CHAPTER 9

COMPARISON OF FEED MECHANISMS OF FINE BORING MACHINE 
AND PREDICTING THE OPTIMUM BASED ON "QUALITY" ANALYSIS

9.1 THE MEANING OF "QUALITY"

Product and service quality can be defined as:

The total composite of product and service characteristics of marketing, engineering, manufacture, and maintenance through which the product and service in use will meet the expectations of the customer.

The purpose of most quality measurements is to determine and evaluate the degree or level to which the product or service approaches this total composite.

Some other terms, such as reliability, serviceability, and maintainability, have sometimes been used as definitions for product quality. These terms are of course individual characteristics which make up the composite of product and service quality.

It is important to recognize this fact because the key requirement for establishing what is to be the "quality" of a given product requires the economic balancing-off of these various individual quality characteristics. For example, the product must perform its intended function repeatedly as called upon, over its stipulated life cycle under intended environments and conditions of use. In other words, it must have good reliability. Of overriding importance, the produce must be safe. The reasonable degree of product must have
appearance suitable to customer requirements, so it must have attractability. When all the other product characteristics are balanced in, the "right" quality becomes that composite which provides the intended functions with the greatest overall economy, considering among other things product and service obsolescence-and it is the total customer-satisfaction-oriented concept of "quality" that is mentioned here.

Important among these customer conditions are (1) the actual end use and (2) the selling price of the product or service. In turn, these two conditions are reflected in 10 additional product and service conditions:

1. The specification of dimensions and operating characteristics.
2. The life and reliability objectives
3. The safety requirements
4. The relevant standards
5. The engineering, manufacturing, and quality costs
6. The production conditions under which the article is manufactured
7. The field installation and maintenance and service objectives
8. The energy-utilization and material conservation factors
9. The environmental and other "side" effects considerations
10. The costs of customer operation and use and product service.
9.2 QUALITY COSTS

Satisfactory product and service quality goes hand-in-hand with satisfactory product and service cost.

One of the major obstacles to the establishment of stronger quality programs in earlier years was the mistaken notion that the achievement of better quality required much higher costs. Nothing could have been farther from the facts of industrial experience.

Unsatisfactory quality means unsatisfactory resource utilization. This involves wastes of material, wastes of labor, and wastes of equipment time—and consequently involves higher costs. In contrast, satisfactory quality means satisfactory resource utilization and consequently lower costs.

What is the Scope of Quality Costs?

Those costs associated with the definition, creation, and control of quality as well as the evaluation and feedback of conformance with quality, reliability, and safety requirements, and those cost associated with consequences of failure to meet the requirements both within the factory and in the hands of customers.

In actual fact, however, quality costs are generated not only throughout the marketing-design-manufacturing-inspection-shipping cycle but continue to accrue throughout the total life cycle of the product in service and use.
Thus, the incidence of quality costs is very broad and falls not only upon producers but upon consumers and merchants and indeed, upon activities throughout the entire production and consumption process.

There is no doubt that the measurement of product life cycle oriented costs, including user quality costs and other wider-ranging quality costs, will continue to evolve and be approached with the same precision now devoted to the more traditional producer operating costs.

Definitions of Operating Quality-Cost Items

Quality costs be defined in four categories.

9.2.1 Cost of prevention
9.2.2 Cost of Appraisal
9.2.3 Cost of internal failure
9.2.4 Cost of external failure.

9.2.1 Cost of prevention

a. Quality planning

Quality planning represents costs associated with the time that all personnel whether in the quality function or in other functions spend planning the ongoing details of the quality system and translating product-design and customer quality requirements into specific manufacturing controls on quality of materials, processes, and products through formal methods, procedures, and instructions. It also represents costs associated with the time spend doing
other quality-planning work, such as reliability studies, reproduction quality analysis, and writing instructions or operating procedures for test, inspection, and process control.

b. **Process control**

Process control represents costs associated with the time that all personnel spend studying and analyzing manufacturing processes (including vendors) for the purposes of establishing a means of control and improving existing process capability, and providing technical support to shop personnel for the purposes of effectively applying or implementing quality plans and initiating and maintaining control over manufacturing operating processes.

**Note:**

Quality planning and process control may be performed in some businesses by the same personnel. The first activity may be thought of as reproduction planning and the second as providing technical support during production. Process control is aimed at controlling process-quality problems. This should be distinguished from test and inspection, defined under 2, cost of appraisal.

c. **Design and development of quality information equipment**

Design and development of quality information equipment represent costs associated with the time that personnel spend designing and developing product-and process-quality measurement, data, control, and related
equipment and devices. This item does not include the cost of equipment or
depreciation.

d. **Quality training and work force development**

Quality training represents the cost of developing and operating formal
quality training programs throughout the company operations, designed to
train personnel and use of programs and techniques for the control of quality,
reliability, and safety. It does not include training costs of instructing operators
to achieve normal quantity proficiency.

e. **Product-design verification**

Product-design verification represents the cost of evaluating product for
the purpose of verifying the quality, reliability, and safety aspects of the
design.

f. **Systems development and management**

Systems development and management represent the cost of overall
quality systems engineering and management and support for quality-systems
development.

g. **Other prevention costs**

Other prevention costs represent administrative costs involving quality
and reliability organisational costs not otherwise accounted for, such as
managerial and clerical salaries and travel expenses.
9.2.2 Cost of appraisal

a. Test and inspection of purchased materials

Test and inspection of purchased materials represent the costs associated with the time that inspection and testing personnel spend evaluating the quality of purchased materials and any applicable costs of supervisory and clerical personnel. Also, this may include the cost of inspectors traveling to vendors' plants to evaluate purchased materials.

b. Laboratory-acceptances testing

Laboratory-acceptance testing represents the cost of all tests provided by a laboratory or testing unit to evaluate the quality of purchased materials.

c. Laboratory or other measurement services

Laboratory or other measurement services represent the cost of laboratory measurement services, instrument calibration and repair, and process monitoring.

d. Inspection

Inspection represents the costs associated with the time that inspection personnel spend evaluating the quality of the product in the plant and applicable costs of supervisory and clerical personnel. It does not include the cost of inspection of purchased materials included in 2a, inspection equipment, utilities, tools, or materials.
e. Testing

Testing represents the costs associated with the time that inspection personnel spend evaluating the technical performance of the product in the plant and applicable costs of supervisory and clerical personnel. It does not include the cost of testing purchased materials included in 2a, test equipment, utilities, tools, or materials.

f. Checking labor

Checking labor represents the costs associated with the time that operators spend checking quality of own work as required by the quality plan, checking product or process for quality conformance at planned points in manufacturing, sorting lots which are rejected for not meeting quality requirements, and other in-process evaluations of product quality.

g. Setup for test or inspection

Setup for test or inspection represents the costs associated with the time that personnel spend setting up product and associated equipment to permit functional testing.

h. Test and inspection of equipment and material and minor quality equipment

Test and inspection material represents the cost of power for testing major apparatus such as steam or oil, and materials and supplies consumed
in destructive tests, such as life test or tear-down inspections. Minor quality equipment includes costs of non capitalized quality information equipment.

i. **Quality audits**

Quality audits represent the costs associated with the time that personnel spend performing audits.

j. **Outside endorsements**

Outside endorsements represent external laboratory fees, insurance inspections costs, and so on.

k. **Maintenance and calibration of quality information test and inspection equipment**

Maintenance and calibration of test and inspection equipment represent the costs associated with the time spent by maintenance personnel calibrating and maintaining quality information test and inspection equipment.

l. **Product-engineering review and shipping release**

Product-engineering review and shipping release represent the costs associated with the time of product engineers who review test and inspection data prior to release of the product for shipment.
m. Field testing

Field testing represents the costs incurred by the department while field testing the product at the customer's site prior to final release. These costs might include traveling costs and living expenses.

9.2.3 Cost of internal failure
a. Scrap

For the purpose of obtaining operating quality costs, scrap represents the losses incurred in the course of obtaining the required level of quality. It should not include materials scraped for other reasons, such as obsolescence, overruns, and product-design changes resulting from further evaluation of customer needs. Scrap might be further subdivided, e.g., between fault of own manufacture and fault of vendor.

b. Rework

For the purpose of obtaining operating quality costs, rework represents the extra payments made to operators in the course of obtaining the required level of quality. It should not include extra payments to operators for any other reasons, such as rework caused by product-design changes resulting from further evaluation of customer needs. Rework might be further subdivided, e.g., between fault of own manufacture and fault of vendor.
c. Material-procurement costs

Material-procurement costs represent those additional costs incurred by the material-procurement personnel in handling both rejects and complaints on purchased materials. Such costs may include getting disposition from vendors for rejected materials, making certain that vendors understand quality requirements for either rejects complaints, and so on.

d. Factory contact engineering

Factory contact engineering represents the costs associated with the time spent by product or production engineers who are engaged in production problems involving quality; e.g., if a product component or material does not conform to quality specifications, a product or production engineer may be requested to review the feasibility of product-specification changes. It does not include engineering development work which may be performed on the factory floor.

9.2.4 Cost of external failure

a. Complaints in warranty

Complaints in warranty represent all costs of specific field complaints within warranty for investigation, repair, to replacement.
b. **Complaints out of warranty**

Complaints out of warranty represent all accepted costs for the adjustment of specific field complaints after expiration of the warranty.

c. **Product service**

Product service represents all accepted product service costs directly attributable to correcting imperfections or special testing, or correction of defects not the result of field complaints. It does not include installation service or maintenance contracts.

d. **Product liability**

Product liability represents quality-related costs incurred as a result of liability judgement related to quality failures.

e. **Product recall**

Product recall represents quality-related costs incurred as a result of the recall of products or components of products.

9.3 **RELIABILITY**

A reliable product is one that will perform the function it is designed to perform when required to do so over its period of use. Reliability is a quality characteristic that represents one of today's principal buyer demands.
Buyers who once concentrated their purchases upon products that were primarily innovative now concentrate upon such products that operate reliably.

What is Product Reliability?

Product reliability is one of the qualities of a product. Quite simply, it is the quality which measures the probability that the product or device "will work".

As a definition,

Product reliability is the ability of a unit to perform a required function under stated conditions for a stated period of time.

The first element in reliability is the consideration of variation, which makes of reliability a probability. Each individual use of product will vary somewhat from other units: some may have a relatively short life and others a relatively long life. Furthermore, a group of units may have a certain average life. Thus it is possible to identify distributions of product failure which permit prediction of the life of units of product.

The second consideration contained in the definition is that reliability is a performance quality characteristic. For a product to be reliable, it has to perform a certain function or do a certain job when called upon.

Implied in the phrase "performing its intended function" is that device intended for a certain application.
The third element in the definition of reliability is time. Reliability stated as a probability of the product's performing a function, must be identified for a stated period of time.

The fourth consideration in the definition are conditions, which include the application and operating circumstances under which the product is put to use.

Comparing the 3 designs based on reliability in conventional design the guide ways are subjected to severe wear and tear and reliability is low because friction type guide ways are used. In conventional design the lead screw is having line contact because of screw and nut mechanism. But in CNC design the guide ways are friction free turcite lined type and rolling contact ball screws give high reliability.

Considering the quality cost of three designs cost of prevention and cost of Appraisal will be high for Electro mechanical feed since it has large number of components. These two costs are low for hydraulic and CNC feed. Cost of internal failure is also high for Electro Mechanical feed since there is possibility of scrap due to material defect rework etc. Cost of External failure is very less in CNC feed because there are less field complaints. Overall the quality costs are less for CNC feed.

As far as Quality is concerned, considering the accuracy of product produced, the maximum tolerance of the fine bored cylinder, the efficiency of transmission the CNC design is the best. The cost of system will justify its quality.
The rapid rate is 10m/min which is higher among 3 designs. So production rate is high. The control is electronic so there is no problem of maintenance like the problems in mechanical system or oil leakage problems in hydraulic design.

The speed is infinitely variable with a speed range 1:20000. This is not possible either in hydraulic or Electro Mechanical design. In hydraulic though the speed is infinitely variable it can't have control as in CNC feed system which is electronically controlled. In Electro Mechanical feed system we get maximum of 45 feeds, by change gear combination.

Positioning of smallest position increments like 1-2 μm is possible. For a feed motor, this represents an angular rotation of approximately 2-5 angular minutes.

Moreover poor quality in designs results

1. Accidents and injury
2. Lost time on investigation
3. Fire fighting
4. Scrap
5. Unnecessary meetings
6. Rework
7. Excessive inventory
8. Failure analysis and reporting
9. Fines and penalties
10. Overtime due to quality problem
11. Unnecessary travel due to quality problem
12. Re-inspection etc.

From the above it is clear that a design with high quality is superior to design with low quality and quality costs are less. For CNC design cost due to poor quality is less. Moreover the above mentioned problem like accidents, loss of time, scrap, customer complaints are less in CNC feed.

9.4 STATISTICAL QUALITY CONTROL ASPECTS

Here in this section statistical techniques like frequency distribution, normal curve, process capability index etc are used to analyse the feed units.

9.4.1 The Concepts frequency distribution

One characteristic of modern manufacturing is that no two pieces are ever made exactly alike. There are many factors that contribute this variations. We are most concerned about the variation caused due to different feed mechanisms used. The part cast iron cylinder whose bore is machined using fine boring machine was inspected. 10 pieces were inspected in each design and the results were tabulated as shown below.

The specification of the bore is 50 ± 0.05 various sets of readings were obtained for components made out of 3 designs, namely Electro Mechanical design, hydraulic design and CNC design.
TABLE 9.1

SAMPLES TAKEN FROM MACHINES MADE OUT OF 3 TYPES OF FEED MECHANISMS
DIAMETER OF BORE AND FREQUENCY FOR 3 FEEDS

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<th>CNC Feed Frequency</th>
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9.4.2 Graphical representation of frequency distribution

(i) Frequency Histogram

(ii) Bar Chart

(iii) Frequency Polygon

i. Frequency histogram

In this graph the sides of the column represent the upper and lower cell boundaries and their heights are proportional to frequency of occurrences within the cells.
The simplicity of construction and interpretation of the histogram makes it an effective tool in the elementary analysis of the data. A random sample is selected as mentioned earlier. The data are charted on a frequency histogram to the specification limits and of drawing appropriate conclusion. Frequency histogram for Electro mechanical feed, Hydraulic feed and CNC feed are given in diagram. (Fig.9.1).

**Bar Chart**

A frequency bar chart is a graphical representation of the frequency distribution to which the bars are centred at mid points of the cells. The heights of bars are proportional to the frequencies in the respective cells. Bar charts are shown in (Fig. 9.2).

**iii Frequency Polygon**

Frequency polygon is got by joining all the small points which are plotted at cell mid points with a height proportional to cell frequency.

Frequency polygons for 3 designs are given in Fig.9.3.

**9.4.3 Quantitative Description of Distribution**

**9.4.3.1 Central Tendency**

One of the salient characteristics of the distribution of the sample data is that most of the observations tend to concentrate in the centre of distribution. The characteristic of distribution is known as central tendency.
Fig. 9.1

FREQUENCY HISTOGRAM FOR CNC FEED

FREQUENCY HISTOGRAM FOR HYDRAULIC FEED

FREQUENCY HISTOGRAM FOR ELECTRO MECHANICAL FEED
BAR CHART FOR CNC FEED

BAR CHART FOR HYDRAULIC FEED

BAR CHART FOR ELECTRO MECHANICAL FEED

Fig. 9.2
Fig. 9.3
Central tendency is expressed in three ways

(i). The average value (Arithmetic means)
(ii). Middle value (Median)
(iii). The most frequency occurring value termed as mode

In this arithmetic mean is discussed here.

(i) Arithmetic mean $x$

The arithmetic mean is the average of all values of the variate in the sample.

$$
\bar{x} = \frac{\sum_{i=1}^{n} f_i x_i}{\sum_{i=1}^{n} f_i}
$$

where $f_i$ - frequency, $x_i$ - value, $n$ - number of samples

1. Arithmetic mean for Electro mechanical feed

$$
= \frac{49.96 + 49.97 + 49.98 + 49.99 + 2 \times 50 + 2 \times 50.01 + 50.02 + 50.03}{10}
$$

$= 49.997.$

2. Arithmetic mean for hydraulic feed

$$
= \frac{49.97 + 49.98 + 2 \times 49.99 + 3 \times 50 + 50.01 + 50.02 + 50.03}{10}
$$

$= 49.999$

3. Arithmetic mean for CNC Feed

$$
= \frac{49.99 \times 2 + 5 \times 50 + 3 \times 50.01}{10}
$$

$= 50.001$
(ii) **Standard deviation (σ)**

Standard deviation is defined as the root mean square of the differences between the observation and the mean.

\[
\sigma = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n}}
\]

\(i\) varies from 1 to \(n\) otherwise

\[
\sigma = \sqrt{\frac{\sum fX^2 - n\bar{X}^2}{n}}
\]

Standard deviation for component samples made out of different feed mechanisms.

**Standard deviation for design 1**

\[
\sigma = \sqrt{\frac{49.96^2 + 49.97^2 + 49.98^2 + 49.99^2 + 2 \times 50^2 + 2 \times 50.01^2 + 50.02^2 + 50.03^2 - 10 \times 49.997^2}{10}}
\]

\[
= 0.021
\]

**Standard deviation for design 2**

\[
\sigma = \sqrt{\frac{3 \times 50^2 + 2 \times 49.99^2 + 49.98^2 + 49.97^2 + 50.01^2 + 50.02^2 + 50.03^2 - 10 \times 49.999^2}{10}}
\]

\[
= 0.017
\]

**Standard deviation for design 3**

\[
\sigma = \sqrt{\frac{5 \times 50^2 + 2 \times 49.99^2 + 3 \times 50.01^2 - 10 \times 50.001^2}{10}}
\]

\[
= 0.007
\]
(iii) Variance

i. Variance for Design 1

\[ \sigma^2 = .021^2 = 4.41 \times 10^{-4} \]

ii. Variance for Design 2

\[ \sigma^2 = .017^2 = 2.89 \times 10^{-4} \]

iii. Variance for Design 3

\[ \sigma^2 = .007^2 = 0.49 \times 10^{-4} \]

The variance, standard deviation and range is very close to zero in CNC feed. So it is highly accurate.

9.4.4 Normal Curve

In the frequency distribution if the number of observation are increased considerably then the number of cells will increase and the width of the cell become smaller and smaller. The series of steps that constitutes the top line of the histogram will then approach a smooth curve. The height of curve at any point is proportional to the frequency at that point, and the area under it between any two limits is proportional to the frequency of occurrences within these limits. Such a curve is called a "frequency curve".
The frequency curves may be of different shapes. The most important of these curves is the normal curve. It is the symmetrical bell shaped curve which is shown in fig.9.4, 9.5 and 9.6.

The greatest usefulness of normal distributions curves lies in the relationship obtainable from the knowledge of area under the curve lying between certain limits on base line.

The following important points should be noted.

1. Normal distribution curve is symmetrical about its mean value and has bell shape. The curve is fully defined by \( X \) and \( \sigma \)

2. Theoretically normal distribution curve extends from \(-\infty\) to \(+\infty\) (minus infinity to plus infinity). However for all practical purposes we can consider normal curve as extending only \( 3 \sigma \) to the left and \( 3 \sigma \) value to the right of the mean \((\bar{X} \pm 3 \sigma)\)

3. If estimates of the average \((\bar{X})\) and standard deviation of the population are obtained then a simple calculation will provide an estimate of the probability that the characteristic will fall between any pair of stated values.

4. The most commonly quoted limits in connection with the curve are as follows:
This means that those distributions which approximate the N.D. Curve we can say that 2/3 occurrences fall within one standard deviation (σ), 95 percent within two standard deviation (2σ) and practically all fall within three standard deviation (3σ).

The normal curve for design (1) Design (2) of Design (3) are shown in fig.

The normal curve shows that in Electro Mechanical feed process variability is high and relative precision is low.

In hydraulic feed process variability is medium and relative precision is medium. In CNC feed process variability is low and relative precision is high.

9.4.5 Process Capability

The ability to achieve the target established for a process determines its accuracy. Its ability to be able to produce the same results over and over again
NORMAL CURVE FOR ELECTRO MECHANICAL FEED

Fig. 9.4
NORMAL CURVE FOR HYDRAULIC FEED

Fig. 9.5
NORMAL CURVE FOR CNC FEED

Fig. 9.6
establishes its precision. For operating process such precision is better known as process capability.

A process that is designed to meet the functional goals of a new product must not only be in a position to meet these goals but also to reproduce its results predictably.

This is a very necessary requirement of world class manufacturers because it allows for interchangeable standardization and the satisfaction of the receivers of the output produced since they consistently receive without variation exactly what they wanted. Quite often the preferred term for an absence of reproduceability is variability process dispersion or spread. These are factors that are possible to determine through a systematic collection and analysis of relevant data.

Many experts like to differentiate between the two main condition under which processes are reproduceable. The term machine capability is used to indicate reproduceability under an unchanging set of conditions (such as one operator, homogenous raw material and uniform manufacturing standard). Whereas process capability is used to express reproduceability over a long period of time with normal changes in workers, input materials and other process conditions. It should be obvious that process capability is likely to be of greater importance and concern for those involved in operating the process over a long period and it is this index that we consider here in detail.
Definition of process capability

Whenever a process is in a state of statistical control and when it is assessed that the quality characteristic exhibits a normal distribution then process capability is defined as the interval within which 99.73% of all recorded values would fall. This corresponds to the interval enclose by six times the standard deviation of the measured process variable represented by the greek symbol $\sigma$. Hence process capability $= 6\sigma$ and must be understood as being indicative of the extent of dispersion that the measured value of the process parameter would demonstrate if the entire output from the process were measured.

Process capability for 3 types of feeds are given below:

1. Process capability for design (1) $C_p = 6 \times 0.021 = 0.126$

ii. Process capability for design (2) $C_p = 6 \times 0.017 = 0.102$

iii. Process capability for design (3) $C_p = 6 \times 0.007 = 0.042$

The figure of process capability is probably not as careful as the measure which indicates how well the process is doing with respect to the specification indicated for the quality characteristic in question. Therefore when upper specification limit (USL) and the lower specification Limit (LSL) are fixed then
it is important to know whether the process can hold tolerances or not. This ability is determined by the process capability index $C_p$ defined as

$$\frac{\text{USL} - \text{LSL}}{6\sigma}$$

This index indicates the ability of the process to meet tolerances and extent of outside tolerance output that the process would produce if $6\sigma$ is greater than (USL-LSL).

Process capability indexes for fine boring machine having different feed units are the following:

Process capability index for machine having electro mechanical feed:

$$\frac{\text{USL} - \text{LSL}}{6\sigma} = \frac{50.05 - 49.95}{6 \times 0.021} = \frac{0.102}{0.126} = 0.794$$

Process capability index of fine boring machine having hydraulic feed system:

$$\frac{50.05 - 49.95}{0.102} = 0.98 \approx 1$$
Process capability index of fine boring machine having CNC feed system.

\[
\frac{50.05 - 49.95}{0.042} = 2.38
\]

When \( C_{pk} = 1 \), then the process is just about meeting the desired specification. A value for \( C_p \) below 1.00 indicates that the tolerances will not always be met. While a value of \( C_p \) beyond 1.33 indicates that the process is satisfactory from the point of meeting the desired tolerances. \( C_p \geq 1.33 \) for machine using CNC feed system. The design is highly satisfactory.

As \( C_{pk} = 1 \) for machine using hydraulic feed system the design is just adequate. As \( C_{pk} < 1 \) for machine using Electro mechanical feed system the design is inadequate in holding tolerances.