Measurement by Comparison

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Measurement by Comparison

Sections:

1. The Dial Indicator
2. Selection of a Dial Indicator
3. Use of Dial Indicators
4. Calibration of Dial Indicators
5. Accessories and Attachments
6. Constructive Use of Error

Measurement by Comparison

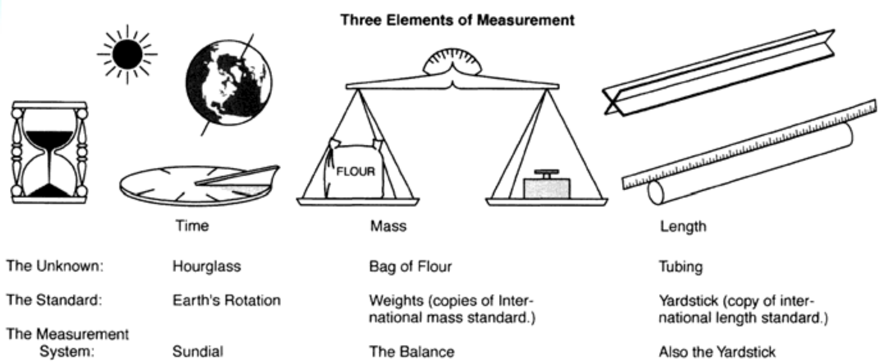


FIGURE 9–1 All measurement is made up of measurement of time, mass, and length. In each of these cases, three elements are involved: the known, the standard, and a system for comparing them. Only in crude length comparison are the standard and the system the same object.

Measurement by Comparison

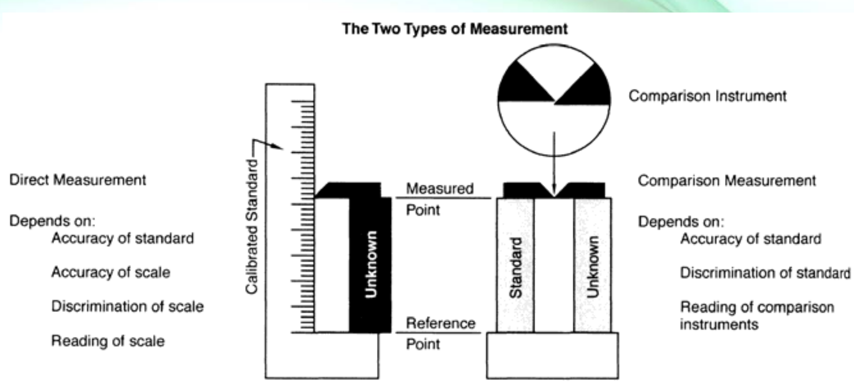


FIGURE 9–2 All measurement requires comparison. Rules, verniers, and micrometer instruments are called direct measurement because they do not require the intercession of another element.

Measurement by Comparison

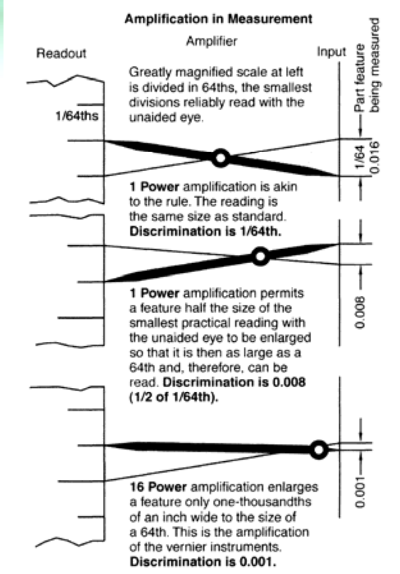


FIGURE 9–3 A simple lever can be used to represent amplification in measurement systems.

Measurement by Comparison

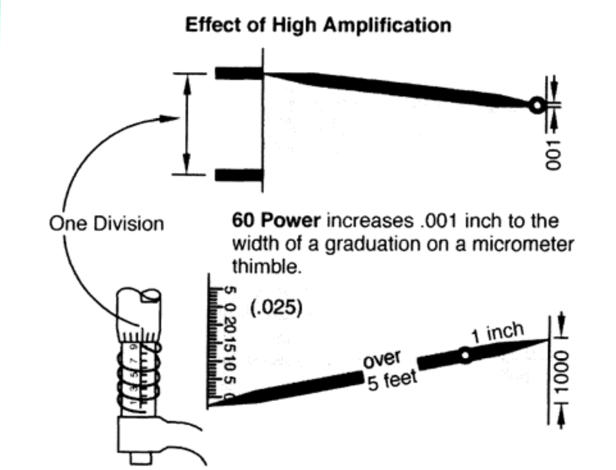


FIGURE 9–4 The micrometer provides the equivalent of an enormous lever arm.

Measurement by Comparison

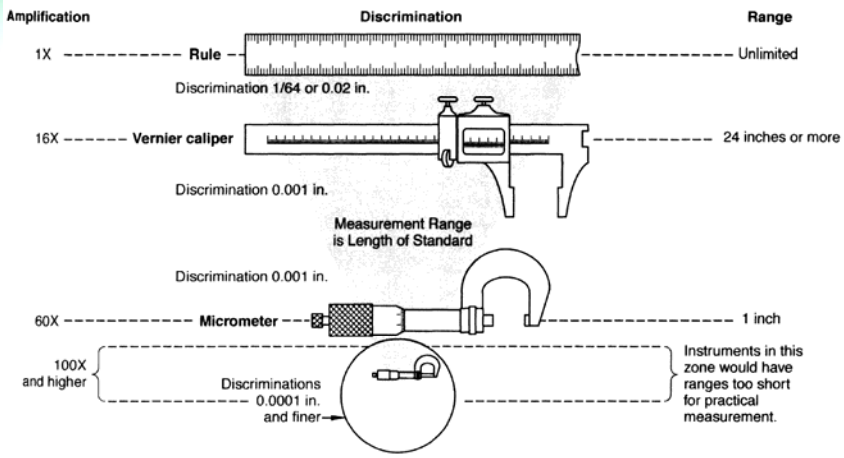


FIGURE 9–5 When the standard is part of the instrument, amplification limits range.

The Dial Indicator

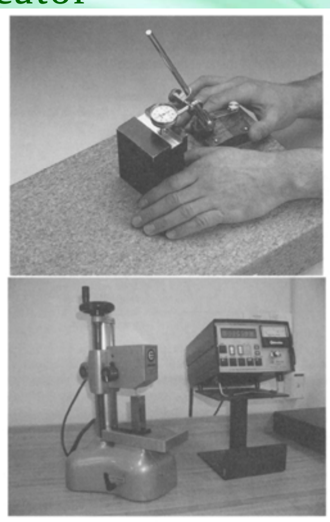
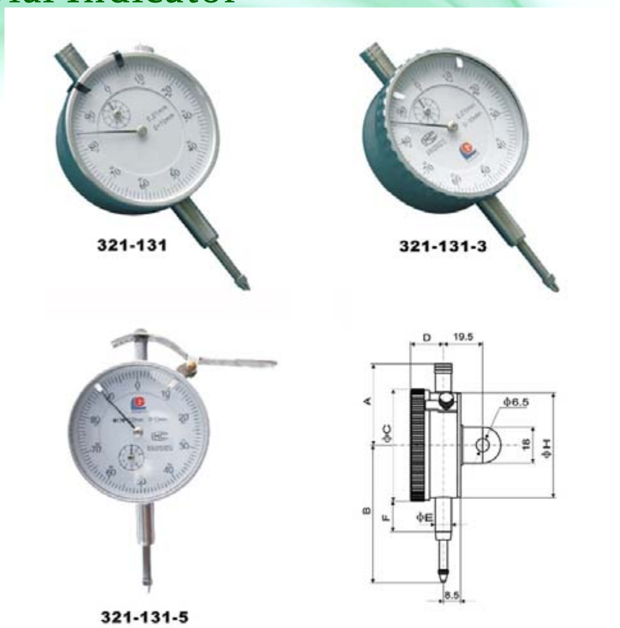


FIGURE 9–6 Indicator instruments range from low-amplification test indicators, used for setup and in process inspection, to highly precise electronics instruments with discrimination in millionths of an inch or meter. *(Courtesy of the L.S. Starrett Co. [top] and Edmunds Gages, Farmington CT [bottom])*

The Dial Indicator



The Dial Indicator

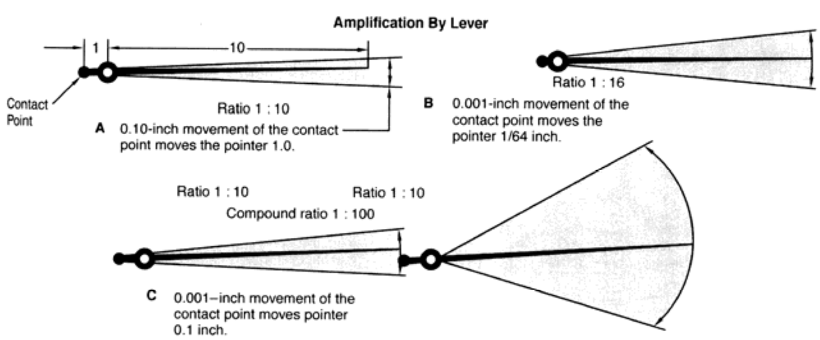
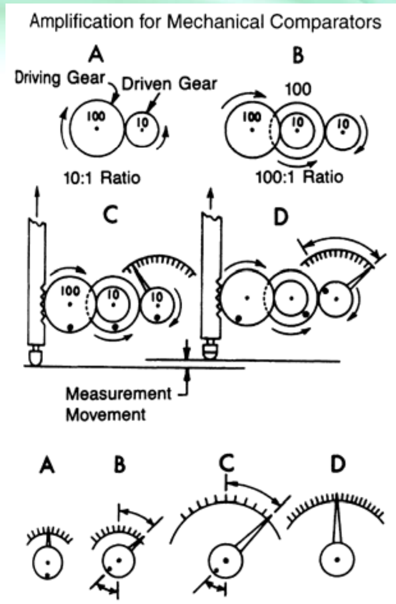


FIGURE 9–7 By means of compound levers, very small movements can be greatly enlarged.

The Dial Indicator



The Dial Indicator

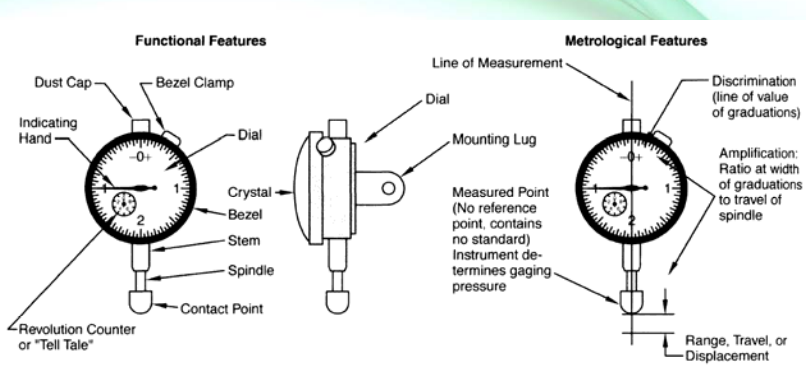
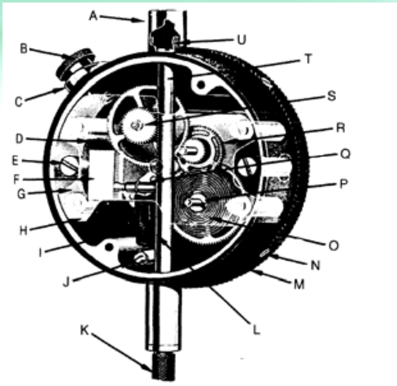


FIGURE 9–9 Both the functional and the metrological features of the dial indicators are very different from previous instruments.

The Dial Indicator



A. Dust cap
B. Bezel-screw clamp
C. Bezel clamp
D. Top plate
E. Screw movement
F. Rack slide
G. Screw top plate
H. Bottom plate
I. Rack spring
J. Rack spring stud
K. Lower point
L. Pin rack slide
M. Bezel
N. Bezel screw
O. Hairspring
P. Gear assembly takeup
Q. Bearing center pinion
R. Intermediate gear assembly
S. Rack gear assembly
T. Rack
U. Top screw

FIGURE 9–10 Phantom view of a typical dial indicator resembles clockwork. *(Courtesy of Federal Products Corp.)*

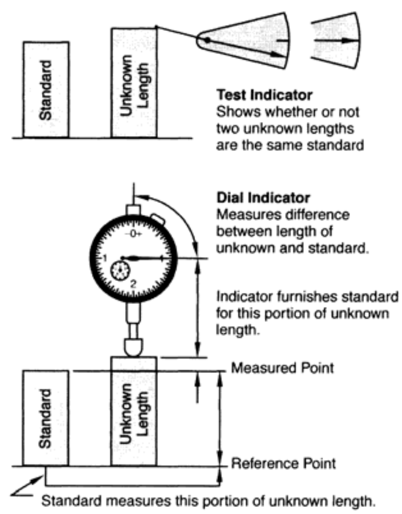


FIGURE 9–11 The dial indicator measures change in length, not length itself.

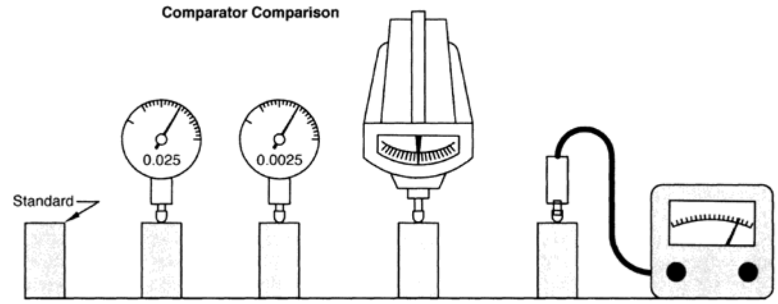
The Dial Indicator

Comparator Instruments

Name	Alternate Name	Use	Discrimination
Test Indicator	Dial test indicator	Setup in process checking	Not intended for measuring
Dial Indicator	Dial comparator, dial gage	Comparison measurement, alignment and positional measurement	0.01 to 0.002 mm 0.001 to 0.0001 in.
Comparator	Mechanical comparator, electronic comparator, air gages, and many are referred to by trade name	Comparison measurement of precise parts and for gage calibration	0.001 to 0.00002 mm 0.0001 to 0.00001 in.

FIGURE 9–13 These are the terms as generally used. They are ambiguous. For example, all are comparators, yet comparator alone usually refers to the higher precision instruments. The test indicator and dial indicator are mechanical comparators, yet those terms are generally used for the more precise types only.

The Dial Indicator



Type	A Dial Indicator	B Dial Indicator	C Mechanical Comparator	D Electronic Comparator
Metric				
Discrimination	0.025	0.0025	0.001	0.00025
Range	±1	±0.1	±0.025	±0.015
English				
Discrimination	0.001	0.0001	0.00005	0.00001
Range	±0.050	±0.005	±0.001	±0.006

FIGURE 9–14 To grasp the significance of these comparisons, see Figure 9–15. (Note: Both C and D instruments are available in other ranges, D in multirange as well as digital models.)

The Dial Indicator

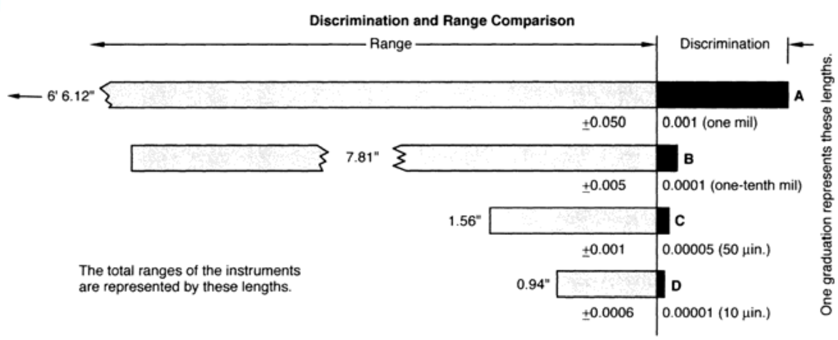


FIGURE 9–15 These bars, drawn to scale of 10 µin. to 1/64 in., show the tremendous differences between the comparators in Figure 9–14.

The Dial Indicator

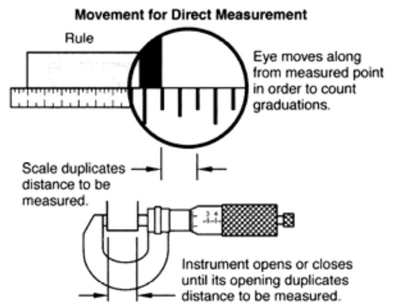


FIGURE 9–16 All measurement requires movement. Indirect measurement consists primarily of correlating the distance to be measured with the instrument's built-in standard, after which the scale is read.

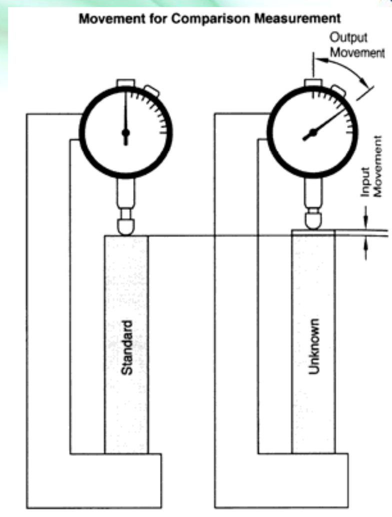


FIGURE 9–17 Comparison measurement requires movement because it is change of length that is desired.

The Dial Indicator

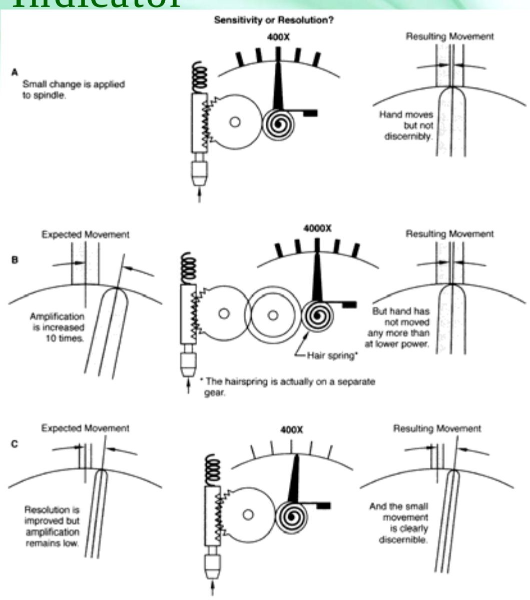


FIGURE 9–18 Increasing amplifications may not be as effective for improving sensitivity as better resolution.

The Dial Indicator

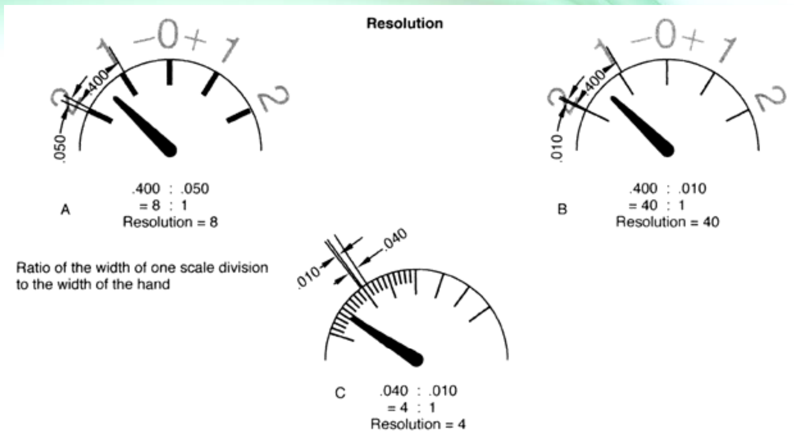


FIGURE 9–19 The larger the resolution factor (without impairment of other readability factors), the greater the reliability.

The Dial Indicator

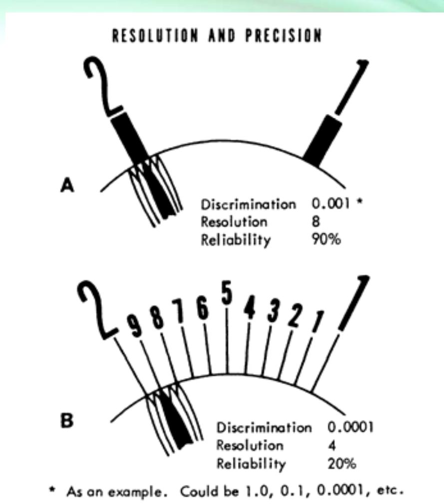


FIGURE 9–20 High resolution will not substitute for high precision.

The Dial Indicator

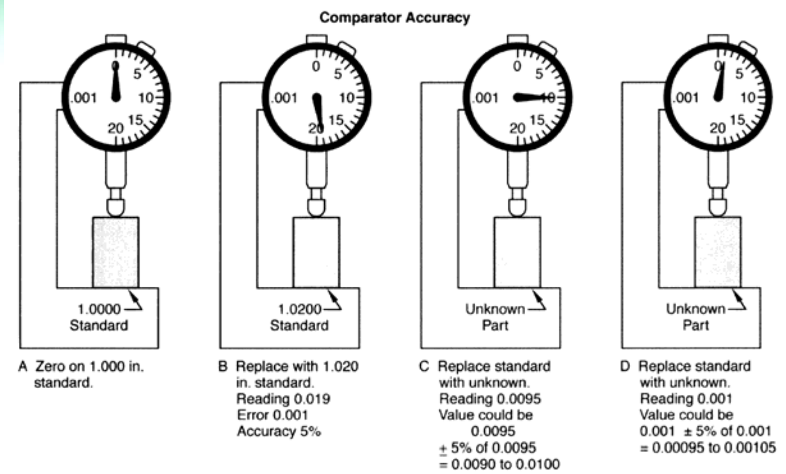
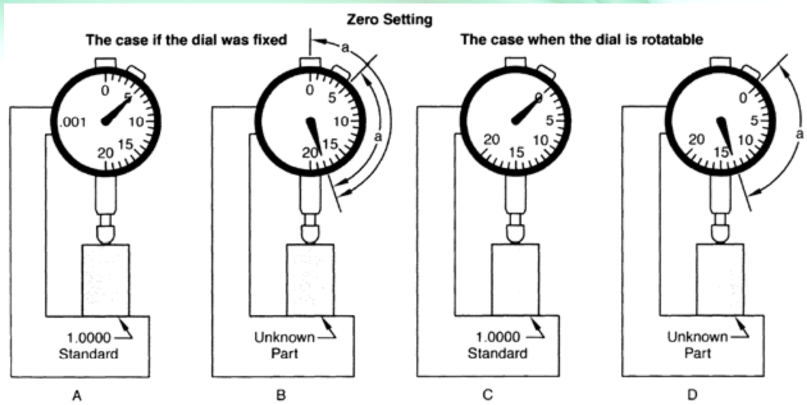


FIGURE 9–21 The percentage method of expressing accuracy proportions the error in measurement by the distance measured.

The Dial Indicator



A. In this case, the 1.0000 standard provides a reading of 0.005.
B. The unknown (a) reading is 0.018. The difference is 0.013. Adding 0.013 to 1.0000 gives the length of the unknown as 1.013.
C. In this case, the dial is turned to provide a zero reading on the 1.0000 standard.
D. The unknown part provides a 0.013 reading directly. The part size is 1.013. There is no question that it is the travel of the hand to which the error correction applies.

FIGURE 9–22 The dial rotation permits zero setting. This eliminates computational errors.

The Dial Indicator

ZERO SETTING ADJUSTMENT

Errors Eliminated:

1. Memory error
2. Computational error

These are random errors and **will not** be contained in all measurements.

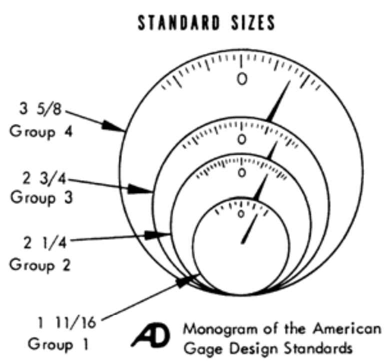
Error Added:

Zero setting error

This is a systematic error and **will** be contained in all measurements.

FIGURE 9–23 Every act in measurement is a source of error. When the errors created are less than those reduced, the act is justified. These are the errors added and eliminated by zero setting.

The Dial Indicator



Group AGD	Bezel Diameter		Discrimination	
	Above	To and Inc.	Inch	SI
1	1 3/8	2	0.0001 0.0005 0.001	0.005 0.01
2	2	2 3/8	0.00005 0.0001 0.0005 0.001	0.001 0.002 0.005 0.01
3	2 3/8	3	0.0001 0.0005 0.001	0.001 0.002 0.005 0.01
4	3	3 3/4	0.00005 0.0001 0.0005 0.001	0.001 0.002 0.005 0.01

FIGURE 9–24 These four standardized dial sizes are available in a wide variety of graduations.

The Dial Indicator

Design and Metrological Factors

Have the following permissible effect on these:

An increase in this factor:	Amplification	Dial Size	Discrimination	Readability	Range
Amplification		Increases	Increases	Increases	Decreases
Dial Size	Decreases		Increases	Increases	Increases
Discrimination	Increases	Increases		Decreases	Decreases
Readability	Increases	Increases	Decreases		Decreases
Range	Decreases	Increases	Increases	Increases	

FIGURE 9–25 Standard indicators compromise these factors for the greatest range of practical applications.

The Dial Indicator

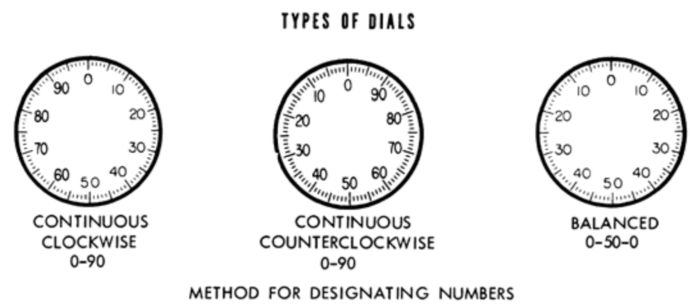


FIGURE 9–26 These are the three types of dials used on dial indicators and the method for designating numbers.

The Dial Indicator

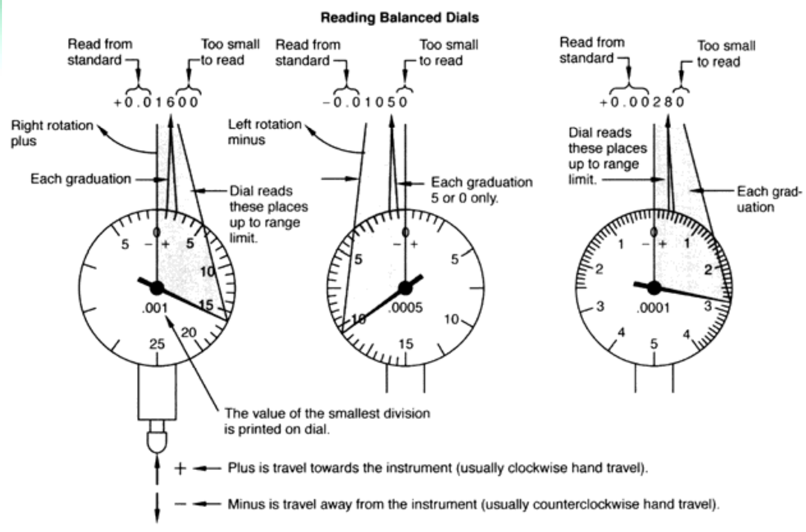


FIGURE 9–27 Although the dials may vary in size and graduations, these general principles apply.

The Dial Indicator

REVOLUTION COUNTERS ON BALANCED DIAL INDICATORS

Not Reliable for measurement.

Reliable for:

1. Showing that you are past the overtravel and within the measurement range.
2. Warning that an indicator with too high an amplification is being used.
3. Warning that something in the setup has shifted.
4. Warning that the part being measured is **out of control.***

*Out of control means that the previous operation has been completely missed or that the machine is completely out of adjustment.

FIGURE 9–28 Balanced dial indicators are reliable for relative or comparative measurement.

The Dial Indicator

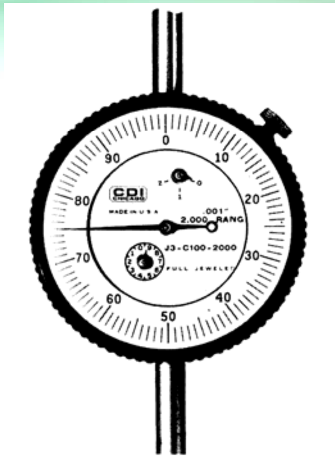


FIGURE 9–29 Long-range indicators have revolution counters and very long-range ones have inch counters. *(Courtesy of Chicago Dial Indicator Co.)*

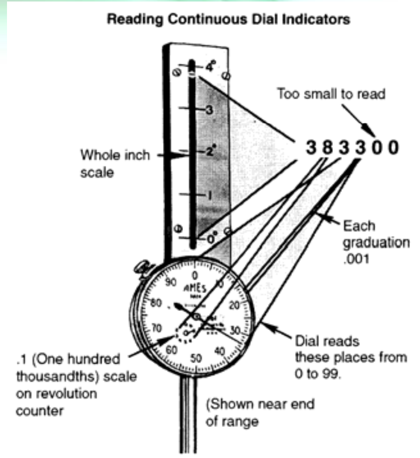


FIGURE 9–30 Continuous dial indicators have ranges up to 10 in. *(Courtesy of B.C. Ames Co.)*

The Dial Indicator

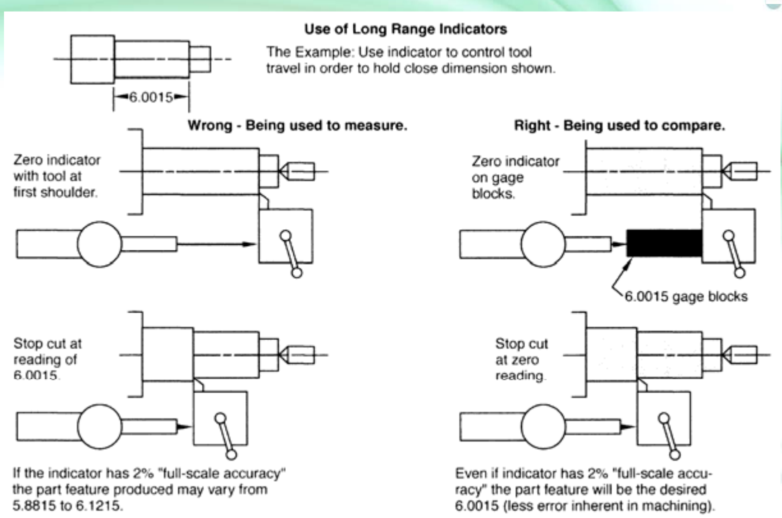


FIGURE 9–31 When used properly, the long-range indicator is not only convenient but reliable as well.

The Dial Indicator

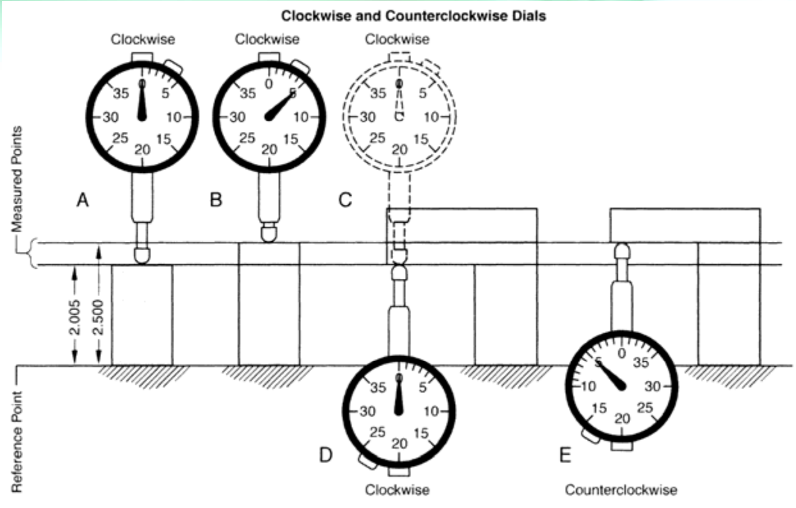


FIGURE 9–32 The dial rotation depends on the side of the measured point that the indicator is on.

The Dial Indicator

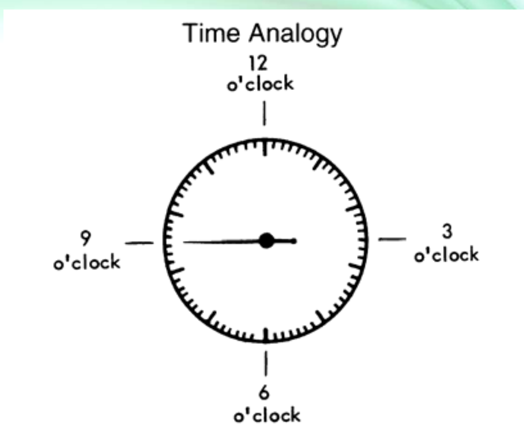


FIGURE 9–33 Because dial faces vary, the time analogy is used to state hand positions.

Selection of a Dial Indicator

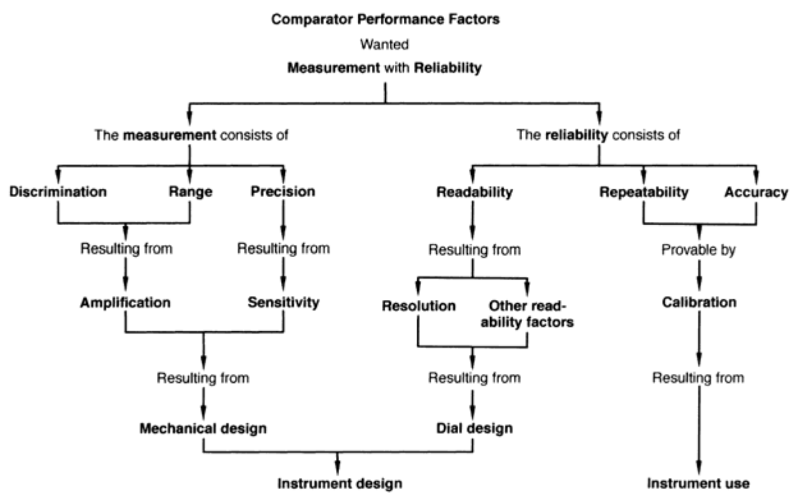


FIGURE 9–34 Although oversimplified, this chart shows the maze of interconnecting relationships that governs dial indicator design, selection, and use.

Selection of a Dial Indicator

DIAL INDICATOR RANGES

Numbering		Class of Precision Instrument				
B*	C**	0.001	0.0005	0.00025	0.0001	0.00005
0-50-0	0-100	0.250				
0-25-0	0-50	0.125	0.125			
0-20-0	0-40	0.100	0.100			
0-15-0	0-30	0.075	0.075	0.075		
0-10-0	0-20	0.050	0.050	0.050		
0-5-0	0-10			0.025	0.025	
0-4-0	0-8				0.020	
0-2-0	0-4				0.010	

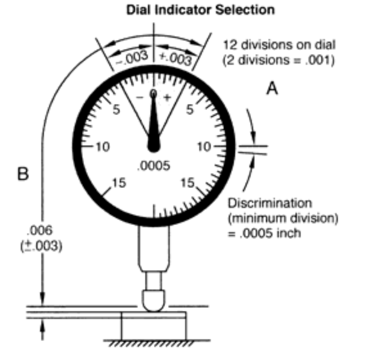
*Balanced **Continuous

Notes:

1. Based on 2 1/2 turns range
2. Same for all dial sizes
3. Same for counterclockwise rotation
4. See manufacturers' catalogs for ranges of long travel types

FIGURE 9–35 The range, as well as the sensitivity, must be considered when selecting an indicator.

Dial Indicator Selection



A. **Discrimination** – approximately 10% of tolerance (total tolerance should cover about 10 divisions).

B. **Range** – total tolerance more than 10% of dial and less than 25% of dial.

C. **Readability** – select largest dial that satisfies A and B and physically meet the requirements.

FIGURE 9–36 These steps ensure a practical selection for most measurement requirements.

Selection of a Dial Indicator

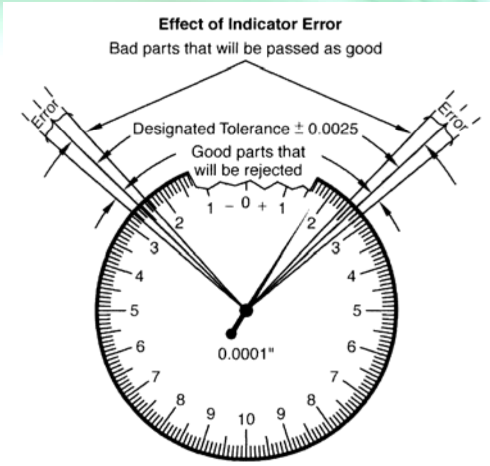


FIGURE 9–37 This exaggerated drawing shows that indicator error causes bad parts to be accepted and good parts to be rejected when used for production inspection.

Use of Dial Indicators

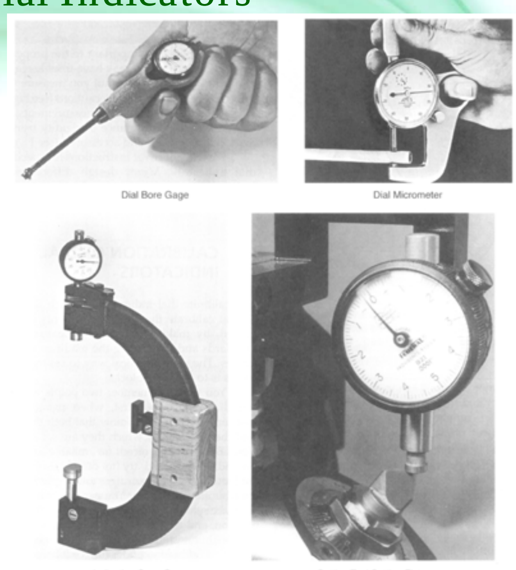


FIGURE 9–38 Dial indicators are often used as the readout portion of gages. They are reliable when treated as special forms of comparators rather than as direct measurement instruments. *(Courtesy of Federal Products Corp.)*

Use of Dial Indicators

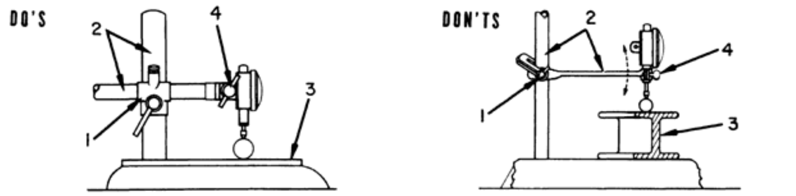
Dial indicator video

Calibration of Dial Indicators

You calibrate dial indicators in much the same way as you calibrate the other instruments we have discussed, by making a series of measurements with standards and comparing the readings with the true values. The most practical way to calibrate dial indicators is to use gage blocks.

Accessories and Attachments

DO'S AND DON'TS FOR INDICATOR USE



DO'S

1. Properly designed clamps are available. Use them. Check frequently for play.
2. Use ample supports and keep them as short as possible.
3. Use reference surface whose features are known and in calibration.
4. Clamp to indicator back whenever possible.

DON'TS

1. Makeshift clamping causes shifts that destroy accuracy and make setups difficult.
2. Slim posts and arms do not provide sufficient support.
3. Do not use odds and ends for supporting reference surfaces.
4. Do not clamp to indicator stem unless adaptor is used.

FIGURE 9–39 These general precautions will add reliability to comparison measurement. *(Courtesy of Federal Products Corp.)*

Accessories and Attachments

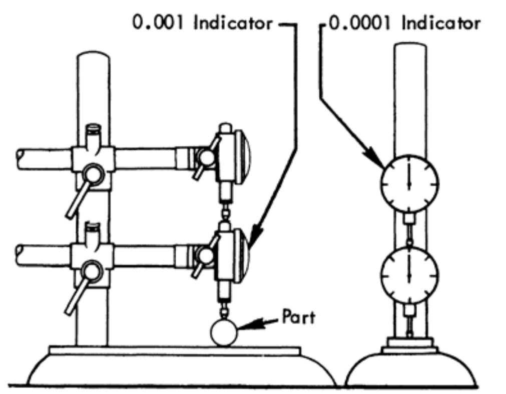


FIGURE 9–40 This simple demonstration will show vividly the deflection in gaging setups. First, zero the thousandths indicator on the part. Remove the part. Zero the tenths indicator on the thousandths indicator. Replace the part and notice the deflection on the tenths indicator. That is only part of the deflection because the tenths indicator is also being deflected.

Accessories and Attachments

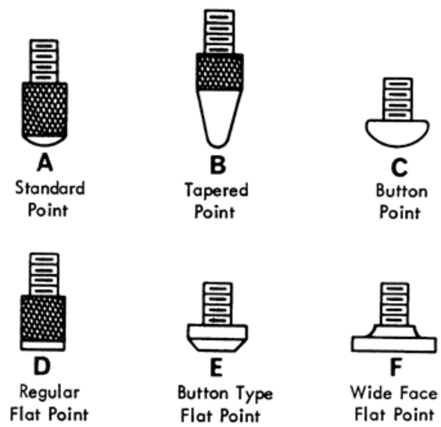


FIGURE 9–41 These standard contact points are interchangeable and available in a variety of wear-resisting materials.

Accessories and Attachments

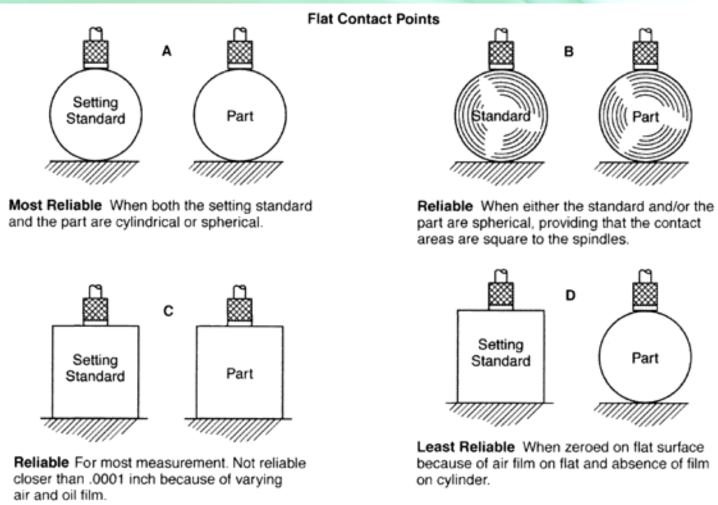


FIGURE 9–42 Flat contact points have an important role but can be a serious cause of error when used improperly.

Accessories and Attachments

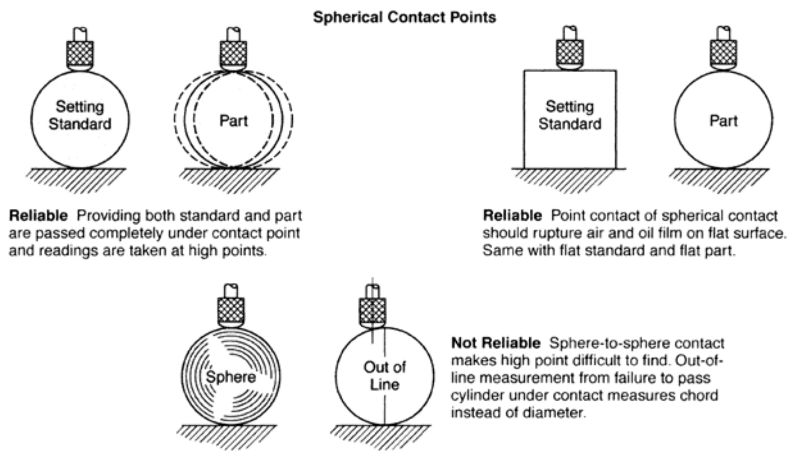


FIGURE 9–43 Excluding the measurement of balls, spherical contacts usually provide greater reliability than flat contacts. At very high amplifications, or with heavy gaging force, they present problems.

Accessories and Attachments

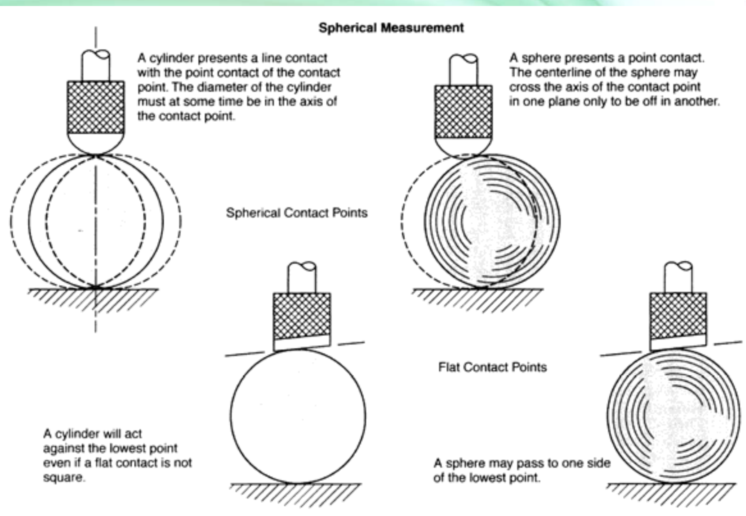


FIGURE 9–44 A sphere presents a problem even to a flat contact point.

Accessories and Attachments

FIGURE 9–45 Weights are used instead of pull-back springs when gaging pressure must be constant and a stipulated amount. This is required when measuring compressible materials. A wide, flat contact point is usually required as well. *(Courtesy of B. C. Ames Co.)*

FIGURE 9–46 There are several types of tolerance hands that can be set to the high and low limits of the measurement. The type shown in Figure 9–47 can be sealed to prevent tampering and has virtually no parallax error.

Accessories and Attachments

FIGURE 9–47 The maximum reading hand is a convenience for indicating the maximum value of a fluctuating variable, such as checking eccentricity or runout. Obviously, it could be a serious cause for error if the total travel required is more than one revolution. *(Courtesy of Federal Products Corp.)*

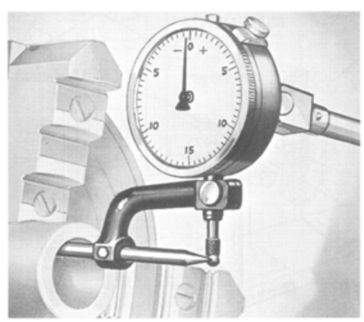


FIGURE 9–48 The hole attachment is used primarily for positional checking, such as concentricity, rather than comparison measurement. *(Courtesy of Federal Products Corp.)*

Accessories and Attachments

FIGURE 9–49 Right angle attachments permit the indicator to be located for best viewing position. Various types are shown at the top and bottom left. For permanent setups, the perpendicular indicators are preferred. *(Courtesy of Federal Products Corp.)*

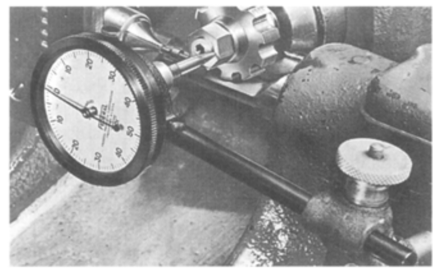


FIGURE 9–50 Perpendicular indicators have the spindle at a right angle to the face. They are mounted on a rod on the side. *(Courtesy of Federal Products Corp.)*

Accessories and Attachments

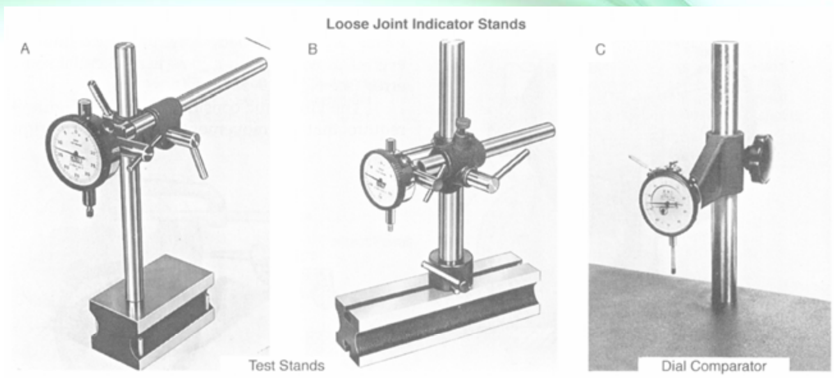


FIGURE 9–51 These indicator stands permit adjustment in all three axes. This gives them both versatility and unreliable positioning. A and B are called test stands because they are intended for use on a reference surface. C is called a dial comparator because it furnishes its own reference surface. *(Courtesy of Chicago Dial Indicator Co.)*

Accessories and Attachments

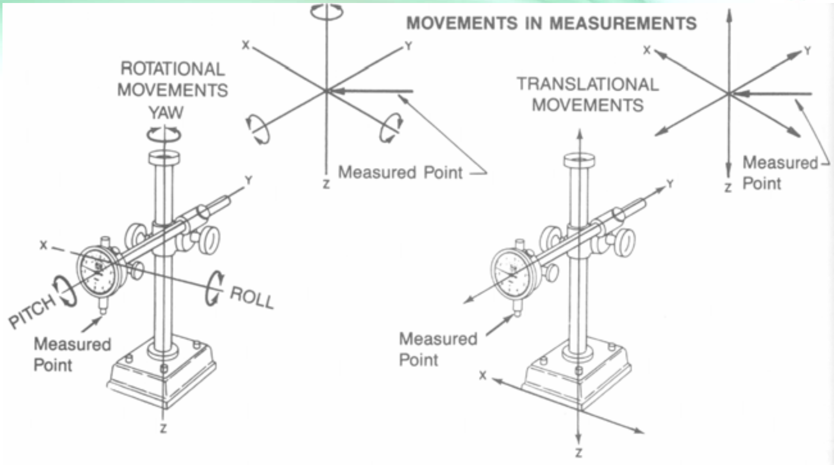


FIGURE 9–52 The loose-jointed test stand shows six separate movements that the measured point may have. Measurements around the rotational axis are known as polar movements. They are often referred to by nautical terms, yaw, roll, and pitch. Those in the translational planes are known as orthogonal measurements.

Accessories and Attachments

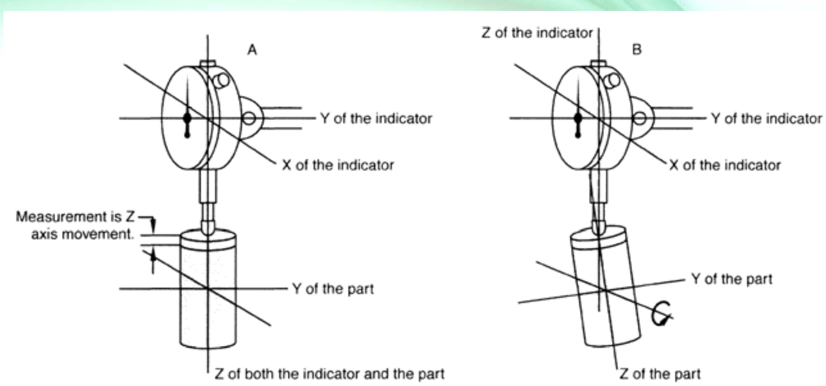


FIGURE 9–53 During setup, both the part and the indicator must be constrained from all x and y movement and their z axes brought in line. The indicator then measures movement along the z axis. If x of the part is not z of the indicator, the measurement will not be accurate as shown on the right.

Accessories and Attachments

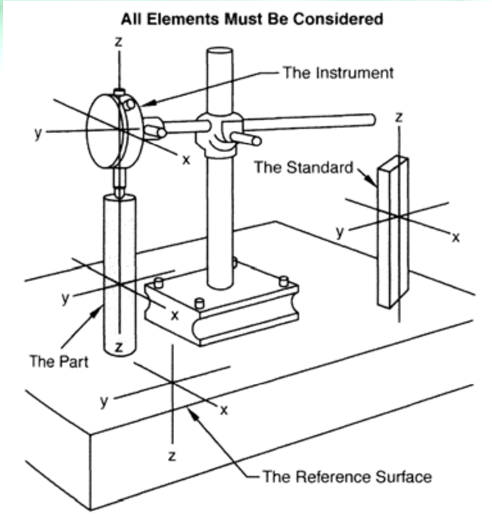


FIGURE 9–54 A rotation around any one of four separate x and y axes will destroy the accuracy of the measurement.

Accessories and Attachments

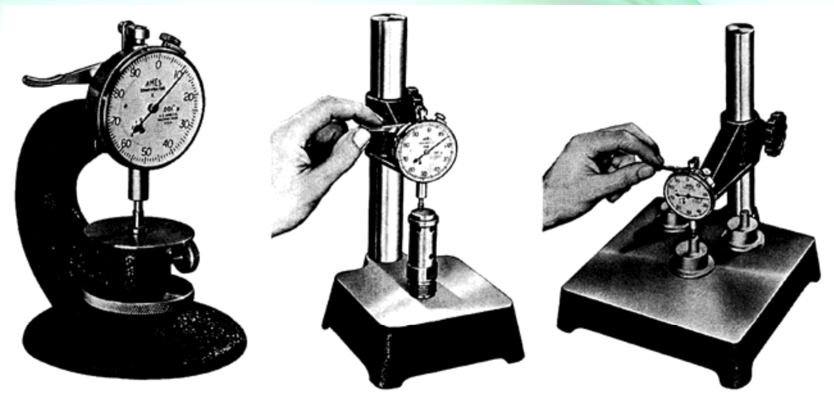


FIGURE 9–55 Dial comparators are indicators with stands that incorporate their own reference surfaces. Note that all the indicators shown have spindle-lifting levers. *(Courtesy of B. C. Ames Co.)*

Accessories and Attachments

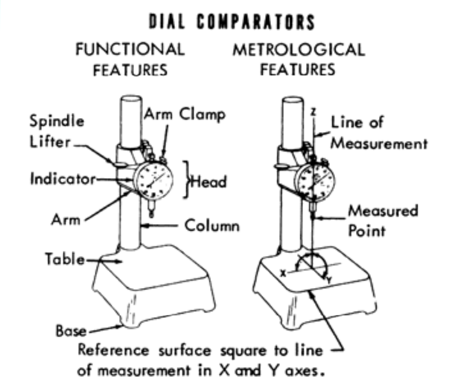


FIGURE 9–56 The dial comparator has the general C shape of all the outside diameter instruments.

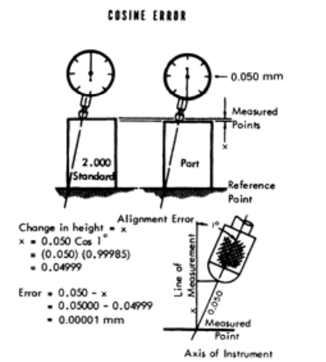


FIGURE 9–57 The cosine error caused by 1° applies only to the travel of the indicator and figures out to an error in length of only 10μin. Note that the same misalignment with a vernier height gage creates an error based on the full length and would be 300 μin.

Accessories and Attachments

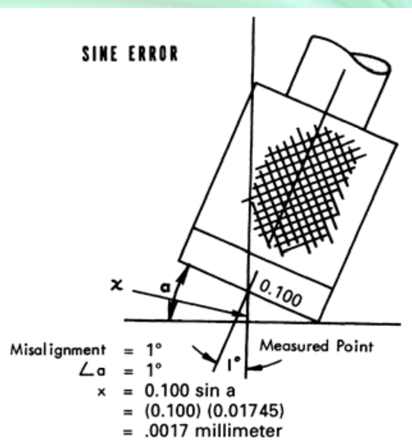


FIGURE 9–58 The sine of the angle caused by misalignment with a flat contact is a much more serious error than the cosine error. **Note:** A misaligned micrometer or snap gage would have this error at each contact surface.

Accessories and Attachments

RELIABLE COMPARISON MEASUREMENT WITH DIAL INDICATORS

1. Determine that this is best way to make the measurement.
2. Select a dial indicator with sufficient precision to spread the tolerance over about 10 divisions and with sufficient range to contain the tolerance in not more than 1/4 of the dial.
3. Select standards of suitable precision.
4. Check calibration data for indicator and standards.
5. Select contact point, indicator stand, and reference surface that will ensure correct alignment.
6. Thoroughly clean part, instrument, and all other components of the setup.
7. Make setup. Check alignment. Check security and rigidity of all joints.
8. Zero set indicator on standard. Repeat until satisfied.
9. Measure part with indicator and adjust with the value of the standard to provide measurement. Repeat.
10. Recheck all above steps.
11. Consciously inquire into possible bias.
12. If it is a critical measurement, have someone else make measurement. Any discrepancy greater than 10% of tolerance is warning that some step is inadequate (probably #1).

FIGURE 9–59 By now you may have noted a strong similarity among items in these checklists. This emphasizes their importance.

Accessories and Attachments

METROLOGICAL DATA FOR DIAL INDICATORS							RELIABILITY	
Instrument	Type of Measurement	Normal Range	Designated Precision	Discrimination	Sensitivity	Linearity	Practical Tolerance for Skilled Measurement	Practical Manufacturing Tolerance
Test indicators	Comparison	0.030 in.	0.001 in.	0.001 in.	0.0005 in.	2%	Not for measurement	
0.001 indicators:								
on height gage stands	Comparison	0.250 in.	0.001 in.	0.001 in.	0.0005 in.	2%	0.001 in.	0.010 in.
on comparator stands	Comparison	0.250 in.	0.001 in.	0.001 in.	0.0005 in.	2%	0.0005 in.	0.005 in.
0.0001 indicators:								
on height gage stands	Comparison	0.050 in.	0.0001 in.	0.0001 in.	0.0001 in.	2%	0.0001 in.	0.001 in.
on comparator stands	Comparison	0.050 in.	0.0001 in.	0.0001 in.	0.00005 in.	2%	0.00005 in.	0.0005 in.
0.00005 indicators:								
on height gage stands	Comparison	0.010 in.	0.00005 in.	0.00005 in.	0.0001 in.	2%	0.0001 in.	0.001 in.
on comparator stands	Comparison	0.010 in.	0.00005 in.	0.00005 in.	0.00005 in.	2%	0.00003 in.	0.0003 in.

FIGURE 9–60 A practical comparison of dial indicators cannot be made without considering the means of supporting the indicator.

Constructive Use of Error

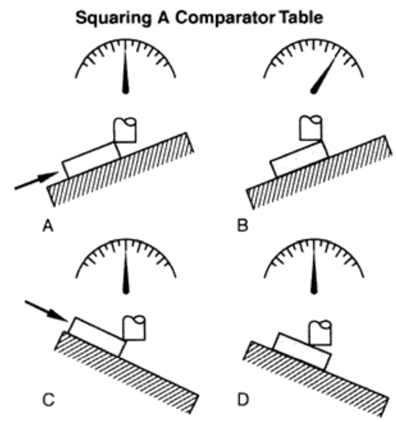
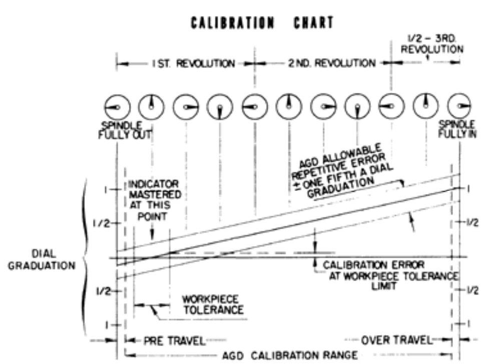


FIGURE 9–61 Passing a gage block between spindle and anvil along several paths can serve to detect and correct the misalignment.

Constructive Use of Error

FIGURE 9–62 The relationship between metrological and functional considerations is shown in this graph. It is based on American Gage Design Committee (AGD) specifications. These specifications permit a maximum repeatability error (precision) of one-fifth the smallest dial graduation at any point on the 2 1/2 turns of useful range. The calibration error (accuracy) is limited to one graduation in the total useful range. Dial indicators should be "mastered" (zeroed) when the pointer is at the 12 o'clock position on the first turn. In this graph a plus calibration error is shown, but it could be either plus or minus. *(Courtesy of Scherr-Tumico, Inc.)*



References

http://www.tresnainstrument.com/dial_indicators.html
http://www.thomasnet.com/products/dial-indicators-39942008-1.html
http://www.directindustry.com/industrial-manufacturer/dial-indicator-80024.html
http://www.encyclopedia.com/doc/1G1-16564331.html
http://benchmark.20m.com/workshop/Jigs_Dial/Jigs_Dial.html
http://www.noga.com/nogaInfo.php?doc_id=contents_dial_indicators
http://www.tresnainstrument.com/dial_indicators.html
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