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LECTURE NOTE

COURSE TITLE: PRODUCTION ENGINEERING II

COURSE CODE: MCE502

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Course contents: Specification and standardization: Interchangeable manufacture, preferred sizes, limits and fits. Fundamentals of measurement: length, standards, sources of error, angular measurements; comparators, autocollimator, indirect measurements, straightness and flatness testing. Surface finish. Fundamentals of gauge design. Screws threads, specification, tolerancing, gauging and measurements. Statistical methods of process control. Principles of planning and tools design. Industrial health and safety. Ergonomics. Elements of cleaner production and applications in mechanical engineering.

1.0 SPECIFICATION AND STANDARDIZATION

1.1 Specification

Specification is a detailed description of an item which must be detailed, exact and correct. It may be drawn up after the design drawings but before production of the item should take place.

The main aim of a designer is the functionality and aesthetic value of the item but the production engineer's main aim is to produce an item efficiently and most economically.

A specification should enable the item or part to be produced on the shop floor using the engineering design drawing indicating all features accurately and without any ambiguity to achieve the desired result.

1.2 Standardization

Standardization is a process which leads to the establishment of desirable criteria with respect to size, material and so on to which everyone can adhere to. If this is done, it is expected that the standard would meet all their requirements and enable them to manufacture and stock the minimum variety of parts. It is of economic advantage if designs make use of standard parts such as screws, splines, gears and so on that have been manufactured with standard cutting tools, inspected with standard gauges, stored and dispatched using standard containers. Though, there may be the need to use non –standard parts but the cost of such special parts would be more as compared to standard parts. Standards are available to engineers to cover dimensions, allowances and tolerances, specification of materials, properties of materials, machines, tools and gauges, methods of installations of engineering products and inspection. The application of standards affects quality and if the criteria which have been established in the standard are desirable, then the quality level should be enhanced.

1.3 Interchangeability

Interchangeability is a system which allows any component to be assembled correctly with any mating part or be substituted for another part both are chosen randomly. Some finished products, units or sub units of the same type could be fitted or be replaced without previous selection or without any work done on it.

Interchangeability can be realized by changing the materials of a component e.g. replacement of gears made of steel with ones made of teflon with the gears having the same geometrical dimensions.

Interchangeability in production occurs when some standardized components or parts are used in the assembly of a machine as specified in the drawing. Such a system makes it possible to assemble a machine or product within the shortest possible time and is thus economical. Interchangeability makes mass production of a component feasible and may reduce set-up time on machines. Instead of producing or manufacturing each part in a product, such part could be bought outright and assembled.

Interchangeability makes it possible to save cost, as some parts in a product have shorter life span and as such can be changed instead of buying the whole product. Imagine what happens if interchangeability is nil and one has a faulty bearings in a car.

1.4 Preferred Numbers and Sizes

Preferred numbers are a series of numbers which are selected for the purpose of standardization in preference to other numbers. This idea of preferred numbers was introduced by Col. Charles Reynard in 1870, and is sometimes referred to as Reynard's series. Reynard was faced with a simplification problem because he used 425 different sizes of cable in his army unit. He then suggested the use of geometric sizes as a basis of selection to standardize in order to reduce the range of series.

Table 1.1 Reynard's Series of Preferred Numbers

Series	Ratio	Steps Increase by
R5	$\sqrt[5]{10}$	60%
R10	$\sqrt[10]{10}$	25%
R20	$\sqrt[20]{10}$	12%
R40	$\sqrt[40]{10}$	6%
R80	$\sqrt[80]{10}$	3%

Standardizing organizations such as International Organization for Standardization (ISO), British Standards Institution (BSI) and American Standards Association (ASA) have issued standards based on the 'R' series

1.5 Limits and Fits

Due to the inevitable inaccuracy of manufacturing methods and the imperfections of workers, it is not possible to produce any part precisely to a given dimension but can only be produced between two limits namely maximum and minimum. Limits are defined as two extreme permissible sizes for any given dimension; the upper permissible size is called a HIGH LIMIT while the lower permissible size is called a LOW LIMIT. The difference between the high and low limits is the margin allowed for variations of workmanship and is called TOLERANCE.

If all the tolerance is allowed on one side of the nominal diameter (e.g. $25^{+0.002}_{+0.00}$), the system is said to be unilateral whilst if it is divided with some on either side of the nominal diameter (e.g. $25^{+0.002}_{-0.002}$), the system is bilateral. The bilateral system has paved way for unilateral system in modern ISO system. An interchangaeble system is generally called a limit system or a system of limits and fits. Dimensions should be given as large a tolerance as possible without jeopardizing the function of the part to reduce the cost of production as the tight the tolerance is the high the production cost.

Definitions

Nominal size: The size designation used for general identification. The nominal size of a shaft and a hole are the same.

Basic size: It is the size whose limit dimensions are specified using the upper and lower deviations. In case of a fit, the basic size of both connected elements must be the same.

It may also be stated to be the exact theoretical size of a part. The number of significant digits implies the accuracy of the dimension.

Design size: The ideal size for each component (shaft and hole) based upon a selected fit. The difference between the design size of the shaft and the design size of the hole is equal to the allowance of the fit. The design size of a part corresponds to the Maximum Material Condition (MMC). That is, the largest shaft permitted by the limits and the smallest hole. Emphasis is placed upon the design size in the writing of the actual limit dimension, so the design size is placed in the top position of the pair.

Tolerance: The tolerance of a size is defined as the difference between the upper and lower limit dimensions of the part. It is also the total amount by which a dimension is allowed to vary.
Standards for limits and fits state that tolerances are applied such that the hole size can only vary larger from design size and the shaft size smaller.

Basic hole system: Most common system for limit dimensions. In this system the design size of the hole is taken to be equivalent to the basic size for the pair (see above). This means that the lower (in size) limit of the hole dimension is equal to design size. The basic hole system is more frequently used since most hole generating devices are of fixed size (for example, drills, reams, etc.) When designing using purchased components with fixed outer diameters (bearings, bushings, etc.) a basic shaft system may be used.

Allowance: The allowance is the intended difference in the sizes of mating parts. This allowance may be: positive (indicated with a "+" symbol), which means there is intended clearance between parts; negative("-"), for intentional interference: or "zero allowance" if the two parts are intended to be the "same size".
In most design situations the nominal size of the combination is chosen through engineering analysis of the problem. A standard fit is then selected based upon function. The fit tables include short descriptions of the applications for the specific fits.

System of fits
Although there can be generally coupled parts without any tolerance zones, only two methods of coupling of holes and shafts are recommended due to constructional, technological and economic reasons, these are:
(i)Hole basis system
The desired clearances and interferences in the fit are achieved by combinations of various shaft tolerance zones with the hole tolerance zone "**H**". In this system of tolerances and fits, the lower deviation of the hole is always equal to zero.

(ii) Shaft basis system
The desired clearances and interferences in the fit are achieved by combinations of various hole tolerance zones with the shaft tolerance zone "**h**". In this system of tolerances and fits, the upper deviation of the hole is always equal to zero.

Classifications of Fit

Depending on the mutual position of tolerance zones of the coupled parts, 3 types of fit can be distinguished:

(A) Clearance fit

It is a fit that always enables a clearance between the hole and shaft in the coupling. The lower limit size of the hole is greater or at least equal to the upper limit size of the shaft.

(B) Transition fit

It is a fit where (depending on the actual sizes of the hole and shaft) both clearance and interference may occur in the coupling. Tolerance zones of the hole and shaft partly or completely interfere.

(C) Interference fit

It is a fit always ensuring some interference between the hole and shaft in the coupling. The upper limit size of the hole is smaller or at least equal to the lower limit size of the shaft.

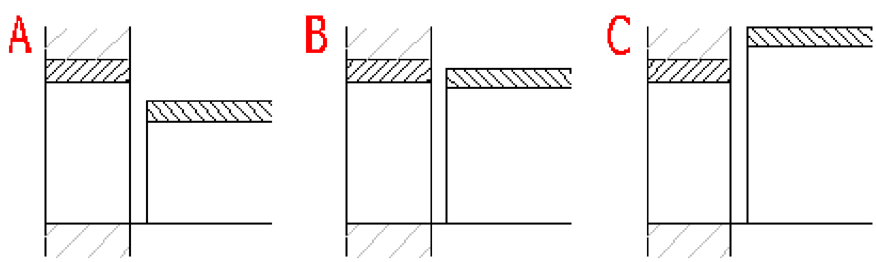


Figure 1.2: Classifications of Fits

2.0 FUNDAMENTAL OF MEASUREMENTS

2.1 Introduction

Measurement, control and certification are necessary to ascertain whether a part meet the required specifications or not. It is therefore essential that a production engineer know about the fundamentals of measurement.

Measurement is a process or experimental procedure through which the value of a size is determined in relation with a unit of given measurement or with a selected unit of measurement. During the process of production, measurements are essential because it is through those characteristics that parameter values of products can be known and their qualities specified.

2.2 Why Measurements?

Measurements are essential in order to:

(i) Ensure that the part to be measured conforms to the established standard.

(ii) Judge the possibility of making some of the defective parts acceptable after minor repairs.

(iii) Provide customer satisfaction by ensuring that no faulty product reaches the customers.

(iv) Coordinate the functions of quality control, production, procurement & other departments of the organization as through measurements a basis for comparison should have been provided.

(v) Meet the principle of interchangeability of manufacture.

2.2. Requirements of measurements

Two basic requirements of measurements are:

(i) Standards for comparison must be accurate and internationally acceptable.

(ii) The process of the measurements must be internationally acceptable.

2.3 Methods of Measurement:

There various methods of measurements are:

(i) **Method of direct measurement**: The value of the quantity to be measured is obtained directly without the necessity of carrying out supplementary calculations based on a functional dependence of the quantity to be measured in relation to the quantities actually measured. *Example:* Weight of a substance is measured directly using a physical balance.

(ii) **Method of indirect measurement**: The value of the quantity is obtained from measurements carried out by direct method of measurement of other quantities, connected with the quantity to be measured by a known relationship. *Example:* Weight of a substance is measured by measuring the length, breadth & height of the substance directly and then by using the relation Weight = Length x Breadth x Height x Density

(iii) **Method of measurement without contact**: The sensor is not placed in contact with the object whose characteristics are being measured.

(iv) **Method of combination measurement closed series**: The results of direct or indirect measurement or different combinations of those values are made use of & the corresponding system of equations is solved.

(v) **Method of fundamental measurement**: Based on the measurements of base quantities entering into the definition of the quantity.

(vi) **Method of measurement by comparison**: Based on the comparison of the value of a quantity to be measured with a known value of the same quantity (direct comparison), or a known value of another quantity which is a function of the quantity to be measured (indirect comparison).

(vii) **Method of measurement by substitution**: The value of a quantity to be measured is replaced by a known value of the same quantity, so selected that the effects produced in the indicating device by these two values are the same (a type of direct comparison).

(viii) **Method of measurement by transposition** : The value of the quantity to be measured is in the beginning, balanced by a first known value A of the same quantity, then the value of the quantity to be measured is put in place of this known value and is again balanced by another known value B. If the position of the element indicating equilibrium is the same in both the cases, the value of the quantity measured is equal to A & B.

(ix) **Method of differential measurement**: Based on the comparison of the quantity to be measured with a quantity of the same kind, with a value known to be slightly difference from that of the quantity to be measured, and the measurement of the difference between the values of these two quantities.

(x) **Method of measurement by complement**: The value of the quantity to be measured is complemented by a known value of the same quantity, selected in such a way that the sum of these two values is equal to a certain value of comparison fixed in advance.

(xi) **Method of measurement by interpolation** : It consists of determining value of the quantity measured on the basis of the law of correspondence & known values of the same quantity, the value to be determined lying between two known values.

(xii) **Method of measurement by extrapolation** : It consists of determining the value of the quantity measured on the basis of the law of correspondence & known values of the same quantity, the value to be determined lying outside the known values.

2.4 Classification of Standards:

(1) Line & End Standards: In the Line standard, the length is the distance between the centres of engraved lines whereas in End standard, it is the distance between the end faces of the standard. *Example:* for Line standard is Measuring Scale, for End standard is Block gauge.

(2) Primary, Secondary, Tertiary & Working Standards: Primary standard: It is only one material standard and is preserved under the most careful conditions and is used only for comparison with Secondary standard. Secondary standard: It is similar to Primary standard as nearly as possible and is distributed to a number of places for safe custody and is used for occasional comparison with Tertiary standards.

Tertiary standard: It is used for reference purposes in laboratories and workshops and is used for comparison with working standard. Working standard: It is used daily in laboratories and workshops. Low grades of materials may be used.

2.5 Types of Errors:

(A) Error of Measurement:

(1) Systematic error: It is the error which during several measurements, made under the same conditions, of the same value of a certain quantity, remains constant in absolute value and sign or varies in a predictable way in accordance with a specified law when the conditions change. The causes of these errors may be known or unknown. The errors may be constant or variable. Systematic errors are regularly repetitive in nature.

(2) Random error: This error varies in an unpredictable manner in absolute value & in sign when a large number of measurements of the same value of a quantity are made under practically identical conditions. Random errors are non-consistent. Random errors are normally of limited time duration.

(3) Parasitic error: It is the error, often gross, which results from incorrect execution of measurement.

B) Instrumental error:

(1) Error of a physical measure: It is the difference between the nominal value and the conventional true value reproduced by the physical measure.

(2) Error of a measuring mechanism: It is the difference between the value indicated by the measuring mechanism and the conventional true value of the measured quantity.

(3) Zero error: It is the indication of a measuring instrument for the zero value of the quantity measured.

(4) Calibration error of a physical measure: It is the difference between the conventional true value reproduced by the physical measure and the nominal value of that measure.

(5) Complementary error of a measuring instrument: It is the error of a measuring instrument arising from the fact that the values of the influence quantities are different from those corresponding to the reference conditions.

(6) Error of indication of a measuring instrument: It is the difference between the measured values of a quantity, when an influence quantity takes successively two specified values, without changing the quantity measured.

(7) Error due to temperature: It is the error arising from the fact that the temperature of instrument does not maintain its reference value.

(8) Error due to friction: It is the error due to the friction between the moving parts of the measuring instruments.

(9) Error due to inertia: It is the error due to the inertia (mechanical, thermal or otherwise) of the parts of the measuring instrument.

C) Error of observation:

(1) Reading error: It is the error of observation resulting from incorrect reading of the indication of a measuring instrument by the observer.

(2) Parallax error: It is the reading error which is produced, when, with the index at a certain distance from the surface of scale, the reading is not made in the direction of observation provided for the instrument used.

(3) Interpolation error: It is the reading error resulting from the inexact evaluation of the position of the index with regard to two adjacent graduation marks between which the index is located.

(D) Based on nature of errors:

(1) Systematic error:

(2) Random error:

(3) Illegitimate error: As the name implies, it should not exist. These include mistakes and blunders, computational errors and chaotic errors. Chaotic errors are random errors but unlike the latter, they create chaos in the final results.

(**E) Based on control:**

(1) Controllable errors: The sources of error are known and it is possible to have a control on these sources. These can be calibration errors, environmental errors and errors due to non-similarity of condition while calibrating and measuring.

Calibration errors: These are caused due to variation in the calibrated scale from its normal value. The actual length of standards such as slip gauges will vary from the nominal value by a small amount. This will cause an error of constant magnitude.

Environmental (Ambient /Atmospheric Condition) Errors: International agreement has been reached on ambient condition which is at 20^0C temperature, 760 mm of Hg pressure and 10 mm of Hg humidity. Instruments are calibrated at these conditions. If there is any variation in the ambient condition, errors may creep into final results. Of the three, temperature effect is most considerable.

Stylus pressure errors: Though the pressure involved during measurement is generally small, this is sufficient enough to cause appreciable deformation of both the stylus and the work piece. This will cause an error in the measurement.

Avoidable errors: These errors may occur due to parallax in the reading of measuring instruments. This occurs when the scale and pointer are separated relative to one another. The two common practices to minimise this error are:
(i) Reduce the separation between the scale and pointer to minimum.
(ii) A mirror is placed behind the pointer to ensure normal reading of the scale in all the cases. These avoidable errors occur also due to non-alignment of work piece centers, improper location of measuring instruments, etc.

Non-controllable errors: These are random errors which are not controllable.

2.6 LINEAR AND ANGULAR MEASUREMENT

Linear measuring instruments: Vernier, micrometer, interval measurement, Slip gauges and classification, interferometery, optical flats, limit gauges.
Comparators: Mechanical, pneumatic and electrical types, applications.
Angular measurements: - Sine bar, angle dekor, Optical bevel protractor

Comparator: It is a precision instrument employed to compare the dimension of a given component with a working standard (generally slip gauges). It does not measure the actual dimension but indicates how much it differs from the basic dimension (working standard).

Uses of Comparator:

- For calibrating the working gauges
- Used as working gauges
- Used as final inspection gauges

Essential **characteristics of a good Comparator**:

- Robust design and construction
- Linear characteristics of scale
- High magnification
- Quick in results
- Versatility
- Minimum wear of contact point
- Free from back lash
- Quick insertion of work piece
- Provision for compensation from temperature effects
- Provision for means to prevent damage during use.

Classification of comparators:

1) Mechanical comparator

a) Dial indicator

b) Johansson „Mikrokator‟ comparator

c) Sigma comparator

d) Reed type mechanical comparator

2) **Optical comparator**:

a) Zeiss Ultra optimeter

b) Zeiss optotest comparator

3) Mechanical – Optical comparator

4) Electrical comparator

5) Fluid displacement comparator

6) Pneumatic comparator

a) Back pressure comparator

b) Flow – velocity Pneumatic comparator
In addition, the comparators used in standards room for calibration of gauges are:

7) Brookes Level comparator

8) Eden-Rolt "Millionth" Comparator

Slip gauges: These gauges are other wise called as Gauge blocks or Block gauges and are universally accepted as end standards of length in industry. Slip gauges are rectangular blocks of high grade steel (or tungsten carbide) with less co-efficient of thermal expansion. These blocks are highly hardened (more than 800 HV) through out to ensure maximum resistance to wear and are then stabilised by heating and cooling successively in stages so that the hardening stresses are removed. After hardening, they are subjected to lapping to a high degree of finish, flatness and accuracy. The cross sections of these gauges are 9 x 30 mm for sizes up to 10 mm and 9 x 35 mm for larger sizes. The dimension (height) is marked on one of the measuring faces of gauge blocks.

Wringing of Slip gauges: The slip gauges are wrung together by hand through a combined sliding and twisting motion. The air gap between the gauge faces is expelled out and the adhesion is caused partly by molecular attraction and partly by atmospheric pressure. The gap between the two wrung slip gauges is only of the order of 0.00635 μ m which is negligible.

Selection of Slip gauges for required dimension: Always start with the last decimal place and deduct this from the required dimension. Select the next smallest figure in the same way, find the remainder and continue this until the required dimension is completed. Minimum number of slip gauges should be selected to build up the given dimension.

Roller gauges: Cylindrical rollers with their lengths equal to their diameters may be used as gauges, secondary to block gauges (slip gauges). These are produced to fine tolerances.

Limit gauges:
These are inspection tools for rigid design, without a scale, which serve to check the dimensions of manufactured parts. Gauges do not indicate the actual value of the inspected dimension on the work.

They can only be used for determining as to whether the inspection parts are made within the specified limits. These gauges are made up of suitable wear resisting steel and are normally hardened to not less than 750 HV and suitably stabilized and ground and lapped. The ‘Go’ and ‘No Go’ gauges may be in the form of separate single ended gauge, or may be combined on one handle to form a double ended gauge. Progressive gauge is the single ended gauge with one gauging member having two diameters to the ‘Go’ and ‘No Go’ limits respectively.

Gauge Design: Every gauge is a copy of the part which mates with the part for which the gauge is designed. For example, a bush is made which is to mate with a shaft; in this case, the shaft is the mating part. The bush is check by a plug gauge which in so far as the form of its surface and its size is concerned, is a copy of the mating part (shaft). Taylor’s principle: According to Taylor, ‘Go’ and ‘No Go’ gauges should be designed to check maximum and minimum material limits which are checked as below: ‘Go’ limit: This is applied to upper limit of a shaft and lower limit of a hole. ‘No Go’ limit: This is applied to lower limit of a shaft and the upper limit of a hole. Taylor’s principle states that the ‘Go’ gauges should check all the possible elements of dimensions at a time (roundness, size, location, etc.) and the ‘No Go’ gauge should check only one element of the dimension at a time. Based on Taylor’s principle, ‘Go’ gauge is designed for maximum material condition and ‘No Go’ gauge is designed for minimum material condition.

Types of Limit Gauges: The various types of limit gauges used for gauging internal diameters of holes are:

(1) **Full form cylindrical plug gauge**: The gauging surface is in the form of an external cylinder. Generally a small circumferential groove is cut near the leading end of the gauge and the remaining short cylindrical surface is slightly reduced in order to act as a pilot.

(2) **Full form spherical plug or disc gauge**: The gauging surface is in the form of a sphere from which two equal segments are cut off by planes normal to the axis of the handle.

(3) **Segmental cylindrical bar gauge**: The gauging surface is in one of the two forms: one form; external cylindrical form from which two axial segments are made by lowering down surface at other places, the other form; external cylindrical form in which segments are formed by removing remaining material.

(4) **Segmental spherical plug gauge**: It is similar to full form spherical plug gauge but has two equal segments cut off by planes parallel to the axis of the handle in addition to the segments cut off by planes normal to the axis of the handle.

(5) **Segmental cylindrical bar gauge with reduced measuring faces**: It is similar to the segmental cylindrical bar gauge but has reduced measuring faces in a plane parallel to the axis of the handle.

(6) **Rod gauge with spherical ends**: It has spherical end surfaces which form part of one single sphere. The various types of limit gauges used for gauging external diameters of shaft are:
(i) **Full form cylindrical ring gauge**: The gauging surface is in the form of an internal cylinder and whose wall is thick enough to avoid deformation under normal conditions of use.
(ii) **Gap gauge**: It has one flat surface and one cylindrical surface, the axis of the two surfaces being parallel to the axis of the shaft being checked. The surfaces constituting the working size may both be flat or both cylindrical also. The gauges (for internal taper) are marked with a ring on the gauge planes another ring to indicate the minimum depth of internal taper. The distance between the two ring marks 'Z' corresponds to the permissible deviation of the gauge plane for particular taper. For testing the external taper of the tanged end shank, the ring gauge is inserted, as far as it goes with light pressure. At the extreme position, no part of the tang under test should extend beyond the surfaces A, B and C. The shank surfaces may however, lie flush with these surfaces.

Autocollimator: It is an optical instrument used for the measurement of small angular differences. It is essentially an infinity telescope and a collimator combined into one instrument.
Principle of Autocollimator: If a point source of light O is placed at the principal focus of a collimating lens, it will be projected as a parallel beam of light. If this parallel beam now strikes a plane reflector which is normal to the optical axis, it will be reflected back along its own path and refocused at the source O. If the plane reflector is now tilted through some small angle 'δ', the reflected parallel beam will turn through 2 δ, and will be brought to a focus at O_1, in the focal plane, a distance x from O. If the ray passing through the geometric centre of the lens is considered, as it is, unaffected by refraction, it can be seen that $x = 2 \delta f$ mm, where f is the focal length of the lens.

The important points about this collimation of a beam of light are:
a) The distance between the reflector and the lens has no effect on the separation x between source and image.
b) For high sensitivity, i.e., a large value of x for a small angular deviation δ, a long focal length is required.
c) Although the distance of the reflector does not affect the reading x, if, at given value of δ, it is moved too far back, all of the reflected rays will miss the lens completely, and no image will be formed. Thus, for a wide range of readings, the minimum distance between lens and reflector is essential.

Angle Dekor: In this system, an illuminated scale is set in the focal plane of the collimating lens outside the field of view of a microscope eyepiece. It is then projected as a parallel beam and strikes a plane reflector below the instrument. It is reflected, and refocused by the lens so that its image is in the field of view of the eyepiece. The image falls, not across a simple datum line, but across a similar fixed scale at right angles to the illuminated image. Thus, the reading on the illuminated scale measures angular deviations from one axis at 90^0 to the optical axis, and the reading on the fixed scale gives the deviation about an axis mutually at right angles to the other two. This feature enables angular errors in two planes to be dealt with or more important, to ensure that the reading on a setting master and on the work is the same in one plane, the error being read in the other. Thus, induced compound angle errors are avoided. The setup consists of a lapped flat and reflective base above which the optical details are mounted in a tube on an adjustable bracket. In use, a master, either a sine bar or a group of combination angle gauges is set up on the base plate and the instrument is adjusted until a reading on both sides is obtained. It is now replaced by the work, a gauge block to give a good reflective surface being placed on the face to be checked. The gauge block can usefully be held in place with elastic bands. The work is now slowly rotated until the illuminated scale moves across the fixed scale, and is adjusted until the fixed scale reading is the same as on the setting gauge. The error in the work angle is the difference in the two readings on the illuminated scale.

Sine bar: It is a precision measuring instrument and is an excellent example of combination of linear measurement and angular measurement when used in conjunction with gauge blocks (slip gauges). It consists of a bar carrying a suitable pair of rollers set a known centre distance. It is made of high carbon, high chromium corrosion resistant steel, suitably hardened, precision ground and stabilised. Relief holes are provided for easy handling of sine bar and for reducing the weight of the sine bar. It should be used on a grade A surface plate.

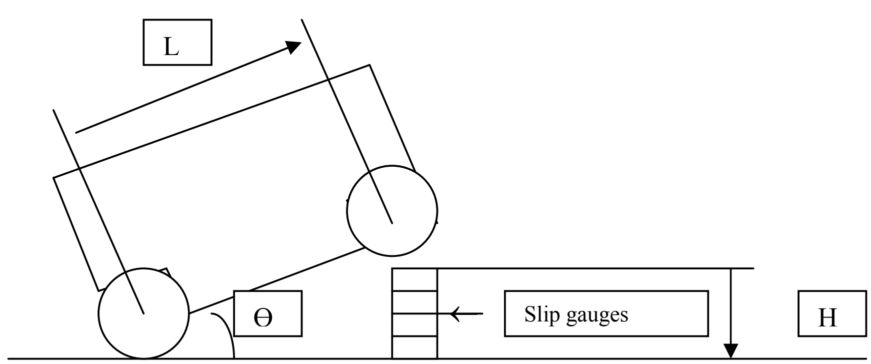


Figure 2.1: Sine Bar

If L is the linear distance between the axes of the rollers and h is the height of the slip gauges, then sin $\Theta = h/L$ The design requirements of a sine bar are as follows, and unless these are carefully maintained the order of accuracy of angular measurement will fall: i) The rollers must be of equal diameter and true geometric cylinders. ii) The distance between the roller axes must be precise and known, and these axes must be mutually parallel. iii) The upper surface of the beam must be flat and parallel with the roller axes, and equidistant from each.

Working principle of Sine bar: The sine bar is first kept on the surface plate. The work piece is then placed on the sine bar such that the surface whose taper angle is to be measured is facing upwards. Place the set of slip gauges under one end of the roller of sine bar such that the upper surface of the work piece is approximately parallel with the table surface. Place the plunger of the dial gauge on the upper surface of the work piece. Take readings with the dial gauge at both ends and note their difference, noting which end of the work is low. If the end nearest the high end of the sine bar is low, then the slip gauges height must be increased by an amount equal to the difference in the dial gauge readings multiplied by the proportion of sine bar length to work length. For example, assuming that the end of a work piece was 0.01mm low, the sine bar being 250 mm long and the work 100 mm long, then the required increase in height of slip gauge set will be 0.01 x 250/100 = 0.025 mm. This will not give an immediately correct setting from a first approximation, but it is much quicker than a trial and error method.

Note: a) No sine bar should be used to set off angles greater than 45^0, as beyond this angle, the errors due to the centre distance of rollers, and slip gauges, being in error are much magnified.

b) Slip gauges should be kept beneath the setting roller attached to the end which is with taper shape but not beneath the hinge roller. This is to enable the slip gauges not to hit the bottom surface of sine bar.

2.7 SCREW THREAD MEASUREMENT:

Introduction: Screw threads have to perform two functions namely

- Transmission of power and motion
- Acts as a temporary fastener
- External threads
- Internal thread

Terminology of screw threads:

- Screw thread

- Crest
- Root
- Flank
- Depth of thread
- Lead
- Pitch
- Helix angle
- Flank angle
- Included angle
- Major diameter
- Minor diameter
- Addendum
- Dedendum

Error in screw thread:

- Major diameter error
- Minor diameter error
- Effective diameter error
- Flank angle error
- Pitch error.

1. Progressive error

2.Periodic error

3. Drunken error

4. Irregular errors

5. Effect of pitch error.

2.8 MEASUREMENT OF VARIOUS ELEMENTS OF THREAD:

Measurement of major diameter:

- Micrometer
- Bench micrometer

Measurement of minor diameter:

- Using taper parallels
- Using rollers

Measurement of effective diameter:

- Thread micrometer method
- One wire method
- Two wire method
- Three wire method

Pitch measurement:

1. Pitch measuring machine
2. Tool maker's microscope
3. Screw pitch gauge

2.9 THREAD GAUGES:

Introduction: Thread geometry procedure cannot be used in normal production work Hence gauges are used where the basis is mating o surfaces.

Thread gauge classification:

- First group
- Second group

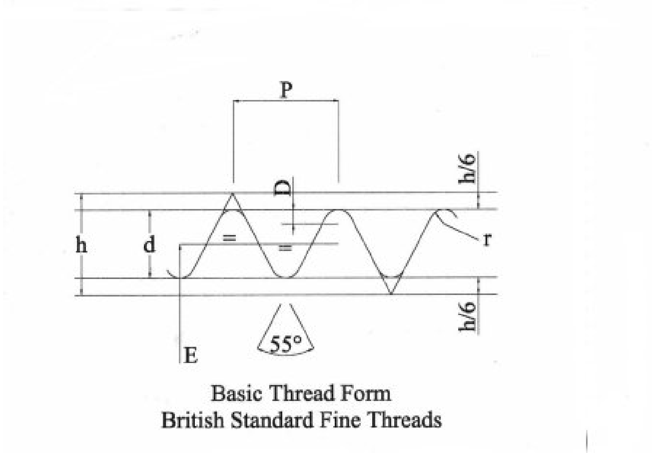
Form of thread gauges:

- Plug ring gauges
- Ring screw gauges
- Caliper screw gauges

Gauge wear: **Screw thread gauge tolerance**: **Adjustable thread gauges**:

- The Wick man Adjustable thread gauge

➢ Roller type Adjustable thread gauges.



P = Pitch = 1/Number of threads per inch (tpi)

h = Angular Depth = 0.960491 x P

D = Depth of Rounding = 0.073917 x P

h/6 = Shortening = 0.160083 x P

d = Actual Depth = 0.640327 x P

r = Radius at the Crest & Root = 0.137329 x P

C = Core diameter = Major Diameter - 1.280654 x P

Effective or Pitch Diameter = Major Diameter - .640327 x P

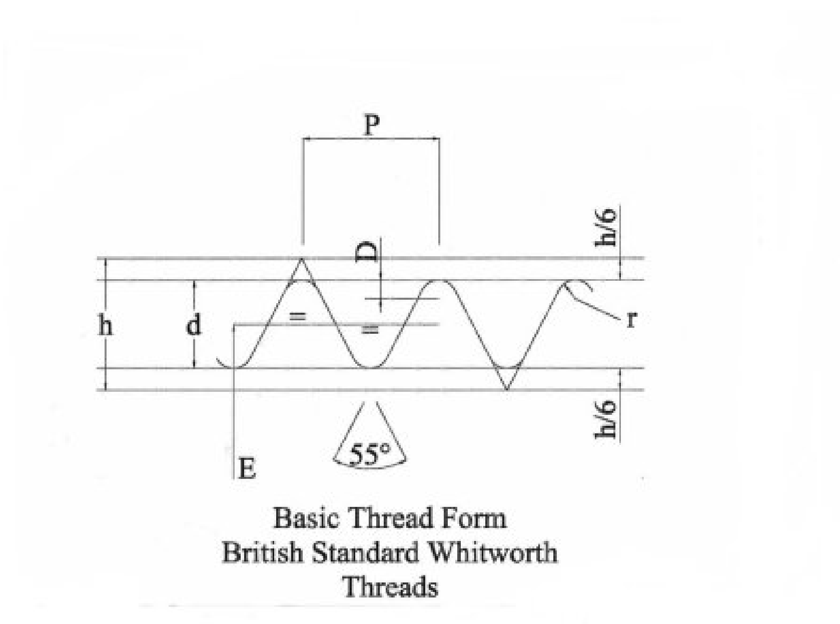


Figure 2.2: British Thread Form

P = Pitch = 1/Number of threads per inch (tpi)

h = Angular Depth = 0.960491 x P

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Effective or Pitch Diameter = Major Diameter - .640327 x P

2.10 Straightness

Straightness commonly can be checked using straightness or a dial indicator. An autocollimator is used to accurately measure small angular deviations on a flat surface. Laser beams are now commonly used to align individual machine elements in the assembly of machine components.

2.11 Flatness

Flatness can be measured by mechanical means using a surface plate and a dial indicator. This method can be used to measure perpendicularity which can also be measured using precision-steel squares.

Another method of measuring flatness is interferometry using optical flat. This device is a glass disk or fused quatz disk called flat surfaces which is placed on the surface of the work piece. When a monochromatic light beam (a light beam with one wavelength) is aimed at the surface at an angle, the optical splits the light beam into two beams, appearing as light and dark bands to the naked eye. The number of fringes that appear is related to the distance between the surface of the part and the bottom surface of the optical flat. Consequently, a truly flat surface (i.e. one in which the angle between the two surfaces is zero) will not split the light beam and fringes will not appear. When surfaces are not flat, the fringes are curved. This method is also used for observing surface textures and scratches.

Care of Measuring Instruments

Measuring tools are delicate and expensive. The following are some of the rules that have to be observed in the use of measuring tools:

(1) When not in use, measuring tools should be coated with a protecting film of oil, say paraffin and stored in a safe place.

(2) Measuring tools should be stored in a tool cribs separately from other tools.

(3) Never grease a gauge before taking measurements since even a small layer of oil between the work and the gauge may cause reading errors.

(4) Since the work is heated during machining and will expand, do not measure freshly machines surface whose temperature exceeds the room temperature.

(5) A calliper or plug gauge should pass over or into the work with its GO element easily without being forced. If the calliper gauge is forced over the work, it may spring and distort the accuracy of the readings. The NOT GO element of the calliper gauge should not pass over the part.

(6) The measured surface and the limit gauge or measuring tool should always be clean. The section of the work to be measured should be cleaned of burrs, chips and dirts.

3.0 STATISTICAL METHODS OF QUALITY CONTROL

Because of the numerous variables involved in manufacturing processes and operations, the implementation of statistical techniques is essential. Statistical sampling techniques enable the inspector to take controlled random samples of components which will then be checked by measurements or gauging. The quality of the whole batch of work produced will then be judged by the results of the sample. If the number of rejects found in the sample is too high, then the quality of the whole batch is unacceptable and vice versa.

The statistical part of the exercise is in collecting the data from the samples in order that the total quality level can be assessed within a certain degree of probability. The inspector is therefore concerned with charts, data and so on as well as measuring instruments and gauges. Instead of carrying out inspection of samples, it is also possible to carry out 100 percent inspection which is expensive and may not guarantee that all the unacceptable parts will be found and therefore rejected. This is especially for activities that are repetitive and boring.

Statistical Process Control (SPC)

SPC is used to monitor a process and detect when a particular feature or dimension is about to go outside of tolerances. Averages and ranges are used in the most common form of an SPC control chart. The following terms are defined:

(i) Sample size: This is the number of parts to be inspected.
(ii) Random sampling: Taking a sample from a population or lot in which each item has equal chance of being selected. It is therefore necessary that samples should not only be taken near the inspector.
(iii) Population: Number of individual parts from which samples are taken.
(iv) Lot size: A subset of the population.

The inspection of samples falls into two main categories:

(1) The method of variables is the quantitative measurement of the part's characteristics such as dimensions, tolerances, surface finish, physical or mechanical properties and comparing the results with earlier specified dimensions.

(2) The method of attributes involves the observation of the presence and absence of qualitative characteristics in each of the units in the group under consideration. Samples for attributes-type data are generally larger than for variables-type data.

The increase in the number of parts that do not meet set standards (defective parts) or out of control situations during a production run may be due to:

(i) Defective incoming materials
(ii) Bad machine controls
(iii) Degradation of metal working fluids
(iv) Operator boredom
(v) Cutting tools, dies and moulds wear
(vi) Environmental conditions such as temperature, humidity and air quality

(vii) Over control of the manufacturing process (setting upper and lower control limits too close to each other hence a smaller standard deviation range)

Appropriate action should then be taken to rectify the causes. SPC is an approach which not only advices the operator to take certain measures and actions but also tell him when to take them in order to avoid producing further defective parts and consists of:

(i) Control charts and control limits

(ii) Capabilities of the particular manufacturing process

(iii) Characteristics of the machinery involved

1. What to Measure

The easiest and most common data used are the measurement of a feature such as a hole's diameter. This is also what an operator is interacting with so it makes it easier to standardize the work performed.

Creating an Average and Range Control Chart

After obtaining data on the dimension for a while, either for a statistically significant sample size or for several shifts where variation can occur, control limits are calculated. Sample size and frequency for the ongoing data collection are then decided.

Charting the Numbers

After measuring the samples, the average is calculated and plotted on the SPC chart. As more points are charted, the average chart shows the trend of the population, while the range chart shows any variation within intervals.

What is "Out of Control" and Reacting to the Data

A point outside of a control limit shows a statistically valid shift of the population and triggers a response. In the case of hole diameter, if the hole has gotten too small, then the bit needs to be replaced.

Other "Out of Control" Conditions

Trends and patterns in the graphed data can also show something has changed (possibly a new lot of raw material).

The bell-shaped normal distribution curve has two important features:

(1) It shows that most part diameters tend to cluster around an average value (arithmetic mean). This average usually is designated as $\bar{X}$ and is calculated from the expression

$$\bar{X} = \frac{X_1 + X_2 + X_3 + X_4 \text{----------} + X_n}{n}$$

where the numerator is the sum of all measured values (shaft diameters) and n is the number of measurements (number of shafts).

(2) The second feature of the curve is its width indicating the dispersion of the diameters measured, the wider the curve, the greater is the dispersion.

RANGE

Range is important so that you can tell if the entire process is shifting and by how much, or if the any shifting is just during certain times. Like when the next shift starts, when material from supplier X starts being pulled from stock, or when the environmental variables change. *(humidity or temperature and the like).*

The difference between the largest value and the smallest value is called the range, R given as:

$R = X_{max} - X_{min}$

Dispersion is estimated by the standard deviation, σ, and is given by the expression

$$\sigma = \sqrt{\frac{\left(x_1 - \bar{x}\right)^2 + \left(x_2 - \bar{x}\right)^2 + \dots\dots\dots\dots + \left(x_n - \bar{x}\right)^2}{n-1}}$$

where x_n is the measured value for each part. Since we know the number of turned parts that fall within each group, we can calculate the % of the total population represented by each group

Part of any quality control, ISO9000, quality assurance, or Six Sigma plan must use some type of SPC, (statistical process control), to implement control charts to control the processes. The origins of SPC, or statistical process control, date back to the 1920's and Dr. Shewhart. Statistical process control was not well received by U.S. manufactures, so Dr. Shewhart first applied his theories in Japan.

The concept is to be able to control your processes by monitoring changes in the process, environment, or labor, using control charts. This is achieved by collecting random data samples from groups or sub-groups of product at various stages of the product's manufacturing using inspection methods. You can then start plotting the data points on a control chart, which is a line chart. Be aware of any sampling bias problems that may occur.
You must also create a distribution chart to know how your data is grouped as a whole. The following is for data that is called variable. Variable data can be taken in sample sizes, or sub-groups of 2 to 5 pieces thus the data can have a range, ($\bar{R}$), and an average or mean also known as $\bar{X}$.

An example of would be like temperatures taken in different spots of a large stadium. If you took 4 readings from the...

Table 3.1: Measurements of Temperatures in a stadium

Measurement Point	Actual Measurement
North	68.5
South	75.5
East	72.3
West	73.4

Your range would be 7.0, (75.5 - 68.5 = 7.0)
Your average, (mean), would be 72.425
(68.5 + 75.5 + 72.3 + 73.4 = 289.7)
(289.7 / 4 = 72.425)
There are 2 types of samples that we deal with. One we will call the observations or sub-groups, and the other we will call the sample. You must decide how many samples you need to take to represent the population for an acceptable result. Think of it as putting the data into a grid. We will call the observations, or sub-groups columns and the samples rows. So the sub-group is a portion of the entire sample you choose. If we decide to take 30 samples, then this could be put into ...
2 sub-groups of 15 observations (2 rows and 15 columns) 2x15=30
6 sub-groups of 5 observations (6 rows and 5 columns) 6x5=30
Some use 30, which is a number that was acquired from the 1930's and based on how many widgets can be produced in one hour now vs. then, it is not very accurate for today's industries. Motorola at one time used 75 and Juran suggested the use 125. However many you use, it must be able to be divided by the observations. So if you used 30 as a sample, you could use 2 columns of observations and 15 rows of samples, or 2 x 15 = 30. You could also use 5 columns of observations and 6 rows of samples, or 5 x 6 = 30.
Note: try to do this so that you do not need to change the observations. There are advantages and disadvantages to using both 2 and 5, which are the most popular to use. The observation is important because it is the basis for the factor table you use to establish control limits. I just find that if you don't keep changing this, you get better results over the long run.
When Motorola used 75, they wanted it as 5 columns of observations and 15 rows of samples, or 5 x 15 = 75.
If our widget is a gear, there could several parameters that we need to chart, but we are only going to look at diameter for simplicity.
We only take the large sample size once to establish control limits. After that we add 1 sample of how ever many observations we choose, typically 2-5, to the grid and calculate the mean and range. So for t he example, we will take 15 samples using 3 observations. Our grid would look like this...

Table 3.2: Measurement of diameters of a Part

Part Number: 54T54						
Parameter: - Diameter					Blue Print Location: A-2	
Specification Minimum - .195			Specification Maximum - 0.208		Specification Nominal - 0.201	
N	**Date/Time**	**X_1**	**X_2**	**X_3**	**X-Bar**	**Range**
1	4/7/1997 22:54	0.206	0.194	0.203	0.201	0.012
2	4/7/1997 23:55	0.196	0.192	0.223	0.204	0.031
3	4/7/1997 24:55	0.215	0.220	0.238	0.224	0.023
4	4/7/1997 25:55	0.230	0.234	0.229	0.231	0.005
5	4/7/1997 26:55	0.223	0.230	0.227	0.227	0.007
				Totals	1.087	0.078
				Avg.	0.217	0.016

Nominal is what the process typically runs at. If you have an upper and lower specification limits, then the nominal is usually the middle of that number, (Max Spec - Min Spec) / 2 + Min Spec or in this case...
(.208 - .195 = 0.013 / 2 = 0.0065 + .109 = 0.2015)
The totals of the Average at the bottom of 0.0217 and 0.16 are also known as Double X-Bar and Double R-Bar. The X Bar control chart should have sigma zones applied to them in order to look at trends.

Six Sigma Concept
A quality standard in increasingly wider practice is the six sigma requirement. The concept was first implemented by Motorola in the 1980's and refers to the range of the distribution. Six sigma means that there are only 3.4 defective parts per million parts on each side of the distribution (99.966 % of parts fall within the range of 6 sigma or a total of 6.8 parts per million). Because of the nature of statistical distributions, this tacitly forces improvements in process capability to reduce variability.

Zones on Control Charts
When doing $\overline{X}$ and Range charts, one needs to establish upper control limits and lower control limits. These limits are +/- 3 sigma from the Double X-Bar.

UCL - Upper Control Limit

UCL, *(Upper Control Limit)*, as it applies to $\overline{X}$, *(mean)*, and $\overline{R}$, *(range)*, charts, is a formula that will calculate an upper most limit for samples to evaluate to. There is usually a LCL, (Lower Control Limit), that is also calculated and used in process control charts.You can also use Pre-Control to establish control limits on control charts.

To calculate the UCL, you use the factor table below. You need to know the number of samples and the number of observations, *(subgroups using* stratified sampling), labelled n, that were used. You must obtain the $\overline{\overline{X}}$, *(grand average)*, or average of the $\overline{X}$ calculations. You must also obtain the R Bar calculation to calculate control limits.

A_2 = a factor used in calculating the control limits for the X chart.
D_4 = a factor used in calculating the upper control limit for the R chart.
D_3 = a factor used in calculating the lower control limit for the R chart.

LCL - Lower Control Limit
LCL, *(Lower Control Limit)*, as it applies to $\overline{X}$, *(mean)*, and $\overline{R}$, *(range)*, control charts, is a formula that will calculate an lower most limit for samples to evaluate to. There is usually a UCL, *(Upper Control Limit)*, that is also calculated. Used in SPC, (statistical process control). You can also use Pre-Control to establish control limits on control charts.

To calculate the LCL, you use the factor table below. You need to know the number of samples and the number of observations, *(subgroups using* stratified sampling), labeled n, that were used. You must obtain the $\overline{X}$, *(grand average)*, or average of the $\overline{X}$ calculations. You must also obtain the $\overline{R}$ calculation to calculate control limits.

The factors A_2, D_4. and D_3 vary with the size of the sample. Select the appropriate factor from the table shown below:

Table 3.3: Table of Factors for X and R Charts

Sample size (n)	A_2	D_4	D_3	D_2
2	1.880	3.267	0	1.128
3	1.023	2.575	0	1.693
4	0.729	2.282	0	2.059
5	0.577	2.115	0	2.326
6	0.483	2.004	0	2.534
7	0.419	1.924	0.078	2.704
8	0.373	1.864	0.136	2.847
9	0.337	1.816	0.184	2.970
10	0.308	1.777	0.223	3.078
12	0.266	1.716	0.284	3.258
15	0.223	1.652	0.348	3.472
20	0.180	1.586	0.414	3.735

X Bar Upper Control Limit, *(XUCL)*, = $\overline{X} + 3\sigma = \overline{X} + A_2 * \overline{R}$

R Bar Upper Control Limit, *(RUCL)* = $D_4 * \overline{R}$

A_2 = a factor used in calculating the control limits for the X chart.
D_4 = a factor used in calculating the upper control limit for the R chart.
D_3 = a factor used in calculating the lower control limit for the R chart.

The factors A_2, D_4 and D_3 vary with the size of the sample. $\overline{X}$ Lower Control

Limit, *(XLCL)*,

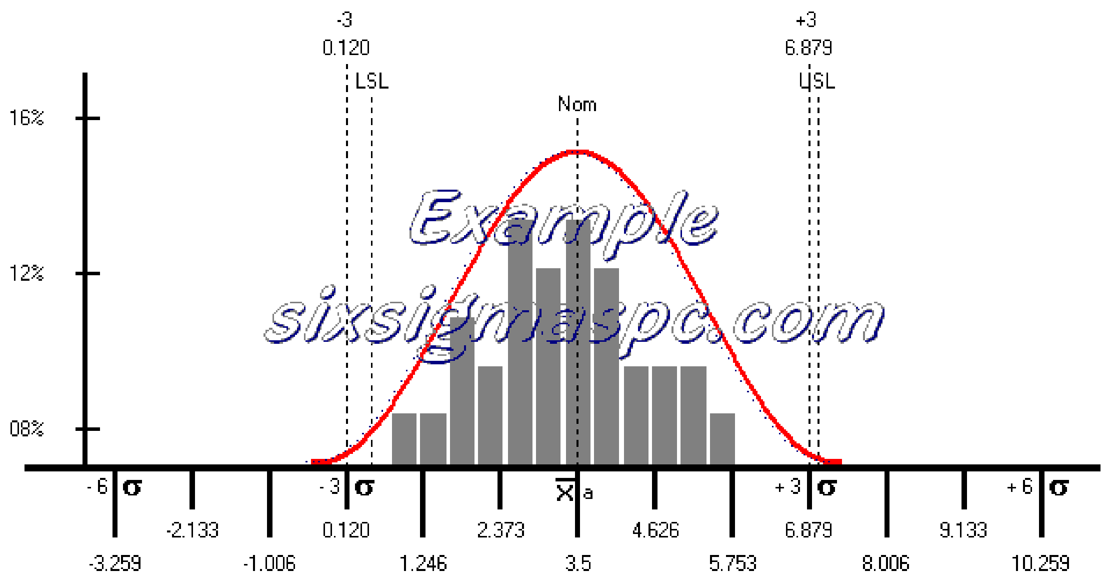
X Bar Lower Control Limit, *(XLCL)*, = $\overline{X} - 3\sigma = \overline{X} - A_2 * \overline{R}$

R Bar Lower Control Limit, *(RLCL)*, Formula

R Bar Upper Control Limit, *(RUCL)* = $D_3 * \overline{R}$

The table also includes d_2, which is used to estimate the standard deviation of the process as:

$$\sigma = \frac{\overline{R}}{d_2}$$



Warning effects for out of control situations are sometimes set at ± 2 σ. Analyzing
Figure 3.1: Sample of graph for Statistical Process Control
patterns and trends in control charts require considerable experience so that one may identify the specific causes of out of control situations and take necessary measures.

4.0 HEALTH AND SAFETY

Industrial safety is related to capacity planning as accidents result in the decrease in the size, efficiency and effectiveness of labour. In order to the increase the availability of the labour by preventing accidents, a company should establish a safety programme. Accident prevention is a programme of integrated and coordinated activities that is directed towards the prevention and control of accidents.
Safety management is concerned with safe equipment and process design, safe work methods design, promotion of safety awareness from an individual and an organizational standpoint, education in safety at all levels in the in the organizational as well as the financial and managerial support for the moral and ethical responsibilities of a safety programme.
The primary objective of a safety programme is accident prevention and is initiated for one or more of the following reasons:
(1) Ethical or moral: Accident prevention responsibilities are undertaken because of human considerations.
(2) Legal: Accident prevention may be embarked upon because of local government, state or federal laws that have prescribed penalties such as fines, shutdown of facilities, law suits and increase in mandatory worker compensations.
(3) Economic: 'Prevention is better than cure' goes a saying. Accident prevention may be embarked upon because it is cheaper than paying costs associated with accidents.

Basic Theories of Accident Causation

There are a number of theories that have been proposed to explain how and why accidents occur. Accident causation models were originally developed in order to assist people who had to investigate occupational accidents, so that such accidents could be investigated effectively. Knowing how accidents are caused is also useful in a proactive sense in order to identify what types of failures or errors generally cause accidents, and so action can be taken to address these failures before they have the chance to occur.

The Domino Theory

In 1931, the late H.W. Heinrich (Heinrich et al, 1980) presented a set of theorems known as 'the axioms of industrial safety'. The first axiom dealt with accident causation, stating that '*the occurrence of an injury invariably results from a complicated sequence of factors, the last one of which being the accident itself.*' Alongside, he presented a model known as the 'domino theory' as this accident sequence was likened to a row of dominoes knocking each other down in a row. The sequence is:-

- Injury, *caused by an*;
- Accident, *due to an*;
- Unsafe act and/or mechanical or physical hazard, *due to the*;
- Fault of the Person, *caused by their*;
- Ancestry and Social Environment.

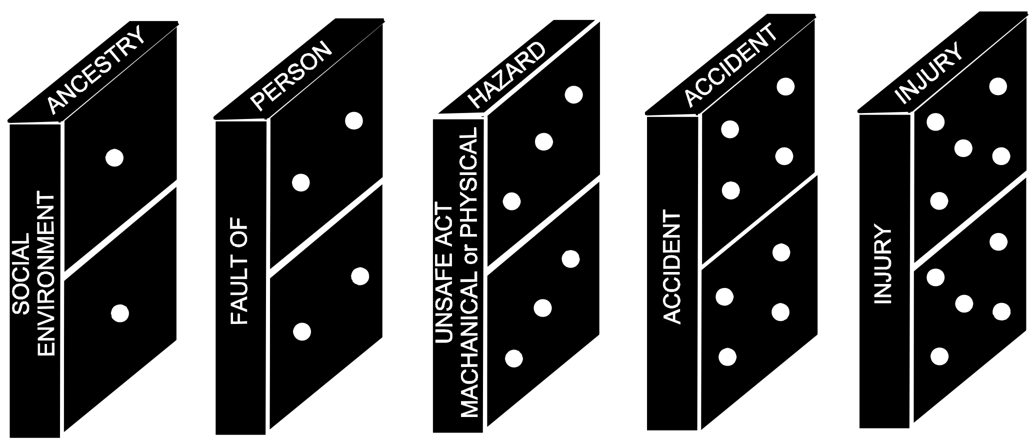


Figure 4.1: Accident Causation Model

The accident is avoided, according to Heinrich, by removing one of the dominoes, normally the middle one or unsafe act. This theory provided the foundation for accident prevention measures aimed at preventing unsafe acts or unsafe conditions.

The first update of the Domino Theory was presented by Bird & Loftus [Heinrich et al, 1980; Bird & Germain, 1986]. This update introduced two new concepts;

- The influence of management and managerial error;
- Loss, as the result of an accident could be production losses, property damage or wastage of other assets, as well as injuries.

This model (known as the International Loss Control Institute or ILCI model) is shown in the figure below:

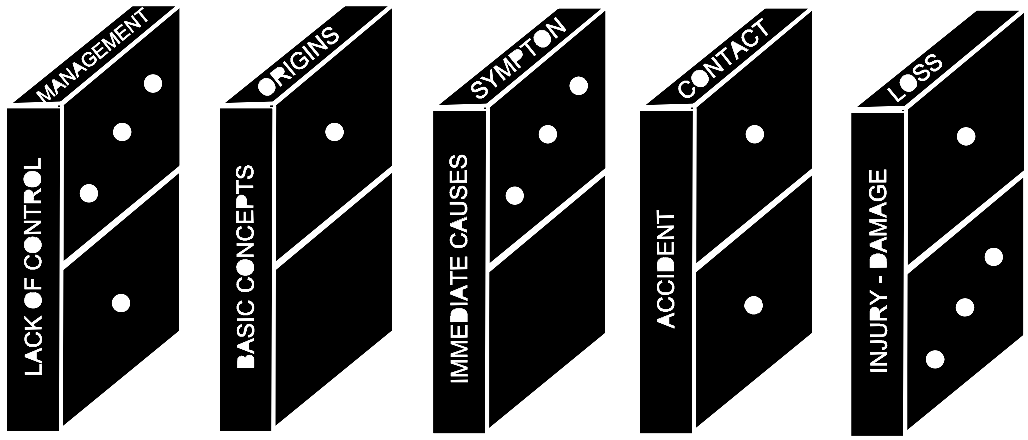


Figure 3.2: The ILCI Model

The domino model has been noted as a one-dimensional sequence of events. Accidents are usually multi-factoral and develop through relatively lengthy sequences of changes and errors'. This has led to the principle of multiple causation.

According to Peterson (1978), behind every accident there lies many contributing factors, causes and sub-causes. The theory of multiple causation is that these factors combine together, in random fashion, causing accidents. So, during accident investigations, there is a need to identify as many of these causes as possible, rather than just one for each stage of the domino sequence. The term safety and lack of control is applied to the five factors in Figure 3.2 and is to describe how an organization and a manager in particular can lose control of factors that result in injury and damage. If there is an interruption in any of the events leading to accident, the accident and the injury that may occur cannot happen.

Management is assigned the responsibility of 'lack of control' and it includes accident investigation, job design and analysis, training, facility inspection, establishment of safety standards as well as equipment and process design.

'Basic causes' are related to origins of the causes of accidents. In includes job-related and human-related causes like lack of incentives, lack of required skills and knowledge, deterioration of equipment and processes and inadequate or poor work standards.

'Immediate causes-symptoms' are usually referred to as 'unsafe acts or conditions' and include housekeeping, operating equipment without authorization and not using safety devices. Eliminating the symptoms without identifying the remote causes of accidents may lead to temporary relief.

'Accident contact' describes the undesirable consequence such as personal injury or property damage. The 'contact' is added to 'accident' to recognize that injury and damage occur only when contact is made with some energy source such an employee's hand in contact with a moving or stationary object.

'Injury damage' is the consequence of accident and it includes bodily damage, physical and mental injury as well as occupational related diseases. Damage also includes damage to facilities such as buildings, equipment and fire damage.

5.0 CLEANER PRODUCTION

Cleaner Production is the **continuous** application of an **integrated**, **preventive** environmental strategy towards **processes**, **products** and **services** in order to increase overall efficiency and **reduce damage** and **risks** for **humans** and the **environment**.

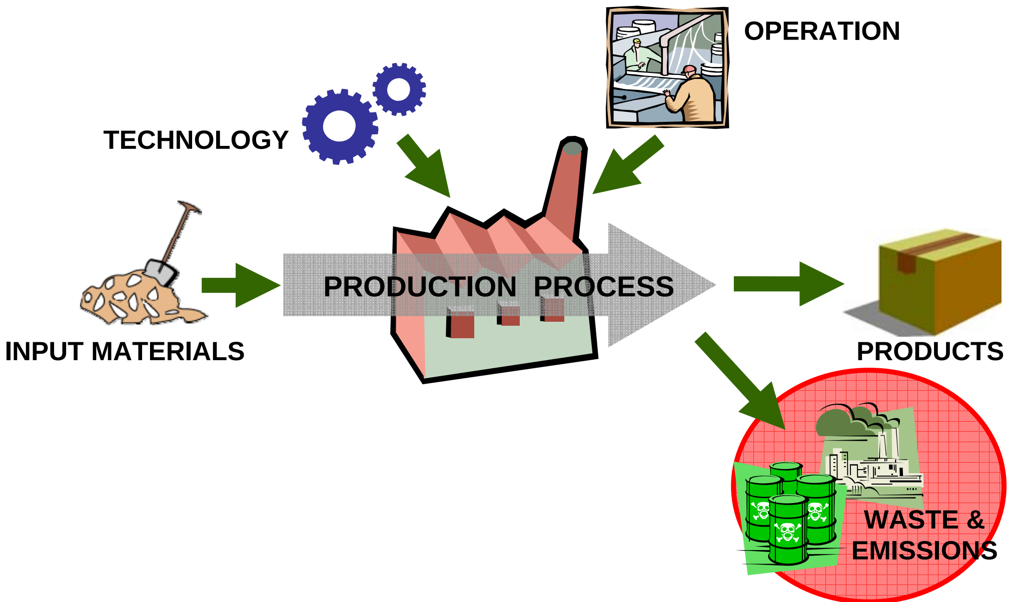


Figure 5.1: Production Process

CP is a method and tool to identify where and why a company are losing resources in the form of waste and pollution, and how these losses can be minimized.
Cleaner Production in 7 points:

1. CP adds value to the Environmental Management System (EMS): it places emphasis on pollution prevention rather than control, with clear improvement in environmental performance.

2. CP does not deny or impede growth but insists that growth can be ecologically sustainable.

3. CP is not limited only to manufacturing industries of a certain type or size, it can be applied towards the provision of services also.

4. CP includes safety and protection of health.

5. CP emphasizes risk reduction.

6. CP improves immediate efficiency as well as long-term efficacy.

7. CP is Win-Win-Win factor: it benefits the environment, communities and businesses.

What are the **benefits for industrials** ?
CP improves products and services

CP lowers risks (liability)
CP improves company image
CP improves worker's health and safety conditions
CP reduces waste treatment and disposal costs
CP can be integrated with the business EMS
CP saves costs on raw material, energy and water
CP makes companies more profitable and competitive

Implementing CP

Change inputs materials, water and energy:
>Replacing toxic or harmful materials with less toxic
> Use of renewable materials
> Use materials with longer lifetime
> Material purification

Technology change:
> Replacing
> Equipment modification
> Optimal process conditions
> Increased automation
> Improved process control
> Improved equipment lay-out

Improved operation practices:
> Production scheduling
> Energy management (peak shaving)
> Maintenance programmes
> Working instructions and procedures
> Training and incentives program
> Adequate process control operations
> Proper maintenance and cleaning

Product modification:
> Recycling friendly design
> Product Life Extension
> More efficient, less material intensive packaging
> Reduction of harmful substances.

On-site reuse and recycling:
> On site recovery and re-use of raw materials in the process, waste water, waste heat and cooling water
> Transforming waste into useful by-products
> Waste segregation and storage

Barriers to CP implementation
INTERNAL BARRIERS

> Traditional philosophy of CEOs (low awareness)

> Internal organisation and communication (initial constraints)

> Limited information, data and expertise on waste and emissions

> Focus on end of pipe solutions and short term profits

> Inadequate cost/profit calculations CP options

> Missing, outdated or unreliable process instrumentation

> No or limited support of middle management

> No EMS to achieve continual improvement

EXTERNAL BARRIERS

> Availability of investment capital

> Availability of CP technologies

CP methodology

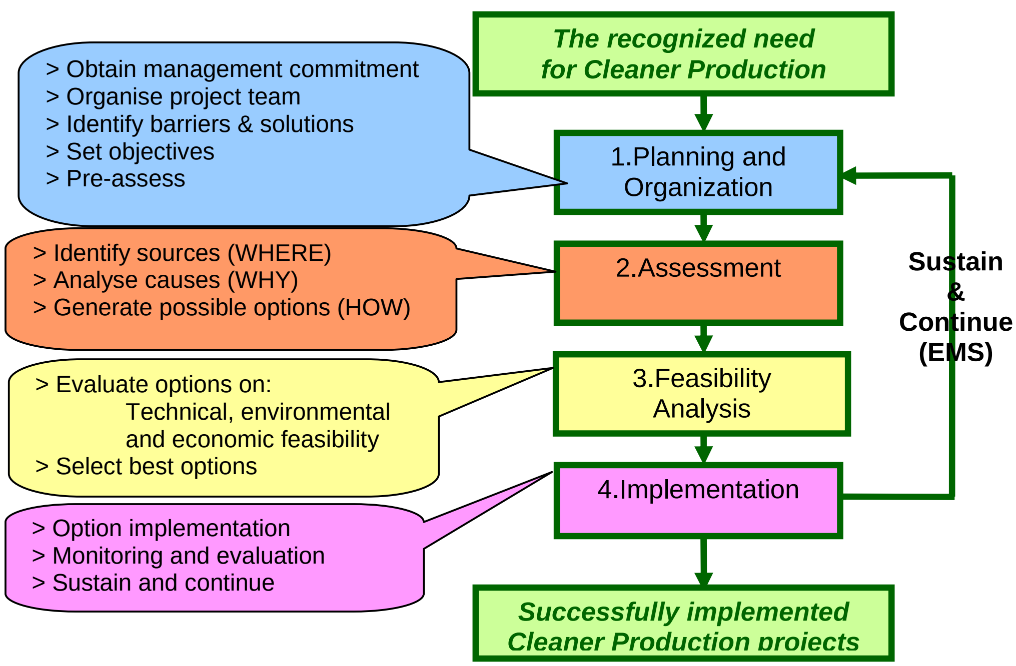


Figure 5.2: Methodology of Cleaner production

6.0 ERGONOMICS

Introduction

Ergonomics is an applied scientific discipline concerned with how humans interact with the tools and equipment they use whiles performing tasks and other activities**.** It was derived from the Greek words ergon, meaning work, and nomos, meaning laws**.** The word ergonomics was coined by British scientist K. F. H. Murrell and entered the English language in 1949. **Ergonomics** is synonymous with **Human factors.**

Ergonomics emphasizes work physiology and anthropometry (individual at work) and is used mainly in Europe for industrial work systems**. Human factors** emphasizes experimental psychology and systems engineering (the human element in a system).

Ergonomics was defined by The Ergonomics Society as "using knowledge of human abilities and limitations to design and build for comfort, efficiency, productivity and safety"

Objectives in Ergonomics

The main objective of Ergonomics is to improve the performance of systems consisting of people and equipment.

The specific objectives of ergonomics are:

- Greater ease of interaction between user and machine
- Avoid errors and mistakes
- Greater comfort and satisfaction in use of the equipment
- Reduce stress and fatigue
- Greater efficiency and productivity
- Safer operation
- Avoid accidents and injuries

Areas of Ergonomics Application

(i) Work system design: interaction between worker and the equipment used in the workplace

- Objectives: safety, accident avoidance, improved functional performance
- Also includes environment such as lighting

(ii) Product design

Objectives: safety, comfort, user-friendly, mistake proof

Our focus: work systems (which in fact overlap with the product design)

What do Ergonomists do?

(i) Research on human capabilities and limitations

- Discover the characteristics of human performance, e.g., how much can an average worker lift?

(ii) Design and engineering applications

- Use the research findings to design better tools and work methods

Philosophy of Ergonomics

The common philosophy prior to ergonomics is 'Fitting the Person to the Job' (FPJ). This considers worker's physical and mental aptitudes (skills) in employment decisions

- Psychometric testing (e.g., tests for intelligence and personality characteristics)
- For example, using worker size and strength as criteria for physical work

FPJ is still important for example using educational requirements for technical positions. However, the philosophy in ergonomics is the opposite of FPJ which is FJP (Fitting the Job to the Person) such that the job is designed in such a way that any member of the work force can perform it.

FJP philosophy has evolved because of:

(i) Changes in worker skill requirements

- Today, companies do not need to be much selective, since workers are much more educated. In stead of investing time in selection procedure, companies spend time to train the new workforce

(ii) Demographic changes (e.g. more women in the workforce, recruiting fewer people of young age)

(iii) Social and political changes (e.g., equal opportunity laws, trade unions, collective bargaining)

- Hiring handicapped workers is encouraged by the laws.

The Human-Machine Model in Ergonomics

This is defined as a combination of humans and equipment interacting to achieve some desired result (e.g. external vs. internal work elements, levels of operator attention)

Types of human-machine systems

There are three types of human-machine systems in ergonomics and these are:

1. Manual systems: a person using some (nonpowered) tool
2. Mechanical systems: one or more humans using powered equipment
3. Automated systems: automated system requiring occasional human attention

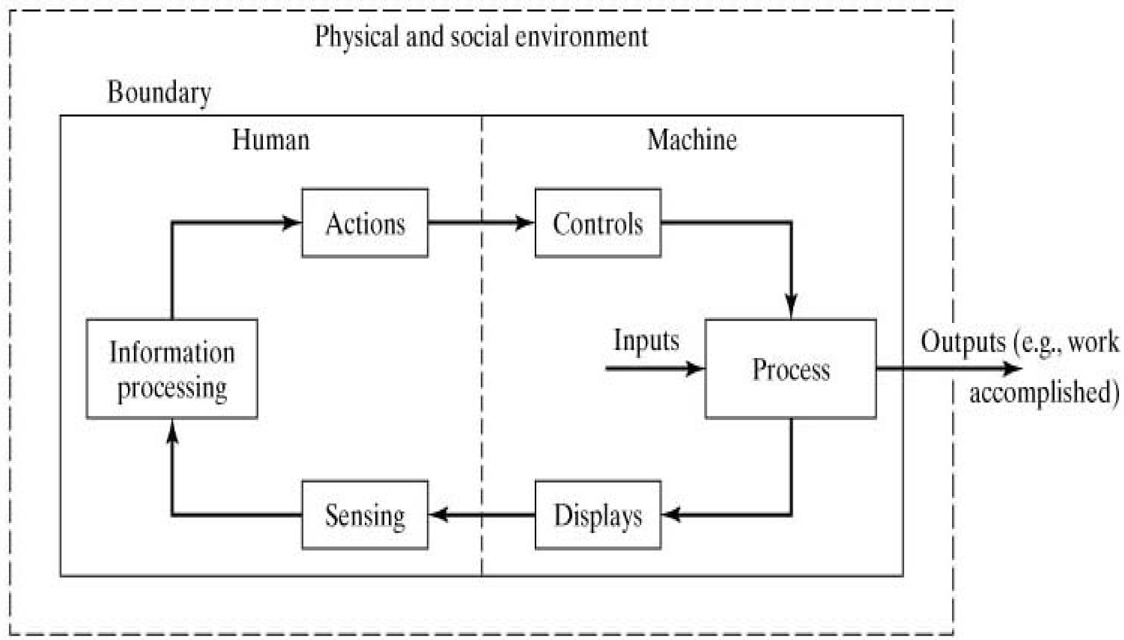


Figure 6.1: The Human-Machine Model in Ergonomics

- A human-machine system has boundaries, that define what components are included within the scope of the system.

- A worker-machine production cell is one component in the larger production department.

- The ergonomist must decide where to draw the boundaries of the human-machine system of interest.

System Components
Setting the boundary matters because
  - it identifies controllable / uncontrollable
  - it reflects what the human -machine system operation is assumed to be

- The human
- The equipment
- The environment (both physical and social)
  - Poor lighting may effect worker's ability to perform an inspection task
  - An unfriendly supervisor may reduce a worker's motivation to work.

Human Components
Functions: (1) sensing the operation, (2) information processing, (3) actions
  - Human senses - to sense the operation
    - Five basic human sense (vision, hearing, touch, taste, and smell)
    - Related with sensory (+ nerveous) system of the body

- Human brain - for information processing by the stimuli received from the senses
    - Thinking, planning, calculating, making decisions, solving problems
    - Related with the brain

- Human effectors - to take action by the impulses from the nervous system
    - Fingers, hands, feet, and voice
    - Related with the musculoskeletal system (+ nerveous) system of the body.

Machine Components

- The machine in a human machine-system can range from a simple hand tool to a complex and sophisticated system of equipment.

- The process – function or operation performed by human-machine system

- Displays - to observe the process
    - Direct observation for simple processes
    - Artificial displays for complex processes (speedometer in a car)

- Controls - to actuate and regulate the process
    - Steering wheel, computer keyboard

- A worker using a shovel to dig a hole in the ground.
    - Process: digging, Displays: direct observation (no need for displays), Controls: handle of the shovel

- A worker monitoring the operation of an automated process. The worker should make sure that the process is within defined tolerances
    - Process: process itself, Displays: a digital monitor, Controls: buttons, levers

Environmental Components

- Physical environment
    - Location and surrounding lighting, noise, temperature, and humidity

- Social environment
    - Co-workers and colleagues at work
    - Immediate supervisors
    - Organizational culture
    - Pace of work

Divisions of Ergonomics

Ergonomics can be divided into the following:

1. Physical Ergonomics
2. Environmental Ergonomics
3. Cognitive Ergonomics and
4. Organizational Ergonomics

Physical Ergonomics is the study of the human anatomical, anthropometric, physiological and biomechanical as they relate to the physical activity of man. It can also be referred to as the physical interactions that people have with devices, making these interactions safe, error free and efficient. The topics under this division of ergonomics include working postures, materials handling, repetitive movements, work related musculoskeletal disorders, workplace layout, safety and health (www.ergonomics.jp/original/inter/ergodef-_physical.html).

Environmental Ergonomics concentrates on the interaction between man and his ambient environment. The topics under this include climate (temperature, humidity, heat and radiation), noise, vibration, lighting, pressure and so on as they affect the man.

Cognitive Ergonomics is concerned with mental processes such as perception, memory, reasoning and motor response as they affect interactions among humans and other elements of a system. It refers to how people or teams interact with a system (or each other while using a system) from a psychological perspective. The topics here include mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress and training as they relate to human-system design.

Organizational Ergonomics is the study of the optimization of socio-technical systems including their organizational structures, policies and processes. The topics under this division of ergonomics include communication, crew resource management, work design, design of working times, teamwork, participatory design, community ergonomics, cooperative work, new work paradigms, organizational culture, virtual organizations and quality management (www.ergonomics.jp/original/inter/ergodef_organizational.html)

Anthropometry

Anthropometry as stated earlier is an aspect of physical ergonomics. It is the subject that deals with the measurement of human body dimensions and is the basic aspect of ergonomics which provide the basis for the compatibility of man with tools and work stations. It provides the data needed to determine allowable space and equipment size and shape used for the work environment. Factors that are considered include agility and mobility, age, sex, body size, strength, and disabilities. Engineering anthropometry applies these data to tools, equipment, workplaces, chairs and other consumer products, including clothing design. The objective is to provide a workplace that is efficient, safe and comfortable for the worker to enhance productivity.

Use of anthropometric data

It is very much essential in the design when items are designed for specific groups such as adult males, children, etc., the data used should be specific for such groups in the country or culture in question.

Principles in the Application of Anthropometric Data

Design for extreme individuals: Designing for maximum population value is the recommended strategy if a given maximum (high) or minimum (low) values of some design feature has to accommodate all.

Design for adjustable range: Designing for adjustable range is to provide adjustment to cover the range of 5^{th} percentile female to the 95^{th} percentile male of the relevant population characteristics.

Design for average: Designers often design for the average as a compromise as they do not have to deal with a large anthropometric data.

Manual Work and Design Guidelines

5.33 kcal/min for men, 4 kcal/min for women, is a proposed limit for acceptable average energy expenditure over an 8 hr day (Bink, 1962)

Energy expenditure produces:

- Lactic acid
- Carbon dioxide
- Heat

Energy expenditure can be measured by oxygen consumption: compare O_2 in air inhaled vs. O_2 in air exhaled.

Heart Rate

- Heart rate should not be allowed to increase more than 40 beats/minute during work over resting pulse.
- Heart rate creep:
  - Watch for a gradually increasing heart rate.
  - If heart rate keeps going up then worker is not getting sufficient rest: fatigue is increasing.
- Factors that may impact heart rate and fatigue:
  - Physical workload
  - Heat
  - Mental stress (e.g. air traffic control)
- Rest may be needed if:
  - Average energy expenditure is too high,
  - Heart rate is too high,
  - Environment is too hot to allow body to rid its self of heat
- Short, frequent rest cycles are best

R = (W – 5.33) / (W – 1.33)

R = Time required for rest as % of total time spent working

W = Average energy expenditure for task

5.33 kcal/min is max allowable energy expenditure for *men*,

(substitute in 4 kcal/min for women)

1.33 kcal/min is the energy expended during rest.

- *Estimate* how much rest needed for an average male performing a shoveling task:
  - Task: shoveling dirt; with approximately 16 lb in each shovel.
  - Energy expenditure = W = 8.5 kcal/min
  - Percent rest required =

R = (W – 5.33) / (W – 1.33) = (8.5 kcal/min – 5.33) / (8.5 kcal/min – 1.33)

= .414 (e.g. 41 percent of the time needs to be rest).

- This means that workers should rest approximately 25 minutes out of every hour.
- Is it better to give workers …?
  - 1.7 hour breaks out of every 4 hours, (2 long breaks per day)

- 8 minutes breaks out of every 20 minutes (many short breaks per day)

- Suppose you find that over course of the work cycle that you have chosen, that the worker's heart rate goes up *more* than 40 beats per min. over his resting pulse?
- Additionally, the worker is complaining of the heat.
- In what ways can you modify the:
  - Work/rest cycle,
  - Task
  - Tools
  - Environment
  - Etc.

to improve the situation?

- Total force on disc L5, S1 (in lower back) should not exceed 770 lb.
- The total force on the spine is the sum of:
  - Force exerted by spine muscles to counter balance torque,
  - Force exerted by load.

$$\mathbf{F_{COMP} = F_M + F_L}$$

$\mathbf{F_M}$ is spine muscle force. $\mathbf{F_L}$ is weight of the load, $\mathbf{F_{COMP}}$ is the total compressive force on the spine.

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