SOME ASPECTS OF DIMENSIONING AND TOLERANCING OF MECHANICAL ENGINEERING DRAWINGS

By: B. Krayer*

1. Introduction

There is a great impact of the dimensions and tolerances on the cost of manufacture and quality of a product.

Therefore it is obvious that the dimension and tolerances have to be carefully selected and it will lead to most unsatisfactory results if just any suitable dimensioning system is taken. Unfortunately very often not enough attention has been paid to that a step of the design process. An analysis of the time spent for assembly show 40 to 50% of the total time is spent on reworking due for badly dimensioned and toleranced parts.

Our goal is to find that dmensioning system which

a) Defines-the element completely (daily task in engineering drawing)

b) Allows to utilize the allowable tolerances given by the function quality etc. as good as possible.

1.1 Tolerance Versus Cost of Manufacture

The cost of manufacture and the tolerance are selected as follows

(Cost of manufacture) x (tolerance) C_1 .... (1)

The constant C_1 is a specific constant for each operation e.g. the figure below shows the relation for operation "drilling".

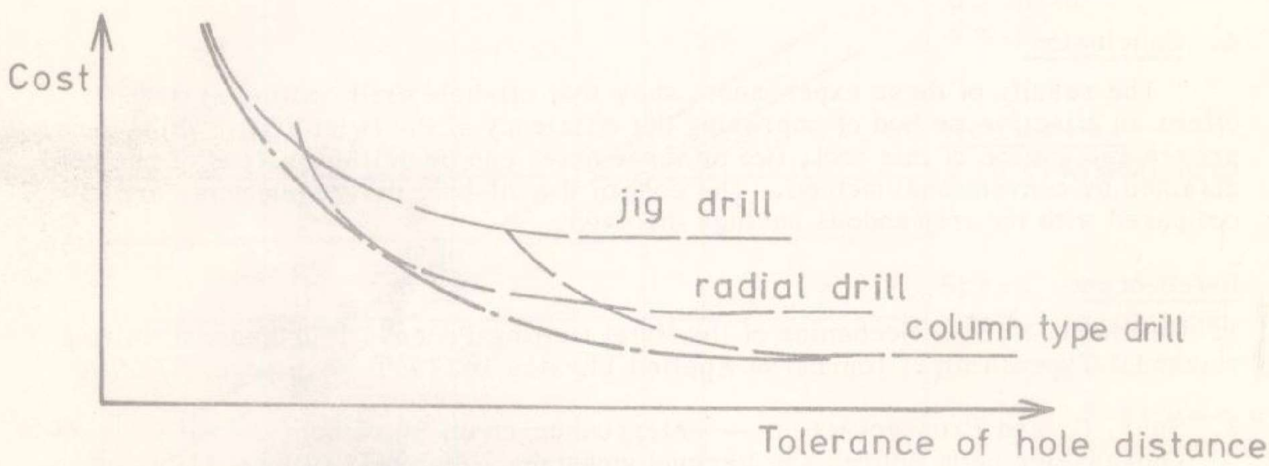


FIG.1

In general we note the following influence factors on the cost of manufacture:

Cost = Function (shape, dimensions, material, mode of manufacture, tolerances surface quality etc.)

---

*Lecturer, Mechanical Engineering Department, University of Dar es Salaam.

On the stage of selecting tolerances the influence factors shape and material and some times also the surface quality are fixed where as the tolerances and the mode of manufacture are still to be established.

Equation (1) and figure 1 show the importance to select as big tolerances as possible, resp. to use such tolerances which can be manufactured without special efforts.

Of course every mode of manufacture has its spcific tolerance range which can be easily observed and they are known as general tolerances (1).

It is strongly recommended if every possible not to deviate too much from the general tolerances and we should bear in mind that the quality of a specific design can also be judged by the possibility to use reasonable tolerance limits. Generally the following thumb rules should be observed:

a) For lengths (general application, not for tools, fixtures etc.). Select tolerance if possible not finer than 1/3 .... 1/4 of the general tolerance medium (1).

b) ISO - tolerance system (for general application, not for tools, fixtures and fine machines). Select tolerance range not finer than class 6 h6, N6, etc.

1.2 Types of dimensions

In mechanical engineering we distinguish three types of dimensions which have different importance for the machine part and manufacturing process. These are:

a) Functional Dimensions

These dimensions are important for the function, quality, assembly etc. of an element. If they are not observed the element will not operate as required, cannot be assembled, suffers a loss in quality etc. This is the most important type and the designing engineer has to make sure their correct manufacture.

b) Non-functional (ordinary) dimensions

These dimensions define the object but they are not important for the function. They may vary within the indicated limits of the general tolerances.

c) Auxilliary dimensions

These dimensions give additional information concerning e.g. assembly, checking, overall dimensions etc. They may be displayed e.g. to avoid adding up of dimensions or to allow an easy checking. They never carry any tolerance and they are shown in brackets and the machine part is not considered as faulty if they are not observed.

2. Dimensioning Systems

2.1 Number of possible dimensioning systems

The theoretical possible number of dimensioning systems for an object within edges can be calculated with the following equation:

$$X = N^{N-2} \qquad \text{.......................... (2)}$$

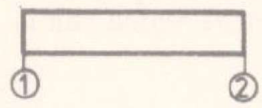
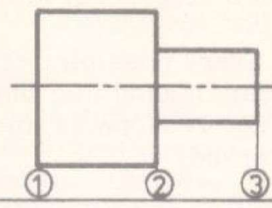
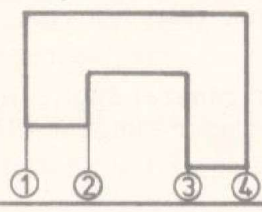
Number of edges	Example	Theoretical number of dim systems
2		1
3		3
4		16

FIG. 2

Out of this enormous number of possibilities we have to find that dimensioning system which meets goal b, (chapter 1). This means only 1 dimensioning system is 100% correct whreas all others do not utilize the allowable tolerances in the same grade as the distinguished one.

3. Method of Function Geometry (MFG)

The MFG allows to calibrate the correct set of dimensions for any machine element. On the basis of the following geometrical functional requirements:

- clearance
- interference
- assembly
- interchangeability
- quality
- etc.

The functional dimensions are elaborated and a set of dimensions and tolerances is worked out.

3.1 The steps of MFG

a) Setting up of a clearance scheme

One considers those clearances and interferances which are important for the function, assembly, quality etc. of the product. By setting up a clearance scheme it is made sure that the most important points are observed.

Looking at the clearances one has to consider the possible effects of a certain bault, i.e. the risk due to a certain fault. We must ask what happens if a certain play is not observed. The faults are classified (2).

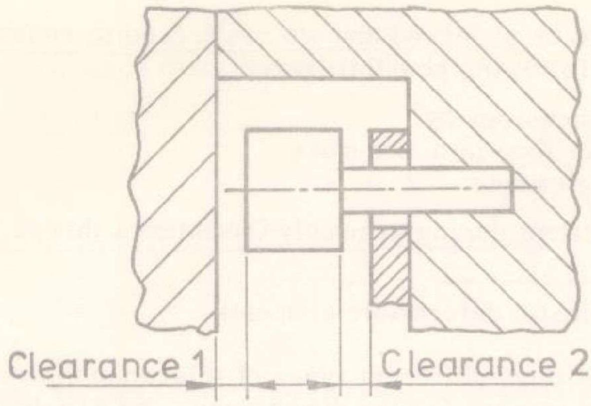


FIG . 3

- Overcritical fault: Danger to life destruction or complete break down of the machine.
- Main fault: Severe affection of the function
- Minor fault: Insignificant influence on the function, minor flaw.

Usually the clearances are investigated on the design stage, but sometimes it is done also on other steps of the design procedure.

b) Elaboration of geometrical functional requirements

The setting of the geometrical functional requirements, i.e. the setting of the tolerance limits must be done with technical knowledge. The establishment of tolerances has a great impact on the facribrication and assembly and therefore on the cost of a product.

Of course one tries to obtain as big tolerances as possible and it has to be observed carefully whether all the considered limits are really necessary. Sometimes these limits are not clearly set and one can either indicate a maximum or a minimum limit.

c) Elaboration of the functional dimensional system

Before fixing any tolerance limits of the dimensions it is important to survey the dimensioning system of a product. This means all dimensions have to be worked out which influence directly the clearance. These dimensions are functional dimensions and are important for the function, interchangeability, assembly etc. It is of extraordinary importance to elaborate the correct set of functional dimensions. This is done in the following way:

Starting with the clearance all dimensions which directly influence this clearance are represented schematically as a loop. Introducing a definite direction as positive we obtain an equation for the loop as a basis of the dimension and tolerance equation.

It is very important that the number of dimensions in one loop is as low as possible because if a loop with more than the minimum number of dimensions is taken the tolerance limits of all dimensions are reduced. This can only be carried out at the complete system (resp. partial system) and not individually for single parts. This loop equations are providing us with all functional dimensions for each single part.

d) Tolerance distribution.

The allocation of different tolerances to the functional dimensions must be carried out as an optimization process. One has not only to pay attention that the functional requirements are fulfilled but also consider the limited possibilites of the manufacturing process.

Often the above rule cannot be observed and we are forced to redesign the system observing one of the following possibilities:

a) reduce the number of dimensions by:
   - cutting one dimensional loop into two more
   - combine two or more elements

b) adaptation and/or adjustment during assembly (sometimes this is costly)

c) introducing elastic or plastic deformable elements.

In principle we can assume three different types of tolerance distribution leading to different individual tolerances for the dimensions. We can distinguish between:

i) Arithmetic tolerance calculation - It is assumed that the sum of all tolerances may not exceed the difference between the maximum and minimum tolerance. The tolerance equation is therefore the following:

$$\sum_{i=1}^{n} t_i = C_{max} - C_{min} \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (3)$$

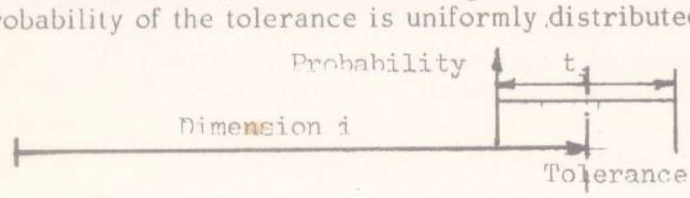
t_i = tolerance zone of the functional dimension i

C_{max} = maximum allowable clearance/interference

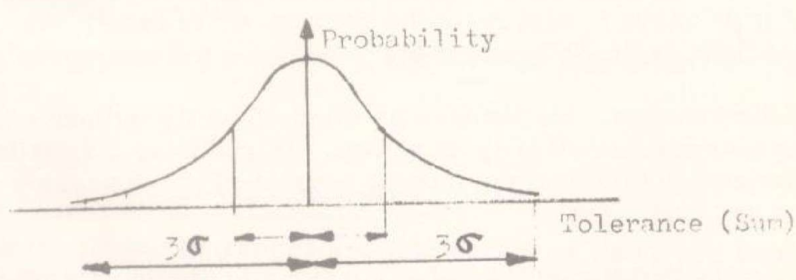
C_{min} = minimum allowable clearance/interference.

This procedure may be applied in all cases, but it leads to relatively small tolerance zones.

ii) Tolerance calculation assuming uniform distribution - It is assumed that the probability of the tolerance is uniformly distributed



The sum of four or more tolerance zones of this type gives a result approaching fairly good a Normal (Gauss) distribution represented below



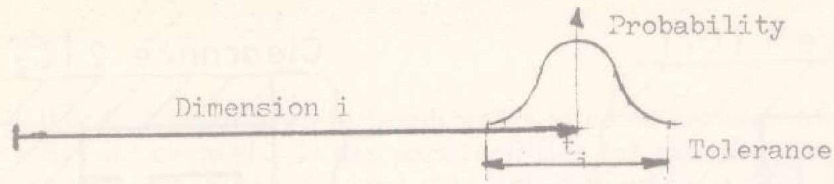
Where: σ - standard deviation.

The range between -3 and +3 covers the probability of 99.7% of all possible results which in most cases is by far sufficient. The equation is the following:

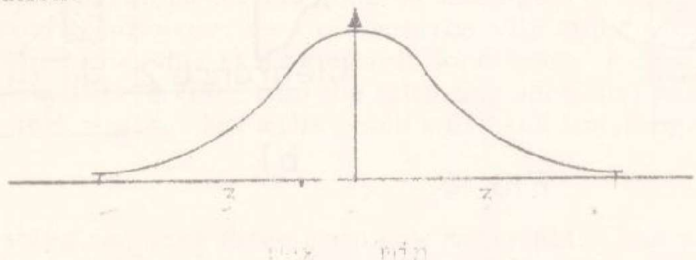
$$\left(\frac{C_{max} - C_{min}}{6}\right)^2 \geq \sigma^2 = \frac{1}{12} \sum_{i=1}^{n} (t_i)^2 \quad \dots\dots\dots\dots\dots \quad (4)$$

As above mentioned this assumption may be taken if there are four or more functional dimensions.

iii) Tolerance calculation assuming Normal (Gauss) distribution – In this case the tolerance distribution is the following:



Of course the sum of several normal distributions will also be a normal distribution:



We assume the range -3σ to $+3\sigma$ to be equal to $C_{max} - C_{min}$ thus covering 99.7% of all possible results (as before). The equation is the following:

$$\frac{(C_{max} - C_{min})^2}{6} \geq \sigma_M^2 = \sum_{i=1}^{n} \left(\frac{t_i}{6}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

This assumption yields the biggest tolerance zones but it may be only taken if the manufacturing process is carefully observed and it is granted by checks that the distribution is really as assumed.

e) Calculation of the functional dimensions

Some dimensions in a loop are certainly given by calculations, standards or other specifications. With the loop equation (6) we can calculate one dimension in every loop. If we have n loops we obtain n equations and we can calculane n dimensions. The loop equation can be indicated as follows:

$$C_N + \sum_{i=1}^{n} \bar{d}_i = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

a) observe sign convention

b) $C_n = \frac{C_{max} + C_{min}}{2}$: nominal clearance

c) $\bar{d}_i = \frac{d_{imax} + d_{imin}}{2}$: nominal (mean) dim.

f) Drawing of detail drawings

By indicating deliberately the functional dimensions with their tolerances on the detail drawing we make sure that the parts are correctly produced and checked.

3.2 Summary

In order to carry out this method systematically the following block diagram can be indicated.

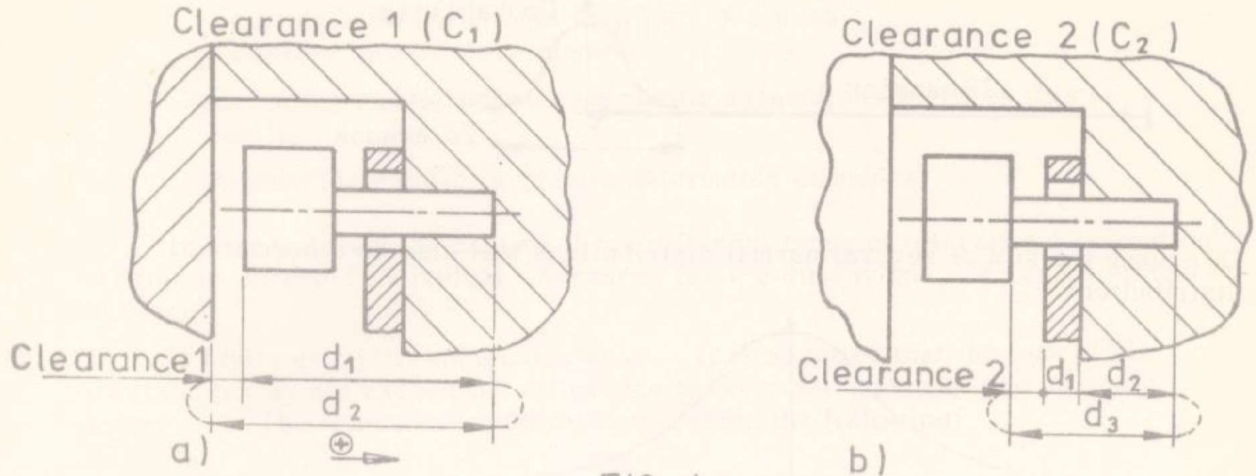
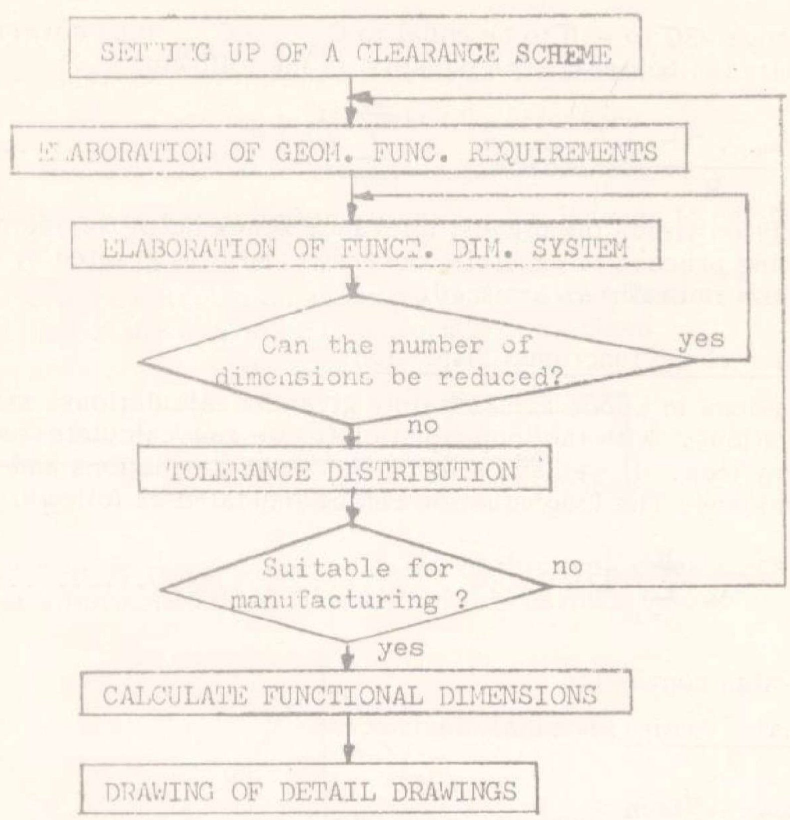


FIG. 4



With the above procedure the correct dimensioning is obtained and for a specific design the biggest possible toerance zones are elaborated.

References

1. DIN 7168

2. DIN 40080