Solutions for Basics of Precision Engineering 1st Edition by Leach

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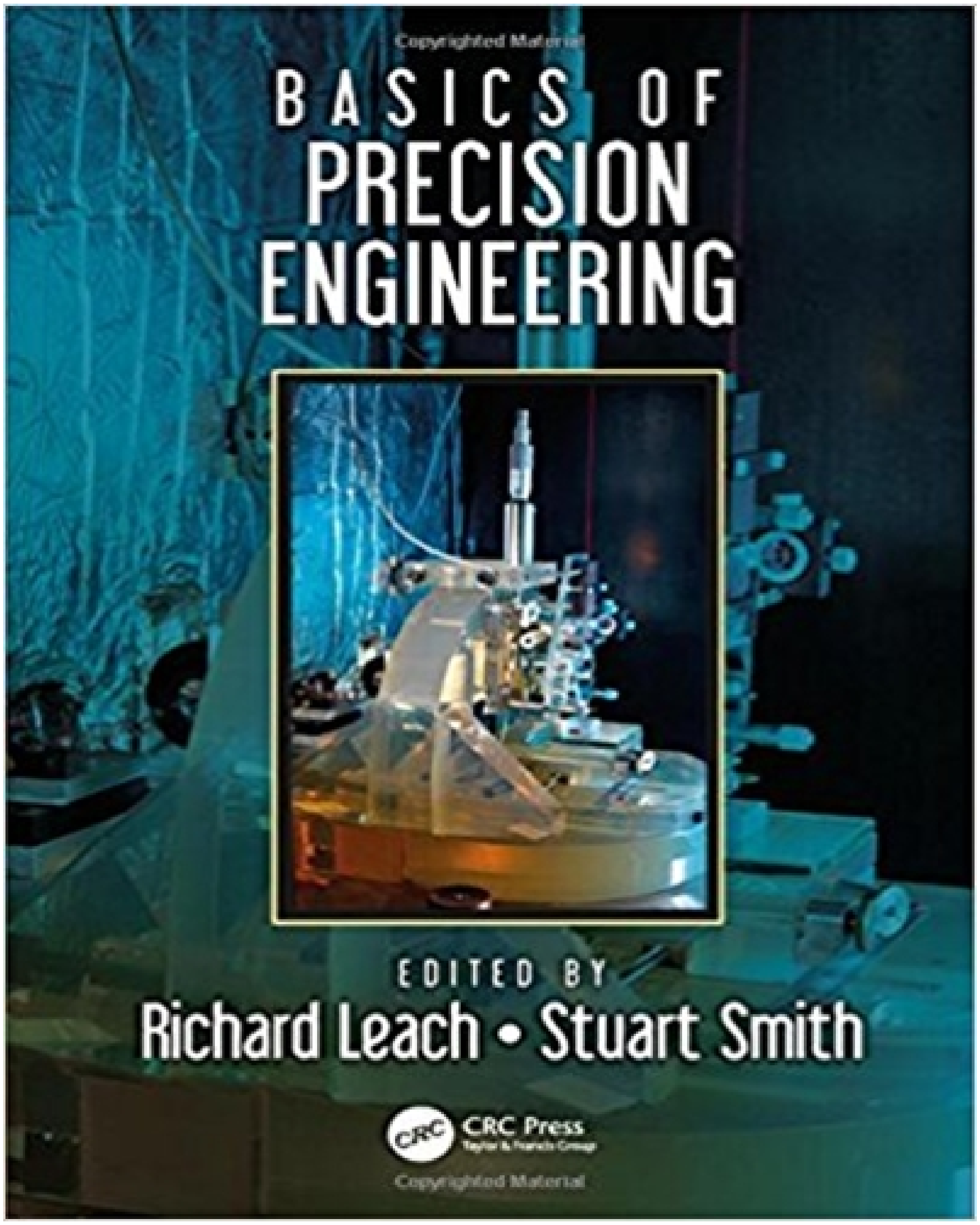

Solutions

2.11 Exercises

1. Choose a specific engineering material (perhaps an alloy), list six material properties and their values with references for those values. For two of the properties, list a reported variant value for one of the properties and describe why you think there is discrepancy. What effect will the variations in values have on an engineered design?

Pure aluminium reported property values

Aluminium Property	**Value** (CRC Handbook of Chemistry and Physics, D. R Lide Editor in Chief)	**Variant value**
Melting Point	660.32 ^{o}C	
Specific heat capacity	0.897 J·g-$^{-1}$·K^{-1} ; 24.2 J·mol^{-1}·K^{-1}	
Electrical resistivity	2.65 × 10^{-8} Ω·cm	
Density	2.70 g·cm^{-3}	
Linear expansion coefficient	23.1 × 10^{-6} K^{-1}	24 × 10^{-6} K^{-1}
Thermal conductivity	237 W· m^{-1}·K^{-1}	205 W· cm^{-1}·K^{-1}

Variants may be due to properties changing with temperature or the year of reporting source. The effects will be dependent on their relation to the engineering relationships. The uncertainties of the reported value will induce uncertainties in any calculations made with them.

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2. Which kind of measurement standard would be used while performing duties on a shop floor to calibrate hand tools? A working standard.

Research the classifications for the quality grades for gauge blocks and their related tolerances.

Sources:
www.prattandwhitney.com/Content/Gage_Block_Calibration_Tolerances.asp
www.nist.gov/document-14649 (Doiron T., Beers J., Gauge block handbook)
www.gagesite.com/documents/Gage%20Block%20Tolerances%20B89_1_9.pdf
www.iso.org/standard/1241.html : ISO 3650 - Geometrical Product Specifications (GPS) -- Length standards -- Gauge blocks

Due to variations in documentation standards, there are various classification schema for grading gage blocks.
ISO 3650 grades are given below (same grade tolerances vary as the thickness of the material increases)

Grade	Deviation from Nominal Length L/μm
00	0.05 + 0.0001L
0	0.10 + 0.0002L
1	0.20 + 0.0004L
2	0.40 + 0.0008L

Other currently used tolerance grades from standards including those superseded
ANSI/ASME B89.1.9M, specifies grades 00, 0, AS-1, AS-2 and K
(AAA:±0.05 μm) ($-0.05 <$ AA $< +0.10$ μm) ($-0.05 <$ A $< +0.15$ μm) ($-0.15 <$ B $< +0.25$ μm)
GGG-G-15C Standard had grades 0.5, 1, 2, and 3

Find three manufacturers of gauge block sets. What materials are commercially available for gauge blocks?

Manufacturer	Materials	Web URL
Mitutoyo	Steel, alumina ceramic (Cera), tungsten carbide	ecatalog.mitutoyo.com/Gage-Blocks-C1164.aspx
Starrett-Weber	Steel, chromium carbide, ceramic	www.starrett.com/metrology/metrology-products/webber-gage-blocks
Fowler	Steel, zirconia ceramic	www.fowlerprecision.com/Products/Gage-Blocks
Mahr	Steel, zirconium oxide (Circonimar) , carbide	www.mahr.com

Why would differing materials be necessary?

Common differentiation between materials for selection of gauge blocks includes wear resistance, corrosion resistance, cost, stability and wringing capability. So durability, environment of use, cost and ease of use would all be driving factors.

3 Find three coordinate measuring system (CMS) manufacturers and compare the range, resolution and accuracy (or uncertainty) specifications given for their most accurate machines. Note that CMS is a relatively new term adopted by ISO – you may want to use coordinate measuring machine (CMM) in your search.

Manufacturer	High accuracy machine	Uncertainty or Accuracy statement for a length measurement (*L*, length in mm)	Source URLs
Zeiss	Xenos	0.3 + *L*/1000 µm	www.zeiss.com
Leitz	PMM-Xi	0.6 + *L*/550 µm	www.leitz.com www.tctmagazine.com
Mitutoyo	Legex	0.28 + *L*/1000 µm	www.mitutoyo.com

4. Name four kinds of sensors that are available on CMSs for geometric measurement of components? Briefly describe the operational principles for two of them.

Sensor type	**Operation Principle** **See also www.zeiss.com/metrology/products/sensors.html** **http://www.hexagonmi.com/products/coordinate-measuring-machines/cmm-sensors**
vision	Optical confocal imaging system with lenses and camera. Intensity variations allow edge discrimination
Touch-trigger	Mechanical contact with a physical feature breaks a kinematic electrical contact to trigger a scale position read.
contact scanning	Sensors in the probe head determine the deviation of the stylus probe from a nominal location. By adding these readings to the scale position readings from the axes, a position of the probe is determined in the machine reference coordinate system
optical linescan	A beam of light is scanned along a surface. The position of the reflected light on to a camera (position sensitive detector) gives a point cloud of part surface position coordinates..
chromatic confocal	Differing color intensities due to color based focal lengths determine the position for the sensor.
fringe projection	Light-dark fringes are projected onto a surface. Cameras viewing the fringes on the part provide data to obtain the surface contour of the part. The location of the cameras must be known within a coordinate frame..

5. A reference ring gauge (10.003 01 mm reference diameter having very low uncertainty) is used to estimate the repeatability and bias of a CMS's measurement. Calculate the statistical standard deviation representing the measurement precision if separate indications of quantity values for the diameter taken in millimetres are

9.9931, 10.017, 9.9953, 9.9875, 10.003, 9.9853, 9.9853, 9.9918, 10.012, 10.001, 9.9921, 9.9935, 9.9998, 10.005, 9.9978, 10.010, 9.9908, 9.9981, 9.9985, 9.9995.

Precision *p* can be estimated by a one statistical deviation through the variance

$p^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(V_i^2 - V_{avg}^2\right)$ from the average indication value $V_{avg} = \frac{1}{n}\sum_{i=1}^{n} V_i$. From these equations the precision p is 0.008 580 mm

What is the estimated instrument bias determined by the ring gauge measurement above?

The average of the measured diameters is 9.997 82 mm. By subtracting the reference value from this value we obtain the instrument bias of -0.005 19 mm.

6. Identify a set of specification standards that applies to an industry of your choice. What are seven of the parametric terms and their definitions associated with that standard? (Hint: ISO.org has partial preview documents available that include the terms and definitions.)

Source: ISO 230-7:2015 Test code for machine tools -- Part 7: Geometric accuracy of axes of rotation	
Terms	**Definition**
functional point	cutting tool centre point or point associated with a component on the machine tool where cutting tool would contact the part for the purposes of material removal
axis average line	straight line segment located with respect to the reference coordinate axes representing the mean location of the axis of rotation
axis shift	quasi-static relative angular and linear displacement, between the tool side and the workpiece side, of the axis average line due to a change in conditions
play	condition of zero stiffness over a limited range of displacement due to clearance between elements of a structural loop
hysteresis	linear (or angular) displacement between two objects resulting from the sequential application and removal of equal forces (or moments) in opposite directions
axis of rotation error motion	unwanted changes in position and orientation of axis of rotation relative to its axis average line as a function of angular position of the rotating component
bearing error motion	error motion due to imperfect bearing between stationary and rotating components of a rotary axis
sensitive direction	direction perpendicular to the workpiece surface at the functional point
radial error motion	error motion in a direction perpendicular to the axis average line and at a specified axial location
axial error motion	error motion coaxial with the axis average line
synchronous error motion	portion of the total error motion that occurs at integer multiples of the rotation frequency
least squares circle centre (LSC)	centre of a circle that minimizes the sum of the squares of a sufficient number of equally spaced radial deviations measured from it to the error motion polar plot

7. Suppose you wanted to make a measurement of the coefficient of thermal expansion of a particular material. What are the indications that would need to be measured? What parameter would need to be controlled to make low uncertainty measurements? Search relevant journals or patents and describe briefly two methods and/or instruments used for that purpose. One term used to identify these instruments is dilatometer.

The parameter of control is the temperature of the material. This involves eliminating or limiting thermal gradients within the material. The indications that would need to be measured are the change in length of the material and the material temperature.

Two dilatometer instruments are:

US 3788746 A (US patent) Optical dilatometer, Baldwin; Richard R. (Saratoga, CA), Ruff; Bruce J. (Sunnyvale, CA)
The description is taken from the patent: "A dilatometer for measuring the linear coefficient of expansion of a specimen block wrung on a platen. The measurement is made by electronically comparing a set of fringes that are responsive to motion of the sample to a set of fringes that are responsive to motion of the platen. Each set of fringes is generated by interference between a reference light beam and a light beam which has twice traversed the distance to the surface whose motion is being monitored, the two traversals being along separate but parallel paths. Each of the two sets of fringes is generated at the surface of the main beam splitter by recombining beams which have been reflected from cube-corners so that there is no requirement for a separate, precisely aligned, output beam splitter"

A double-pass interferometer for measurement of dimensional changes Dongmei Ren, K M Lawton and Jimmie A Miller, Measurement Science and Technology, 19/2 (2008) 531-534 Source URL: dx.doi.org/10.1088/0957-0233/19/2/025303
A nanoscale absolute interferometric dilatometer was used to measure the coefficient of expansion. A double-ended measurement of a sample using a single-detection double-pass interference system was built. A nearly balanced design, in which the measurement beam and the reference beam have equal optical path lengths was utilized . This interferometer was designed to measure dimensional changes with uncertainty at the nanometer level.

8. Use other resources to find and describe the operation principle and mathematical modelling for three of the following: RTDs, thermistors, thermocouples, temperature integrated circuits, pyrometers and liquid thermometers.

Omega provides one resource on temperature measurement at www.omega.com/techref/.

Another useful reference is the OMEGA Complete Temperature Measurement Handbook and Encyclopedia®.

Thermocouples: When two dissimilar materials are in contact the junction produces a voltage which is sensitive to the temperature of the materials. This is called the Seebeck voltage. By measuring this voltage a temperature can be calculated. A reference is also needed with which to compare for low uncertainty measurement. Common dual wire thermocouples types are J, K, T, E and N. Reference tables typically relate the measured voltage to the temperature of the junction of the materials.
Thermistors: The resistance of a thermistor changes inversely with temperature. By measuring the resistance R the temperature T (Kelvin) can be determined through the he Steinhart-Hart Equation which is $T^{-1} = A + B\,[Ln(R)] + C\,[Ln(R)]^3$ where: A, B and C are constants derived from three temperature test points. Electronic bridge circuits are often used for high sensitivity determination of the resistance.
Resistance temperature detectors (RTD) are sensors whose material resistance changes nearly proportionally with temperature. Common materials are platinum, nickel and copper. The relationship between resistance R and temperature T (°C) is reffered to as the Callendar-Van Dusen equation and although found in many forms is given here as $R(T)=R(0)[1+A*T+B*T^2+(T-100)C*T^3]$ with A, B, and C being constants that are determined experimentally.
Pyrometer: A device that measures the temperature of a surface from a distance using the spectrum of the thermal radiation that it emits. The output signal of the detector (T in Kelvin) is related to the thermal radiation or irradiance $j^* = \varepsilon\,\sigma\,T^4$ (via the Stefan–Boltzmann law), The constant of proportionality σ is the Stefan-Boltzmann constant and ε the emissivity of the object.
Temperature integrated circuits are sensors that have electronics and signal conditioning

circuits to linearise, amplify and/or digitise the output signal.
Liquid thermometers are thermo- mechanical devices that uses a liquid in a vacuum that expands with temperature to move across a scale that can be visibly read by an observer.

9. Measure the diameter of a stock (as purchased) cylindrical bar with a set of calipers. First take ten measurements at the same location then repeat at several different locations. Determine the diameter, and the precision (statistical variation) of the diametrical measurement the cylindrical bar. Compare these results with those of your classmates or others who are willing to repeat the experiment. What do the comparisons suggest about the reproducibility of your measurement results?

The table of measurements on a nominal one inch aluminum bar is shown below. Method 1 measured the same diameter repeatedly. Method 2 measured various diameters as the bar was rotated with the axial location the same. Methods 3 and 4 took diameters from random axial positions and rotations. The most consistent results came from method 1 which may be more dependent on the operator. Method 2 had a larger variation which may be due to the roundness of the bar. The arbitrary measurements showed the greatest variations and should be indicative of the manufacturing variations of the bar.

indication	method 1/mm	method 2/mm	method 3/mm	method 4/mm
1	25.34	25.33	25.32	25.35
2	25.33	25.34	25.34	25.37
3	25.33	25.33	25.39	25.4
4	25.33	25.35	25.3	25.32
5	25.34	25.38	25.31	25.41
6	25.33	25.37	25.42	25.32

7	25.32	25.36	25.37	25.36
8	25.33	25.35	25.3	25.38
9	25.33	25.33	25.36	25.27
10	25.33	25.31	25.32	25.29
precision (variation)	0.006	0.021	0.041	0.046
average diameter	25.331	25.345	25.343	25.347

10. What are three reference points from the ITS-90 would be best for calibrating thermistors to measure from below the freezing point of water to above the boiling point of water?

You would want to use points close to the stated range of measurement. The points from the ITS that are closest to the stated range are:

ITS-90 reference point	Temperature °C
Triple point of mercury	−38.8344
Triple point of water	0.01
Melting point of gallium	29.7646
Freezing pointof indium	156.5985

URL Source: www.bipm.org/utils/common/pdf/its-90/ITS-90_metrologia.pdf

The water, gallium and indium points would be best if the temperature to measure never went far below the triple point of water. Otherwise mercury, gallium and indium would be best for calibration.