1

Quality Concepts

1.1 Introduction

Quality is perceived differently by different people. Yet, everyone understands what is meant by "quality." In a manufactured product, the customer as a user recognizes the quality of fit, finish, appearance, function, and performance. The quality of service may be rated based on the degree of satisfaction by the customer receiving the service. The relevant dictionary meaning of quality is "the degree of excellence." However, this definition is relative in nature. The ultimate test in this evaluation process lies with the consumer. The customer's needs must be translated into measurable characteristics in a product or service. Once the specifications are developed, ways to measure and monitor the characteristics need to be found. This provides the basis for continuous improvement in the product or service. The ultimate aim is to ensure that the customer will be satisfied to pay for the product or service. This should result in a reasonable profit for the producer or the service provider. The relationship with a customer is a lasting one. The reliability of a product plays an important role in developing this relationship.

1.2 Quality and Reliability Defined

There are many definitions of quality available in the literature. A definition attributed to quality guru Crosby states the following:

> ***Quality is conformance to requirements.***

The preceding definition assumes that the specifications and requirements have already been developed. The next thing to look for is conformance to these requirements. Another frequently used definition comes from Juran:

> ***Quality is fitness for use.***

This definition stresses the importance of the customer who will use the product.

W. Edwards Deming defined quality as follows:

> ***Good quality means a predictable degree of uniformity and dependability with a quality standard suited to the customer.***

The underlying philosophy of all definitions is the same – consistency of conformance and performance, and keeping the customer in mind.

Another definition that is widely accepted is

> ***Quality is the degree to which performance meets expectations.***

This definition provides a means to assess quality using a relative measure.

We provide here the definition adopted by the American Society for Quality (ASQ):

> ***Quality denotes an excellence in goods and services, especially to the degree they conform to requirements and satisfy customers.***

This definition assimilates the previous ones and is our definition of choice.

Reliability implies dependability – reliability introduces the concept of failure and time to failure:

> ***Reliability is the probability that a system or component can perform its intended function for a specified interval under stated conditions.***

Quality and reliability go hand in hand. The customer expects a product of good quality that performs reliably.

1.3 Historical Development

The history of quality is as old as civilization. The Harappans of the ancient Indus Valley civilization (3000 BC) achieved high precision in the measurement of length, mass, and time. The smallest division, which is marked on an ivory scale from Lothal, was approximately 1.704 millimeters, recorded in the Bronze Age. The dimensions of the pyramids, built around 2500 BC, show a high degree of accuracy. However, the use of tolerancing systems for the specification of quality and statistical principles to monitor quality are of recent origin. The quality movement may be traced back to medieval Europe. Craftsmen began organizing into unions called guilds in the late thirteenth century. Manufacturing in the industrialized world followed the craftsmanship model throughout the eighteenth century. The factory system, with its emphasis on product inspection, started in Great Britain in the mid-1750s and grew into the Industrial Revolution in the early nineteenth century. In 1798 Eli Whitney introduced the concept of producing interchangeable parts to simplify assembly.

Objective methods of measuring and ensuring dimensional consistency evolved in the mid-1800s with the introduction of go gages. A go gage for a hole checks for its lower limit (maximum material condition). No-go gages, which are used to check the upper limit for a hole, were introduced much later. Frederick W. Taylor introduced the principles of scientific management around 1900 and emphasized the division of labor with a focus on productivity. There was a significant rise in productivity but it had a negative effect on quality. Henry Ford's moving automobile assembly line was introduced in 1913. This required that consistently good-quality parts were available so that the production assembly line would not be forced to slow down. In 1924 Walter A. Shewhart introduced the basic ideas of the statistical process control chart, which signaled the beginning of the era of statistical quality control. By the mid-1930s, statistical quality control methods were widely used at Western Electric, a manufacturing arm of the Bell system.

World War II brought increased recognition of quality in manufacturing industries and military applications. The American Society for Quality Control was formed in 1946. (Eventually it shortened its name to ASQ in 1997.) A quality revolution in Japan followed World War II: the Japanese began applying the lessons learned in producing military goods produced for export. Quality stalwarts W. Edwards Deming and Joseph M. Juran lectured extensively in Japan. As a result, the Japanese became leaders in quality by the 1970s. Japanese manufacturers began increasing their share in American markets, resulting in widespread economic effects in the United States. The U.S. response emphasized not only statistics but approaches that embraced the entire organization – a movement that became known as Total Quality Management. Several other quality initiatives followed. The ISO 9000 quality system standards were published in 1987. The Baldrige National Quality Program and the Malcolm Baldrige National Quality Award were established by the U.S. Congress in the same year. The quality philosophies that introduced the modern concepts of quality are presented in the next section.

1.4 Quality Philosophies

Several individuals made significant contributions to quality control and improvement. We take a closer look at the approach and philosophies of W. Edwards Deming, Joseph M. Juran, Philip B. Crosby, and Armand V. Feigenbaum.

W. Edwards Deming

W. Edwards Deming is perhaps the best-known quality expert in the world. He was instrumental in the post-war industrial revival of Japan. Subsequently his ideas were increasingly adopted in industry in the United States and other countries. Deming received his electrical engineering degree from the University of Wyoming and his Ph.D. in mathematical physics. He worked for the Western Electric Company with Walter A. Shewhart, the developer of the control chart. Deming then worked with the U.S. Department of Agriculture and the U.S. Census Bureau. Starting in 1950 he delivered a series of lectures to top management in Japan on statistical process control. Japanese industry adopted his methods which resulted in a significant improvement in quality. Deming firmly believed that quality is the responsibility of the management. The Deming philosophy is summarized in the following fourteen points,[1] which were included in his monumental work *Out of the Crisis*.

The fourteen points apply to both small and large organizations, to the service industry as well as to manufacturing. They also apply to a division within a company. The fourteen points are presented here.

1. *Create constancy of purpose for improvement of product and service.* The point stresses the need for a mission statement which must be understood by all employees, suppliers, and customers. The strategic plan should look for the long-term payback.

2. *Adopt the new philosophy.* Management must learn the responsibilities and take on leadership for change. Poor workmanship, defective products, or bad service are not acceptable.

3. *Cease dependence on mass inspection.* Eliminate the need for inspection on a mass basis by building quality into the product in the first place. Statistical methods of quality control are more efficient.

4. *End the practice of awarding business on the basis of price tag alone.* Instead, minimize the total cost. The aim in the purchase of new tools and other equipment should be to minimize the net cost per hour of operation or per piece produced. Move toward a single supplier for any one item, on a long-term relationship of loyalty and trust.

5. *Improve constantly and forever the system of production and service.* The improvement of product and service is an ongoing process. The Deming cycle involves the four-step process of plan, do, check, act. At the *plan* stage, the opportunities for improvement are identified. The theory is tested on a small scale at the *do* stage, the results of the test are analyzed at the *check* stage, and the results are implemented in the *act* stage.

6. *Institute training.* On-the-job training must be provided for all employees. Employees must be encouraged to implement the knowledge developed through training.

7. *Adopt and institute leadership.* The aim of supervision should be to help people to do a better job using machines. Supervision must create an environment where the workers take leadership roles in accomplishing their work.

[1] Deming, W. Edwards, *Out of the Crisis*, pp. 23–24, © 2000, Massachusetts Institute of Technology, by permission of the MIT Press.

8. *Drive out fear.* Management must create an environment where workers are encouraged to ask questions and make suggestions. A climate of innovation leads to progress.

9. *Break down barriers between departments.* People in research, design, material procurement, sales, and production must work as a team. They must understand the requirements and specifications. Teamwork leads to improvements in quality and productivity.

10. *Eliminate slogans, exhortations, and targets for the work force.* Exhortations such as asking for zero defects and new levels of productivity only create adversarial relationships. The bulk of the causes of low quality and low productivity belong to the system and thus lie beyond the power of the work force.

11. *Eliminate numerical quotas for the work force and eliminate numerical goals for people in management.* Quotas lead to the deterioration of quality. Learn the capabilities of processes and methods to improve them.

12. *Remove barriers that rob people of pride of workmanship.* Quality is achieved in the company when all employees are satisfied and motivated. Management must create an environment where the workers take pride in their job.

13. *Encourage education and self-improvement for everyone.* An organization needs people that are improving with education.

14. *Take action to accomplish the transformation.* The transformation is everybody's job.

Joseph M. Juran

Joseph M. Juran is the founder of the Juran Institute, which offers consulting and management training in quality. Juran obtained his degree in electrical engineering from the University of Minnesota in 1924 and then worked with Shewhart at Western Electric. He worked with a team from Bell Laboratories in 1926 to set up the first statistical process control techniques for factories. He published his *Quality Control Handbook* in 1951. In 1954 he was invited to Japan, where he conducted training courses in quality management. Juran contributed to quality through his original ideas and the vast amount of literature he developed on quality. He defined quality as *fitness for use*. Juran proposed the *quality trilogy*: quality planning, quality control, and quality improvement to develop a universal thought process for quality. Quality planning is the process for preparing to meet the company's goals. Both internal and external customers are identified and their needs are determined. Products and services are developed to fulfill these needs. Quality control is the process for meeting company goals during operations, and statistical process control techniques are the primary tools of control. Quality improvement is the process for breaking through to superior, unprecedented levels of performance. Juran stated categorically that waste must be identified and eliminated. Juran conceptualized the

Pareto principle, which helps in identifying the *vital few* out of the *trivial many*. This is commonly referred to as the 80–20 principle – 80% of the problems are created by 20% of the causes.

Philip B. Crosby

Philip B. Crosby is a businessman and author who influenced quality improvement through his writings and lectures. He started the Crosby Associates, which provides consulting and training in quality management. In his book *Quality Is Free*, Crosby provides a detailed quality management grid which provides various stages of management understanding and attitude, quality organization status, problem handling, cost of quality in relation to sales, quality improvement actions, and company quality posture. Crosby's response to the quality crisis was the principle of "doing it right the first time." He also included four major principles: (1) quality is "conformance to requirements," (2) the management system is prevention, (3) the performance standard is *zero defects*, and (4) the measurement system is the cost of nonconformance. The concept of zero defects was ahead of its time. More recently the concept of zero defects has led to the creation and development of Six Sigma, pioneered by Motorola, which has since been adopted worldwide by many other organizations.

Armand V. Feigenbaum

Armand V. Feigenbaum is a pivotal figure in the history of quality. He received his Ph.D. from MIT. In 1951 he published his book *Quality Control: Principles, Practice and Administration*, which was later published under the title *Total Quality Control* in 1961. Feigenbaum broadened a discipline that had relied primarily on production employees to a new stage in which everyone in an organization participates in the process of quality improvement. His book influenced much of the early philosophy of quality management in Japan in the early 1950s. He proposed a three-step process for quality improvement: quality leadership, quality technology, and organizational commitment. Total quality control is an effective system for integrating the quality development, quality maintenance, and quality improvement efforts of the various groups in an organization, enabling production and service to operate at the most economical level to achieve full customer satisfaction.

We have briefly described the philosophies of Deming, Juran, Crosby, and Feigenbaum. Each of them stressed the importance of quality and the pivotal role management must play in the implementation of quality improvement.

1.5 Conclusion

We have presented a brief description of quality history and the philosophies that influenced the quality movement. There are many others who contributed to quality improvement. Readers are encouraged to study current trends such as the Six Sigma approach and ISO 9000 certification. Quality improvement is an ongoing process, and the implementation of quality principles is not limited to industry – these principles are for all businesses, offices, services, education, healthcare, and other organizations.

Questions for Discussion

1. The chapter discussed four quality gurus. Who are the other major contributors to quality improvement?
2. What is the Malcolm Baldridge National Quality Award? What are the criteria for this award? Which organizations are the past recipients?
3. What is the underlying philosophy of Six Sigma? Which companies spearheaded this movement?
4. Who proposed the "zero defects" concept? Why did this philosophy lose its appeal?
5. How does improvement in quality benefit a manufacturing company?
6. Why do quality and reliability go hand in hand?

2

Tolerances and Fits

2.1 Introduction

Quality in a product starts at the specification stage. A number of choices are made in a design with respect to dimensions, sizes, and tolerances. *Preferred numbers* play an important role in simplifying these choices. The concept of preferred numbers is discussed and then the topics of tolerances and fits are developed, followed by a discussion of how tolerances are related to manufacturing processes.

2.2 Preferred Numbers

To reduce variety, it is a standard practice to select the sizes of objects from a preferred series of numbers, which follow a geometric progression. The size recommendations in worldwide metric standards use these numbers. Charles Renard, a French army captain, developed a set of these numbers in 1877 and reduced the number of different sizes of rope used in military balloons from 425 to 17. The series of numbers are designated R5, R10, R20, and R40 (where R stands for Renard). Each is a geometric series of numbers that are rounded. The R5 series has a progression ratio of $\sqrt[5]{10} = 1.584893192\ldots$ ($\sim$1.6), the R10 series has a progression ratio of $\sqrt[10]{10} = 1.2589254117\ldots$ ($\sim$1.25), and so on. The numbers are calculated using these exact ratios and are then rounded. The preferred numbers are included in the ANSI Z17.1-1973 and ISO 3-1973 standards. Four basic series of preferred numbers are given here:

R5: 10, 16, 25, 40, 63, 100.
R10: 10, 12.5, 16, 20, 25, 31.5, 40, 50, 63, 80, 100.
R20: 10, 11.2, 12.5, 14, 16, 18, 20, 22.4, 25, 28, 31.5, 35.5, 40, 45, 50, 56, 63, 71, 80, 90, 100.

R40: 10, 10.6, 11.2, 11.8, 12.5, 13.2, 14, 15, 16, 17, 18, 19, 20, 21.2, 22.4, 23.6, 25, 26.5, 28, 30, 31.5, 33.5, 35.5, 37.5, 40, 42.5, 45, 47.5, 50, 53, 56, 60, 63, 67, 71, 75, 80, 85, 90, 95, 100.

We note that multiples of 10, 100, ... and fractions 1/10, 1/100, ... are also included within each series.

Other rounded numbers are suggested for preferred metric sizes. These may be used for choosing dimensions, capacities, and so on:

First choice	10				16				25				40				60				100
Second choice			12				20				30				50				80		
Third choice		11		14		18		22		28		35		45		55		70		90	

As an example, the automotive engine capacity designations 1 liter, 1.6 liter, 2.5 liter, 4 liter, etc., are numbers that originate from this series. The rounded off preferred numbers here may be used as preliminary values for design. For more detailed use, we recommend the use of values from ISO or ANSI standards.

The use of preferred sizes is a step toward standardization, which reduces variety.

Example 2.1. An automotive engine manufacturer produces engines with 1.6-liter, 2.5-liter, and 4-liter capacities from the R5 series. Based on the demand, it is determined that a new engine is to be introduced with a capacity between 1.6 and 2.5 liters. What capacity do you suggest?

Solution. We note that 1.6 and 2.5 are also included in the R10 series and 2 is the value between these numbers. The suggested capacity is 2 liters. We also observe that 2 is the geometric mean ($2 \sim \sqrt{(1.6)(2.5)}$) of 1.6 and 2.5. Thus, the geometric mean is included in one of the R series.

Another example of preferred sizes is the spindle speed in machine tools. Geometric speed steps are used in multiple-speed gear boxes.

Part sizes and tolerance values are chosen from the preferred numbers. The tolerance of a part is a measure of quality, and the specification of tolerance plays an important role in making economic decisions.

2.3 Tolerances and Fits

No engineering component can be manufactured repeatedly to an exact size. If a number of components of specified dimensions are made by the same process, their sizes will vary and these variations will be random in nature. The variations may be reduced by controlling the variables of the process. The designer must make a

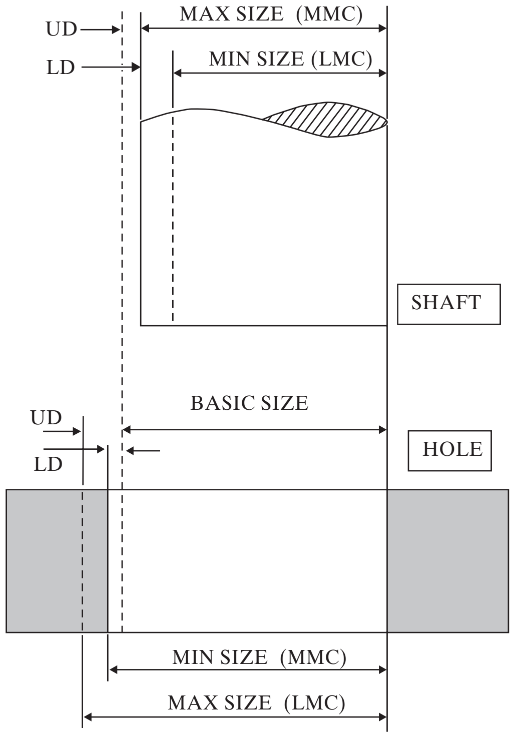

Figure 2.1. Definitions of tolerances for shafts and holes (LD, lower deviation; UD, upper deviation; MMC, maximum material condition; LMC, least material condition)

decision about these variations based on the function of the part. The smaller the specified variation, the higher the cost. This leads to the concept of tolerance.

Tolerance is the difference between the maximum and minimum size limits on a part. The tolerance is specified by the international tolerance (IT) grade. International tolerance grades range from IT01 to IT16. The tolerance values for various grades are discussed after introducing some important definitions.

Engineering products generally consist of several parts that are assembled together. An assembly may be viewed as a shaft fitting in a hole, as shown in Fig. 2.1. The various definitions related to tolerances, limits, and fits become clear from this figure. The *basic size* is the size to which tolerance and deviations are assigned; it is the same for the hole and its mating shaft. The *deviation* is the algebraic difference between a size and the corresponding basic size. The *upper deviation* is the algebraic difference between the maximum size limit and the basic size, whereas the *lower deviation* refers to the algebraic difference between the minimum size limit and the basic size. The *fundamental deviation* is the deviation of the size closer to the basic size and is specified by a letter: Upper case letters designate holes and lower case letters designate shafts. The tolerance on a part is completely specified by specifying