40 QUALITY CONTROL AND INSPECTION

Review Questions

40.1 What are the two principal aspects of product quality?

Answer. The two quality aspects are (1) product features and (2) freedom from deficiencies.

40.2 How is a process operating in statistical control distinguished from one that is not?

Answer. The process in statistical control is characterized by only random variations that are normally distributed. A process that is out of control exhibits additional variation that is not normal, called assignable variation. This indicates that something is wrong with the process.

40.3 Define *process capability*.

Answer. Process capability is the limits of the normally-distributed random variations of the process when it is in statistical control. The limits are defined as the process mean ± 3 standard deviations.

40.4 What are the *natural tolerance limits*?

Answer. The natural tolerance limits are when the tolerance on a part is set equal to the process capability; that is $\pm 3\sigma$ of the process mean.

40.5 What is a *control chart*?

Answer. A control chart is a graphical technique in which statistics computed from measured values of a certain process characteristic are plotted over time to determine if the process remains in statistical control.

40.6 What is the difference between control charts for variables and control charts for attributes?

Answer. In control charts for variables, the characteristic of interest is measured. In control charts for attributes, the characteristic of interest is identified as being either acceptable of not acceptable.

40.7 Identify the two types of control charts for variables.

Answer. The two charts are (1) $\bar{x}$ chart for sample means and (2) R chart for ranges.

40.8 What are the two types of control charts for attributes?

Answer. The two charts are (1) p chart for proportion of defects in a sample, and (2) c chart for count of defects in a sample.

40.9 When interpreting a control chart, what does one look for to identify problems?

Answer. Problems are indicated by the following: (1) $\bar{x}$ or R lie outside their respective *LCL* or *UCL* limits; (2) trends or cyclical patterns in the data; (3) sudden changes in average; and (4) points consistently near the upper or lower limits.

40.10 What are the three main goals in total quality management (TQM)?

Answer. The three main goals in TQM are (1) achieving customer satisfaction, (2) encouraging the involvement of the entire workforce, and (3) continuous improvement.

40.11 What is the difference between external customers and internal customers in TQM?

Answer. External customers are those who purchase the company's products and services. Internal customers are inside the company, such as the company's final assembly department which is the customer of the parts production departments.

40.12 Why is the normal statistical table used in a Six Sigma program different from the standard normal tables found in textbooks on probability and statistics?

Answer. The normal statistical tables used in a Six Sigma program differ from the standard normal tables in the following two ways: (1) the Six Sigma table includes only one tail of the normal distribution and (2) the Six Sigma table is shifted by 1.5σ, so that 6σ in the Six Sigma table is the same as 4.5σ in the standard normal tables.

40.13 A Six Sigma program uses three measures of defects per million to assess the performance of a given process. Name the three measures.

Answer. The three measures are (1) defects per million opportunities, (2) defects per million units, and (3) defective units per million units.

40.14 Automated inspection can be integrated with the manufacturing process to accomplish certain actions. What are these possible actions?

Answer. Possible actions discussed in text are (1) parts sortation and (2) feedback of data to adjust the process.

40.15 Give an example of a noncontact inspection technique.

Answer. Non-contact inspection techniques include machine vision, laser measuring methods, and electrical field techniques.

40.16 What is a *coordinate measuring machine*?

Answer. A CMM is an automated measuring machine consisting of a contact probe and a means to position the probe in three dimensions relative to workpart features and surfaces; when the probe contacts the part, the *x-y-z* coordinates are recorded.

40.17 Describe a *scanning laser system*.

Answer. The scanning laser system uses a laser beam deflected by a rotating mirror to produce a beam of light that sweeps past an object. A photodetector on the far side of the object senses the light beam during its sweep except for the short time when it is interrupted by the object. This time period can be measured quickly accurately. A microprocessor measures the time interruption that is related to the size of the object in the path of the laser beam, and converts from time to a linear dimension.

40.18 What is a *binary vision system*?

Answer. In a binary vision system, the light intensity of each pixel is reduced to either of two values (white or black = 0 or 1).

40.19 Name some of the nonoptical noncontact sensor technologies available for inspection.

Answer. The technologies include electrical fields (capacitance, inductance), radiation (X-ray), and ultrasonic techniques (high frequency sound).

Problems

Answers to problems labeled **(A)** are listed in an Appendix at the back of the book.

Process Capability and Tolerances

40.1 **(A)** (SI units) A turning operation produces parts with a mean diameter = 4.500 cm. The process is in statistical control, and the output is normally distributed with a standard deviation = 0.008 cm. Determine the process capability.

Solution: Process capability $PC = \mu \pm 3\sigma = 4.500 \pm 3(0.008) =$ **4.500 ± 0.024 cm**
The upper and lower limits of the process capability range are: 4.476 to 4.524 cm

40.2 A sheet-metal V-bending operation bends parts to an included angle = 46.1°. The process is in statistical control, and values of included angle are normally distributed with a standard deviation = 0.33°. (a) Determine the process capability. (b) The design specification on the angle is 45° ± 1°. If the process were adjusted so that its mean = 45.0°, determine the value of the process capability index. Also, using Table 40.1, estimate the proportion of defects that would be produced at the 45° mean.

Solution: (a) $PC = 46.1 \pm 3(0.33) = 46.1° \pm 0.99°$
The upper and lower limits of the process capability range are: 45.11° to 47.09°

(b) Given $\mu = 45°$ and tolerance range $T = 46° - 44° = 2°$
$PCI = 2°/(6 \times 0.33°) = 2°/1.98° =$ **1.01**
Based on Table 40.1, this *PCI* indicates a fraction defect rate of less than 0.27%.

40.3 (SI units) A plastic extrusion process produces round tubular extrudate with a mean outside diameter = 24.5 mm. The process is in statistical control, and the output is normally distributed with standard deviation = 0.30 mm. (a) Determine the process capability. (b) The design specification on the OD is 25.0 mm ± 0.75 mm. If the process were adjusted so that its mean = 25.0 mm, determine the value of the process capability index.

Solution: (a) Process capability $PC = \mu \pm 3\sigma = 24.5 \pm 3(0.30) =$ **24.5 ± 0.90 mm**
The upper and lower limits of the process capability range are: 23.6 to 25.4 mm.

(b) Given $\mu = 25.0$ mm and tolerance range $T = 25.75 - 24.25 = 1.5$
$PCI = 1.5/(6 \times 0.30) =$ **0.833**

Control Charts

40.4 **(A)** (SI units) In 25 samples of size $n = 7$, the average value of the sample means is $\bar{\bar{x}} =$ 2.812 cm for the dimension of interest, and the mean of the ranges of the samples is $\bar{R} =$ 0.023 cm. Determine the lower and upper control limits for the (a) $\bar{x}$ chart and (b) R chart.

Solution: (a) $\bar{x}$ chart: $\bar{x}$ = **2.812 cm = *CL***
$LCL = \bar{x} - A_2\bar{R} = 2.812 - 0.419(0.023) =$ **2.802 cm**
$UCL = \bar{x} + A_2\bar{R} = 2.812 + 0.419(0.023) =$ **2.822 cm**

(b) R chart: $\bar{R}$ = **0.023 = *CL***

$LCL = D_3\,\bar{R} = 0.076(0.023) =$ **0.00175 cm**
$UCL = D_4\,\bar{R} = 1.924(0.023) =$ **0.04425 cm**

40.5 In 15 samples of size $n = 9$, the grand mean of the samples is $\bar{\bar{x}} = 84$ for the characteristic of interest, and the mean of the ranges of the samples is $\bar{R} = 6.5$. Determine the lower and upper control limits for the (a) $\bar{x}$ chart and (b) R chart.

Solution: (a) $\bar{x}$ chart: $\bar{x}$ = **84** = CL
$LCL = \bar{x} - A_2\,\bar{R} = 84 - 0.337(6.5) =$ **81.81**
$UCL = \bar{x} + A_2\,\bar{R} = 84 + 0.337(6.5) =$ **86.19**

(b) R chart: $\bar{R}$ = **6.5** = CL
$LCL = D_3\,\bar{R} = 0.184(6.5) =$ **1.196**
$UCL = D_4\,\bar{R} = 1.816(6.5) =$ **11.804**

40.6 (USCS units) Seven samples of 5 parts each have been collected from an extrusion process that is in statistical control, and the diameter of the extrudate has been measured for each part. The calculated values of $\bar{x}$ for each sample are 1.002, 0.999, 0.995, 1.004, 0.996, 0.998, and 1.006 (in). The values of R are 0.010, 0.011, 0.014, 0.020, 0.008, 0.013, and 0.017 (in), respectively. (a) Determine the values of the CL, LCL, and UCL for $\bar{x}$ and R charts. (b) Construct the control charts and plot the sample data on the charts.

Solution: $\bar{\bar{x}} = \Sigma\,\bar{x}/7 = (1.002 + 0.999 + 0.995 + 1.004 + 0.996 + 0.998 + 1.006)/7 = 1.000$
$\bar{R} = \Sigma\,R/7 = (0.010 + 0.011 + 0.014 + 0.020 + 0.008 + 0.013 + 0.017)/7 = 0.0133$

(a) $\bar{x}$ chart: $\bar{x}$ = **1.000 in =** CL
$LCL = \bar{x} - A_2\,\bar{R} = 1.000 - 0.577(0.0133) =$ **0.9923 in**
$UCL = \bar{x} + A_2\,\bar{R} = 1.000 + 0.577(0.0133) =$ **1.0077 in**

R chart: $\bar{R}$ = **0.0133 =** CL
$LCL = D_3\,\bar{R} = 0(0.0133) =$ **0**
$UCL = D_4\,\bar{R} = 2.114(0.0133) =$ **0.0281 in**

(b) Student exercise.

40.7 In an $\bar{x}$ chart used for an industrial process, $UCL = 53.5$ and $LCL = 39.9$ for a critical process variable of interest. The following ten sample means were collected at random times from the process: 45.6, 47.2, 49.3, 46.8, 48.8, 51.0, 46.7, 50.1, 49.5, and 48.9. (a) Plot the data together with the CL, LCL, and UCL on a piece of graph paper. (b) Interpret the data. Is anything amiss?

Solution: The central line $CL = (UCL + LCL)/2 = (53.5 + 39.9)/2 = 46.7$. All of the data points lie inside the upper and lower control limits. However, only the first data point (45.6) is below the CL. The rest are above CL. That is like flipping 10 coins and getting 9 out of 10 heads or 9 out of 10 tails. In addition, if the first five data values are averaged (47.54) and compared to the average of the last five points (49.24), an upward moving trend is suggested. To sum up, the data are not consistent with a process that is in statistical control. An investigation should be launched to figure out what is causing the process to behave like this.

40.8 **(A)** A *p* chart is based on six samples of 40 parts each. The average number of defects per sample is 1.6. Determine the center, *LCL*, and *UCL* for the *p* chart.

Solution: $\bar{p}$ = 1.6/40 = **0.04 =** ***CL***

$LCL = \bar{p} - 3\sqrt{p(1-p)/n} = 0.04 - 3\sqrt{0.04(0.96)/40} = 0.04 - 3(0.031) = \mathbf{-0.053 \rightarrow 0}$

$UCL = \bar{p} + 3\sqrt{p(1-p)/n} = 0.04 + 3\sqrt{0.04(0.96)/40} = 0.04 + 3(0.031) = \mathbf{0.133}$

40.9 The yield of good chips during a critical step in the silicon processing of integrated circuits averages 96%. The number of chips per wafer is 250. Determine the center, *LCL*, and *UCL* for the *p* chart that might be used for this process.

Solution: Use p = 1 – 0.96 = **0.04 =** ***CL***

$LCL = \bar{p} - 3\sqrt{p(1-p)/n} = 0.04 - 3\sqrt{0.04(0.96)/250} = 0.04 - 3(0.0124) = \mathbf{0.00282}$

$UCL = \bar{p} + 3\sqrt{p(1-p)/n} = 0.04 + 3\sqrt{0.04(0.96)/250} = 0.04 + 3(0.0124) = \mathbf{0.07718}$

40.10 Twelve cars were inspected after final assembly. The number of defects found ranged between 87 and 139 defect per car with an average of 110. Determine the center and upper and lower control limits for the *c* chart that might be used in this situation.

Solution: *CL* **= 110**

$LCL = \bar{c} - 3\sqrt{\bar{c}} = 110 - 3\sqrt{110} = \mathbf{78.5 \rightarrow 78}$

$UCL = \bar{c} + 3\sqrt{\bar{c}} = 110 + 3\sqrt{110} = \mathbf{141.5 \rightarrow 142}$

Six Sigma Program

40.11 **(A)** A foundry that casts turbine blades inspects for six features considered critical-to-quality. During the previous month, 948 castings were produced. During inspection, 37 defects among the six features were found, and 21 castings had one or more defects. Determine *DPMO*, *DPM*, and *DUPM* in a Six Sigma program for these data and convert each to its corresponding sigma level.

Solution: Summarizing the data, N_u = 948, N_o = 6, N_d = 37, and N_{du} = 21. Thus,

$$DPMO = 1{,}000{,}000\frac{37}{948(6)} = \mathbf{6505}$$

The corresponding sigma level is about 4.0 from Table 40.3.

$$DPM = 1{,}000{,}000\frac{37}{948} = \mathbf{39{,}030}$$

The corresponding sigma level is about 3.2.

$$DUPM = 1{,}000{,}000\frac{21}{948} = \mathbf{22{,}152}$$

The corresponding sigma level is about 3.5.

40.12 The inspection department in an automobile final assembly plant inspects cars coming off the production line against 55 quality features considered important to customer satisfaction. The department counts the number of defects found per 100 cars, which is the same type of metric used by a national consumer advocate agency. During a one-month period, a total of 16,582 cars rolled off the assembly line. These cars included a total of 6045 defects of the 55 features, which translates to 36.5 defects per 100 cars. In addition, a total of 1955 cars had one or more of the defects during this month. Determine *DPMO*, *DPM*, and *DUPM* in a Six Sigma program for these data and convert each to its corresponding sigma level.

Solution: Although the inspection department uses number of defects per 100 cars, a Six Sigma program uses defects per million as its metric. Summarizing the data, N_u = 16,582, N_o = 55, N_d = 6045, and N_{du} = 1955. Thus,

$$DPMO = 1{,}000{,}000\frac{6045}{16582(55)} = \mathbf{6628}$$

The corresponding sigma level is about 4.0 from Table 40.3.

$$DPM = 1{,}000{,}000\frac{6045}{16582} = \mathbf{364{,}552}$$

The corresponding sigma level is about 1.8.

$$DUPM = 1{,}000{,}000\frac{1955}{16582} = \mathbf{117{,}899}$$

The corresponding sigma level is about 2.7.

Laser Measurement Technologies

40.13 (USCS units) A laser triangulation system has the laser mounted at a 35° angle from the vertical. The distance between the worktable and photodetector is 24.000 in. Determine the (a) distance between the laser and the photodetector when no part is present and (b) height of a part when the distance between the laser and photodetector is 12.025 in.

Solution: (a) L with no part when D = 0: D=H – L cot A;
0 = H – L cot A; L = H/cot A = H tan A
L = 24.000 tan(35) = **16.805 in**

(b) D = H – L cot A = 24.000 – 12.025 cot(35)
D = 24.000 – 12.025(1.42815) = **6.8265 in**

40.14 (SI units) A laser triangulation system is used to determine the height of a steel block. The system has a photosensitive detector that is located 750.000 mm above the working surface and the laser is mounted at a 30.00° angle from the vertical. With no part on the worktable, the position of the laser reflection on the photosensor is recorded. After a part is placed on the worktable, the laser reflection shifts 70.000 mm toward the laser. Determine the height of the object.

Solution: Need to find the distance of the reflection from the laser.
L with no part when D = 0: D = H – L cot A; 0 = H – L cot A; L = H/cot A = H tan A
L = 750 tan(30) = 433.0127 mm
L with part = 433.0127 – 70 = 363.0127 mm
D = H – L cot A = 750 – 363.0127 cot(30) = 750 – 363.0127(1.732) = **121.262 mm**