DIMENSIONING & TOLERANCING FOR QUANTITY PRODUCTION

M. F. Spotts

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Preface

The object of this book is to establish basic rules and procedures for good dimensioning practice. The book is not a drafting standard, but attempts to provide the background that will aid in the solution of dimensioning problems as they arise in day-to-day work. At present, such information is fragmentary and scattered throughout the literature. This book, therefore, attempts to present a unified treatment of the subject.

Many production difficulties would disappear if the simple rules explained herein were followed in general practice.

The manufacture of machine parts is founded on the technical drawing. Everyone engaged in manufacturing has a direct or indirect interest in understanding the meaning of the drawings on which the entire production process is established.

The engineer in industry is constantly faced with the fact that no two objects in the material world can ever be made exactly the same. He learns that the small variations that occur in repetitive production must be considered in the design so that the tolerances placed on the dimensions will restrict the variations to acceptable limits. Proper tolerancing practice ensures that the finished product functions in its intended manner and operates for its expected life. At the same time, the tolerances must not be so small that production costs are increased beyond the original intent of the design.

Ambiguities in engineering drawings can be the cause of much confusion and expense. When specifying the tolerances, the designer must keep in mind that the drawing is the most important communication between the engineering department and the finished product. The drawing must contain all requisite information if the designer's intent is to be fully realized. The drawing must therefore give complete information and at the same time be as simple as possible. The details of the drawing must be capable of being universally understood. The drawing must have one and only one meaning to everyone who will use it—the design, purchasing, tool design, production, inspection, assembly, and servicing departments. The widespread diversification in time and space of these activities has made this requirement imperative.

Only knowledge of the simplest mathematics is required for the reading of this book. Numerous worked-out examples illustrate how numerical values can be used when applying the principles presented. To reduce cumulation of rounding-off errors, the calculations are sometimes carried out to more decimal places than would be used in practice.

No attempt has been made to have the illustrations represent complete shop details. Only sufficient information has been given to illustrate the point under discussion.

When the designer's thinking is conditioned by some knowledge of statistics, he is able to visualize much better what will probably happen in production and assembly. A few principles from probability theory as applied to dimensioning are therefore presented. These applications are valuable in showing, among other things, how piece-part tolerances can sometimes be widened with only a nominal risk that assembly will be adversely affected.

Many homework problems are included at the ends of the chapters. It is hoped that a study of this book will hasten the process of professional development for the reader and assist him in achieving a proficiency that is usually attained only after many years of experience.

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I

Introduction

TOLERANCES

It is impossible to manufacture a dimension to an exact value. Tolerances must therefore be placed on the drawing to restrain the variations to permissible limits. The tolerances provide zones in which the outline of the finished part must lie. A designer is well aware that the cost of a finished product can increase rapidly as the tolerances on the components are made smaller. Designers are constantly admonished to use the widest tolerances possible. Situations may arise, however, in which the relationship between the various tolerances required for proper functioning has not been fully explored. Under such conditions the designer is tempted to specify part tolerances that are unduly tight in the hope that no difficulty will arise at the time of assembly. This is obviously an expensive substitute for a more thorough analysis of the tolerancing situation.

The allocation of proper production tolerances is therefore a most important task if the finished design is to achieve its intended purpose and yet be economical to produce. The size of the tolerance, as specified by the designer, depends on the many conditions pertaining to the design as well as on past experience with similar products if such experience is available. A knowledge of shop processes and machine capabilities is of great assistance in helping to determine the tolerances in the most effective manner. A revision of the design may be called for if the tolerances are too small to be maintained by the equipment available for producing the dimension.

Unless otherwise specified, tolerances are assumed to apply after the application of inorganic coatings, such as plating, anodic processes, and so on. Tolerances are assumed to apply before the application of organic coatings, such as primers, paint, and lacquer.

METHODS FOR SPECIFYING TOLERANCES

The manner of placing tolerances on a drawing depends somewhat on the kind of product or type of manufacturing operation. If the tolerance on a dimension is not specifically stated, the drawing can contain a general note that gives the value of the tolerance for such dimensions. Sometimes, however, notes are not used, on the supposition that if each dimension is considered individually, wider tolerances than those called for in the note could probably be used.

Tolerances may be placed on the drawing in a number of different ways. In the *unilateral* system (Fig. 1-1) one tolerance is zero and all the variation

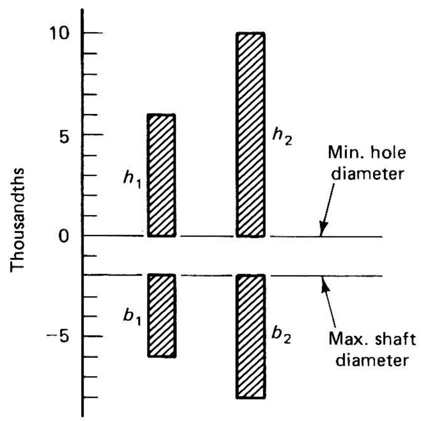


Figure 1-1 Unilateral tolerances.

of the dimension is given by the other tolerance. In *bilateral* dimensioning (Fig. 1-2) a mean dimension is used with plus and minus variations extending each way from the mean dimension.

Unilateral tolerancing has the advantage that a tolerance revision can be made with the least disturbance to the remaining dimensions. Thus in Fig. 1-1, suppose that the fit had been originally dimensioned with tolerances h_1 and b_1 for hole and shaft. Suppose that after some experience with this fit it is found that larger tolerances could be used. The tolerances can be easily changed to h_2 and b_2 without affecting other dimensions already present. In the bilateral system (Fig. 1-2) a change in the tolerances also involves a change in at least one of the mean dimensions. Tolerances can be easily changed back and forth between unilateral and bilateral for the purpose of making calculations.

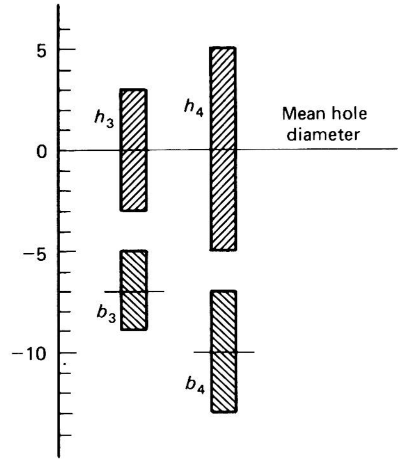


Figure 1-2 Bilateral tolerances.

MAXIMUM MATERIAL CONDITION; MINIMUM MATERIAL CONDITION

A part is said to be at the *maximum material condition* (MMC) when the dimensions are all at the limits that will give a part containing the maximum amount of material. For a shaft or external dimension, the fundamental dimension is the largest value permitted, and all the variation, as permitted by the tolerance, serves to reduce the dimension. For a hole or internal dimension, the fundamental dimension is the smallest value permitted, and the variation as given by the tolerance serves to make the dimension larger.

A part is said to be at the *least material condition* (LMC) when the dimensions are all at the limits that give a part with the smallest amount of material. For LMC the fundamental value is the smallest for an external dimension and the largest for an internal dimension. The tolerances thus provide parts containing larger amounts of material.

Maximum material tolerances have a production advantage. For an external dimension, should the worker aim at the fundamental or largest value but form something smaller, the parts may be reworked to bring them within acceptable limits. A worker keeping the mean dimension in mind would have smaller margins for any errors. The actual quantity of material between MMC and LMC parts may be of small consequence. These terms do, however, provide convenient expressions for denoting the different methods for specifying the tolerances on drawings.

Example 1

A hole is dimensioned 0.756–0.750 in. The shaft is dimensioned 0.747–0.743 in. Change these dimensions into bilateral form and also into maximum material dimensioning.

Solution

Bilateral:

hole mean = .753 dimension is .753 ± .003

shaft mean = .745 dimension is .745 ± .002

Maximum material condition:

Hole dimension is $.750\begin{smallmatrix}+.006\\-.000\end{smallmatrix}$

Shaft dimension is $.747\begin{smallmatrix}+.000\\-.004\end{smallmatrix}$

DIMENSIONING OF CYLINDRICAL FIT

Different methods may be used for the dimensioning of cylindrical fits. For a clearance fit the most dangerous situation occurs for a minimum hole and a maximum diameter shaft. Hence it is safest to use MMC dimensioning as was done in Fig. 1-3(a). Unilateral tolerances are used and they are shown to an exaggerated scale at the left side. It is noted that the fundamental dimensions give the tightest fit and that the tolerances give larger holes and smaller shafts—in other words, looser fits.

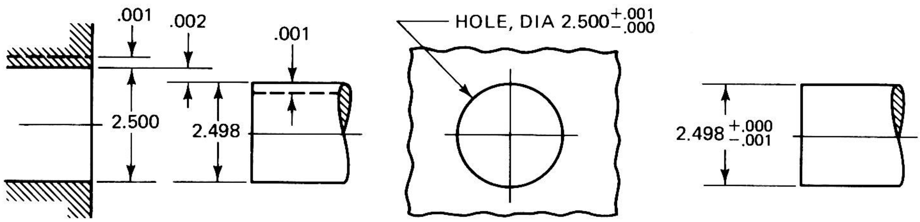
Figure 1-3(a) comprises what would nominally be called a $2\frac{1}{2}$-in. shaft fit. It is noted, however, that the $2\frac{1}{2}$-in. dimension occurs on the drawing for the hole rather than for the shaft. These dimensions will permit the hole to be finished with a $2\frac{1}{2}$-in. stock reamer while the shaft is machined to fit. Such dimensioning is called the *basic hole system.*

Figure 1-3(b) shows the same fit, but the dimensioning here is for the LMC and the $2\frac{1}{2}$-in. dimension appears on the detail for the shaft. This accordingly is called the *basic shaft system* of dimensioning. Here stock shafting might be used with the hole machined to fit.

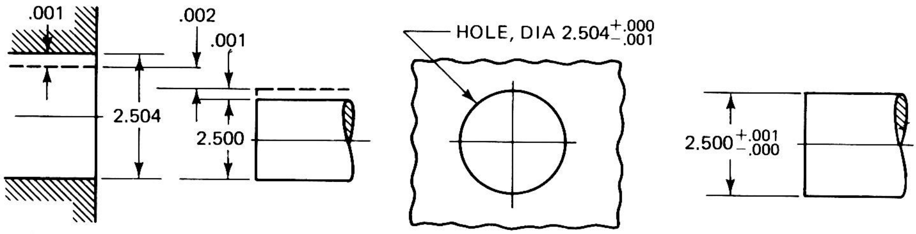
For an interference fit, as in Fig. 1-3(c), the shaft is always larger than the hole. The fit that is most likely to loosen in service is the one with largest hole and smallest shaft (i.e., at the LMC). It is therefore used in part (c) in conjunction with basic hole dimensioning.

A similar fit is shown in Fig. 1-3(d), but here the dimensioning is at the MMC and basic shaft system.

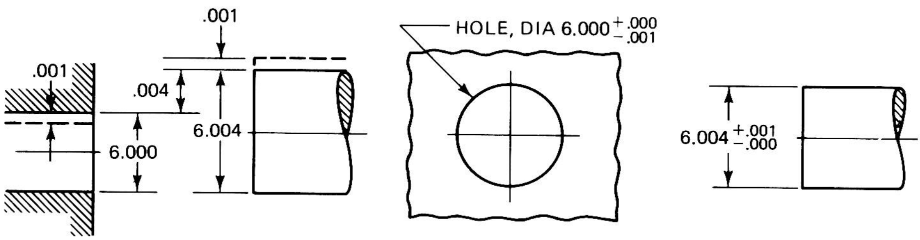
Other methods can of course be used for cylindrical fits. Figure 1-4(a) shows bilateral dimensioning, and Fig. 1-4(b) shows the limit dimensions for both hole and shaft.



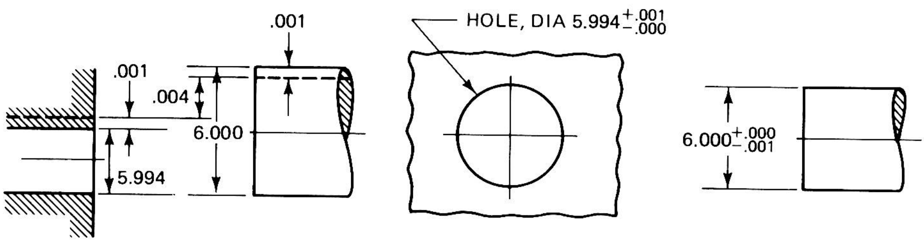
(a) $2\frac{1}{2}$ in. clearance fit; MMC; basic hole



(b) $2\frac{1}{2}$ in. clearance fit; LMC; basic shaft

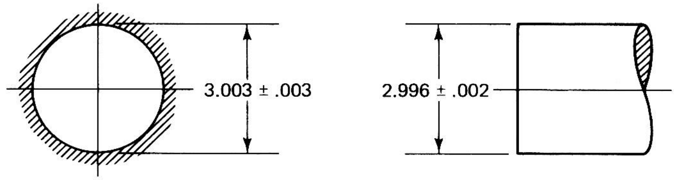


(c) 6 in. interference fit; LMC; basic hole

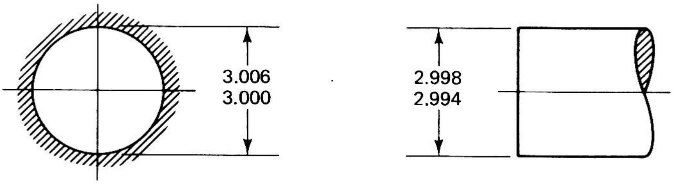


(d) 6 in. interference fit; MMC; basic shaft

Figure 1-3 Dimensioning of cylindrical fits with unilateral tolerances.



(a) Clearance fit; bilateral tolerancing



(b) Clearance fit; limit dimensioning

Figure 1-4 Methods for placing tolerances on drawing.

CUMULATIVE AND NONCUMULATIVE TOLERANCES

Consider the details for the parts of Fig. 1-5. The designer no doubt believed that the dimensions of Fig. 1-5(a) would give satisfactory parts that would assemble with each other. However, as shown in Fig. 1-5(b), it is possible for parts to be made in accord with (a) and yet interfere on assembly. The difficulty can be easily corrected if the dimensions for all surfaces extend from the left side, as shown in Fig. 1-5(c).

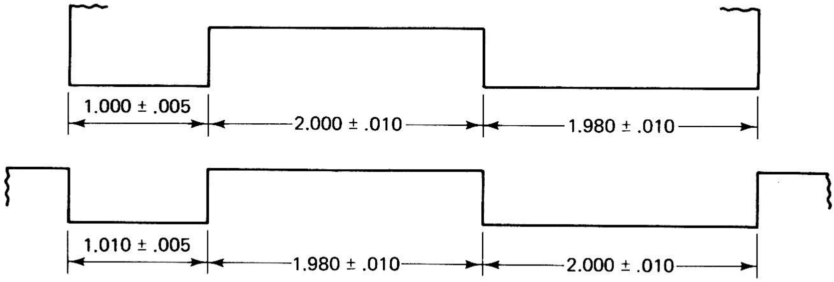
The left edge, from which all the dimensions in Fig. 1-5(c) originate, is accordingly called the *datum* and is so marked. Datums are usually marked with a letter of the alphabet and placed in a box attached to the edge view of the surface.

The drawing may of course contain many unimportant details which have nothing to do with functioning and assembly. The dimensions for these need not, of course, originate at the datum.

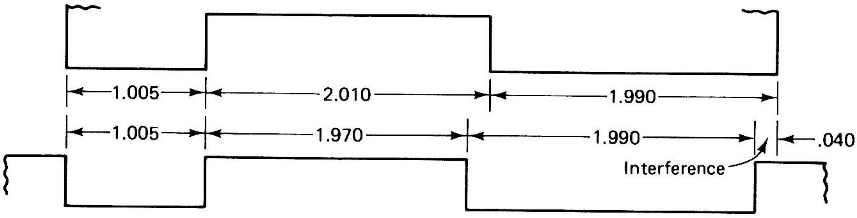
REDUNDANT DIMENSIONING

In a given direction, a surface should be located by one and only one dimension. Much confusion and expense can arise from violation of this rule.

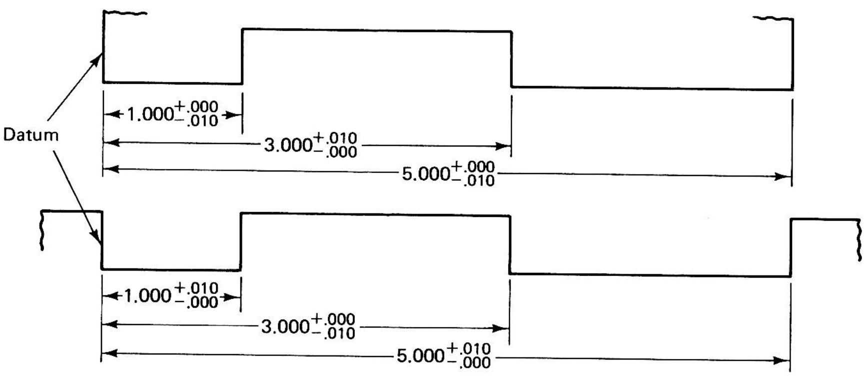
For example, consider the horizontal dimensions of the part shown in Fig. 1-6(a). For a part made as in Fig. 1-6(b), lengths *AB* and *AC* are in accord with the drawing, but *BC* is not. Perhaps length *BC* is the important one for



(a) Detail drawing showing chain dimensioning of parts to be assembled



(b) Measurements on parts made from details of (a)



(c) Noncumulative dimensioning will ensure assembly of all parts

Figure 1-5 Ill effects resulting from cumulative dimensioning.

proper functioning, but a production man could argue that technically he had followed the drawing by making *AB* and *AC* correctly.

Similarly, in Fig. 1-6(c), lengths *BC* and *AC* are in accord with the drawing, but *AB* is not.

The difficulty can be corrected simply by omitting one of the dimensions in Fig. 1-6(a). The two dimensions that should be retained depend on manu-