parts interchange readily, and the assembled product meets all performance specifications satisfactorily, it is conclusive proof that the problem has been solved. On the other hand, if difficulty is met in any of these places, it is equally conclusive proof of incomplete planning, or mistakes, and the preparation group is responsible for these conditions, and must take prompt steps to complete or to correct its work.

Investigation and Correction of Initial Troubles

Experience in the problem of starting production on a new product indicates that some difficulties exist always at the initial stages of production. Some of them are due to ignorance or lack of the necessary special training on the part of the operators; some may be caused by misunderstandings, and lack of full cooperation between the planning group and the production group; some are present because of the incompleteness of the planning; but too often most of them are caused by definite mistakes or ignorance on the part of the planning group. The majority of changes on the part drawings during the first days of production—most of them made to facilitate manufacture—are evidence of an incorrect or an incomplete production design. Unfortunately, many of these escape attention until some of all parts have been made and the first assemblies are on test. Regardless of the cause of the trouble, however, the planning group should be responsible for investigating each of them and for correcting the trouble at its source. Close cooperation with the production group will prove invaluable here also.

The foregoing is an attempt at a brief outline of the more important activities involved in the preparation for production. Whether a plant is large or small, these problems will be present. In a small plant, one person or a small group may be responsible for their solution. With a large plant, a considerable organization may be required and the various problems may be divided and sub-divided among several sections.

Let us now consider the more important problems of production

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after what is often a "nightmare" of starting difficulties is well behind us.

Production Operation and Control

Production Schedules and Follow-Up

The production requirements are established by the general management, but these are usually in terms of assembled products. The requirements must be broken down, not only into the individual component parts, but also into the individual operations on each part. Schedules must be prepared for the production which will take into consideration all the other work in the plant. All schedules must be followed up, and hold-ups and conflicts with other schedules reported if predetermined delivery schedules are to be met. Among the component parts will often be found some which are common to several of the products. These are known as stock, or standard parts. They may be made in lots without reference to the specific product orders. It is necessary, in such cases, to determine the economical size of lot to manufacture and the minimum quantity of this stock part to have on hand before starting the manufacture of a new lot. The planning and control of the details are responsibilities of the production engineer. The clerical work involved may be done in some centralized clerical department, but it is the responsibility of the production engineer to see that it is done correctly and on time.

Material Procurement and Schedules

The material required to make the product is usually ordered by the purchasing agent, but it is the responsibility of the production engineer to see that the purchasing agent has the necessary information to buy the materials required and to keep him informed of the amount needed and when it must be on hand. The amount of any specific material ordered may be based directly upon the production orders in hand, or it may be ordered for stock, as is done with standard parts, when there is any economic advantage in so doing, or if it is a critical material that may be difficult to get at short notice. Such conditions may change with time, and the whole material procurement problem may involve a question of policy which needs the approval of the general management. Here the detailed requirements are furnished by the production engineer, the procurement problem is stated by the purchasing agent, and the policy is established by the general management.

Training of Labor

The training of operators for specific duties is generally the responsibility of the department foremen. The actual hiring may be through a centralized employment department. Such training might well be a part of the process engineer's responsibility. The selection of persons for specific duties should be under the control of the department foreman. The majority of productive operations are relatively simple, and many of them are quite similar. For these the training and assignment of operators should cause little difficulty. In almost every plant, however, there are a few operations that require an unusual combination of skill, temperament, and integrity, and the training of such operators may become an acute problem. Hence the routine training for the ordinary operations may well be left to the foremen, but the unusual should receive special attention from the process engineer.

Furthermore, every opportunity should be offered to each operator to increase his skill and value to himself and to the plant. Here, a definite policy, established by the general management and administered by some part of the production engineering staff, might be worth serious consideration.

Wage Incentives

The most effective wage incentive is one that helps to make the individual realize, to a large extent, that he is in business for himself. Conditions are so varied that it is doubtful if any single system of wage incentive will be the most effective for any given plant. Piecework, bonus, group bonus, and many other types of wage incentives have their place.

Furthermore, wage incentives alone are not enough to secure and maintain the full active support and cooperation of each individual operator. Concentration on the mechanical advances and refinements tends to push the human factor into the background, although this factor is as important as or even more important than the mechanical phase.

The problem of wage incentives is one of policy, to be established by the general management and administered by the production engineering staff.

Labor Relations

The subject of labor relations has many aspects, and many books have been written on this subject alone. Among its problems are the following: seniority, promotion, and security; organized labor (union) relationships or individual agreements; a man's right to a job and a man's rights in his job; and the human relationships between the many individuals in an organization. All, except the last, are largely matters of policy which must be established, to a large extent, by the general management. The last—and the most important—is a matter of individual relationships. Improvements in these may be fostered by the management, most effectively by personal example, and self-centered and individualistic persons may be assigned tasks that do not depend on group effort; but for the most part, results really depend upon the behavior of the individuals. We should realize that some valuable potential creative ability is present in every individual of any organization; the great problem is to develop our personal inter-relationships so that this potential energy may be transformed into kinetic energy. One of my colleagues remarked, when speaking of assistance given him by mechanics in the shop, "Their field of knowledge may be quite limited, but they illuminate a small spot brightly." The responsibility for improving these human relationships rests with every single member of the organization.

Quality Control

The quality of any product is tested by its performance in service. Norman F. Harriman, in his excellent treatise on *Standards and Standardization*, gives this definition of quality: "Quality, in the sense here used, is that which fits a product for a given use. A product is not simply good, it is good for a certain purpose, and the word quality is meaningless apart from the use in view. Good quality means good for a definite use."

Quality in a product does not develop of itself; it must be definitely and consistently striven for. The effort to achieve it must start with the original design, selection of materials, and choice of manufacturing processes; it must continue through all the productive effort, including the assembling and testing; and it must frequently include adequate servicing even after the article is in the hands of the customer. An attitude of "good enough" brings sooner or later a deterioration of quality. Constant effort must be applied to the improvement of quality, always with a view to making the product better for a given use. Changes in design or in processes adopted to reduce costs should always be such as to improve the product.

Quality control during actual production requires a considerable amount of inspection. This inspection may be divided into several phases. For one, we have the preventive measures undertaken to minimize the chances of making mistakes. These include the checking and testing of materials, new tools and machines, and original set-ups. If the members of the production design staff are responsible for the performance of their design, this preventive inspection will logically be their responsibility.

For another, we have the process or floor inspection as the parts progress through the several machining operations. The department foreman is responsible for the accuracy of the work produced in his department so that this inspection may logically be his responsibility also. On the other hand, if a general inspection organization exists, the foreman's responsibility should be exercised through the machine adjusters and other assistants, and the routine process inspection should be done by members of the general inspection staff. This does not mean any divided responsibility; the foreman is still responsible for results in his department, whereas the general inspection staff is responsible for calling to his attention any details overlooked by him or his agents, and for preventing faulty parts from proceeding farther.

Following this, we have the finished-parts inspection to make sure that only correct parts are permitted to flow through to the finished-parts stock room or to the assembly department. This is logically the responsibility of the production design staff.

After assembly, the finished product is often tested for performance, for the making of any special adjustments that may be necessary. Such testing should be logically a part of the responsibilities of the production design staff, possibly supervised or rechecked by the functional design authority.

One advantage of having the production design staff responsible for quality control through production is that this responsibility will keep members of this staff in constant contact with the production staff and with many of its problems; and such contact will tend to eliminate the chasm that seems to exist, unfortunately, in too many shops between the drawing room and the shop.

Such quality control should extend to a study of the performance of the product in the hands of the customers. This might be limited to an investigation of complaints from them; but for adequate product development in the future, definite studies of the performance of the product in the field will prove invaluable.

Maintenance of Equipment

The maintenance of equipment is the responsibility of the staff which uses it. The machine operator or his immediate supervisor is often responsible for reporting the need of repairs. This plan works well in general where there is a single shift of workmen; but when more than one shift is used, the equipment is likely to suffer unless there is a definite organized effort for its maintenance. The responsibility still remains with that part of the production staff which uses it.

Cost Reduction

Cost reduction efforts include the improvement and re-arrangement of the equipment to reduce the productive effort, as well as the introduction of new and improved processes whenever they may become available. In the original selection and design of processes and equipment we should use the best information available. It is obvious, however, that after production has actually started, we learn much more about its unique problems than we knew before. The slogan for cost reduction effort might well be: "No matter how well we have done a job in the past, it is always possible to do it better and more cheaply." The only question is whether or not we are capable of making that improvement. This is a place where the whole-hearted cooperation of the man who does the actual work of production may mean the difference between failure and success.

Cost reduction is the responsibility of the process engineer. He may be attached to the production staff or to the preparation staff. In fact, the same process engineer may be transferred from one staff to the other as press of work may dictate.

Correction and Development of Production Design

The initial production design is nothing more than our first best guess as to the detailed specifications of the component parts of our product that will use the available equipment most effectively, and still retain and, if possible, improve upon the original functional design as regards its performance. If we can learn by experience, it is clear that after production has started, we should know much more about it; and the more extended our experience with it, the more we should continue to learn. In addition, the initial production design represents in general the opinions and experiences of a small group. As production continues, more and more competent persons become familiar with it. Furthermore, even with the best intentions and reasonable care, mistakes will creep in. All these conditions make it apparent that the development of the production design is a continuing process that is never finished. The production design staff is responsible for the correctness of this design, and changes should be made without question as their need or value becomes apparent. If this group is also made responsible for the quality control through production, members of its staff are in constant contact with the progress of events in the shop, and this necessary information will be first-hand knowledge. Otherwise the production group must keep them informed, because a record of these developments is essential, not only to keep the records up to date, but also to have the benefits of this experience which should be incorporated in any new designs.

Cost Control and Budgeting

Without definite control, the costs of any project tend to mount alarmingly. To keep costs within reasonable bounds, it is necessary to be cost- and time-conscious. Probably the best way to develop this sense of time and cost is to budget the estimated amounts available. Each individual and group should then strive to accomplish its specific tasks within the budgeted allowance. If these budgets must be exceeded, it is good practice to require that requests for additional amounts, with the reasons for making them, be made before the original amount is exceeded. In other words, let each explain before the account is overdrawn rather than make excuses afterwards.

It should be the responsibility of each group involved to give its own estimate, or agree to the estimate made by others, for the time or money required to carry through any project to a definite stage. These detailed estimates form part of the basis of the estimate that is submitted to the general management. From this information, the general management makes its decision, and sets up the actual budget which is to be followed.

We have now considered the more important problems of routine production. For the solution of these, and also of those dealing with preparation for production, many supporting and continuing activities must be carried on, not all of them an integral part of production engineering, but all having a definite bearing on the problem or its solution. A list of these supporting activities is as follows.

Supporting Activities

Standardization

The subject of standardization covers so wide a field that it is difficult to know where to start. It includes the standardization of elementary parts and surfaces, materials, processes, specifications, tools and machines, and methods of test. In one respect, it is the attempt to reduce to routine as many of the elements of engineering as possible. Here, as with routine, these standards are developed to meet the normal conditions—exceptional cases will always need special consideration. Departures from such standards should always be permissible whenever it can be proved that such departures lead to better results than the use of the standards would do.

Standards may be classified under many different headings. Our general engineering standards are formulated under the procedure of

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