Beginning Engineering Graphics
7th Week Lecture Notes
Instructor: Edward N. Locke

Topic: Dimensions, Tolerances, Graphs and Charts

1st Subject: Types and Conventions of Dimensions and Notes

A. Definitions and general principles: Placing the sizes of objects on drawings is called dimensioning. Dimensions are usually placed outside the object. Dimension lines are drawn on each side of the dimension figure to show its direction and extent, with arrowheads at the ends to touch the extension lines. The extension lines project from the object but do not touch the object. Dimensions relate to the actual size of the object, NOT to the size shown on the drawing paper because most drawings are "to scale" (not drawn to full size).

B. THE CORRECT CONVENTIONS OR STANDARD PRACTICES OF DIMENSIONING:

Line type: thin but dark and solid lines (drawn with a sharp medium hard pencil such as H or 2H) that include the following four types.

- **Extension line:** the gap between the extension line and the object line is 1/16" (.062"). **The extension line continues to around 1/8" (.125") beyond the outermost arrowhead.**
  The gap between the extension line and the object outline: 1/16" or 1.5 mm.
  There is never any gap where an extension line crosses any other line.
- **Dimension line:** it has an **arrowhead** at each end. Except in architectural or structural drawings, a gap is left near the middle of the dimension line for placing the dimension figure.
  The size of the arrow: L=1/8" (3 mm), H=L/3 (for average use). The length of the arrowhead should be equal to the height of the dimension whole numbers.
  Spacing between dimension lines: at least 1/4" (.250", or 6 mm) for small drawings.
  Spacing between the object line and the nearest dimension line: at least 3/8" (.375")
  for small drawings.

NOTE: The spacing must stay uniform and consistent throughout the entire drawing.

The dimension line meets the extension lines at right angle EXCEPT under special circumstances related to the need for clearness or to availability of space in a drawing (See attached Dimensions Examples Sheet).

- **Center line:** Center lines are thin and dark lines composed of alternate long and short dashes, and are used for locating the center of holes or axis of symmetrical parts. Center lines should ALWAYS end in a long dash and about ¼" (.250") outside the hole or feature.
- **Leader:** it "leads" from a note or dimension figure with a short horizontal "shoulder" extending from the mid-height of the lettering, and terminates with an arrowhead touching the part of the related object. Leaders are straight inclined lines drawn at any convenient angle (usually at 45°, 60° or 30° with horizontal), and are NEVER vertical

or horizontal. The inclined line should be able to pass the center of a circle if extended. Leaders may extend from either the start or end of a note or dimension.

Principles of Correct Placement of Dimensions:

- The smallest dimensions should be placed closest to the object and lined up in "chain".
- The overall dimension should always be farthest from the object. Avoid crossing dimension lines whenever possible.
- The dimension lines should NEVER coincide with an object line or join end to end with a line of the object without using extension lines.
- Avoid placing dimensions on a view EXCEPT when it is difficult to find places for dimensions with clearness and directness in some complicated drawings.
- Unless absolutely necessary, NEVER allow the extension lines to cross object lines.
- Extension lines may cross each other freely and should never be shortened or broken with a gap at crossing points (with each other or with an object line under necessary circumstances).
- Smaller dimensions should be lined up and grouped as much as possible.
- In crowded conditions, and in order to clarify the dimensions, gaps in extension lines may exist near arrowheads.
- In general, avoid dimensioning of hidden lines of complicated object interior; instead, dimension the object lines in sectional views.
- **The Principle of Contour Dimensioning:** dimensions should be attached directly to the view that shows the shapes (or contours) of the various features of the object. Doing so will automatically prevent the attachment of dimensions to hidden lines or to a particular view that does not clearly show the meaning of a particular visible line.
- For sectional view, place dimensions outside of the sectioned area as much as possible. When it is absolutely necessary to place dimensions inside the sectioned area, leave gaps in the sectional lines for dimension figures. NEVER letter any dimension figure over any line on the drawing, but break the line if necessary.
- In a group of parallel dimension lines, stagger the numerals instead of stacking them one above the other.
- When using decimal-inch dimensions, a zero is not used before the decimal point of values smaller than 1". The decimal-inch dimensions are expressed to the same number of decimal places as its tolerance; therefore, zeros are added to the right of the decimal point as necessary, like

  1.500 ±.002

  Avoid superfluous, duplicate or unnecessary dimensioning, give dimensions in the most direct and simple way according to shop requirements. (See attached Dimensions Examples Sheet for problems of superfluous dimensioning).
- Dimension figure should be about 1/8" (3 mm) high for whole numbers and ¼" (6 mm) for fractions.
- Fraction bars should always be horizontal, NOT inclined, except in confined areas such as in tables.
- In general, circles are dimensioned by their diameters, and arcs are dimensioned with their radii.

For dimensioning circles, always place the symbol ϕ before a metric diameter dimension value, DIA after a customary diameter value. For dimensioning arcs, always place the letter R before a metric Radius dimension value, the letter P after a customary radius value. The radial dimension line should have only one arrowhead, and it should touch both the arc center and the arc.

C. Dimensioning angles: use circular dimension lines; and preferably, letter the dimension figures on horizontal guidelines, EXCEPT for larger angles where circular guidelines may be used.

D. Two ways to place dimensions on a drawing:

1. **Aligned system:** the dimension figures are lettered parallel to the dimension lines; in this system, horizontal dimension figures are parallel with the bottom of the drawing paper, vertical dimensions are parallel with the right side of the paper.
2. **Unidirectional system:** all dimensions are lettered parallel with the bottom of the drawing paper. This is the preferred system.

E. Dual Dimensioning: both customary and metric dimension figure are placed on a drawing in either one of the two following methods:

1. Both customary and metric dimension sizes are placed where the dimension figures normally go, the "Design Size" (the units used to design the object in the first place) is shown first, followed by the equivalent conversion size in [ ], and a unit footnote in the drawing. Examples:
   3 [76.2], or in [mm]
   DIMENSIONS IN [ ] ARE MILLIMETERS
2. Show the sizes in a "Conversion Table" with the design size or the "Code" lettered on the dimension lines. The "Design Size" (the units used to design the object in the first place) shown first, followed by the equivalent conversion size. Examples:

CONVERSION TABLE		
CODE	IN.	MM
A	1	25.4
B	3	76.2

With CODE shown on dimension lines

CONVERSION TABLE	
IN.	MM
1	25.4
3	76.2

With customary sizes shown on dimension lines and a footnote that reads: ALL DIM. IN INCHES

NOTE: The method used for dual dimensioning in any drawing should be uniform and consistent.

F. Bill of Materials: a list of materials needed to build a project.

Example 1:

BOOKRACK BILL OF MATERIALS

1 PIECE - ¾” x 5¾” x 16” [19MM x 146MM x 406MM]
2 PIECES - ¾” x 5¾” x 16” [19MM x 146MM x 203MM]
4 ROUND HEAD WOOD SCREWS

Example 2:

KNIFE HOLDER	BILL OF MATERIALS
SLOTS FOR KNIVES	1 PIECE WOOD - 10 x 45 x 250MM
40MM LONG	1 PIECE WOOD - 20 x 60 x 250MM
50MM APART	1 PIECE ACRYLIC - 250 x 250MM
	2 ROUND HEAD WOOD SCREWS

METRIC

G. Dimensioning of Fillets and rounds: only a few typical radii (but not every single fillet or round) need dimensioning. In case all fillets and rounds are uniform in size, dimensions may be omitted and replaced by a note such as:
ALL FILLETS R.75 AND ROUNDS R.150
or ALL FILLETS & ROUNDS R.250

H. Inch Mark: when all dimensions are in inches in a drawing, it is common practice to omit all inch marks EXCEPT in case this may lead to misinterpretation of dimensions or notes. Examples of the use of inch marks: 1” DRILL

I. Finish Marks: A finish mark is a symbol to indicate that a surface is to be finished or machined; it tells the patternmaker to allow extra material on the pattern which will provide extra metal on the casting to be removed in machining; and it also tell the machinist to machine the surface. The finish mark can be:

- V-type finish mark: a 1/8” high V with the point pointing inward toward the solid metal like a cutting tool.
- f-type finish mark: an italic 3/16” high f with both the left segment of the bar and the main stroke forming a 60º angle with the surface line.

J. Dimensioning Arcs: give the radius in the view that shows the true shape of the arc. The letter R always follows the figure (Example: 1½R). The dimension figure and arrowhead should be inside the arc EXCEPT when the space is too crowded.

K. Geometric Breakdown and Dimensioning: All objects can be broken down into basic geometric solids, i.e. prism, cylinder, cone, and sphere, either positive (shaft) or negative (hole).

1. **Size Dimensions of Prisms:** it needs three dimensions (width, height, and depth). Dimensions should be placed between the views or aligned on one side.
2. **Size Dimensions of Cylinders:** place both its diameter and length in the rectangular view. Never give the radius of a cylinder or give the diameter in the circular view, either diagonally across the circle or between extension lines from the circle. An exception to this rule is made when dimensioning a hole where the shop operation is given in a note, or in dimensioning a large hole or a bolt circle. The letters DIA follows the figure if necessary for showing that the dimension refers to a cylindrical shape (Example: 1¼DIA) but can be omitted.
3. **Size Dimensions of Cone:**

- Place both the diameter of the base and the altitude in the triangular view.

- Place both the diameter of the base and the angle in the triangular view.
- Place two diameters and the altitude in the triangular view.
- Place one diameter and the taper by note in the triangular view.

4. **Size Dimensions of Pyramids:** place the two dimensions of the base in the square or rectangular view, and the altitude in the other view. If the base if a square, give one dimension only with the letters SQ following the figure (Example: 2 SQ).

L. Location Dimensions: location dimensions are used to locate the distance between geometric shapes after the size dimensions of these shapes have been given. Rectangular shapes are located from surface to surface. Cylinders are located from their center lines. Location dimensions for holes should be given in the circular view of the holes if possible. For symmetrical cases, location dimensions are needed for one side only. In case of multiple holes with their centers arrayed in a circle, a reference diagonal diameter is needed, and letters REF follows the figure (Example: 3.250 REF)

M. Dimensioning Rounded Ends: rounded ends are dimensioned according to the shop methods used. Generally, give the center-to-center distance and the radii of the ends. For milled slot, give the full length of the milled slot which represents the total travel of the milling cutter, as well as the width or diameter of the slot. (See attached Dimensions Examples Sheet).

N. Dimensioning Curves:

1. **For continuous curve made up of a series of circular arcs,** give the various radii and the center of the arcs. For extremely large radius of the arcs, the center of the arc may be drawn closer to the arc with a zigzagging dimension line to indicate that it is a representative rather than the actual center of the arc (See attached Dimensions Examples Sheet).
2. **For curves not made up of circular arcs or if the use of radii is not desired,** then give a series of dimensions (horizontal and vertical) at regular intervals.

O. Pattern and Machine Dimensions: The pattern maker and the machinist both follow the same working drawing which shows the completed object; however, some dimensions are used only by the pattern maker, some only by the machinist, some by both. For large and complicated parts, two separate drawings are sometimes made for the pattern maker and the machinist. For forgings, it is a common practice to make separate forging drawings and machining drawings.

The pattern maker uses only the dimensions needed to make the wood pattern from which the rough work piece is molded in sand; since castings are not exactly uniform or accurate, therefore, pattern dimensions are rough, to about the nearest 1/16", and given in whole number or fractions.

The machinist uses only the dimensions needed to machine the various holes and surfaces. If accuracy no greater than the nearest 1/64" is required (corresponding to the 1/64" divisions on the machinists scale), the dimensions are given in whole numbers and fractions. If greater accuracy is required, such as for the size of the hole for the shaft, the dimensions are given in decimals.

P. Decimal Dimensions: some parts (some locomotive, railroad car or agricultural machinery parts, etc) do not need to be more accurate than 1/64", and are therefore dimensioned entirely with whole numbers and common fractions in their drawings.

Others (such as milling or sewing machine parts) require higher degree of accuracy, and therefore, dimensions must be given in decimals. Most parts require only certain key dimensions to be high accurate and given in decimals while the others can be "rough" and given in common fractions. Architectural drawings or woodwork drawings only need dimensions in whole numbers and fractions. A system increasingly used and preferred by the ANSI (American National Standards Institute) is the complete decimal system (especially in the automobile and aircraft industries). The complete decimal system uses two or more decimal places.

Q. Notes: Notes are used to supply additional information usually related to shop requirements, should be brief and accurate, permitting only one interpretation, and following standardized wording and form. Notes should always be lettered horizontally and placed in an appropriate, open space, to the correct view (not between views if possible). Notes and leaders should always be placed after the dimensioning is substantially completed. Two types of notes:

- **General Notes:** They give general information about the whole drawing. They are usually placed in the lower-right portion of the drawing sheet, above or to the left of the title block, or in a central position below the related view. Many general notes for material, heat treatment, pattern information, number of pieces required and general tolerances are carried by the title strip in machine drawings. Example of a general note:

  FINISH ALL OVER (FAO)
  FILLETS AND ROUNDS ¼ R
  BREAK SHAPE EDGES TO R.8
  ALL DRAFT ANGLES 3° UNLESS OTHERWISE SPECIFIED

- **Local Notes:** They apply to specific items or operations and are connected by a leader to the appropriate point on the drawing. The leaders are always attached at the front of the first word or after the last word of a note, and never to any other part. Examples:
  ½ DRILL 3 HOLES
  1/8 x 45° CHAMFER

Use of symbols and abbreviations in notes: See attached ANSI Standards.
Notes for Holes: See Handouts.

R. Tabular Dimensioning: For a series of objects with similar features but different dimensions, one drawing is usually made with all dimension figures substituted by letters, and with the varying dimensions listed in a table. This method is used for dimensions of many standard parts in catalogs and handbooks. See attached Dimensions Examples Sheet.

2nd Subject: Tolerances

A. Mating Dimensions: two or more parts that fit together are matting parts; on two matting parts, some dimensions must correspond to make the parts fit together. Mating dimensions are those that correspond in the separate drawings of the mating

parts needed for the accurate fitting of the parts; dimensions that agree on two mating parts but are not essential for accurate fitting are not matting dimensions. The actual values of two corresponding mating dimensions, while close, may not be exactly the same, for example, the width of a slot may be 1/32" or 1/64" or several thousands larger than the projection that fits in the slot. This is necessary for providing the mating parts with some "space" to fit properly.

General Types of Fits: A fit is a range of tightness that may result from the application of a specific combination of allowances and tolerances in the design of mating parts. There are three general types:

- **Clearance fit:** one having limits of size so given that a clearance always results when mating parts are assembled. If there is a positive allowance or difference between the largest shaft and the smallest hole, then the resulting fit is a clearance fit.
- **Interference fit:** one having limits of size so given that an interference always results when mating parts are assembled. If there is a negative allowance or difference between the smallest shaft and the largest hole, then the resulting fit is an interference fit.
- **Transition fit:** one having limits of size so given that either a clearance or an interference may results when mating parts are assembled. (See attached Dimensions Examples Sheet).

Basic Hole and Shaft systems:

- **A basic hole system** is a system of fits in which the hole size is considered as the basic size, and the allowance is applied to the shaft. For a clearance fit, the difference or allowance is subtracted from the basic hole size; the minimum clearance is the difference between the smallest hole and the largest shaft, and the maximum clearance is the difference between the largest hole and the smallest shaft. For an interference fit, the desired allowance or maximum interference is added to the basic hole size.
- **A basic shaft system** is a system of fits in which the shaft size is considered as the basic size, and the allowance is applied to the hole. For a clearance fit, the difference or allowance is added to the basic shaft size; the minimum clearance is the difference between the smallest hole and the largest shaft, and the maximum clearance is the difference between the largest hole and the smallest shaft. For an interference fit, the desired allowance or maximum interference is subtracted to the basic hole size.

Note the contrasts and similarities between the two systems.

Definition of "Size" adopted by ANSI Standards (ANSI B4.1 and Y14.5):

- **Nominal Size:** The designation used for the purpose of general identification**.** For example:
  If among the two mating parts, the limits of size for the shaft are 1.498 and 1.496, the limits of size for the hole are 1.502 and 1.500, then,
  the nominal size is 1½" for both shaft and hole.
- **Basic Size:** The size from which the limits of size are derived by the application of allowances and tolerances. In the above example, the basic size is the decimal equivalent of the nominal size 1½", or 1.500".
- **Design Size:** The size from which the limits of size are derived by the application of tolerances. When there is no allowance, the design size is the same as the basic size.

In the above example, the design size for the shaft is 1.498" (diameter of largest shaft), and the design size of the hole is 1.500" (diameter of smallest hole).

- **Actual Size:** A measured size.

P. Limit Dimensions: the permissible amount of "oversize" or "undersize' for each dimension of mass-produced parts, which allows every part to fit properly in assembly.

- **Limits of Size:** The maximum and minimum sizes.
- **Tolerance:** The total permissible variation of a size, or the difference between the limits of size. Tolerances can be **Unilateral Tolerance** (variation permitted only in one direction from the design size, either toward a larger size or toward a smaller size; either the plus or the minus value must be zero), or **Bilateral Tolerance** (variation permitted in both direction of the design size, toward both larger and smaller size).
- **Allowance:** An intentional difference between the maximum material limits of mating parts, either a minimum clearance (positive allowance) or maximum interference (negative allowance) between mating parts. For example, the minimum space between the largest shaft and the smallest hole is clearance or positive allowance.

Two ways to give limit dimensions:

- Larger figure on top and smaller figure at bottom.
- A basic size figure followed by stacked plus and minus figures.

Note: in drawings containing limit dimensioning, give baseline dimensioning from one common surface. Never give a complete chain of tolerance dimensions and also an overall tolerance dimension. Otherwise, difficulties will arise due to the accumulation of tolerances in a chain of dimensions.

3rd Subject: Title Blocks

A. Functions of the Title Blocks: to show all necessary information not given directly on the drawing with its dimensions and notes, in an organized manner, using forms preferred by ANSI or adapted by respective companies. Title blocks pre-printed on standard-size sheets in increasing use, allowing drafters to merely fill in the blank spaces. The title form is usually placed along the bottom of the sheet, but can be along other edges of the drawings depending on the company's usage. Letters should be single-stroke vertical or inclined Gothic capitals. The items in the title form should be lettered according to their relative importance, using line weight, size, spacing of letters or a combination of all of them. The drawing number should receive greatest emphasis, followed by the name of the object and the name of the company. See attach ANSI Y14.2M-1979 Recommended Minimum Letter Heights Table.

B. Information Needed in the Title Blocks:

- Name of the object.
- Name and address of the manufacturer, and of the purchasing company, if any.
- Name and signature of the drafter and the date of completion.
- Signature of the checker and the date of completion.

- Signature of the chief drafter, chief engineer, or other official, and the date of approval.
- Scale of the drawing.
- Number of the drawing (Some companies use serial numbers with prefix or suffix to indicate the sheet size, such as A67009 or 67009–A; other use other numbering scheme with various parts of the drawing numbers that indicate different things such as model number of the machine or the general use and nature of the parts.). Use a simple numbering system. Letter the drawing number 7 mm (.250") high and place it in the lower-right corner (right-side up) and upper-left corner (up-side down) of the sheet. See attached example.

C. Additional Information That May Be Given: material, quantity, heat treatment, finish, hardness, pattern number, estimated weight, superseding and superseded drawing numbers, symbol of machine, etc..

4th Subject: Application of Charts, Graphs and Diagrams

- **Bar charts:** used to show comparison.
- **Line charts:** used to show trends.
- **Pie charts:** used to show percentage.
- **Pictographs:** use picture symbols to represent units or quantities.

Study Questions:

1. What is dimensioning? Where are dimensions usually placed?

2. Do dimensions relate to the actual size of the object or to the size shown on the drawing paper?

3. Use ruler, compass and pencil to draw a rectangle, an angle, a circle and an arc and add dimensions (including center line for the circle).

4. How do dimension lines look?
5. How big is the gap between the extension line and the object line?
6. To what length does an extension line continue beyond the outermost arrowhead?
7. The gap between the extension line and the object outline is:

8. Can there be any gap where an extension line crosses any other line?
9. What is the size of the arrow of a dimension line?
10. What is the minimum spacing between dimension lines for small drawings?
11. What is the minimum spacing between the object line and the nearest dimension line for small drawings?
12. Refer to examples on the handouts, draw a few leaders with notes including one with a circle.

13. Identify the objects that are dimensioned in a wrong way on the attached handout.
14. Tell me if the following dimension figure is expressed correctly or not and explain the reason: $1.3 \pm .002$

15. What is superfluous dimensioning?

16. Draw four simple objects with similar shape such as a rectangle and give an example of aligned, unidirectional, dual dimensioning and dual dimensioning with a conversion table.

17. Draw a V-type finish mark and a f-type finish mark.

18. Tell me what dimensions are needed and where to place them for the following solids:

Type of solids	**Dimensions needed**	**Location to place dimensions**
Prisms		
Cylinders		
Cones		
Pyramids		

19. What is the purpose of using location dimensions and when should they be made?

20. How are rectangular shapes located? Draw an example.

21. How are cylinders shapes located? Draw an example.

22. How are holes located? Draw an example.

23. Draw a continuous curve made up of a series of circular arcs and give dimensions. Then, draw a curves not made up of circular arcs and give dimensions.

24. Refer to examples on the handouts, draw an example for each of the three fits: Clearance,
Interference, and Transition.

25. Draw two mating parts and give a definition and an example of the following concepts: Nominal Size, Basic Size, and Design Size.

26. Give a definition and an example of the following concepts: limit dimensions (two methods), limits of size, unilateral tolerance, bilateral tolerance, allowance (clearance and interference).

27. What is the smallest division on the machinists scale?
28. When is decimal dimensioning needed? and usually to how many decimal places?

29. What are the major difference between general notes and local notes?

30. Under what circumstances is tabular dimensioning usually used?

31. Give examples of customary and metric dimensioning of circles and arcs.

32. The height of whole numbers and fractions in dimension figures should be how much? How should the fractional bar usually look like?

33. What items should be included in the title block? Draw an example.