Chapter 11: Engineering Metrology, Instrumentation, and Quality Assurance

Introduction. Engineering **metrology** is defined as the measurement of dimensions, such as length, thickness, diameter, **taper**, angle, **flatness**, and **profile**. Note that these are **geometric** measures; mechanical and physical property measurements are not included in metrology. Traditionally, measurements have been made after the part has been produced, an approach known as **post-process inspection**. Here, the term inspection means checking the dimensions of what has been produced or is being produced, and determining whether those dimensions comply with the specified dimensional **tolerances** and other **specifications**. Today, measurements are being made while the part is produced on the machine, an approach known as **in-process**, **online**, or **real-time inspection**. An important aspect of metrology is dimensional tolerance, defined as the permissible variation in the dimensions of a part. Tolerances are important because of their major role on part **interchangeability**, proper functioning of the product, and manufacturing costs; generally, however, the smaller the tolerance, the higher are the production costs.

Numerous measuring instruments and devices are used in engineering metrology, each of which has its own **resolution**, **precision**, and other features. Two terms commonly used to describe the type and quality of an instrument are: **1. Resolution:** The smallest difference in dimensions that the measuring instrument can detect or distinguish; a wooden yardstick, for example, has far less resolution than a micrometer. **2. Precision:** Sometimes incorrectly called **accuracy**, it is the degree to which the instrument gives repeated measurements of the same standard. For example, an aluminum ruler will expand or contract, depending on temperature variations in the environment in which it is used; thus, its precision can be affected even when being held by hand.

A. Fill in the blanks with the following words.

instruments, interpolate, features, analog, temperature, concentricity

Geometric Features of Parts: Analog and Digital Measurements. The most commonly used quantities and geometric …………………… in engineering practice include:

Length, Diameter, Roundness, includes out-of-roundness, …………………… and eccentricity, **Depth, Straightness, Flatness, Parallelism, Perpendicularity, Angle,**

Profile. A wide variety of …………………..… and machines is now available to accurately and rapidly measure these quantities, either on stationary parts or on parts that are in continuous production. In engineering metrology, the words **instrument** and **gage** often are used interchangeably. Because of major global trends in automation and computer control of manufacturing operations, modern measuring equipment and **instrumentation** are now an integral part of production machinery. The implementation of **digital** instrumentation and developments in **computer integrated manufacturing** (CIM) have, together, led to the total integration of measurement technologies within manufacturing systems. …………………..… control is very important, particularly for making measurements with precision instruments. The standard measuring temperature is 20°C, and all gages are **calibrated** at this temperature. In the interest of accuracy, measurements should be taken in controlled environments maintaining the standard temperature, usually within ±0.3°C. An …………………..… instrument, such as a **vernier caliper** (Fig. 1a) or **micrometer** (Fig. 1b), relies on the skill of the operator to properly …………………..… and read the **graduated scales**. In contrast, in a digital micrometer, measurements are indicated directly (Fig. 1c). More importantly, digital equipment can easily be integrated into other equipment, including production machinery and systems for **statistical** process control (SPC).

Linear Measurement (Direct Reading) instruments. • **Rules:** The simplest and most commonly used instrument for making linear measurements is a steel rule (machinist's rule), bar, or tape, with fractional or decimal graduations. Lengths are measured directly, to an accuracy that is limited to the nearest division, usually 1 mm. • **Calipers:** Also called **caliper gages** and vernier calipers (named for P. Vernier, who lived in the 1600s), they have a graduated beam and a sliding jaw. Digital calipers are now in wide use. • **Micrometers:** These instruments are commonly used for measuring the thickness and inside or outside dimensions of parts. Micrometers also are available for measuring internal diameters (inside micrometer) and depths (micrometer depth gage, Fig. 1d). The **anvils** on micrometers can be equipped with conical or ball contacts, to measure **recesses**, threaded-rod diameters, and wall thicknesses of tubes and curved sheets or plates.

a

b

c

d

Fig. 1 (a) Vernier caliper, (b) micrometer, (c) digital micrometer, (d) micrometer depth gage.

B. Fill in the blanks with the following words.

stock, debonding, cooperation, malfunction, embrittlement, external

Product Quality. Manufactured products develop certain external and internal characteristics that result, in part, from the type of production processes employed. ………………….… characteristics most commonly involve dimensions, size, and surface finish and integrity considerations. Internal characteristics include such defects as porosity, impurities, inclusions, phase transformations, residual stresses, ………………….… cracks, and ………………….… of **<u>laminations</u>** in composite materials. Some of these defects may exist in the original material (………………….…), while others are introduced or induced during the particular manufacturing operation. Before they are marketed, manufactured parts and products are **<u>inspected</u>** in order to • Ensure dimensional accuracy, so that parts fit properly into other components during assembly; recall that a Boeing 747-400 aircraft has six million parts to be assembled. • Identify products whose failure or ………………….… may have serious **<u>implications</u>**, including **<u>bodily</u>** injury or even **<u>fatality</u>**. Typical examples are elevator cables, switches, brakes, grinding wheels, railroad wheels, welded joints, turbine blades, and **<u>pressure vessels</u>**. Product quality always has been one of the most important aspects of manufacturing operations. In view of a global competitive market, continuous improvement in quality is a major priority; in Japan, the single term **kaizen** is used to signify never-ending improvement. Quality must be built into a product and not merely considered after the product already has been made. Thus, close ………………….… and communication among design and manufacturing engineers, and the direct involvement and encouragement of company management are vital.

Quality Assurance. Quality assurance is the total effort made by a manufacturer to ensure that its products conform to a detailed set of specifications and standards. It can be defined as all actions necessary to ensure that quality requirements will be satisfied. **Quality control** is the set of operational techniques used to fulfill quality requirements. The standards cover several types of parameters, such as dimensions, surface finish, tolerances, composition, and color, as well as mechanical, physical, and chemical properties and characteristics. In addition, standards usually are written to ensure proper assembly, using interchangeable defect-free components and resulting in a product that performs as intended by its designers. A major aspect of quality assurance is the capability to analyze defects as they occur on the production line, and promptly eliminate or reduce them to acceptable levels. In an even broader sense, quality assurance involves evaluating the product and its customer satisfaction. The sum total of all these activities is referred to by terms such as as **total quality control** and **total quality management.**

C. Fill in the blanks with the following words.

probability, operate, economic, fail, military

Reliability of Products and Processes. All products eventually …………………..… in some manner or other: Automobile tires become worn, electric motors burn out, water heaters begin to leak, dies and cutting tools wear out or break, and machinery stops functioning properly. **Product reliability** is generally defined as the …………………..… that a product will perform its intended function, and without failure, in a given environment for a specified period of time while in normal use by the customer. The more critical the application of a particular product, the higher its reliability must be. Thus, the reliability of an aircraft jet engine, a medical instrument, or an elevator cable, for example, must be much higher than that of a kitchen faucet or a mechanical pencil. One may notice that, as the quality of each component of a product increases, so, too, does the reliability of the whole product. Predicting reliability involves complex mathematical relationships and calculations. The importance of predicting the reliability of the critical components of civilian or …………………..… aircraft is obvious. The reliability of an automated and computer controlled high-speed production line, with all of its complex mechanical and electronic components, also is important, as its failure can result in major economic losses to the manufacturer. **Process reliability** can be defined as the capability of a particular manufacturing process to …………………..… predictably and smoothly over time. It is **<u>implicit</u>** that there must be no significant **<u>deterioration</u>** in performance, which otherwise would require downtime on machines, interrupt production, and result in major …………………..… loss.

<u>Nondestructive</u> Testing. Nondestructive testing (NDT) is carried out in such a manner that product integrity and surface texture remain unchanged. The techniques employed generally require considerable operator skill and **<u>interpreting</u>** test results accurately, which may be a difficult task. The extensive use of computer graphics and other enhancement techniques, however, has significantly reduced the likelihood of human error. Current systems have various capabilities for data **<u>acquisition</u>** and for qualitative and quantitative inspection and analysis.

Destructive Testing. As the name suggests, the part tested by destructive-testing methods no longer retains its integrity, original shape, or surface characteristics. Mechanical test methods, such as tensile, flexure and creep tests , are all destructive, in that a sample or specimen has to be removed from the product in order to test it. Examples of other destructive tests include the speed testing of grinding wheels to determine their **bursting** speed and the high-pressure testing of pressure vessels to determine their bursting pressure. Hardness tests that leave relatively large indentations also may be regarded as destructive testing. **Microhardness** tests, however, may be regarded as nondestructive because of the very small permanent indentations produced; this distinction is based on the assumption that the material is not notch sensitive, as typically is the case with brittle materials. Generally, most glasses, highly heat-treated metals, and ceramics are notch sensitive; consequently, a small indentation produced by the indenter can greatly reduce their strength and toughness significantly.

CASE STUDY. A Coordinate-measuring Machine for Car Bodies

A large horizontal CNC **coordinate-measuring machine** (CMM) used to measure all dimensions of a car body is shown in Fig. 2. This machine has a measuring range of 6 m × 1.6 m × 2.4 m high, a resolution of 0 .1 μ m, and a measuring speed of 5 mm/s. The system has temperature compensation within a range from 16° to 26°C, in order to maintain good measurement accuracy. For efficient measurements, the machine has two heads, with **touch-trigger probes** that are controlled simultaneously and have full three-dimensional movements. The probes are software controlled, and the machine is equipped with safety devices to prevent the probes from inadvertently hitting any part of the car body during their movements. The equipment, shown around the base of the machine, includes supporting hardware and software that controls all movements and records all measurements.

Fig. 2 A large coordinate-measuring machine with two heads measuring various dimensions on a car body.

Video: Basics of CMM Coordinate Measuring Machine

(Click this link or scan the QR code).

D. Translate the following sentences into English.

۱. هرچه بازه رواداری های تعریف شده کوچکتر باشد، هزینه تولید نیز بیشتر می شود. بنابراین رواداری ها باید تا حد امکان بزرگ باشد در عین حال نیازهای عملکردی محصول باید حفظ شود.

۲. مدیریت کیفیت جامع (Total quality management) رویکردی از یک سیستم است که در آن هم مدیریت و هم کارمندان تلاش هماهنگی را برای تولید پیوسته محصولات با کیفیت بالا انجام می دهند. هدف اصلی پیشگیری از نقص است تا تشخیص نقص.

۳. به دلیل متغیرهای متعددی که در فرآیندها و عملیات تولیدی دخالت دارند، بکارگیری روش‌های آماری کنترل کیفیت ضروری است.