MODULE 2

2.1 LIMITS FITS AND TOLERANCES

Product Design for Manufacturing

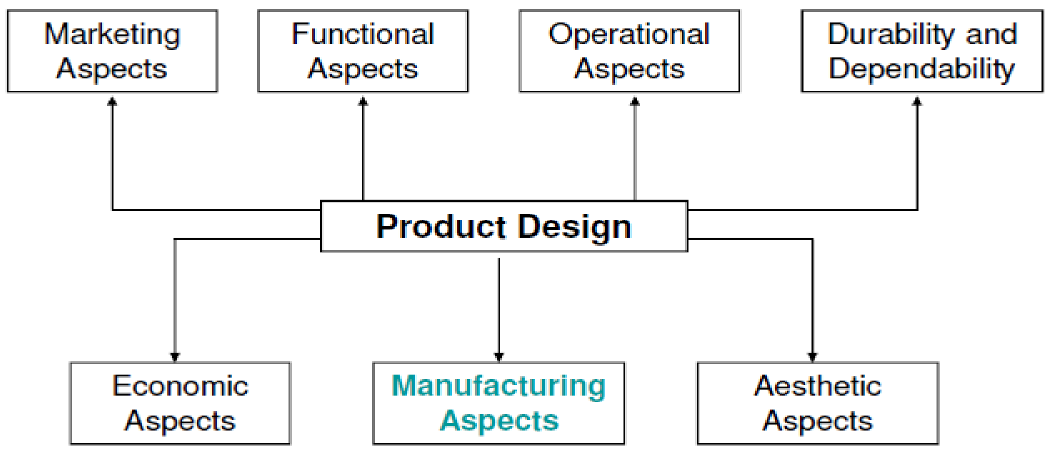


Fig. 1 Typical Stages in a Product Life Cycle

Role of Metrology in Design for Manufacturing

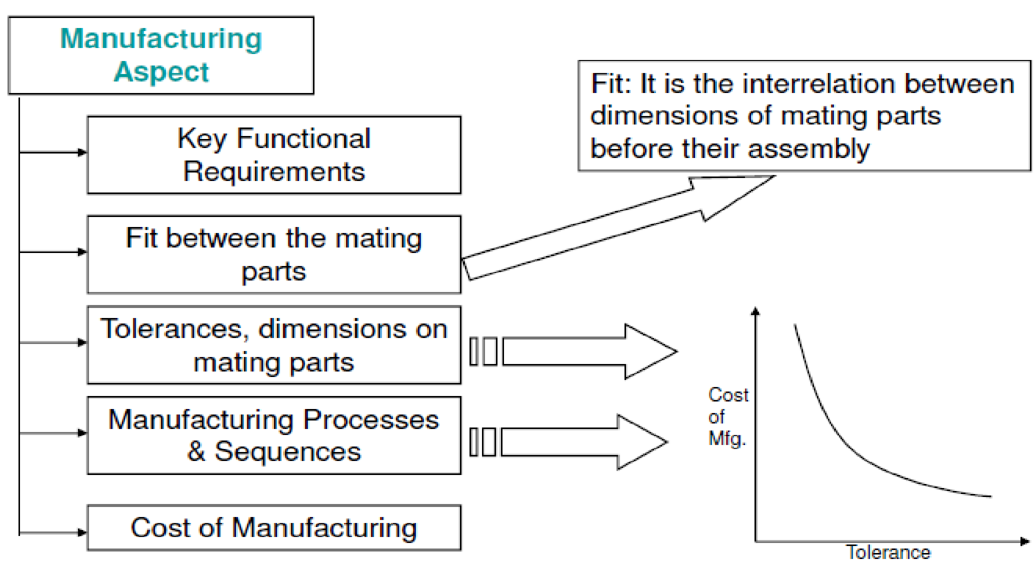


Fig. 2 Implications of Manufacturing aspects

2.2 Interchangeability of Parts and Selective Assembly

Back before the Industrial Revolution machines were manufactured independently of one another. One engineer might make the whole machine. If a part broke on a machine it would have to be manufactured again to suit the machine in question. It was not possible to use the same part from another machine. Screws and nuts were manufactured to suit the machinist and their use. Standardization had not yet arrived.

During the Industrial Revolution a new concept in manufacturing was developed. Parts were manufactured by individuals and the individual stuck to making that part. Then the whole machine was assembled from these parts. Now that the parts were the same, if a part broke in a machine it could be replaced by the same part from another machine. This concept led to what we now call **Interchangeability of Parts**.

Interchangeability of Parts and other inventions around the same time revolutionized mass manufacture and reliability of machines. A machine could have spares at the ready that the owner new would work. If a screw or nut broke, another screw or nut of the same dimensions could be easily obtained. It also ensured that machinists became more specialized and therefore more accurate as their skills were honed in a specific direction as opposed to needing to have an overall knowledge.

Selective Assembly was the next step in the evolution of improved assembly manufacturing. A machinist would produce a large number of parts with a low tolerance. A mating part would be produced in the same numbers and to the same tolerance by another machinist. Each machinist would then grade the parts that they manufactured to similar higher tolerances. The parts could then be assembled by taking parts from the same grade and assembling them.

Selective Assembly has a number of advantages over earlier manufacturing methods. There are a larger number of acceptable parts as original tolerances are greater. This in turn allows the manufacture of cheaper parts as less will be consigned to the waste bin.

Selective Assembly assures better and more accurate assembly of parts by insuring closer tolerances between the mating parts.

2.3 Systems of Limits and Fits

2.3.1 Limits

When machining, it is impossible to manufacture a number of pieces to an exact measurement. There will always be some difference in size. As a result Limits are set. This means that what the machinist manufactures can differ from the proper size by the small amount stated by the Limits, and still be able to be used.

The required size of the component, before the Limits are set, is called the **Basic Size** or **Nominal Size**. Then the **Upper Limit** and the **Lower Limit** are set.

The Limits are the maximum and minimum sizes allowable.

E.g. 22.00 mm …. Nominal size

22.02 mm… upper limit

21.97 mm…. lower limit

To get the :

Upper Deviation ---- Subtract the Nominal Size from the Upper Limit. i.e. 0.02 mm
Lower Deviation ---- Subtract the Lower Limit from the Nominal Size. i.e. 0.03 mm

Limits are usually written in this way: $22.00^{+0.02}_{-0.03}$

These Limits tell the manufacturer that the component can be any size between 22.02mm and 21.97mm.

2.3.2 Tolerance

The Tolerance is the difference between the Upper Limit and the Lower Limit. i.e. 0.05 mm in this case.

The Tolerance is the total amount by which the size of the component can differ from the Nominal Size.

A Tolerance is said to be **Bilateral** if it is spread over both sides of the Nominal Size. The above example is an example of a Bilateral Tolerance.

A Tolerance is said to be **Unilateral** if it is only on one side of the Nominal Size. E.g. $22.00^{+0.02}_{0.00}$

These Limits tell the manufacturer that the component can be any size between 22.00mm and 22.02mm.

2.3.3 Types of Fit

In any machine, parts must fit together in certain ways in order to operate. An axle must be able to rotate in a bearing, but the bearing itself must be fixed into it's housing. The Fit is determined by the size of the mating parts. **Allowance** is what determines the type of Fit.

There are **3** Types of Fits:

- Clearance Fit
- Transition Fit
- Interference Fit

Clearance Fit

In the case of a Clearance fit, the shaft is always smaller than the hole.
eg. Axle in a bearing, the axle must be free to rotate without friction.

Transition Fit

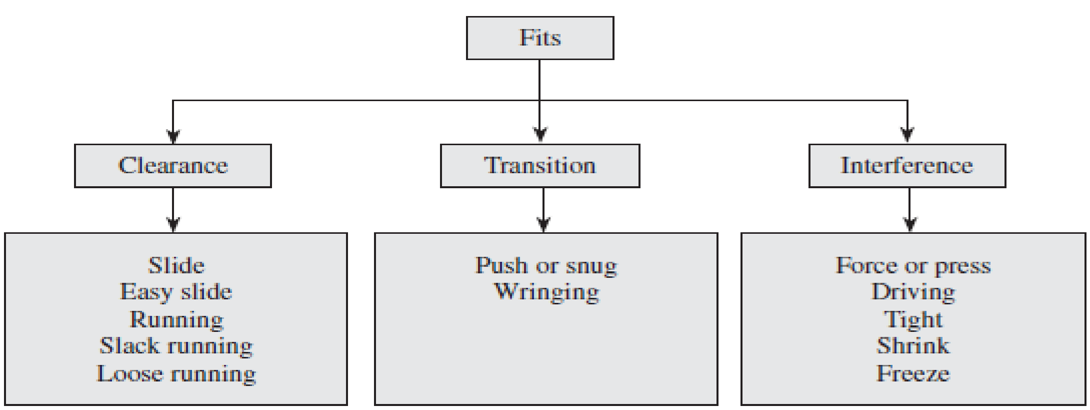
With a Transition Fit some shafts may be a little smaller than the hole and some may be a little larger.
eg. The lid of a pen. The lid must fit on securely but not be too difficult to remove. This is a push fit.

Interference Fit

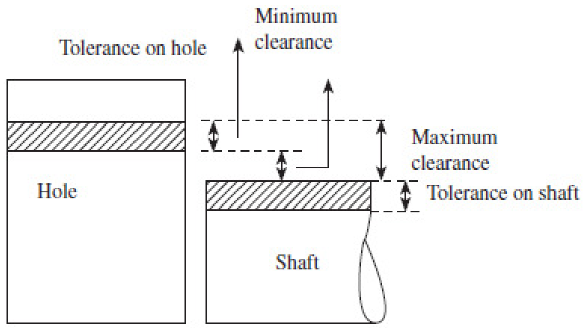
In the case of an Interference Fit, the shaft is always larger than the hole.
eg. Bearing in a chassis. The bearing must not rotate in the chassis. This is a force fit.

In a clearance fit, minimum clearance is the difference between minimum size of the hole, that is, low limit of the hole (LLH), and maximum size of the shaft, that is, high limit of the shaft (HLS), before assembly. In a transition or a clearance fit, maximum clearance is the arithmetical difference between the maximum size of the hole, that is, high limit of the hole (HLH), and the minimum size of the shaft, that is, low limit of the shaft (LLS), before assembly.

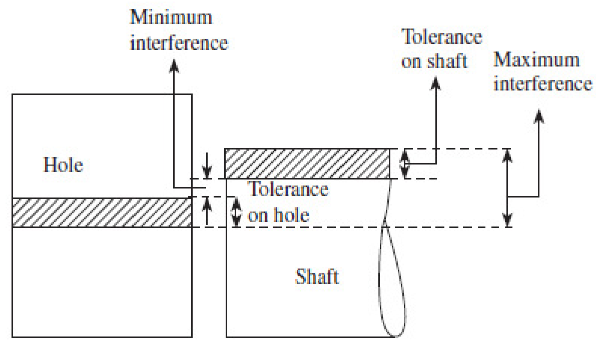
In an interference fit, minimum interference is the arithmetical difference between maximum size of the hole, that is, HLH, and minimum size of the shaft, that is, LLS, before assembly. In a transition or an interference fit, it is the arithmetical difference between minimum size of the hole, that is, LLH, and maximum size of the shaft, that is, HLS, before assembly. Thus, in order to find out the type of fit, one needs to determine HLH − LLS and LLH − HLS. If both the differences are positive, the fit obtained is a clearance fit, and if negative, it is an interference fit. If one difference is positive and the other is negative, then it is a transition fit.



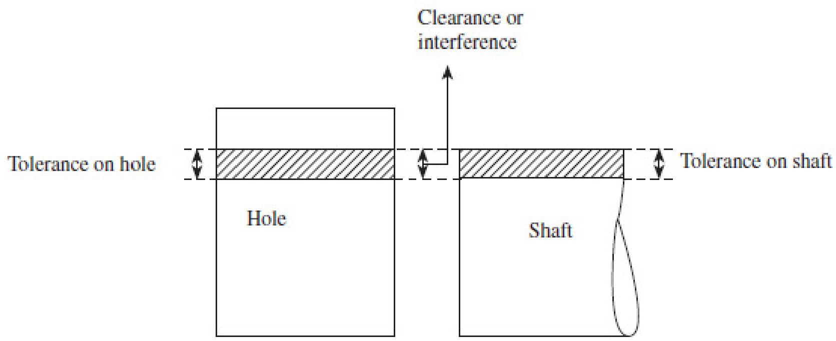
Detailed classification of fits



Clearance fit



Interference fit



Transition fit

2.3.4 Allowance

An allowance is the intentional difference between the maximum material limits, that is, LLH and HLS (minimum clearance or maximum interference) of the two mating parts. It is the prescribed difference between the dimensions of the mating parts to obtain the desired type of fit. Allowance may be positive or negative. Positive allowance indicates a clearance fit, and an interference fit is indicated by a negative allowance.

Allowance = LLH – HLS

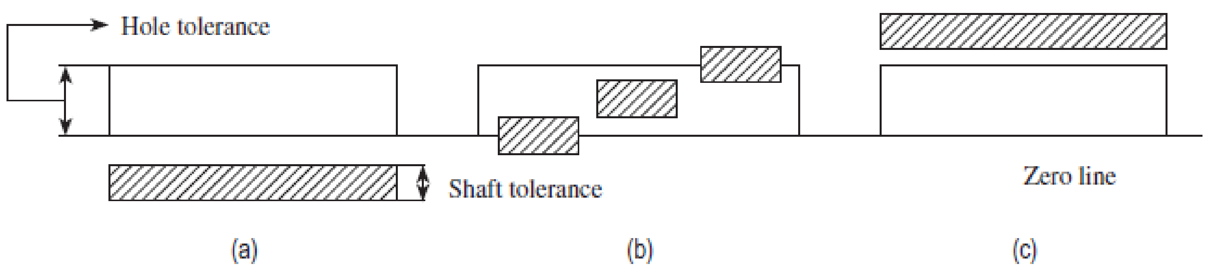
2.4 Hole Basis and Shaft Basis Systems

To obtain the desired class of fits, either the size of the hole or the size of the shaft must vary. Two types of systems are used to represent the three basic types of fits, namely clearance, interference, and transition fits. They are (a) hole basis system and (b) shaft basis system.

Although both systems are the same, hole basis system is generally preferred in view of the functional properties.

The Hole Basis System

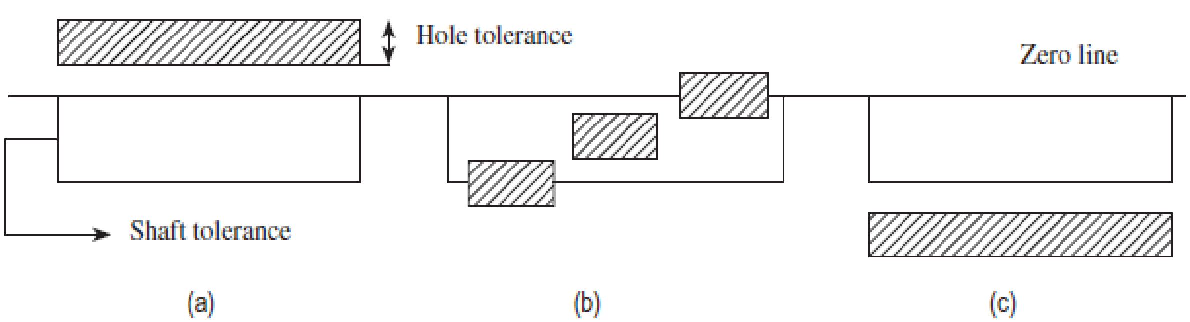
In this system the holes are drilled to a specific size and the size of shaft varies. Here, the lower deviation of hole is zero, i.e, the lower limit of hole is the same as the basic size. This is the preferred system as drills and reamers come in standard sizes and it is relatively easy to modify the size of a shaft.



Hole basis system (a) Clearance fit (b) Transition fit (c) Interference fit

The Shaft Basis System

In this system the shaft has a fixed size and the holes are varied to suit the type of fit necessary. Here, the upper deviation of shaft is zero, that is, the high limit of hole (HLH) equals the basic size. This is a relatively expensive system as a wide range of drills and reamers are required.



Shaft basis system (a) Clearance fit (b) Transition fit (c) Interference fit

2.5 General Terminology

The following are the commonly used terms in the system of limits and fits.

Basic size This is the size in relation to which all limits of size are derived. Basic or nominal size is defined as the size based on which the dimensional deviations are given. This is, in general, the same for both components.

Limits of size These are the maximum and minimum permissible sizes acceptable for a specific dimension. The operator is expected to manufacture the component within these limits. The maximum limit of size is the greater of the two limits of size, whereas the minimum limit of size is the smaller of the two.

Tolerance This is the total permissible variation in the size of a dimension, that is, the difference between the maximum and minimum limits of size. It is always positive.

Allowance It is the intentional difference between the LLH and HLS. An allowance may be either positive or negative.

Allowance = LLH – HLS

Grade This is an indication of the tolerance magnitude; the lower the grade, the finer the tolerance.

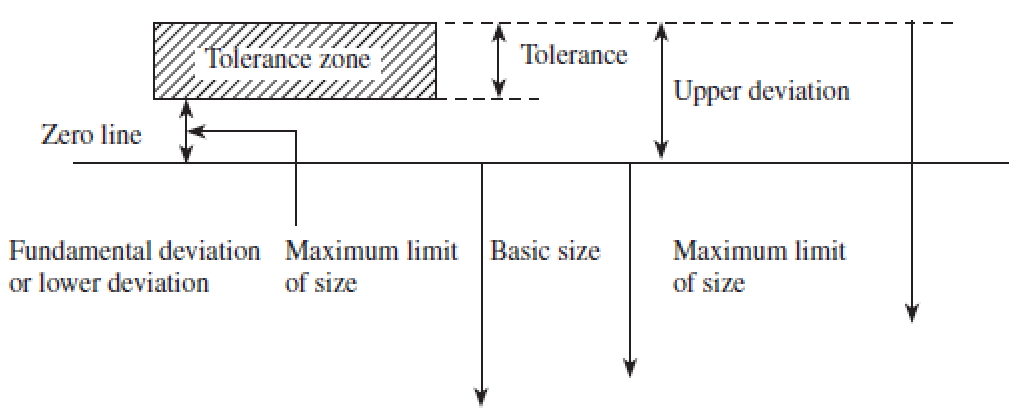
Deviation It is the algebraic difference between a size and its corresponding basic size. It may be positive, negative, or zero.

Upper deviation It is the algebraic difference between the maximum limit of size and its corresponding basic size. This is designated as 'ES' for a hole and as 'es' for a shaft.

Lower deviation It is the algebraic difference between the minimum limit of size and its corresponding basic size. This is designated as 'EI' for a hole and as 'ei' for a shaft.

Actual deviation It is the algebraic difference between the actual size and its corresponding basic size.

Fundamental deviation It is the *minimum* difference between the size of a component and its basic size. This is identical to the upper deviation for shafts and lower deviation for holes. It is the closest deviation to the basic size. The fundamental deviation for holes are designated by capital letters, that is, A, B, C, …, H, …, ZC, whereas those for shafts are designated by small letters, that is, a, b, c…, h…, zc. The relationship between fundamental, upper, and lower deviations is schematically represented in Figure below.



Relationship between fundamental, upper, and lower deviations

Zero line This line is also known as the line of zero deviation. The convention is to draw the zero line horizontally with positive deviations represented above and negative deviations indicated below. The zero line represents the basic size in the graphical representation.

Shaft and hole These terms are used to designate all the external and internal features of any shape and not necessarily cylindrical.

Fit It is the relationship that exists between two mating parts, a hole and a shaft, with respect to their dimensional difference before assembly.

Maximum metal condition This is the maximum limit of an external feature; for example, a shaft manufactured to its high limits will contain the maximum amount of metal. It is also the minimum limit of an internal feature; for example, a component that has a hole bored in it to its lower limit of size will have the minimum amount of metal removed and remain in its maximum metal condition, (i.e., this condition corresponds to either the largest shaft or the smallest hole). This is also referred to as the GO limit.

Least metal condition This is the minimum limit of an external feature; for example, a shaft will contain minimum amount of material, when manufactured to its low limits. It is also the maximum limit of an internal feature; for example, a component will have the maximum amount of metal removed when a hole is bored in it to its higher limit of size, this condition corresponds to either the smallest shaft or the largest hole. This is also referred to as the NO GO limit.

Tolerance zone The tolerance that is bound by the two limits of size of the component is called the tolerance zone. It refers to the relationship of tolerance to basic size.

International tolerance grade (IT) Tolerance grades are an indication of the degree of accuracy of the manufacture. Standard tolerance grades are designated by the letter IT followed by a number, for example, IT7. These are a set of tolerances that varies according to the basic size and provides a uniform level of accuracy within the grade.

Tolerance class It is designated by the letter(s) representing the fundamental deviation followed by the number representing the standard tolerance grade. When the tolerance grade is associated with letter(s) representing a fundamental deviation to form a tolerance class, the letters IT are omitted and the class is represented as H8, f7, etc.

Tolerance symbols These are used to specify the tolerance and fits for mating components. For example, in 40 H8f7, the number 40 indicates the basic size in millimeters; capital letter H indicates the fundamental deviation for the hole; and lower-case letter f indicates the shaft. The numbers following the letters indicate corresponding IT grades.

2.6 LIMIT GAUGES

- A limit gauge is not a measuring gauge. Just they are used as inspecting gauges.
- Limit gauge are mainly used for checking for cylindrical holes of identical components with a large numbers in mass production.
- This gives the information about the products which may be either within the prescribed limit or not.

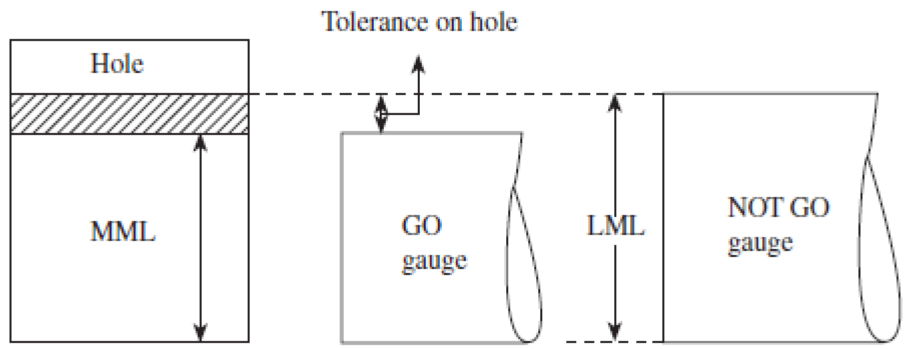
2.6.1 Purpose of using limit gauges

- Components are manufactured as per the specified tolerance limits, upper limit and lower limit. The dimension of each component should be within this upper and lower limit.
- If the dimensions are outside these limits, the components will be rejected.
- If we use any measuring instruments to check these dimensions, the process will consume more time. Still we are not interested in knowing the amount of error in dimensions.
- It is just enough whether the size of the component is within the prescribed limits or not. For this purpose, we can make use of gauges known as limit gauges.

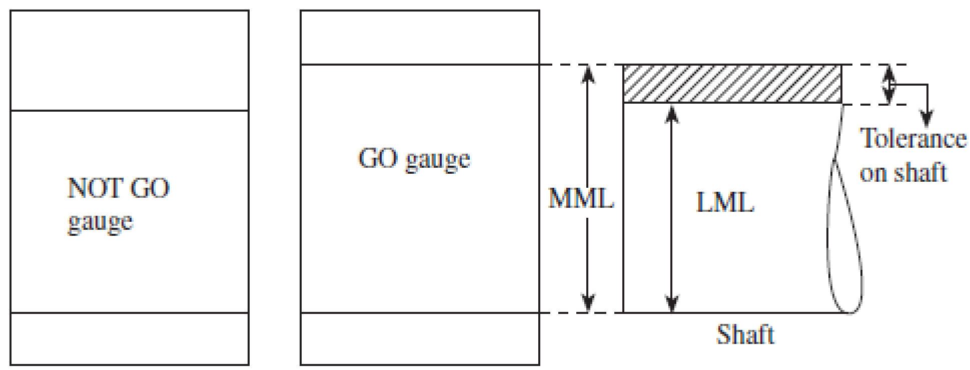
2.7 **GO and NO-GO GAUGES**

The gauges required to check the dimensions of the components correspond to two sizes conforming to the maximum and minimum limits of the components. They are called GO gauges or NO GO or NOT GO gauges which correspond, respectively, to the MML and LML of the component, as shown in Figures. MML is the lower limit of a hole and higher limit of the shaft and LML corresponds to the higher limit of a hole and lower limit of the shaft. The GO gauge manufactured to the maximum limit will assemble with the mating (opposed) part, whereas the NOT GO gauge corresponding to the low limit will not, hence the names GO and NOT GO gauges, respectively.

For gauging the MMLs of the mating parts, GO gauges are used. Whenever the components are gauged for their MMLs, if the GO gauges fail to assemble during inspection, the components should not be accepted under any circumstances. The minimum limits in a clearance fit of a product are not so critical because even if they exceed the specified limits and the NOT GO gauge assembles, its acceptance may result in functional degradation and because of the reduced quality the useful life of the product may get affected. Hence, it becomes essential that more care is taken especially when GO gauges are used, when compared to NOT GO gauges during inspection.



Metal limits for hole gauging



Metal limits for shaft gauging

2.8 CLASSIFICATION OF GAUGES

The detailed classification of the gauges is as follows:

1. Plain gauges

(a) According to their type:

(i) Standard gauges

(ii) Limit gauges

(b) According to their purpose:

(i) Workshop

(ii) Inspection

(iii) Reference, or master, or control gauges

(c) According to the form of the tested surface:

(i) Plug gauges for checking holes

(ii) Snap and ring gauges for checking shafts

(d) According to their design:

(i) Single- and double-limit gauges

(ii) Single- and double-ended gauges

(iii) Fixed and adjustable gauges

2. Adjustable-type gap gauges

3. Miscellaneous gauges

(a) Combined-limit gauges

(b) Taper gauges

(c) Position gauges

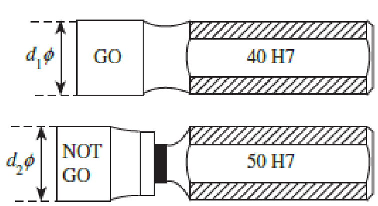
(d) Receiver gauges

(e) Contour gauges

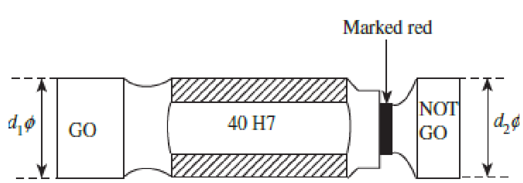
(f) Profile gauges

2.8.1 Plug Gauge

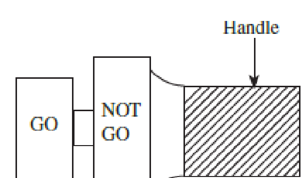
A plug gauge is a cylindrical type of gauge, used to check the accuracy of holes. The plug gauge checks whether the whole diameter is within specified tolerance or not. The 'Go' plug gauge is the size of the low limit of the hole while the 'Not-Go' plug gauge corresponds to the high limit of the hole.



Single-ended GO and NOT GO plug gauges



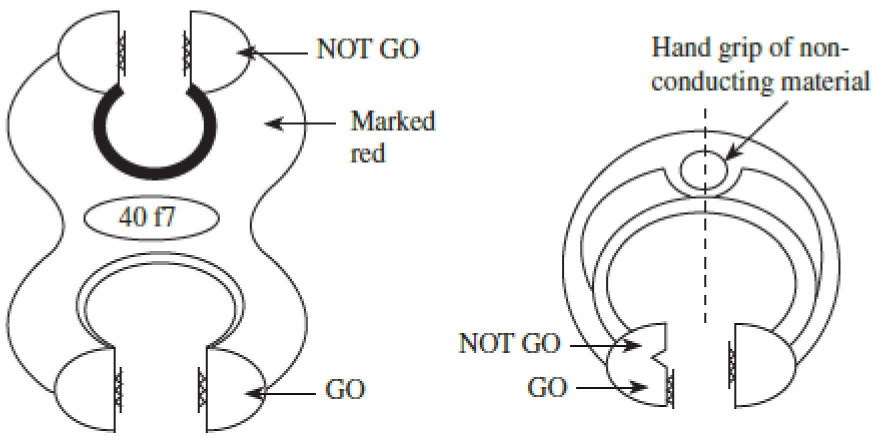
Double-ended plug gauges



Progressive plug gauges

2.8.2 Snap Gauge

A snap gauge is a U-Shaped frame having jaws, used to check the accuracy of shafts and male members. The snap gauge checks whether the shaft diameter is within specified tolerances or not. The 'Go' snap gauge is the size of the high (maximum) limit of the shaft while the 'Not-Go' snap gauge corresponds to the low (minimum) limit of the shaft.



Double-ended snap gauge Progressive snap gauge

2.9 TAYLOR'S PRINCIPLE OF GAUGING

Taylor's principle states that the GO gauge is designed to check maximum metal conditions, that is, LLH and HLS. It should also simultaneously check as many related dimensions, such as roundness, size, and location, as possible.

The NOT GO gauge is designed to check minimum metal conditions, that is, HLH and LLS. It should check only one dimension at a time. Thus, a separate NOT GO gauge is required for each individual dimension. During inspection, the GO side of the gauge should enter the hole or just pass over the shaft under the weight of the gauge without using undue force. The NOT GO side should not enter or pass. The basic or nominal size of the GO side of the gauge conforms to the LLH or HLS, since it is designed to check maximum metal conditions. In contrast, the basic or nominal size of the NOT GO gauge corresponds to HLH or LLS, as it is designed to check minimum metal conditions.

It can be seen from Fig. A that the size of the GO plug gauge corresponds to the LLH and the NOT GO plug gauge to the HLH. Conversely, it can be observed from Fig. B that the GO snap gauge represents the HLS, whereas the NOT GO snap gauge represents the LLS.

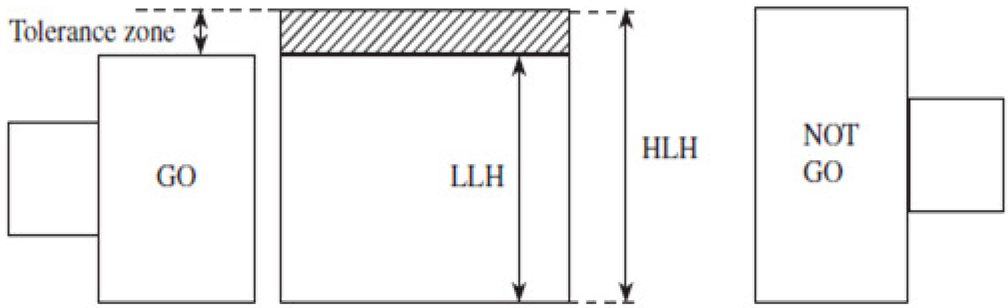


Fig. A GO and NOT GO limits of plug gauge

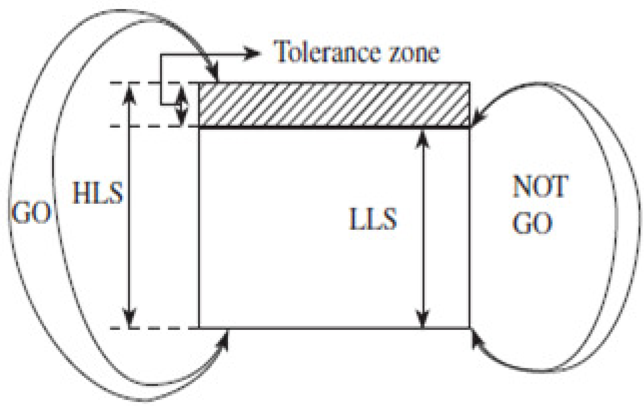


Fig. B GO and NOT GO limits of snap gauge

2.10 GAUGE TOLERANCE (GAUGE MAKER'S TOLERANCE)

Gauges, like any other component, cannot be manufactured to their exact size or dimensions. In order to accommodate these dimensional variations, which arise due to the limitations of the manufacturing process, skill of the operator, etc., some tolerance must be allowed in the manufacture of gauges. Thus, the tolerance that is allowed in the manufacture of gauges is termed gauge maker's tolerance or simply gauge tolerance.

Logically, gauge tolerance should be kept as minimum as possible; however, this increases the gauge manufacturing cost. There is no universally accepted policy for deciding the amount of tolerance to be provided on gauges. The normal practice is to take gauge tolerance as 10% of the work tolerance.

2.11 WEAR ALLOWANCE

According to Taylor's principle, during inspection the NOT GO side should not enter or pass. The NOT GO gauge seldom engages fully with the work and therefore does not undergo any wear. Hence, there is no need to provide an allowance for wear Taylor's principle also states that the GO side of the gauge should enter the hole or just pass over the shaft under the weight of the gauge without using undue force. During inspection, the measuring surfaces of the gauge constantly rub against the mating surfaces of the work piece.

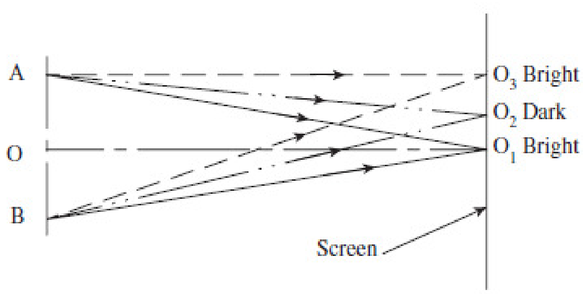
Therefore, the GO gauges suffer wear on the measuring surfaces and thus lose their initial dimension. Hence, wear allowance is provided for GO gauges to extend their service life. As a consequence of this wear, the size of the GO plug gauge decreases while that of the ring or gap gauge increases. The wear allowance provided for the GO gauges are added in a direction opposite to wear. This allowance is added in for a plug gauge while subtracted for a ring or gap gauge. A wear allowance of 10% of gauge tolerance is widely accepted in industries. If the work tolerance of a component is less than 0.1 mm, no wear allowance on gauges is provided for that component, since a wear allowance of less than 0.001 mm will not have any practical effect on the gauges.

2.15 OPTICAL MEASUREMENT

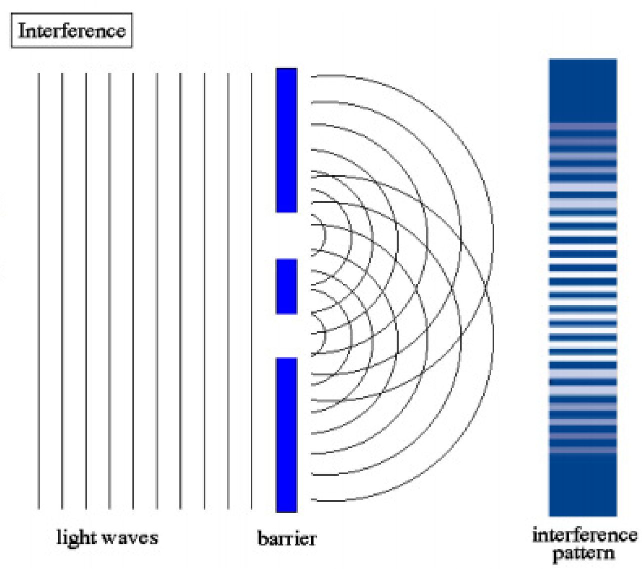
Optical measurement provides a simple, easy, accurate and reliable means for carrying out inspection and measurements in the industry .The projected image should be clear, sharp and dimensionally accurate. Application of interference of light is extreme interest in metrology. Lasers are also being increasingly used in interferometers for precision measurement. Optical magnification is one of the most widely used techniques in metrology. The primary requirement is visual magnification of small objects to a high degree with the additional provision for taking measurement.

2. 15.1 PRINCIPLE OF INTERFERENCE

When two light waves interact with each other, the wave effect leads to the phenomenon called interference of light. The instruments designed to measure with interference are known as interferometers. Let us consider two monochromatic light rays from the same light source, but originating from two point sources A and B. The distances AO_1 and BO_1 are equal, the two rays are in phase, and results in maximum illumination at point O_1. On the other hand, at point O_2, the distance BO_2 is longer than the distance AO_2.Therefore, by the time the two rays arrive at the point O_2, they are out of phase Suppose the phase difference $\delta = \lambda / 2$, where λ is the wave length of light, then it leads to complete interference and formation of a dark spot. This process repeats on either side of O_1 on the screen, resulting in the formation of alternate dark and bright areas.



Formation of fringes

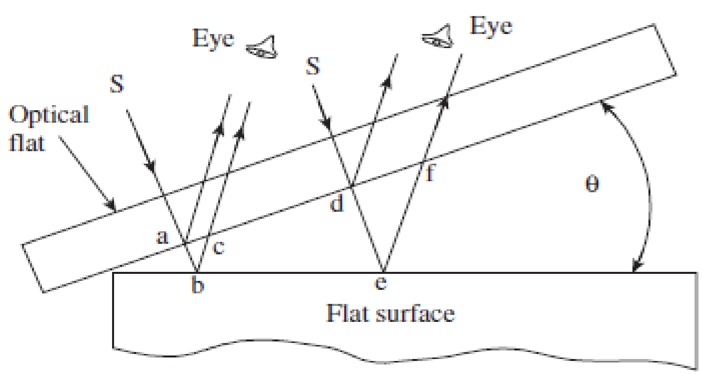


The phenomenon of interference is made use of for carrying out precise measurements of very small linear dimensions, and the measurement technique is popularly known as interferometry. This technique is used in a variety of metrological applications such as inspection of machine parts for straightness, parallelism, flatness, measurement of very small diameters, and so on. The instrument used for making measurements using interferometry technique is called an interferometer.

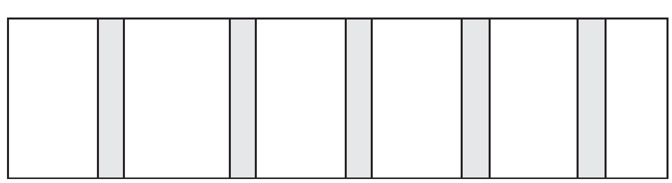
2.16 OPTICAL FLATS

An optical flat is a disk of high-quality glass or quartz. The surface of the disk is ground and lapped to a high degree of flatness. Sizes of optical flats vary from 25 to 300 mm in diameter, with a thickness ranging from 25 to 50 mm. When an optical flat is laid over a flat reflecting surface, it orients at a small angle θ, due to the presence of an air cushion between the two surfaces. Consider a ray of light from a monochromatic light source falling on the upper surface of the optical flat at an angle. This light ray is partially reflected at point 'a'. The remaining part of the light ray passes through the transparent glass material across the air gap and is reflected at point 'b' on the flat work surface. The two reflected components of the light ray are collected and recombined by the eye, having travelled two different paths whose length differs by an amount 'abc'. If 'abc' = $\lambda/2$, where λ is the wavelength of the monochromatic light source, then the condition for complete interference has been satisfied.

Next, consider another light ray from the same source falling on the optical flat at a small distance from the first one. This ray gets reflected at points'd' and 'e'. If the length 'def' equals $3\lambda/2$, then total interference occurs again and a similar fringe is seen by the observer. However, at an intermediate point between the two fringes, the path difference between two reflected portions of the light ray will be an even number of half wavelengths. Thus, the two components of light will be in phase, and a light band will be seen at this point. When light from a monochromatic light source is made to fall on an optical flat, which is oriented at a very small angle with respect to a flat reflecting surface, a band of alternate light and dark patches is seen by the eye. In case of a perfectly flat surface, the fringe pattern is regular, parallel, and uniformly spaced. Any deviation from this pattern is a measure of error in the flatness of the surface being measured.



Fringe formation in an optical flat



Interference fringes

2.16.1 Comparative Measurement with Optical Flats

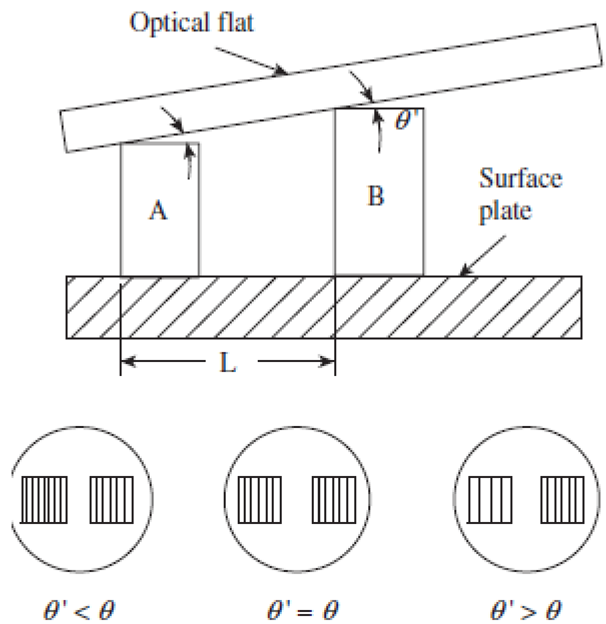
One of the obvious uses of an optical flat is to check the heights of slip gauge blocks. The slip gauge that is to be checked is kept alongside the reference gauge on a flat table. An optical flat is then placed on top of both gauges, A monochromatic light source is used and the fringe patterns are observed with the help of a magnifying glass. It can be seen from the figure that the optical flat makes inclinations of θ and θ' with the top surfaces of the two slip gauges. Ideally, the two angles should be the same.

However, in most cases, the angles are different by virtue of wear and tear of the surface of the slip gauge that is being inspected. This can easily be seen by looking at the fringe pattern that is formed on the two gauges, as seen from the magnified images. The fringes seen on both the gauges are parallel and same in number if both the surfaces are perfectly flat; otherwise, the number of fringes formed on the two gauges differs, based on the relationship between θ and θ'.

Now, let the number of fringes on the reference block be N over a width of l mm. If the distance between the two slip gauges is L and λ is the wavelength of the monochromatic light source, then the difference in height h is given by the following relation:

$h = \pi LN/2l$

This simple procedure can be employed to measure very small height differences in the range of 0.01–0.1 mm. The accuracy of this method depends on the accuracy of the surface plate and condition of the surfaces of the specimen on which the optical flat is resting.



Height measurement using an optical flat

2.17 INTERFEROMETERS

Interferometers are optical instruments that are used for very small linear measurements. They are used for verifying the accuracy of slip gauges and measuring flatness errors

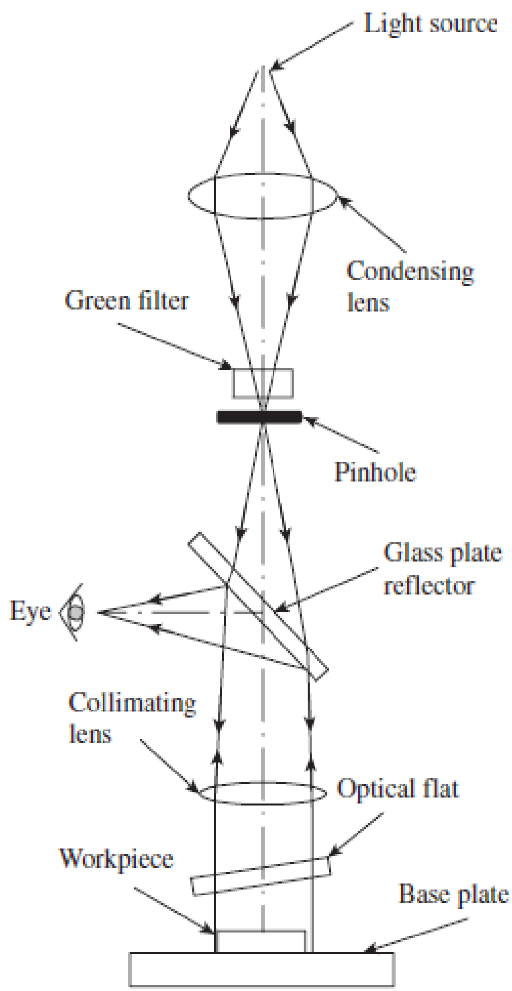
2.17.1 NPL Flatness Interferometer

This interferometer was designed and developed by the National Physical Laboratory of the United Kingdom. It comprises a simple optical system, which provides a sharp image of the fringes so that it is convenient for the user to view them. The light from a mercury vapour lam is condensed and passed through a green filter, resulting in a green monochromatic light source. The light will now pass through a pinhole, giving an intense point source of monochromatic light. The pinhole is positioned such that it is in the focal plane of a collimating lens. Therefore, the collimating lens projects a parallel beam of light onto the face of the gauge to be tested via an optical flat. This results in the formation of interference fringes. The light beam, which carries an image of the fringes, is reflected back and directed by 90° using a glass plate reflector.

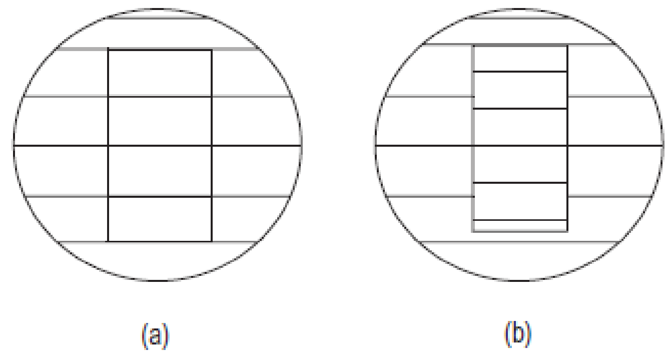
The entire optical system is enclosed in a metal or fiber glass body. It is provided with adjustments to vary the angle of the optical flat, which is mounted on an adjustable tripod. In addition, the base plate is designed to be rotated so that the fringes can be oriented to the best advantage.

Figure.(a), illustrates the fringe pattern that is typically observed on the gauge surface as well as the base plate. In Fig. (a), the fringes are parallel and equal in number on the two surfaces. That is, the two surfaces are parallel, which means that the gauge surface is perfectly flat. On the other hand, in Fig. (b), the number of fringes is unequal and, since the base plate surface is ensured to be perfectly flat, the work piece surface has a flatness error.

Due to the flatness error, the optical flat makes unequal angles with the work piece and the base plate, resulting in an unequal number of fringes. Most of the times fringes will not be parallel lines, but will curve out in a particular fashion depending on the extent of wear and tear of the upper surface of the work piece. In such cases, the fringe pattern gives a clue about the nature and direction of wear.



Optical system of an NPL flatness interferometer



Example of fringe patterns (a) Equal fringes on parallel surfaces (b) Unequal fringes due to flatness error

2.17.2 Pitter–NPL Gauge Interferometer

This interferometer is used for determining actual lengths of slip gauges. Since the measurement calls for a high degree of accuracy and precision, the instrument should be used under highly controlled physical conditions. It is recommended that the system be maintained at an ambient temperature of 20 °C, and a barometric pressure of 760 mmHg with a water vapour pressure of 7 mm, and contain 0.33% by volume of carbon dioxide.

The optical system of the Pitter–NPL interferometer is shown in Figure. Light from a monochromatic source (the preferred light source is a cadmium lamp) is condensed by a condensing lens and focused onto an illuminating aperture. This provides a concentrated light source at the focal point of a collimating lens. Thus, a parallel beam of light falls on a constant deviation prism. This prism splits the incident light into light rays of different wavelengths and hence different colours. The user can select a desired colour by varying the angle of the reflecting faces of the prism relative to the plane of the base plate. The prism turns the light by 90° and directs it onto the optical flat. The optical flat can be positioned at a desired angle by means of a simple arrangement. The slip gauge that is to be checked is kept right below the optical flat on top of the highly flat surface of the base plate. The lower portion of the optical flat is coated with a film of aluminium, which transmits and reflects equal proportions of the incident light. The light is reflected from three surfaces, namely the surface of the optical flat, the upper surface of the slip gauge, and the surface of the base plate.

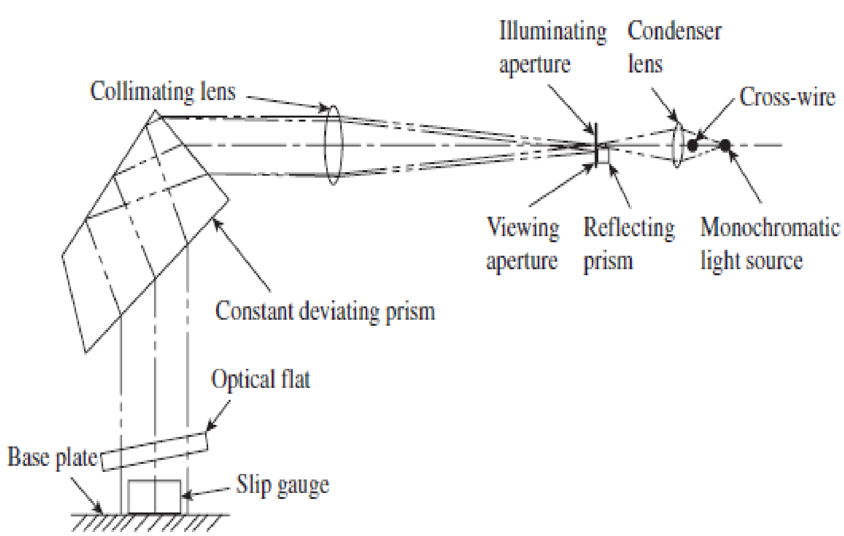
Light rays reflected from all the three surfaces pass through the optical system again; however, the axis is slightly deviated due to the inclination of the optical flat. This slightly shifted light is captured by another prism and turned by 90°, so that the fringe pattern can be observed and recorded by the user.

The typical fringe pattern observed is also shown in Figure. It can be seen that the two sets of fringes are displaced by an amount *a* with respect to each other. The value of '*a*' varies depending on the colour of the incident light. The displacement '*a*' is expressed as a fraction of the fringe spacing *b*, which is as follows:

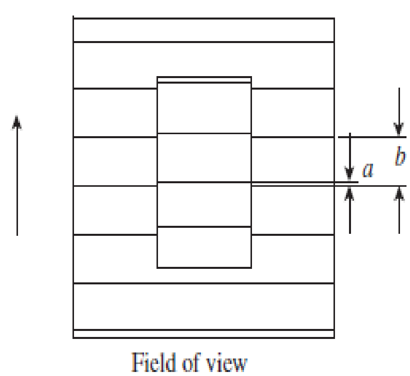
$f = a/b$

The height of the slip gauge will be equal to a whole number of half wavelengths, *n*, plus the fraction *a*/*b* of the half wavelengths of the radiation in which the fringes are observed.

Therefore, the height of the slip gauge, $H = n(\lambda/2) + (a/b) \times (\lambda/2)$, where *n* is the number of fringes on the slip gauge surface, λ is the wavelength of light, and *a*/*b* is the observed fraction.



Optical system of the Pitter–NPL gauge interferometer



Field of view of fringe pattern