PROCESSES AND DESIGN FOR MANUFACTURING

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PREFACE

Although manufacturing has always been considered a prestigious science in West Europe and Japan, it is still being thought of in the United States as the manual skills that are acquired by on-site training in a foundry or a machine tool shop. This erroneous picture leads to the regrettable situation that engineering faculty and students alike tend to distance themselves from that area. In fact, this is a major shortcoming of our engineering education system and is one of the main reasons for the problems encountered in U.S. industry. Unfortunately, that distorted idea about manufacturing has been assisted by the shallow, descriptive, and qualitative manner in which the vast majority of textbooks covered that subject. Nevertheless, thanks to the great efforts of the Society of Manufacturing Engineers and its associations and instituations, as well as to the perseverence and deligency of many colleagues in the universities nationwide, that gloomy picture is vanishing day after day. The present text is actually a contribution to promote the latter trend.

The major goal of this book is to strike a balance between the quantitative analysis and the applied technology aspects of manufacturing. The approach is aimed at linking the design features of a product and the manufacturing processes required to produce it, thus emphasizing the new concept *design for manufacturability.* As a consequence, readers must have adequate knowledge of physics as well as fundamental engineering subjects such as statics, dynamics, mechanisms, and strength of materials in order to get the most from this book. A thorough and profound understanding of physical metallurgy is extremely essential.

In order to achieve these goals and meanwhile limit the physical size of the book, all supporting materials that do not fall directly under manufacturing, e.g., extractive metallurgy, were not covered. It has also been kept in mind that the text is not an encyclopedia and is not intended to be so, so a list of selected references for further reading is provided at the end of the text.

The author would like to express his deepest gratitude to his wife and children for their patience as well as for sacrificing their family time during the past two years. Last but not least, acknowledgments must also go to many organizations that supplied various figures and gave permission for reproduction, particularly, M.D.S.I./Applicon, Prab Robots, and the Aluminum Association, Inc.

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INTRODUCTION

DEFINITION OF MANUFACTURING

Manufacturing can be defined as the transformation of raw materials into useful products through the use of the easiest and least-expensive methods. It is not enough, therefore, to process some raw materials and obtain the desired product. It is, in fact, of major importance to achieve that goal through employing the easiest, fastest, and most efficient methods. If less efficient techniques are used, the production cost of the manufactured part will be high, and the part will not be as competitive as similar parts produced by other manufacturers. Also, the production time should be as short as possible to enable capturing a larger market share.

The function of a manufacturing engineer is, therefore, to determine and define the equipment, tools, and processes required to convert the design of the desired product into reality in an efficient manner. In other words, it is the engineer's task to find out the most appropriate, optimal combination of machinery, materials, and methods needed to achieve economical and trouble-free production. Thus, a manufacturing engineer must have a strong background in materials and up-to-date machinery as well as the ability to develop analytical solutions and alternatives for the open-ended problems experienced in manufacturing. This is in addition to having a sound knowledge of the theoretical and practical aspects of the various manufacturing methods.

RELATION BETWEEN MANUFACTURING AND THE STANDARD OF LIVING

The standard of living in any nation is actually reflected in the products and services available to its people. In a nation with a high standard of living, a middle-class family usually owns an automobile, a refrigerator, an electric stove, a dishwasher, a washing machine, a vacuum cleaner, a stereo, and—of course—a television set. Such a family also enjoys health care that involves modern equipment and facilities. As you can easily see, all the above-mentioned goods, appliances, and equipment are actually raw materials that have been converted into manufactured products. Therefore, the more active in manufacturing raw materials the people of a nation are, the more plentiful those goods and services become; as a consequence, the standard of living of the people in that nation attains a high level. On the other hand, nations that have raw materials but do not fully exploit their resources by manufacturing those materials are usually poor and are referred to as "underdeveloped." It is, therefore, the know-how and the capability of converting raw materials into useful products that basically determines the standard of living of a nation and not just the availability of minerals or resources within its territorial land. In fact, many industrial nations, such as Japan and Switzerland, import most of the raw materials which they manufacture and yet still maintain a high standard of living.

THE PRODUCTION TURN

In almost all cases, the main goal of a manufacturing project is to make a profit, the exception being projects that have to do with the national security or prestige. Now, let us establish a simplified model that illustrates the cash flow through the different activities associated with manufacturing, so we can see how to maximize the profit. As shown in Figure 1-1, the project starts by borrowing money from a bank to purchase machines and raw materials and to pay the salaries of the engineers and other employees. Next, the raw materials are converted into products, which are the output of the manufacturing domain. Obviously, those products must be sold (through the market-

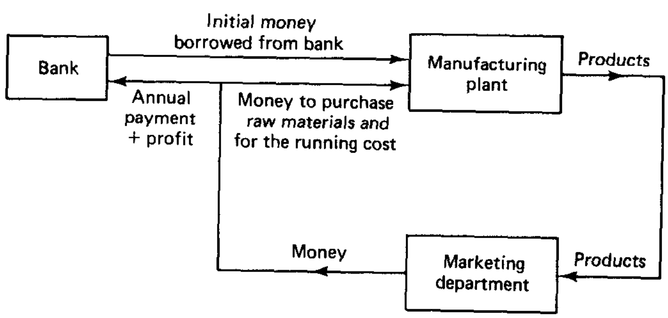

Figure 1-1 The production turn.

ing department) in order to get cash. The latter is, in turn, used to cover the running costs as well as required payments to the bank; any surplus money left is actually the profit.

We can see in this model that the sequence of events forms a continuous cycle (i.e., a *closed circuit*). This cycle is usually referred to as the *production turn*. We can also realize the importance of marketing, which ensures the continuity of the cycle. If the products are not sold, the cycle is obviously interrupted. We can also see that maximum profit is obtained through maximizing the profit per turn and/or increasing the number of turns per year (i.e., running the cycle faster). Obviously, these two conditions are fulfilled when products are manufactured in the easiest and least expensive way.

TYPES OF PRODUCTION

Modern industries can be classified in different ways. These include classification by process, classification by product, and classification based on the production volume and the diversity of products. The classification by process is exemplified by casting industries, stamping industries, and the like. When classifying by product, industries may belong to the automotive, aerospace, and electronics groups. The third method, i.e., classification based on production volume, identifies three main distinct types of production, mass, job shop, and moderate. Let us briefly discuss the features and characteristics of each type. We also discuss these subjects in greater depth in Chapter 12.

Mass Production

Mass production is characterized by the high production volume of the same (or very similar) parts for a prolonged period of time. An annual production volume of less than 50,000 pieces cannot certainly be considered as mass production. As you may expect, the production volume is based upon an established or anticipated sales volume and is not directly affected by the daily or monthly orders. The typical example of mass-produced goods is automobiles. Since that type attained its modern status in Detroit, it is sometimes referred to as the Detroit type.

Job-Shop Production

Job-shop production is based on sales orders for a variety of small lots. Each lot may consist of 20 up to 200 or more similar parts, depending upon the customers' needs. It is obvious that this type of production is most suitable for subcontractors who produce varying components to supply various industries. The machines employed must be flexible to handle variations in the configuration of the ordered components, which are usually frequent. Also, the employed personnel must be highly skilled in order to handle a variety of tasks, which differ for the different parts that are manufactured.

Moderate Production

Moderate production is an intermediate phase between the job-shop and the mass-production types. The production volume ranges between 10,000 to 20,000 parts, and the machines employed are flexible and multipurpose. This type of production is gaining popularity in industry because of an increasing market demand for customized products.

FUNDAMENTALS OF MANUFACTURING ACCURACY

Modern industry is based on flow-type "mass" assembly of components into machines, units, or equipment without the need for any fitting operations performed on those components. That was not the case in the early days of the Industrial Revolution, where machines or goods were individually made and assembled, and there was always the need for the "fitter" with his or her file to make final adjustments before assembling the components. At the beginning of the nineteenth century, a crude form of the mass-production assembly technique was developed by Eli Whitney when he received an order from the U.S. government for 10,000 rifles, which had to be manufactured in a short period of time. The components of each rifle were manufactured separately by different workers. Each worker was assigned the task of manufacturing a large number of the same component. Meanwhile, the dimensions of those components were kept within certain limits, so that they could possibly replace each other and fit their mating counterparts. By doing so, Eli Whitney established two very important concepts, on which modern mass production was based, namely, *interchangeability* and *fits*. Let us now discuss the different concepts associated with the manufacturing accuracy required for modern mass-production technologies.

Tolerances

A very important fact of the manufacturing science is that it is almost impossible to obtain the desired nominal dimension when processing a workpiece. This is actually caused by the inevitable, though very slight, inaccuracies inherent in the machine tool as well as by various complicated factors like the elastic deformation and recovery of the workpiece and/or the fixture, temperature effects during processing, and sometimes the skill of the operator. Since it is very difficult to analyze and completely eliminate the effects of these factors, it is more feasible to establish a permissible degree of inaccuracy or a permissible deviation from the nominal dimension that would not affect the proper functioning of the manufactured part in a detrimental way. According to the ISO (International Standardization Organization) system, the nominal dimension is referred to as the *basic size* of the part. The deviations from the basic size to each side (i.e., positive or negative) determine the high and the low limits, respectively, and the difference between those two limits of size is called the *tolerance*. The latter is an absolute value without a sign and can also be obtained by adding the absolute values of the deviations. As you may expect, the magnitude of the tolerance is dependent upon the basic size and is designated by an alphanumeric symbol called the *grade.* There are eighteen standard grades of tolerance in the ISO system, and the tolerances can be obtained from the fomulas or the tables published by the ISO.

It is obvious that smaller tolerances require the use of high-precision machine tools in manufacturing the parts and therefore increase production costs. Figure 1-2 indicates the relationship between the tolerance and the production cost. As can be seen, very small tolerances necessitate very high production cost. Therefore, small tolerances should not be specified when designing a component unless they serve a certain purpose in that design.

Fits

Before two components are assembled together, the relationship between the dimensions of the mating surfaces must be specified. In other words, the location of the zero line to which deviations are referred must be established for each of the two mating surfaces. As can be seen in Figure 1-3a, this actually determines the degree of tightness or freedom for relative motion between the mating surfaces. Figure 1-3a also shows that there are basically three types of fits, namely, clearance fit, transition fit, and interference fit. In all cases of clearance fit, the upper limit of the shaft is always smaller than the lower limit of the mating hole. This is not the case in interference fit, where the lower limit of the shaft is always larger than the upper limit of the hole. The transition fit, as the name suggests, is an intermediate fit. According to ISO, the internal enveloped part is always referred to as the *shaft,* whereas the surrounding surface is referred to as the *hole.* Accordingly, from the fits point of view, a key is referred to as the shaft and the keyway as the hole.

It is clear from Figure 1-3a and b that there are two ways for specifying and expressing the various types of fits, the ***shaft-basis*** and the ***hole-basis*** systems. The location of the tolerance zone with respect to the zero line is indicated by a letter, which is always capital for holes and lowercase for shafts, whereas the tolerance grade is indicated by a number, as previously explained. Therefore, a fit designation can be H7/h6, F6/g5, or any other similar form.

Figure 1-2 The relationship between tolerance and production cost.

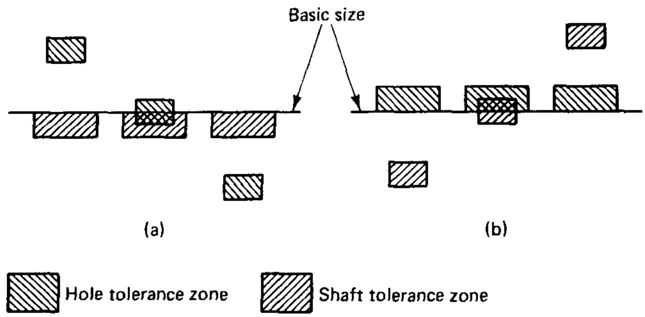

Figure 1-3 The two systems of fit according to ISO. (a) Shaft-basis system. (b) Hole-basis system.

Interchangeability

When the service life of an electric bulb is over, all you do is buy a new one and replace the bulb. This easy operation, which does not need a fitter or a technician, would not be possible without two main concepts, interchangeability and standardization. Interchangeability means that identical parts must be interchangeable, i.e., able to replace each other, whether during assembly or subsequent maintenance work, without the need for any fitting operations. As you can easily see, interchangeability is achieved by establishing a permissible tolerance, beyond which any further deviation from the nominal dimension of the part is not allowed. On the other hand, standardization involves limiting the diversity and total number of varieties to a definite range of *standard dimensions.* This is exemplified by the standard gauge system for wires and sheets. Instead of having a very large number of sheet thicknesses in steps of 0.001 inch, the number of thicknesses produced was limited to only 45 (in U.S. standards). As you can see, standardization has far-reaching economical implications and also promotes interchangeability. It is obvious as well that the engineering standards differ for different countries and reflect the quality of technology and the industrial production in each case. In Germany the standards are referred to as DIN (Deutsche Ingenieure Normen), which are finding some popularity worldwide. The Soviet Union adopted the GOST, which was suitable for the period of industrialization of that country.

PRODUCT DESIGN

The Proper Approach for Product Design

The conventional procedure for product design used to start with an analysis of the desired function, which usually dictated the form as well as the materials of the product to be made. The design (the blueprint) was then sent to the manufacturing department, where the kind and sequence of production operations were determined mainly by the form and materials of the product. This is clearly illustrated in Figure 1-4, which indicates the old procedure for product design. In fact, that design procedure had several disadvantages and shortcomings:

1. In some cases, nice-looking designs were impossible to make, and in many other cases the designs had to be modified so that they could be manufactured.

2. Preparing the design without considering the manufacturing process to be carried out and/or the machine tools available would sometimes result in a need for special-purpose, expensive machine tools. The final outcome was an increase in the production cost.

3. When the required production volume was large, parts had to be specially designed to facilitate operations involved in mass production, such as, for instance, assembly.

4. A group of different products produced by the same manufacturing process has common geometric characteristics and features, which are dictated by the manufacturing process employed. In other words, forgings have certain characteric design features that are different from those of castings, extrusions, or stampings. Ignoring the method of manufacturing during the design phase could undermine these characteristic design features and result in an impractical or faulty design.

Because of these reasons and also because of the trend of integrating the activities in a manufacturing corporation, the modern design procedure involves considering the method of manufacturing during the design phase. As can be seen in Figure 1-5, design, material, and manufacturing are three interactive, interrelated elements that form the manufacturing system, whose prime inputs are conceptual products (and/or functions), and whose outputs are manufactured products. In fact, the barriers and borders between the design and manufacturing departments are fading out and will eventually disappear. The tasks of the designer and those of the manufacturing engineer are going to be combined and done by the same person. It is, therefore, the mission of this text to emphasize concepts like design for manufacturability and to promote the systems approach for product design.

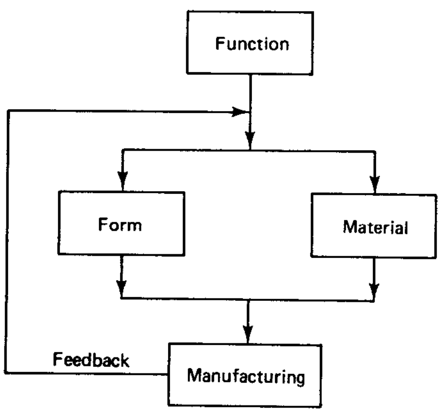

Figure 1-4 The old procedure for product design.

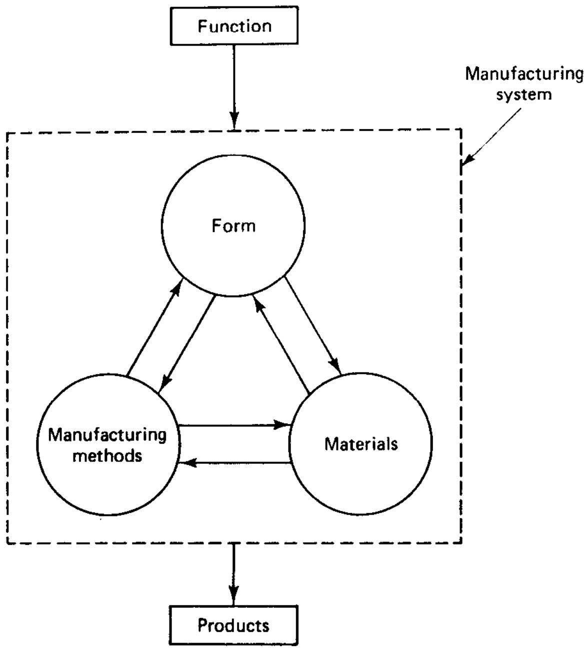

Figure 1-5 The new concept of a manufacturing system for achieving rational product designs.

Factors Affecting Constructional Details

In addition to common sense, good design practice, and manufacturing considerations, there are also some important factors that must be taken into account when preparing the constructional details. Some of those important factors are as follows.

Accessibility of different parts or areas. All components and parts of the product should be accessible to facilitate regular cleaning and maintenance work. Unaccessible areas lend themselves to the accumulation of dirt, with the final outcome being corrosion and/or malfunctioning of the product. Crevices, narrow slots, and bolts and nuts located in places where it is difficult to clean, mount, tighten or loosen, or remove them should be avoided.

Handling of the workpiece or product. Easy handling and locating of a part, whether while it is being manufactured or for lifting and transportation, is important. For example, sometimes projections are added to the desired shape of forgings, not to serve any functional reasons but just for the sake of easy handling and locating of the part in a jig or a fixture during machining. This is particularly important where robots are used extensively for the handling of workpieces and finished products.

Safety requirement. Sharp corners, tiny projections that cannot be seen easily, and other features that may cause injuries must be avoided. Also, the use of toxic or