A Text Book on

PRODUCTION ENGINEERING

(THIRD EDITION)

Useful for GATE / ESE / PSUs and other competitive examinations

Dr. Swadesh Kumar Singh
B.Tech. AMU Aligarh, Gold Medalist
M. Tech. and Ph.D. from IIT Delhi
Ex. IES officer, Govt. of India
Professor, GRIET, Hyderabad

MADE EASY
Publications

MADE EASY Publications Pvt. Ltd.

Corporate Office: 44-A/4, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi-110016
E-mail: infomep@madeeasy.in
Contact: 011-45124660, 8860378007
Visit us at: www.madeeasypublications.org

A text book on Production Engineering

First Edition: 2010
Second Edition: 2014
Third Edition: 2016
Reprint : 2017
Reprint : 2019
Reprint : 2020

Reprint : 2021

To my teacher,

Who not only taught me Bhagavad-Gita as it is
but also trained me how to follow its teachings

FOREWORD

"Invention of tools to extend the capabilities of their bare hands has been one of the greatest advances made by the ancient humans that helped in the progress of civilization. Assembling individual tools having different functions into harmonious units called machines which could perform a range of complex functions was the next major step that ushered in an industrial society which brought unprecedented prosperity to a vast majority of people. Today's comfortable lifestyles which we so take for granted owe not a little to the manufacturing sector that produces not only the goods that are indispensable to our existence but also all the machinery that makes those goods. Production Engineering is the subject that deals with the techniques of converting a variety of raw materials into useful articles.

Metalworking is one of the oldest professions practised by human beings. From the ancient village blacksmithy to the present day robotic controlled automatic manufacturing, production technology has made mind boggling advances. Today's production technologies encompass a breath taking range and can satisfactorily address humongous challenges. Be it the fabrication of flawless individual components weighing a few hundred tons each such as the bulkheads of fusion reactors or nano-scale robots that could propel themselves through the bloodstream of a human being, be it the making of very-high temperature resistant nose cone of a ballistic missile or the layer-by-layer building-up of millions of transistors and other electronic components on a single crystal of silicon to make a VLSI chip of a few mm size, today's technologies have the answers.

Ancient man may have used only a simple stone to make his tools (the flint tools of prehistoric man), but the present day engineer has a bewildering variety of materials to work with. Although still most preoccupied with the forming of metals and alloys (especially steels) using traditional methods such as casting, forging, rolling, extrusion, machining and welding, he has to master the technologies required to shape a number of other materials such as ceramics (slip casting, sol-gel processing etc), polymeric materials (blow moulding, pultrusion etc), composites (co-extrusion, sintering, polymeric curing etc) and electronic materials (photogravuring, CVD, laser processing etc). Even a mere enumeration and brief description of the large number of production technologies is a daunting task. But a full understanding of these technologies can only come about by a study of the underlying science and material behaviour under different conditions of stress, temperature and environment. This latter part requires a thorough knowledge of the structure of materials from the atomic scale to the microscopic scale and its correlation to the externally observed properties and mechanical behaviour. Further, precise mathematical analysis of the response of materials to applied stress, strain rate and temperature is a necessary concomitant to a comprehensive description of the production processes. Study of the subject of Production Engineering is thus not only useful and practical but also highly exciting and rewarding in view of its multidimensional reach and approach."

Prof. V V Kutumba Rao

Formerly Professor Department of Metallurgical Engineering, IT BHU

Formerly Director, Jawaharlal Nehru Aluminium Research, Design & Development Centre, Nagpur

I heartily acknowledge my best wishes for the publication of the book on "Production Technology" by Dr. Swadesh Kumar Singh. He is an accomplished researcher and academician. I have read the book. Since I am in India, I know something about the competitive examinations like GATE and UPSC, there is a need for a book which can elucidate concepts and give the appropriate exercises for the students who appear for GATE/IES and other competitive exams. From this perspective, concepts are aptly presented and are absolutely lucid. Especially, the explanations on 'Material Science' and 'Metal Forming' are extremely impressive. I know him personally and his efforts for the welfare of the students are bountiful. My best wishes for his unique contribution to reach the many students who yearn for such wonderful compilations. Thank You!

Prof. Narsingh Bahadur Singh, FASM, FSPIE, FOSA, FRSC

University of Maryland, Baltimore County (UMBC), USA

PREFACE

I have great pleasure in writing the book of core subject of Mechanical Engineering viz. Production Technology/ Engineering. A thorough understanding of the concepts developed in this book will prepare the reader for more advanced course on the subject. The entire syllabus of Production Engineering is presented in a simple and lucid style to make it comprehensible to an average student.

In this book I tried to present the approach not only for competitive examinations like GATE, IES and IAS but also for university examinations of JNTU, UPTEC etc. especially on the subjects like Material Science, Metrology and Production Processes. I also understood by teaching various categories of students that it becomes easy for the students when things are explained by going through the fundamentals. So in the present book I tried to explain most of the topics through the basics. The questions which already appeared in competitive examinations like GATE, IES and university exams (both subjective and objective) are incorporated in each chapter.

I would like to thank All India Council for Technical Education (AICTE), Department of Science and Technology (DST) Govt. of India, Defence Metallurgical Research Laboratory (DMRL) and my present place of work GRIET for giving me opportunity to learn and keep in touch with recent advances in the production technology either by supporting the research or providing the forum of eminent personalities to discuss various technology related issues.

I would like to express my heartfelt regard and gratitude to my teacher from whom I have learned the subject matter and which gave me inspiration to write this book. I thank Mahesh, Apurv, Limbadri, Srinivasu, Gangadhar, Swathi and other students of mine for typing, drawing various figures and proofreading the text.

Dr. Swadesh Kumar Singh

CONTENTS

1. Metrology

2. Material Science

3. Casting

4. Metal Cutting

5. Metal Forming

6. Welding

❍❍❍❍

CHAPTER 1

Metrology

1.1 INTRODUCTION

Metrology or industrial inspection involves inspection of components produced from production, a unit to check whether the dimensions fall within the acceptable limits assigned by the consumer. Inspection is divided into active and passive type. In active inspection parts are checked when it is being produced in any production system. It is also called online inspection i.e. if something goes wrong, correction can be taken. But in passive inspection parts are checked when it is already being produced and inspection, is meant for segregation of the components as good or bad. In industries generally active inspection are encouraged but it depends upon the type of application.

Parts which are produced from any manufacturing system follow a normal distribution. Machine environment can be considered as infinite universe and machined components are considered as random data collection. When data is collected randomly from an infinite universe, the data follows a normal distribution as shown in Fig. 1.1.

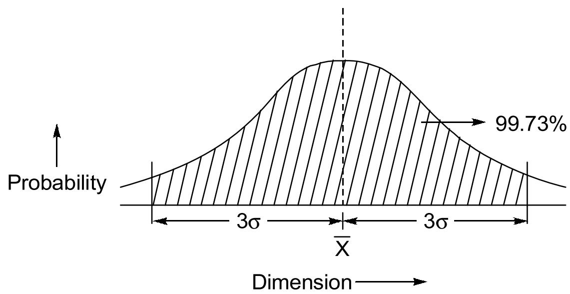


Fig. 1.1 (Normal Distribution)

Let us take one example to understand the concept. There is a lathe machine aimed at producing shafts of 25.0 mm diameter. As the shafts are coming out of the machine, no two dimensions will match and there will be some variation in the dimensions like 25.002 mm, 24.985 mm etc. It is because these dimensions are following a normal distribution. That is why it is said that what ever component you have made from your production systems, no two components will match and you cannot duplicate the part. In the above normal distribution $\bar{X}$ is mean or targeted value of the machine and σ is the process dispersion or standard deviation. Following are the factors that may change the process or targeted mean ($\bar{X}$) value in a typical machine environment :

1. Tool and die wear.
2. Excessive machine vibrations.
3. Wear or minor failure or loosening of machine parts.
4. Change of machine and process.
5. Measurement error or change in material property.

Following factors changes the standard deviation of the process.

1. Carelessness of operator.
2. New or inexperienced operator.
3. Deterioration in the condition of machine.
4. Frequent resetting or readjustment of the process.
5. Increase variability of the material.

99.73% area of the normal distribution takes between $\pm 3\sigma$ limits of this normal distribution. It means 99.73% components will be produced in 6σ range. This 6σ is called proves capability of machine. To move further with inspection let us understand normal distribution with following examples.

Example : 1.1

A lathe machine is targeted to produce shafts of 25.0 mm diameter. This conventional lathe is having process dispersion of 0.15 mm. Determine:

1. **How many shafts, machine is producing below 24.9 mm?**
2. **How many shafts, machine is producing above 25.2 mm?**
3. **Normally machine will produce shafts in what range?**
4. **If the acceptable limits of shafts by consumer is 25 ± 0.35 mm, how many defective shafts machine is producing?**

Solution :

Problems related to normal distribution can be solved by making use of normal distribution tables given at the end of book. These tables are given in terms of a variable Z which is

$$Z = \frac{X - \bar{X}}{\sigma}$$

X is the value up to which the total area under the normal distribution from $-\infty$ to X is to be calculated as shown in the given Fig. 1.2.

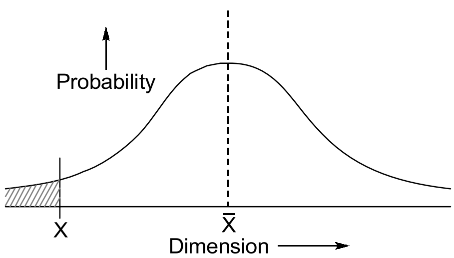


Fig. 1.2

1. In the given problem we have to calculate = $\int_{-\infty}^{24.9} P(X)dX$

where P(X) is the probability function

$$X = 24.9$$
$$\bar{X} = 25$$
$$\sigma = 0.15$$

So $$z = \frac{X - \bar{X}}{\sigma} = \frac{24.9 - 25}{0.15} = \frac{-0.1}{0.15} = -0.666$$

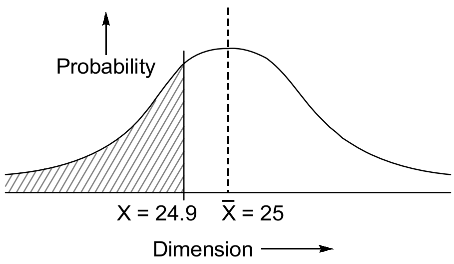


Fig. 1.3

Corresponding to this Z value, the area under normal distribution up to 24.9 mm from the table is 0.2546. So 25.46% shafts will be produced below 24.9 mm or 74.54% shafts will be produced more than 24.9 mm diameter.

2. In the above problem the shaded area has to be calculated as shown in Fig. 1.4.

$$z = \frac{X - \bar{X}}{\sigma} = \frac{25.2 - 25}{0.15} = \frac{0.2}{0.15} = 1.33$$

The area corresponding to this value from the table is 0.9082.
So the shaded area is (1 – 0.9082) = 0.0918. So 9.18% will be dimension more than 25.2 mm.

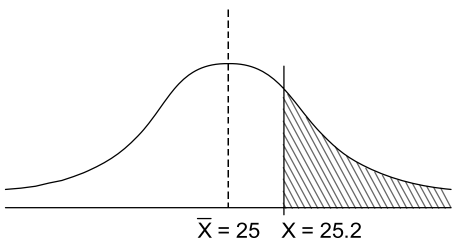


Fig. 1.4

3. Around 99.73% components will be produced within 25 ± 3(0.15) mm. So machine will produce components between 24.55 – 25.45 mm range.
4. Shaded area shows the defective components produced by the machine. Since the distribution is symmetrical, upon calculating area on one side defectives can be calculated by multiplying it by 2. Area under the distribution below 24.65 mm.

$$z = \frac{24.65 - 25}{0.15} = -2.33$$

Area from the table corresponding to Z = – 2.33 is 0.0099. So shafts below 24.65 are 0.99%.

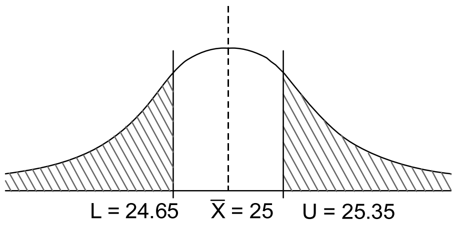


Fig. 1.5

Total defective percentage = 2 × 0.99 = 1.98%

Example : 1.2

To honor guests in a function there is a machine to sprinkle fragrant water on each guest's head. In a particular random observation the machine sprinkles 4 grams of fragrant water. The normal distribution of the machine is 0.04 grams. If 2% of time machine injects 4 grams of water what is the mean amount of water machine is injecting.

Solution :

$$z = \frac{4 - \overline{X}}{0.04}$$

The value of Z corresponding to 0.02 area = – 2.055 (from normal distributions tables)

$$-2.055 = \frac{4 - \overline{X}}{0.04}$$

$$\Rightarrow \quad \overline{X} = 4.0822$$

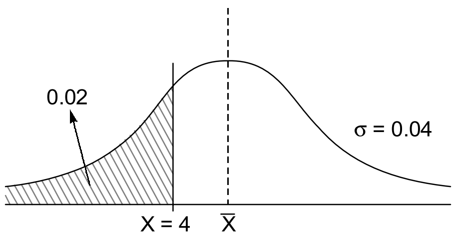


Fig. 1.6

Example : 1.3

A milling machine is programmed to produce round shape of 45 mm diameter. The machine has process dispersion of 0.2 mm. The customer has given specifications of product as 44.8 ± 0.3. If the product is over size it can be reworked and if it is undersize it will be scrapped. In the present settings how much percentage of scrap and rework machine is produced?

Solution :

Calculation of scrap

$$z = \frac{44.5 - 45}{0.2} = -2.5$$

Area corresponding to this value = 0.0062

So scrap = 0.62%

Calculation of rework

$$z = \frac{45.1 - 45}{0.2} = 0.5$$

$$\text{Area} = 0.6915$$

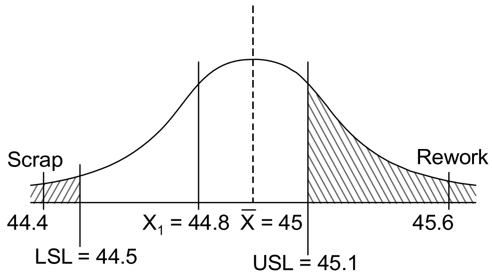


Fig. 1.7

So, percentage rework = 100 – 69.15 = 30.85%

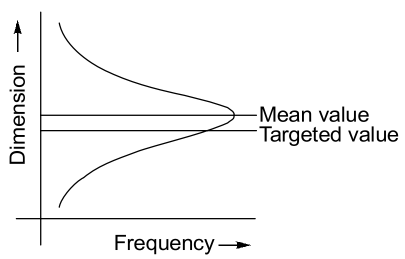
1.2 ACCURACY AND PRECISION

Accuracy is defined as closeness to the exact value and precision is repeatability. Accuracy is something related to the mean value of the parts produced and precision is related to the process dispersion. In Fig.1.8 (i) mean value of the observations is very close to the targeted value but there are large fluctuations in the observations due to higher process capability, such systems are accurate but not precise.

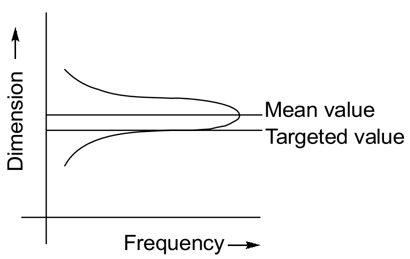
In Fig.1.8 (ii) standard deviation of observations is low and also the mean is close to the targeted value, so such systems are precise and accurate.

In Fig.1.8 (iii) although the process dispersion of the system is low but due to the improper setting of the machine mean value is far from the targeted value. Such systems are called precise but are not accurate.

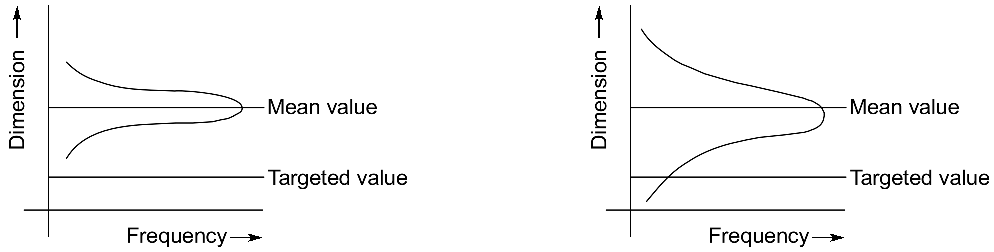
In Fig.1.8 (iv) the process dispersion is large and the mean is far from the targeted value. Such systems are said to be neither precise nor accurate.



(i) Accurate but not precise



(ii) Accurate and precise

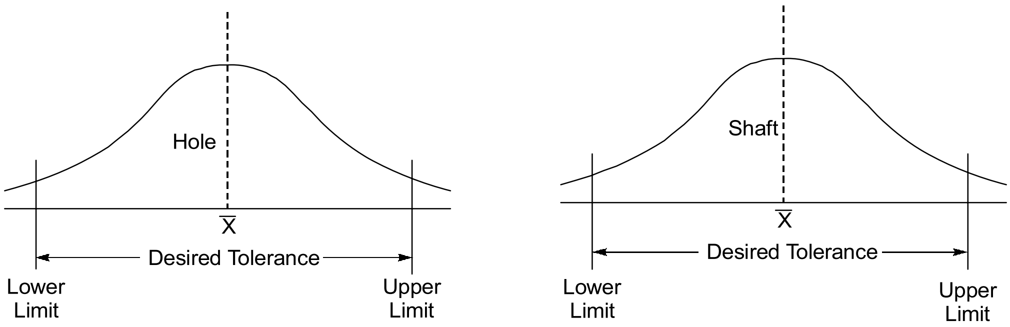


(iii) Precise but not accurate (iv) Neither precise nor accurate

Fig. 1.8 : Accuracy Vs Precision

1.3 INTERCHANGEABILITY

Any assembly is made up of a combination of hole and shaft. Hole is any internal feature of part and may not be circular and similarly any external feature of part is called shaft, may not be circular. In most of the cases it is the hole which is made first because standard size of drills and reamers are available. If shaft is made first holes are called make to suit. As discussed earlier that it is impossible to duplicate the part, so limits are provided on the dimensions which are acceptable. This difference between upper and lower limit is called desired tolerance by the consumer. The targeted value of the hole and shaft is called basic size and nearest round number as per the standard is called nominal size.



(i) (ii)

Fig. 1.9 : Full Interchangeability

Suppose there are two different machines producing holes and shafts. If it so happens that process capability is equal to the desired tolerance individually (as shown in Fig. 1.9 (i) and (ii)), if a hole is selected randomly from hole lot and a shaft is selected randomly from shaft lot, assembly can be made. Such systems are called a fully interchangeable system which does not require any inspection after machining. Interchangeability is having following advantages :

1. Cost of the assembly decreases because of holes and shafts can be made at different places where the material and the labour is cheap.
2. Standardization of hole and shaft is possible.
3. Quality of product increases.
4. Maintenance of the assembly becomes cheap and easy because when either hole or shaft fails one does not have to throw away the complete assembly and the failed parts only needs to be replaced.

1.4 SELECTIVE ASSEMBLY

To increase the quality of assembly, the desired tolerances for both hole and shaft should decrease but machines will have certain process capabilities. By converting conventional machines to NC, process capability decreases but desired tolerances are decreasing more than that. Selective assembly is a mathematical procedure to achieve full interchangeability although machines are not capable i.e. process capability is much larger than the desired tolerance. Let us understand it by discussing some cases.

Case : I

Process capability of hole and shaft are equal but more than the desired tolerance.

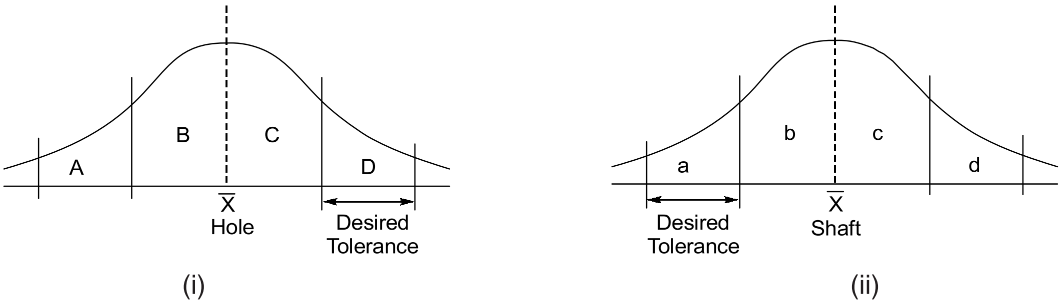


Fig. 1.10 : Selective Assembly Case - I

Let us assume that process capability is 4 times the desired tolerance of both hole and shaft. The process capability range of both hole and shaft is divided into 4 equal parts as shown in Fig. 1.10 (i) and (ii). This means in case of selective assembly each component has to be inspected after manufacturing and it is put into different subgroups according to its dimensions. The variation of dimensions with in one word the subgroup is equal to the desired tolerance. So when randomly a hole is selected from subgroup 'A' and a shaft is selected randomly from subgroup 'a', assembly can be made.

Case : II

Process capability of hole is equal to the desired tolerance and process capability of shaft is worse than the desired tolerance.

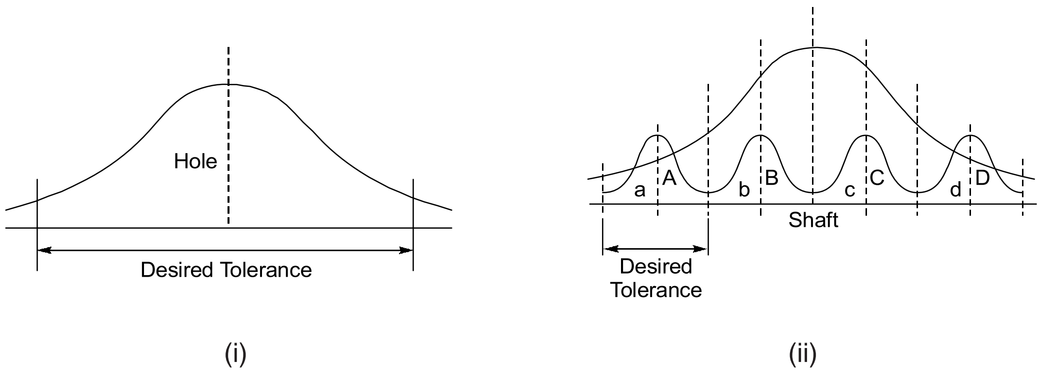


Fig. 1.11 : Selective Assembly Case - II

In this case process capability range of shaft is divided into 4 equal divisions so that variation with in the subgroup is equal to the desired tolerance. For producing holes of subgroup of shafts 'a', the machine is targeted at the mean of subgroup of shafts 'a' and the holes will be directly categorized as subgroup 'A' without any inspection because process capability of machine producing hole is equal to the desired tolerance. When variations are equal to the desired tolerances assembly can be made to give a quality of assembly.

Case : III

Process capability of both holes and shafts are different and worse than the desired tolerance.

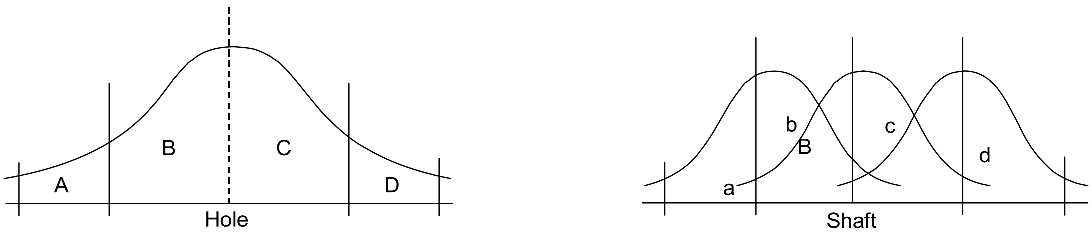


Fig. 1.13 : Selective Assembly Case - III

Let us consider that process capability of hole is 4 times the desired tolerance and process capability of shaft is not integer multiple of tolerance. Similar to the previous cases process capability of hole is divided into 4 subgroups by measuring each and every part. For shafts e.g. in subgroup 'b' shafts will be produced in two different settings. So in this case also each and every component must be inspected after manufacturing.

1.5 LIMITS, FITS AND TOLERANCES

As discussed earlier that due to process capabilities it is not possible to duplicate any part, so for assembly parts (either hole or shaft) should come within certain range of dimensions. This acceptable variation is called tolerance. Larger size is called upper limit and smaller size is called lower limit.

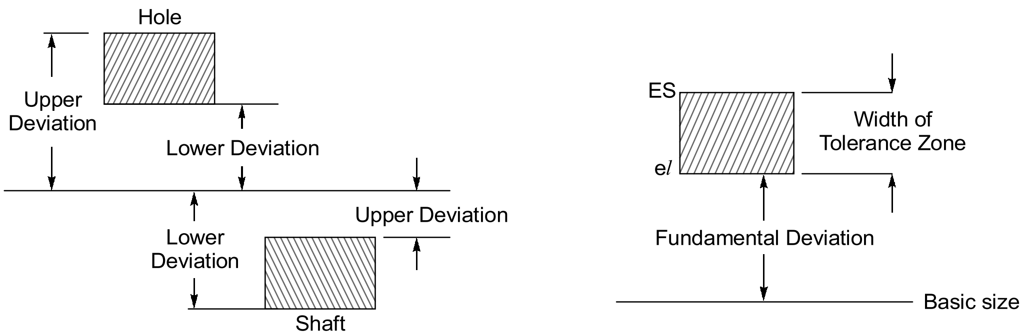


Fig. 1.13 : Tolerance and Fundamental Deviation

The distance from the basic size where the tolerance zone is situated is called fundamental deviation. The upper limit is called Ecart Superieur (ES) (a French name) and the lower limit is called Ecart Inferieur (EI). There are 25 different types of fundamental deviation as shown in Fig. 1.14.

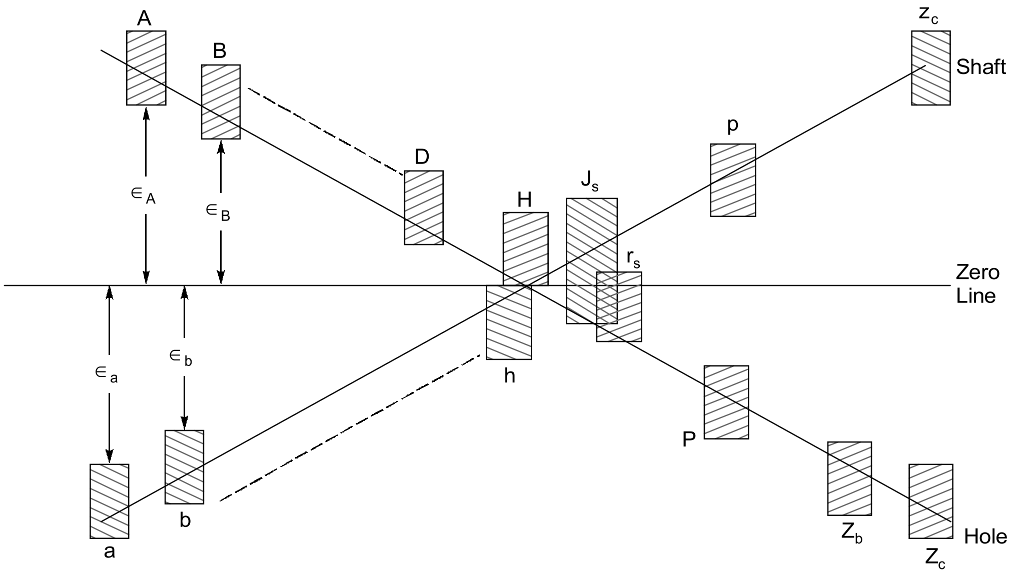
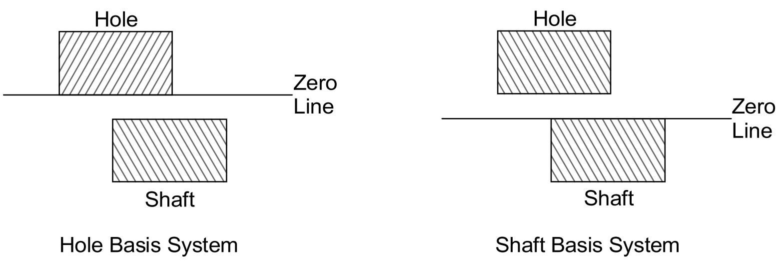


Fig. 1.14 : Variation of Different Fundamental Deviation types

Some of the alphabets are missing and some extra alphabets are there e.g. j_s, z_a, z_b and so on. Value of fundamental deviation for 'A' type hole will be same as 'a' type of shaft with a difference of sign and so on. All fundamental deviation has empirical formulas. An assembly is made up of a combination of hole and shaft. In this assembly if 'H' type of hole appears, the system is called **hole basis system** and if 'h' type of shaft is present it is called **shaft basis system**.



(i) **(ii)**

Fig. 1.15 : Hole and Shaft basis system

Fundamental deviation is also expressed as the distance between zero line and the limit closer to it i.e. either EI or e_s. Any information in capital letters refers to hole and any information given in smaller letters refers to shaft.

It is a common sense that large size shaft and small size hole will have more material. So these limits are called Maximum material limit and lower limits of shaft upper limit of hole is called Minimum material limits. A fit is defined as the relationship between hole and shaft before assembly.

Broadly there are three types of fits:

1. **Clearance fit** : If lower limit of hole is larger than the upper limit of shaft [as shown in Fig. 1.16 (i)]. It is considered as clearance fit.

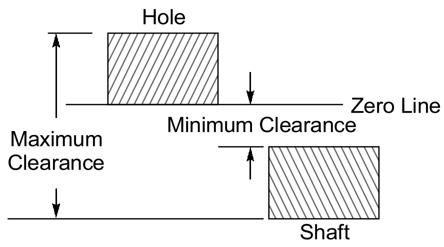


Fig. 1.16 (i) : Clearance Fit

2. **Transition fit :** This type of fit appears when there is overlap in the tolerance zones. Physically it indicates that when a part is selected randomly from hole lot and a shaft lot, some of the assemblies can be made without the application of force and for some of the assemblies force will be required.

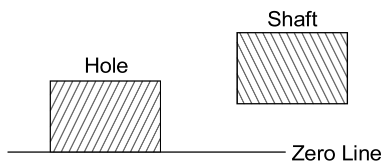


Fig. 1.16 (ii) : Transition Fit

3. **Interference fit :** If maximum size of hole is smaller than the minimum size of shaft then force has to be applied to make the assembly. Such fits are called interference fits.

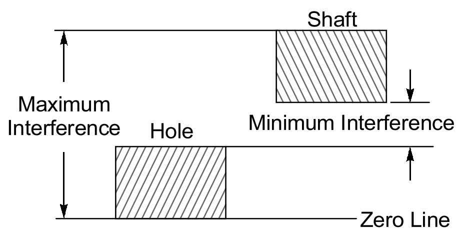


Fig : 1.16 (iii) : Interference fit

1.6 ALLOWANCE

It is defined as the difference between maximum material limit of hole and shaft. Depending upon the type of fit either it is equal minimum clearance or maximum interference.

1.6.1 Width of Tolerance Zone

There are three systems used in the world.

1. British Standard BS-4500-1969
2. International Standard ISO: 286-1988
3. Indian Standard IS-919

But the standards of fundamental deviation and width of tolerance zone are same. As discussed previously there are 25 different types of fundamental deviations that are standardized. For the tolerance width initial recommendation was to vary tolerance according to cubical expression.

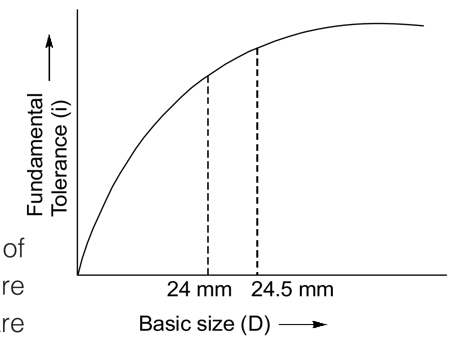
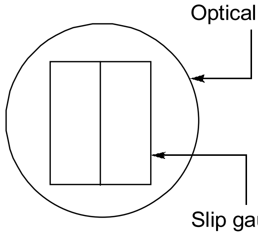


Fig : 1.17 : Fundamental Tolerance

PRACTICE QUESTIONS

1. A ring gauge is used to measure
(a) Outside diameter but not roundness
(b) Roundness but not outside diameter
(c) Both outside diameter and roundness
(d) Only external threads

2. Two slip gauges of 10 mm width measuring 1.000 mm and 1.002 mm a are Kept side by side in contact with each other lengthwise. An optical flat is kept resting on slip gauge as shown in the figure monochromatic light of wavelength 0.00058928 mm is used in the inspection. The total number of straight fringes that can be observed on both slip gauges is



(a) 2 (b) 6
(c) 8 (d) 13

3. What is the dominant direction of the tool marks or scratches in a surface texture having a directional quality called?
(a) Primary texture (b) Secondary texture
(c) Lay (d) Flaw

4. A component requires a hole which must be within the two limits of 25.03 mm and 25.04 mm which of the following statement about the reamer size are correct
(i) Reamer size cannot be below 25.03 mm
(ii) Reamer size cannot be above 25.04 mm
(iii) Reamer size can be 25.04 mm
(iv) Reamer size can be 25.03 mm
Select the correct answer using the code given below
(a) 1 and 3 (b) 1 and 2
(c) 3 and 4 (d) 2 and 4

5. GO and NO-GO plug gauges are to be designed for a hole $20.000^{+0.050}_{+0.010}$ mm gauge tolerance can be taken as 10% the hole tolerance following ISO design of gauge design, sizes of GO and NO – GO will be respectively
(a) 20.010 mm and 20.050 mm (b) 20.014 mm and 20.046 mm
(c) 20.006 mm and 20.054 mm (d) 20.014 mm and 20.054 mm

6. In strain gauge dynamometers the use of how many active gauge makes the dynamometers more effective
(a) Four (b) Three
(c) Two (d) One

7. Match **List-I** (Measuring device) with **List-II** (Parameter measured) and select the correct answers using the codes given below the list:

List-I		**List-II**	
A.	Diffraction grating flat Surface	**1.**	Small angular deviations
B.	Optical flat	**2.**	Online Measurement of Moving Parts
C.	Auto Collimators	**3.**	Measurement of Gear pitch
D.	Laser scan of micrometer	**4.**	Joining hydraraulic Piston rod for Agriculture Machinery
		5.	Taper of any surface

Codes:

	A	**B**	**C**	**D**
(a)	5	4	2	1
(b)	3	5	1	2
(c)	3	5	4	1
(d)	5	4	1	2

8. Consider the following statement A nomenclature $50H_8P_8$ denotes that

1. hole basic size is 50mm
2. it is shaft basis system
3. 8 indicates fundamental deviation

Which of the statements given above are correct

(a) 1,2 and 3 (b) 1 and 2 only

(c) 1 and 3 only (d) 1 only

9. The value of surface roughness 'h' obtained during turning operation at a feed f with a round nose tool having a radius 'r' is given as

(a) f/8r (b) $f^2/8r$

(c) $f^3/8r$ (d) $f^3/8r^2$

10. A threaded nut of M 16,ISO metric type, having 2 mm pitch with a pitch diameter of 14.701 mm is to be checked for its pitch diameter using two or three number of balls or rollers of following size

(a) rollers of 2 mm φ (b) rollers of 1.155 mm φ

(c) balls of 2 mm φ (d) balls of 1.155 mm φ

11. which one of the following is a clearance fit

(a) $\phi\ H50^{+0.015}_{+0.005}\ h50^{-0.010}_{+0.000}$ (b) $\phi\ H50^{+0.015}_{+0.010}\ h50^{+0.025}_{+0.015}$

(c) $\phi\ H50^{-0.015}_{+0.000}\ h50^{+0.025}_{+0.005}$ (d) $H50^{-0.010}_{-0.000}\ h50^{+0.030}_{+0.005}$

12. In tolerance specification 25 D 6 the letter D represents

(a) garage of tolerance (b) upper deviation

(c) lower deviation (d) type of fit

13. what symbol is used to indicate surface roughness

(a) = (b) $\sqrt{\ }$

(c) 0.1 (d) ∇

ANSWERS

METROLOGY

1. (c)	**2.** (d)	**3.** (c)	**4.** (b)	**5.** (d)	**6.** (b)	**7.** (b)
8. (d)	**9.** (b)	**10.** (b)	**11.** (a)	**12.** (c)	**13.** (d)	**14.** (c)
15. (d)	**16.** (c)	**17.** (b)	**18.** (a)	**19.** (d)	**20.** (a)	**21.** (b)
22. (a)	**23.** (a)	**24.** (c)	**25.** (d)	**26.** (b)	**27.** (c)	**28.** (b)
29. (c)	**30.** (a)	**31.** (c)	**32.** (d)	**33.** (a)	**34.** (b)	**35.** (c)
36. (b)	**37.** (b)	**38.** (c)	**39.** (a)	**40.** (d)	**41.** (c)	**42.** (d)
43. (c)	**44.** (d)	**45.** (c)	**46.** (a)	**47.** (b)	**48.** (b)	**49.** (c)
50. (c)	**51.** (c)	**52.** (b)	**53.** (b)	**54.** (d)	**55.** (93.3)	