CHAPTER 10
Measurement and Inspection

Review Questions

1 .In order for parts to be interchangeable, they must be manufactured to the same standards of measurement. Simply put, everybody's definition of an inch or a centimeter must be the same identical measurement. In addition, certain sizes and shapes (like threads on a shaft or teeth on a thread) are standardized. Thus, all spark plugs for automobile engines have a standard diameter size and thread shape to fit into everyone's sockets. Standardization is fundamental to interchangeability and interchangeability is fundamental to repetitive part manufacture and mass production.

2. The least expensive time to make a change in the design is before the part is being made. Putting the manufacturing engineering requirements into the design phase helps insure that the part can be economically fabricated.

3. Attributes inspection seeks to determine if the part is good or bad. Variables inspection requires a measurement be made to determine how good or how bad and thus, more information about part quality is obtained. If your car has an oil pressure gage, you always know what the oil pressure is (variables), but if it only has a warning light, you only know whether the pressure is good (no light) or bad (light comes on).

4. Warning lights (usually red) readily alert the driver to a bad situation, whereas the driver may completely ignore a low gage reading. The driver may not even know what a bad reading is or that a dangerous condition exists, or worse, what the gage is actually informing him or her about. Most cars today have both kinds of inspection devices to keep the driver informed. Sometimes the decision to change is based on economics as attributes gages are usually less expensive than variables types.

5. The four basic measures are: length, time, mass, and temperature.

6. Gage blocks are small solid pieces, either rectangular, square, or round with two very flat and parallel surfaces that are a certain specified distance apart. They are made from steel, carbides or ceramics and provide linear standards of high accuracy.

7. The grades of gage blocks are laboratory, precision, and working - in decreasing level of accuracy. The blocks come in sets so that they can be "wrung" together into any length needed from 0.1001 to over 25 inches in increments of 0.0001 inch.

8. The surface tension of an ultrathin film of oil between the very smooth, flat, block faces keeps the blocks locked together. Because they are so smooth and in such intimate contact, they can actually weld together via diffusion if left in contact for prolonged periods of time.

9. To determine the aim of a process, one needs measures of accuracy. To determine

the variability in a process, one needs measures of precision. Accuracy is measured by distribution means and precision is measured by variances or standard deviations (square roots of variances). A process capability study is usually performed by taking samples of the output from the process and measuring them for the desired characteristic.

10. The allowance determines the desired basic fit between mating parts. Tolerance takes into account deviations from a desired dimension and fit, and are necessary in order to make manufacturing practicable and economical.

11. (a) Sliding fit would be too loose and wring fit, too tight - therefore, snug fit, hand assembled. (b) Obviously, a sliding fit as the speed is very low. (c) Free fit with liberal allowance as speeds are high and so are pressures.

12. A shrink fit is permanent, but can be disassembled by proper heating and/or cooling of the members. The word shrink implies that one element is heated (to expand it) and the other is cooled (to shrink it). Then the elements are joined to form a shrink fit. A weld is absolutely permanent -- cannot be disassembled without ruining the parts.

13. The axles are made out of steel and are subject to fatigue. The wheels are a form of iron and subject to wear. Welding would make a permanent joint whereas shrink fitting allows the wheels to be removed if worn or reused if the axle fails.

14. Repeatability is a measure of the consistent accuracy of the measuring instrument. Reproducibility factors in the skill of the operator making the measurement. How consistent would this individual achieve the same measurement with the same instrument.

15. In timing operations or processes, it is important to be accurate. Multiple timings quickly reveal the variability in the timing process, often resulting in handheld measurements being replaced by automatic/electronic devices. A good example would be timing a 100 meter race or in football, the 40 yard dash - accuracy is what is needed in order to know how the numbers compare to other runners.

16. Interferometry is an example of an optical inspection.

17. The factors should include the rule-of-ten, linearity, repeat accuracy, stability, resolution and magnification, the type of device, the kind of information desired (attributes or variables), the size of the items to be measured, the rate at which they must be measured, and the economics of buying, installing, and using the device.

18. Magnification of the output of a measuring device beyond the limits of its resolving capability is of no value. Magnification of a photographic negative beyond the size of the silver halide grains results in grainy photographs. Every measuring device has a limit to its resolving capability. All the magnification in the world will not change that limit.

19. Parallax is the apparent change in the position of an object when it is viewed from a different direction, i.e. the position from which the object is viewed has an effect on the apparent position of the object. Tennis linesmen want to maintain their position so that the apparent position of the ball does not change due to the linesman moving his/her position.

The linesman looks right down the line and tries not to move his/her head. A spectator with a different viewing angle than the line judge will see an apparently different ball position.

20. The measuring instrument should be an order of magnitude (10 times) more precise than the object being measured. This rule actually refers to the gage capability. Gage capability is determined by gage R&R studies. See Statistical Quality Design and Control by DeVor, et al.

21. The 25 divisions of the moveable vernier plate are equal in length to the 24 divisions on the main scale. Thus each division on the vernier equals 1/25 of .6 or .024 inches. Each division on the main scale is equal to 1/24 of an inch or .6 or 0.025 inches. Thus each division on the vernier is 0.025 - 0.024 = 0.001 inches less than each division on the main scale.

22. The micrometer is sensitive to the closing pressure and the lack of pressure control. Errors in analogue devices are also made by misreading the barrel by a factor of 0.025.

23. They are both about the same order of magnitude in terms of their precision and repeatability, but the micrometer has a limited size range and, thus, must be purchased in sets (quite expensive), whereas a vernier can measure a wide range of sizes with one device.

24. The micrometer is more rugged and better suited for the industrial setting (shop floor). It is also less sensitive to dirt and it is easier to teach someone how to read it.

25. The device tends to lift itself off the surface if too much torque is applied.

26. Optical means are used so that nothing touches and thus distorts a delicate part.

27. Parts can be measured directly using the micrometer dials or compared with a profile or template drawn directly on the screen. The images on the screen can also be directly measured by a ruler and these dimensions then divided by the magnification being used --usually 10 to 20X. The projector magnification should be checked, however, when this technique is used by projecting a known standard onto the screen.

28. Because of the large distance and the accuracy and precision needed, a laser interferometer would probably be most suitable.

29. The laser scanner is more precise and likely to be faster with less image processing.

30. The CMM is a mechanical device with precise X - Y - Z movements for precision 3D measurements. Usually a probe is used to touch the surfaces of parts being measured and the dimensions are read on digital displays and computer terminals.

31. The principle of the sine (definition of sine) is that the sine of an angle in a right triangle is the ratio of the length of the side of the triangle opposite the angle to the length of the triangle hypotenuse.

32. The not-go member is usually made shorter than the go member because it undergoes less wear.

33. In using a dial gage, one must be sure that the axis of the spindle is parallel with the dimension being measured. Dial indicators also suffer from friction in the gears, so multiple readings are highly recommended.

34. The gage is designed so that if it errors, it will reject a good part rather than accept a bad part. The gage has a tolerance added for manufacturing and a tolerance added for wear.

35. The go ring should slip over the shaft. If it does not, the shaft is too large. The not-go ring should not slip over the shaft. If it does, the shaft is too small.

36. Air gages will detect both linear size deviation and out-of-round conditions of holes. They are fast and there is virtually no wear on the gage or part.

37. Monochromatic light waves will interfere with each other (producing light and dark bands) if they get out of phase. Thus, a dark band indicates that the two beams have cancelled each other out. Light from a single source can be shifted out of phase by having it travel different distances.

38. An optical flat is made from glass or quartz, is transparent, and the two faces are flat and parallel to a high degree of accuracy. A toolmaker's flat is made of steel, with the two faces very flat, but they do not have to be exactly parallel.

Problems:

1. Reading 1.436 in.

Inches are numbered in sequence over the full range of the bar. Every fourth graduation between the inch lines is numbered and equals one-tenth of an inch or 0.100". Each bar graduation is one twenty-fifth of an inch or 0.025". The vernier plate is graduated in 25 parts, each representing 0.001 ". Every fifth line is numbered - 5, 10, 15, 20, 25 - for easy counting. To read the gage, first count how many inches, tenths (0.100") and twenty-fifths (0.025") lie between the zero line on the bar and the zero line on the vernier plate and add them. Then count the number of graduations on the vernier plate from its zero line to the line that coincides with a line on the bar. Multiply the number of vernier plate graduations you counted times 0.001" and add this figure to the number of inches, tenths and twenty-fifths you counted on the bar. This is your total reading. The vernier plate zero line is the one inch (1.000") plus four tenths (0.400") plus one twenty-fifth (0.025") beyond the zero line on the bar, or 1.425". The 11th graduation on the vernier plate coincides with a line on the bar (as indicated by stars). 11 x .001" (.011 ") is therefore added to the 1.425 bar reading, and the total reading is 1.436".

2. Reading 41.68 mm

Each bar graduation is 0.5 mm. Every twentieth graduation is numbered in sequence - 10 mm, 20 mm, 30 mm, 40 mm, etc. - over the full range of the bar. This provides for direct reading in millimeters. The vernier plate is graduated in 25 parts, each representing 0.02 mm. Every fifth line is numbered in sequence -0.10 mm, 0.20 mm, 0.30 mm, 0.40 mm, 0.50 mm - providing for direct reading in hundredths of a millimeter. To read the gage, first count how many mm lie between the zero line on the bar and the zero line on the vernier plate. Then find the graduation on the vernier plate that coincides with a line on the bar and note its value in hundredths of a mm. Add the vernier plate reading in hundredths of a mm to the number of mm you counted on the bar. This is your total reading. The vernier plate zero line is 41.5 mm beyond the zero line on the bar, and the 0.18 mm graduation on the vernier plate coincides with a line on the bar (as indicated by stars.) 0.18 is therefore added to the 41.5 mm bar reading, and the total reading is 41.68 mm.

3. A = 0.359; B = 0.242; C = 0.376

4. $\sin \varphi = 3.250 / 5.000 = 0.65$
$\varphi = 40.54$ degrees

5. The error due to the gage blocks will be covered up by the dial indicator error

+0.000,008 or -0.000,004 for gage blocks versus
+0.001 or -0.001 for dial indicator

The error will be 3.249 to 3.251 due to leveling of the part with the dial gage. =
40.53 to 40.55
Error ~.02 degrees, due to dial indicator not the gage blocks.

6. A = 0.2991; B = 0.3001

7. Metric vernier micrometers are used like those graduated in hundredths of a millimeter (0.01 mm), except that an additional reading in two-hundredths of a millimeter (0.002 mm) is obtained from a vernier scale on the sleeve. The vernier consists of five divisions each of which equals one fifth of a thimble division - 1/5 of 0.01 mm or 0.002 mm. To read the micrometer, obtain a reading to 0.01 mm. Then see which line on the vernier coincides with a line on the thimble. If it is the line marked 2, add 0.002 mm; if it is the line marked 4, add 0.004 mm, etc.

The left side micrometer reads 5.500 mm:
The 5 mm sleeve graduation is visible 5.000 mm
The 0.5mm line on the sleeve is visible 0.500 mm
Line 0 on the thimble coincides with the reading line on the sleeve 0.000 mm
The 0 line on the vernier coincides with lines on the thimble 0.000 mm
The micrometer reading is 5.500 mm

The right side micrometer reads 5.508 mm
The 5 mm sleeve graduation is visible 5.000 mm
The 0.5mm lines on the sleeve is visible 0.500 mm
Line 0 on the thimble lies below the reading line on the sleeve, indicating that a vernier reading must be added.
Line 8 on the vernier coincides with a line on the thimble 0.008 mm.
The micrometer reading is 5.508 mm

8. The equation for thermal expansion is: $\Delta L = \alpha L \Delta T$
where ΔL is the change in length for a given change in temperature, ΔT, α is the coefficient of thermal expansion (11 x 1 0^{-6}/°C), and L is the length of the bar (2 feet). 20°F = 6.67°C and 2 ft = 24 inches. Therefore:

$$\Delta L = 11 \times 10^{-6} \times 24 \times 6.67 = 0.017768 \text{ in.}$$

which is well within the measuring capability of a supermicrometer. However, don't forget that the supermicrometer will also expand (or contract) with this temperature change, so if you tried this experiment, you would not get this reading unless only the steel bar expanded, not the supermicrometer itself. You can detect a change in length of a bar with a supermicrometer simply due to heating with your hands.

9. The lower vernier reading is the inch scale and
0 on vernier is less than 1 on beam and past the 4 on beam => .4 inch
0 on vernier is 3 divisions past 4 on beam => (3/4)(.100 in) = 0.075 inch
vernier and beam graduations are given as lining up at 14 on vernier =>0.014 inch
Reading = .400 + .075 + .014 = 0.489 inch

For the top, metric, scale
0 on vernier indicates 12 mm
vernier and beam graduations are said to line up at 0.38 mm (0.41-0.42 may look better)
=> 0.38 mm
Reading = 12 + .38 = 12.38 mm

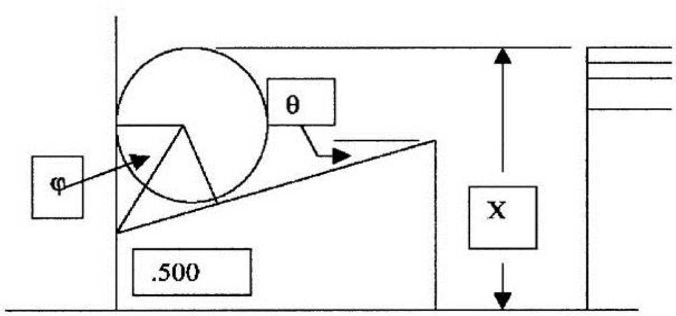
10.

Hole Basis	Shaft Basis	Fit Description	Example
H11/c11	C11/h11	Loose-running	door hinges
H9/d9	D9/h9	Free-running	pulley held on shaft by set screw
H8/f7	F8/h7	Close-running	keyed gear on shaft
H7/g6	G7/h6	Sliding	folding knife pivot
H7/h6	H7/h6	Locational-clearance	flat electrical cable connectors
H7/k6	K7/h6	Locational-transition	tapered shank drill – lathe tailstock
H7/n6	N7/h6	Locational-transition	locating pins between cylinder and crankcase on single cylinder engines
H7/p6	P7/h6	Locational-interference	ball bearing inner race on shaft

H7/s6	S7/h6	Medium-drive	cast iron drive gear on shaft
H7/u6	U7/h6	Force	steel drive gear on shaft

Case Study: Measuring an Angle

The probe is used to find the stack of gage blocks that exactly matches the height of the ball sitting on the part.



1.

The angle ϑ is 17.354 degrees, from:

$\tan \vartheta = (1.125 – 0.800) / 2.000 = 0.3125$

X = height of gage blocks = 0.500 + d + r

$X = 0.500 + .5 \cot \phi + 0.500$

$\cot \phi = X – 0.500 – 0.500 / 0.500$

$90^o = 2\phi + \vartheta$

$\phi = (90^o - \vartheta) / 2 = 36.3^o$

X = Height of blocks = 1.68

2. 1.0000 + 0.5000 + 0.10000 + 0.05000 + 0.0200 + 0.0100

3. Put the plate in a optical projector and directly measure the angle. Use a bevel protractor – Figure 10-30. Use angle gage blocks.

4. See Figure 10-31 and the discussion below the figure.