UNIT 2 AUTOMATED INSPECTION SYSTEM

Structure

2.1 INTRODUCTION

Inspection has become an essential part of any manufacturing system. It is the means of rejecting nonconformities and assuring good quality products. The advent of technologically updated inspection equipment helped to overcome the problems associated with traditional approaches. Traditional approach used labour-intensive methods that resulted in the increase of manufacturing lead time and production cost. Moreover, there is a significant delay in detecting an out of control limit. Thus the products that are not conforming to the specified standards accrue to the additional cost of scrap and rework.

New approach to quality control laid down conditions under which inspection should be carried out. The new approach includes :

(i) Manual inspection method surrogated by 100% automated inspection.

(ii) Offline inspection performed later is replaced with online sensor systems to accomplish inspection during or immediately after the manufacturing process.

(iii) Feedback control of the manufacturing operation in which process variable that determines product quality are monitored rather than the product itself.

(iv) Statistical process control is ensured using software tools to track and analyze the sensor measurement over time.

(v) Advanced inspection and sensor technologies, interfaced with computer based systems to automate the operations of the sensor systems.

Objectives

After studying this unit, you should be able to

- Describe the fundamentals of inspection procedures and inspection accuracy,
- explain the modern approaches to inspection with an emphasis on automating the inspection function,
- reject the product if it fails to meet the specified standards, and
- assess the quality of the workmanship and materials used during production.

2.2 FUNDAMENTALS OF INSPECTION

The term *inspection* can be defined as the activity of examining the products, its components, sub-assemblies, or materials out of which it is made, and to determine whether they adhere to design specifications. The design specifications are prescribed by the product designer.

2.2.1 Types of Inspection

Classification of inspection is based on the amount of information derived from the inspection procedure about the item’s conformance to its specifications.

Inspection for variables, in which, appropriate measuring instruments or sensors are used to measure one or more quality characteristics.

Inspection for attributes, where the parts or products are inspected to conform to the inspected quality standard. The determination is sometimes based simply on the judgement of inspector. Attribute inspection involves counting the number of defects in a product.

In general, inspection for attributes uses P-chart and C-chart whereas inspection for variables uses the X-and R-chart.

2.2.2 Inspection Procedure

The steps in the inspection performed on an individual item, such as part, sub-assembly or final product are as follows :

Presentation

The item is presented for evaluation.

Examination

The item is examined for non-conforming features. Measurement of a dimension or other attributes of the part or product are examined, while inspecting the variables.

Decision

It is based on the evaluation, a decision is made whether the item adhere to the defined quality standards. The simplest case involves a binary decision, in which the item is deemed either acceptable or unacceptable.

Action

Action should be taken based on the decision to accept or reject the item, or sort the items to the most appropriate quality grade.

In the past few decades, massive growth has taken place in the sensor and computer technology and this resulted in the wide ranging acceptance of automated inspection systems for the maintenance of strict quality standards. Naturally, emergence of automated inspection system has put the manual inspection process in the back seat due to advantages felt by the industries in terms of accuracy and time saving. In some production situation, inspection procedure is applied only to one item (e.g. a one of a kind of machine or a prototype). In batch and mass production system, either inspection of whole lot is done (called screening) or a sample is taken from a lot (sampling inspection). When only one item or few samples are inspected, it is done manually whereas for the mass production, automated systems are used for 100% inspection.

It is time consuming and expensive task to inspect all the specified dimensions and attributes of the parts. Certain dimensions and specifications are imperative in terms of assembly or function of the product and are called key characteristics (KCs).

2.2.3 Inspection Accuracy

There are normally two errors committed on the part of manufacturers while carrying out the inspection. These two kinds of mistake are called Type I and Type II errors. Type I error occurs when a good lot is rejected and is called *producers risk*. Type II error occurs when a bad lot is accepted and is called *consumers risk*. An error is committed by the inspector that misses some of the defect during inspection of an assembly line.

In manual inspection, these errors result from factors such as :

- (i) Complexity and difficulty incurred while performing an inspection task.
- (ii) Inherent variations in the inspection procedure.
- (iii) Requirement of judgment by the human inspector.
- (iv) Mental fatigue.
- (v) Inaccuracies or problems with the gages or measuring instruments used in the inspection procedure.

After establishing methodology for an automated system, inspection errors occur due to factors such as :

- (i) Complexity and difficulty of the inspection task.
- (ii) Resolution of the inspection sensors affected by "gain" and similar control parameters setting.
- (iii) Malfunctioning of equipments.
- (iv) Faults or "bugs" in the computer program controlling the inspection procedure.

The capability of the inspection process to avoid these types of errors is termed as *inspection accuracy*. Inspection accuracy is high when few or no errors are committed. Drury (1992) suggested measures of inspection accuracy for the case in which parts are classified by an inspector (or automatic inspection system) into either of two categories, conforming or nonconforming. Considering this binary case, let p_1 be the probability corresponding to the correct decisions. Thus $(1–p_1)$ is the probability that a conforming item is classified as nonconforming (Type I error). Similarly, if p_2 is probability that a nonconforming item is classified as nonconforming then, $(1–p_2)$ is the probability that a nonconforming item is classified as conforming (Type II error).

Let q be the actual fraction defect rate in the batch of items. A table of possible outcomes can be constructed as shown in Table 2.1 to reveal the fraction of parts classified correctly and incorrectly and those incorrectly classified, whether the error is Type I and Type II.

Empirically, these proportions (probabilities) would be assessed for individual inspectors by determining the proportion of correct decisions made in each of the two cases of conforming and nonconforming items in parts batch of interest. Unfortunately, the proportions vary for different inspection tasks. The more difficult inspection tasks generally have high error rates (p_1 and p_2 values are lower). Also, p_1 and p_2 rates are different for different inspectors. Typical values of p_1 ranges between 0.9 and 0.99 and that of p_2 between 0.80 and 0.90, but values as low as 0.50 for both p_1 and $p2$ have also been reported (Drury 1992). p_1 is inclined to be higher than p_2 for human inspectors because inspectors are usually on the look out for defects and examining good quality.

Table 2.1 : Table of Possible Outcomes in Inspection Procedure, Given q, p_1 and p_2

	True State of Item		
Decision	**Conforming**	**Nonconforming**	**Total**
Accept item	$p_1(1-q)$	$(1-p_2)\,q$ Type II error	$p_1 + q\,(1- p_1 - p_2)$
Reject item	$(1-p_1)\,(1-q)$ Type I error	$p_2\,q$	$1 - p_1 - q\,(1 - p_1 - p_2)$
Total	$(1-q)$	q	1.0

For an automated inspection system or human inspector, the workable measures of inspection accuracy are the values of p_1 and p_2. The values of p_1 and p_2 are expected to vary independently to some degree depending on the inspection task and system performing the inspection and hence provide some very useful information. Nevertheless, simple average can be taken to combine the two values into a single measure of inspection accuracy.

$$A = \frac{p_1 + p_2}{2}$$

where,

A = measure of inspection accuracy that ranges between zero (all inspection decision incorrect) and 1.0 (all decisions correct = perfect accuracy);

p_1 = probability that a conforming item is classified as confirmed; and

p_2 = probability that a defective item is classified as defective, as previously defined.

A practical difficulty in applying the measure is determining the true values of p_1 and p_2. Another inspection process has to be applied to determine these values resulting in further cropping up of similar errors as in the first process whose accuracy is being assessed.

2.2.4 Inspection vs. Testing

Quality control (QC) utilizes both inspection and testing procedures that are equally important in a company's quality control program. Testing is a term in quality control referring to assessment of functional aspects of product whereas inspection is used to assess the quality and its design specifications. The item tested in the *QC testing* is observed during actual operation or under conditions that might be present during operation. For example, to know whether the product is functioning properly, it is tested, by running it for a certain period of time.

Sometimes, testing procedures are of destructive nature, in which limited numbers of items are sacrificed to ensure the quality of majority of items. Efforts are made to devise methods known as *nondestructive testing* (NDT) and *nondestructive evaluation* (NDE) to save the expenses incurred during destructive testing.

SAQ 1

(a) Discuss the various steps involved in inspection procedure.

(b) What do you mean by inspection accuracy?

(c) What are Type I and Type II errors?

2.3 AUTOMATED INSPECTION

In present scenario, manual inspection is largely replaced by automated inspection as errors are reduced to great extent by automation of the process. Economic justification of an automated inspection system depends on whether the savings in labour cost and improvement in accuracy will be more than the investment and/or development costs of the system.

Automated inspection is defined as the automation of one or more steps involved in the inspection procedure. Automated or semi-automated inspection can be implemented in the number of alternative ways.

(d) Automated *presentation* of parts by an automatic handling system with manual examination and decision steps.

(e) Machine with manual loading parts into the machine doing, *automated examination* and *decision making*.

(f) Completely automated inspection system in which parts *presentation*, *examination* and *decision*s are performed automatically.

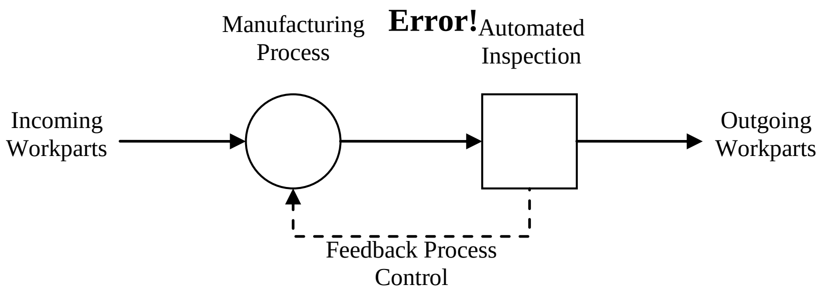
The inspection procedure is performed by a human worker in the first case, with all of the possible errors in this form of inspection. In second and third case, the actual inspection operation is accomplished by an automated system.

As in manual inspection, automated inspection can be performed using statistical sampling or 100% inspection. Sampling errors are possible when statistical sampling is used. Similar to human inspector, automated system can commit inspection error with either sampling or 100% inspection. Human inspectors can make such errors. Automated system operates with high accuracy for simple inspection tasks such as automatic gauging of a simple dimension on a part. With the increase in complexity of inspection, the error rate tends to increase. Some machine vision applications fall into this category; for example, detecting defects in integrated circuit chips or printed circuit boards. The inspection tasks of PCB are complex and difficult for human workers. This is one of the reasons for developing automated inspections systems that can do such jobs.

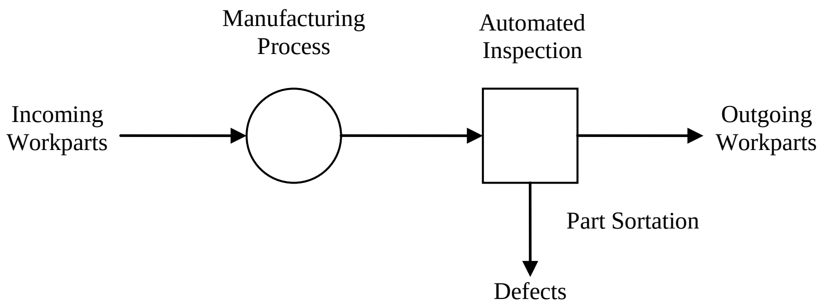
As stated earlier, inspection errors can be classified as Type I and Type II. A Type I error occurs when the automated system indicates a false alarm while the process is in control. The sensitivity of some automated inspection systems can be adjusted by the way of adjusting their "gain" or similar control. When the sensitivity adjustment is low, the probability of a Type I error is low but the probability of a Type II error is high. When the sensitivity adjustment is increased, the probability of a Type I error increases, whereas the probability of a Type II error decreases. This relationship is described in Figure 2.1. Because of these errors, a system with inspection cannot guarantee 100% good quality product.

Figure 2.1 : Relating the Sensitivity of an Automated Inspection System and Probability of Two Types of Errors

The full potential of automated inspection is best achieved when it is integrated into the manufacturing process and 100% inspection is used, and when the results of the procedure lead to some positive action. The positive actions can take either or both of two possible forms, as illustrated in Figure 2.2.



(a)



(b)

Figure 2.2 : Action Step Resulting from Automated Inspection : (a) Feedback Process Control and (b) Sortation of Parts into Two or More Quality Levels

Feedback Process Control

In the inspection operation, data are feedback to the manufacturing process responsible and the same is evaluated. The motive behind the feedback is to allow compensating adjustments to be made in the process to reduce variability and improve quality. If the output of process starts drifting toward the high side of tolerance (e.g. tool wear may cause a part dimension to increase over time), adjustment can be made in the input parameters to bring the output back to the nominal value. In this way, average quality is maintained within a smaller variability range than is possible with sampling inspection methods. As a result, process capability is improved.

Parts Sortation

Here, parts are sorted on the basis of quality level and classified as accepted or rejected part. There may be more than two levels of quality appropriate for the process (e.g. acceptable, reworkable, and scrap). Sortation and inspection may be accomplished in several ways. One alternative is to both inspect and sort at the same station. Other installation locates one or more inspections along the processing line, with a single sortation station near the end of the line. Inspection data are evaluated and inspections are put forth to the sortation station indicating what action is required for each part.

2.3.2 Timing of Inspection

An important consideration in quality control is the determination of timings of the inspection procedure. Three different options can be identified as shown in Figure 2.3 which are :

(a) off-line inspection,

(b) on-line/in-process, and

(c) on-line/post process inspection.

Off-line Inspection Methods

In off-line inspection, the inspection equipment is usually dedicated and does not make any physical contact with machine tools. There is always a time delay between production and inspection. Manual inspection is common that tend to promote the use of offline inspection that include:

(i) variability of the process is well within the design tolerance,

(ii) processing conditions are stable and the risk of significant deviation in the process is small, and

(iii) cost incurred during inspection is high in comparison to the cost of few defective parts.

The disadvantage of offline inspection is that the parts have already been made by the time poor quality is detected. Sometimes by default a defective part may not be included into the sample. A coordinate measuring machine (CMM) is an example of off-line inspection. CMM is discussed in detail in the next section.

On-line/In-process and On-line/Post-process Inspection Methods

If the task of inspection is done as the parts are manufactured, then it is called as online inspection. There are two variations of on-line inspection. If the inspection is performed during the manufacturing operation, it is called on-line/in-process inspection. If the inspection is performed immediately following the production process, it is called on-line/post-process inspection as shown in Figure 2.3.

Figure 2.3 : Three Inspection Alternatives : (a) Off-line Inspection, (b) On-line/In-process Inspection and (c) On-line/Post-process Inspection

The classical examples of online inspection are inspection probes. These probes can be used in a large variety of ways. For example, they can be mounted in holders, inserted into machine-tool spindles, or stored in a tool magazine to be exchanged by an automatic tool exchanger just as tools are handled. In flexible manufacturing system machine tools spindle mounted probes are commonly used. The primary inspection elements of the probes are sensors. Signals are transmitted to the controller as the contact is made with the part surface. Numerous technologies are available for transmitting the signals. Some of them are direct electrical connection, induction coil, infrared data transmission. The task of the data processing and interpretation is facilitated through the controller.

SAQ 3

(a) What do you mean by automated inspection?

(b) Enlist the steps involved in automation of an inspection procedure in an industry.

(c) What is feedback process control?

(d) Differentiate between on-line/in-process and on-line/post-process inspection methods.

2.4 COORDINATE MEASURING MACHINE

The measurement of original shape and dimension of an object and their comparison with desired shape and dimensions as described in part drawing that comes into the broad area of *Coordinate Metrology***.** Evaluations of the location, orientation, dimension and geometry and part or the objects are the various components of coordinate metrology. A coordinate measuring machine is an electromechanical system designed to perform coordinate metrology. A CMM consists of a contact probe, and this contact probe is positioned in three-dimensional (3-D) spaces relative to the surface of a work-part. In order to obtain, dimensional data pertaining to the part geometry, x, y, z coordinates of the probe are accurately measured.

In three-dimensional coordinate system, a basic CMM is composed of the following components.

(i) Probe head and probe,

(ii) Mechanical structure and displacement transducer,

(iii) Drive system and control units, and

(iv) Digital computer system with application software.

2.4.1 Constructional Details of CMM

The construction of CMM can best be described with the help of its two basic components: (1) Probe and (2) Mechanical structure.

Probe

The contact probe is an important component of CMM. The probe is fastened to mechanical structure that allows movement of probe relative to the part. When contact has been made with part surface during measurement. The tip of the probe is made of ruby ball. Ruby is a form of Corundum (aluminum oxide). High hardness for wear resistance and low density for minimum inertia are the required characteristics for the application of ruby in probe. Probe is of two types (1) single tip (Figure 2.4(a)), and (2) multiple tips (Figure 2.4 (b)). Touch trigger probes are most widely used probes. The probe actuates when the contact is made with part surface.

Figure 2.4 : Coordinate Measuring Machine

The various triggering mechanism, which are used commercially are discussed as follows.

(i) The trigger is based on the principle that, when the tip of the probe is deflected from neutral position then the highly sensitive electrical contact switch starts emitting signal.

(ii) The trigger actuates when there is an electrical contact between probe and metallic part surface.

(iii) The trigger uses a piezoelectric sensor that generates a signal based on tension or compression loading of the probe.

As contact exists between the probe and the surface of the object then with the help of displacement transducer the coordinate position of the probe are accurately measured. Various displacement transducers such as optical scales, rotary encoding, and magnetic scales etc are used in CMM. Probe occupies its neutral position when it has been separate out from the contact surface.

Example 2.1

Dimensional Measurement with Probe Tip Compensation

The part-dimension L in Figure 2.5 given is to be measured. The dimension is aligned with the *x*-axis, so it can be measured using x-coordinate locations. When the probe is moved toward the part from the left, contact made at $x = 70.93$ is recorded (mm). When the probe is moved toward the opposite side of the part from the right, contact made at $x = 137.44$ is recorded. The probe tip diameter is 3.00 mm. What is the dimension L?

Figure 2.5 : Set Up for CMM Measurement in Example 2.1

Solution

Given that the probe tip diameter $D_t = 3.00$ mm, the radius $R_t = 1.50$ mm each of the record x values must be corrected for this radius.

$$x_1 = 70.93 + 1.50 = 72.43 \text{ mm}$$

$$x_2 = 137.44 - 1.50 = 135.94 \text{ mm}$$

$$L = x_1 - x_2 = 135.94 - 72.54 = 63.51 \text{ mm}$$

Mechanical Structure

In order to achieve the motion of the probe, various physical components are used. Mechanical configurations of CMM are categorized into six types. Each has advantages and disadvantages associated with them. These are :

Cantilever

The cantilever configuration of a CMM is shown in Figure 2.6 (a). Such type of construction uses three movable components. These components move along mutually perpendicular guide ways. The workpiece is supported on the worktable with the help of CMM holding fixture. Three-dimensional measurements are accomplished by having the probe attached to vertical quill, which moves vertically in the z direction relative to the horizontal arm. In order to achieve y axis motion, the quill can also move horizontally in the y direction along the length of the arm. The arm is supported at one end only in cantilever fashion and moves horizontally in the x direction relative to machine base. The advantages of this construction are :

(i) Small size, low cost and minimum floor space requirement.

(ii) Convenient access to the work table.

(iii) Capacity to measure large work parts.

(iv) High rate of mounting and measuring on CMM.

Its disadvantages are limited accuracy due to cantilever nature of system and lower rigidity than most other CMM construction.

Moving Bridge

This provides a more rigid structure than the cantilever design and give rise to more accuracy. Figure 2.6(b) represents moving bridge design. In this, the probe is mounted on the bridge structure. The part, which is to be measured, is positioned on the table and the bridge structure is moved relative to the stationary table. The common difficulty associated with moving bridge design is *yawing* (walking). This happens because two legs of the bridge move at slightly different speeds and resulted in the twisting of the bridge. This phenomenon reduced the accuracy of the measurement. These types of designs are most widely used in industry.

Fixed Bridge

Figure 2.6 (c) shows the fixed bridge structure. The bridge is attached to the CMM bed and worktable is moved in the x direction beneath the bridge. This structure eliminates the phenomena of yawing and leads to more accuracy and more rigidity. However, in this design throughput is somewhat affected due to involvement of additional mass.

Horizontal Arm

Horizontal arm CMMs come in a variety of configuration such as moving ram, moving table, and fixed table. Figure 2.6(d) represents the horizontal arm (moving ram type) type CMM design. These CMMs are mainly used to measure the dimensional and geometric accuracy of the machined or fabricated workpieces.

These machines are quite similar in their operation to horizontal machine tools. Due to cantilever design of the horizontal arm, it becomes less rigid and hence less accurate. But, it allows good accessibility to the work area.

Gantry

This type of construction as shown in Figure 2.6(e) is used for the inspection of large objects. It is gantry crane type of construction in which *x* axis motion is obtained by moving the cross beam along two elevated rails. The probe quill moves vertically relative to a cross beam to obtain its axis motion.

Column

This configuration is shown in Figure 2.6 (h). Its construction is quite similar to that of the machine tool. The work table is used to obtain the *x* axis and *y* axis motion. The probe quill is moved vertically to obtain z axis motion. These machines are also referred as universal measuring machine (UMMs).

Figure 2.6 : Six Types of CMM Construction : (a) Cantilever, (b) Moving Bridge, (c) Fixed Bridge, (d) Horizontal Arm (Moving Ram Type) (e) Gantry, and (f) Column

In all of these constructions, special design features are used to build high accuracy and precision into the frame. These features include precision rolling-contact bearings and hydrostatic-bearings, installations mountings to isolate the CMM and reduce vibrations in the factory from being transmitted through the floor, and various schemes to counter balance the overhanging arm in the case of the cantilever construction.

2.4.2 CMM Operation and Programming

There are several ways in which the probe can be positioned that varies from manual operation to the direct computer control (DCC). Computer-controlled CMMs must be programmed and they must operate similar to CNC machine tools. In this section aspects of CMMs taken into account are :

(i) types of CMM controls; and

(ii) programming of computer-controlled CMMs.

CMM Controls

On the basis of operating and controlling of CMM, it can be classified in the four following ways :

(i) manual drive,

(ii) manual drive with computer-assisted data processing,

(iii) motor drive with computer-assisted data processing, and

(iv) DCC with computer-assisted data processing.

The probe is physically moved by human operator along the machine's axes for making contact with the part and the measurements are recorded in *manual drive* CMM. The three orthogonal slides are designed to be nearly frictionless to permit the probe to be free floating in the *x*, *y*, and *z*-directions. A digital readout provides the measurements that the operator can record either manually or with paper printout. Only operator is allowed to carry out calculations on the data that includes the enumeration of the center and hole diameter.

Data processing and computational capability for performing the calculations that are required to evaluate a given part feature are provided by a CMM with *manual drive CMM with computer-assisted data processing***.** The different types of data processing and computations are ranging from simple conversions between US customary units and metric to more complicated geometry calculations, such as determining the angle between two planes. The probe is free floating and permits the operator to bring it into contact with the desired part surfaces.

Electric motors are used in a *motor driven* CMM *with the computer-assisted data processin**g*** to drive the probe along the machine axes under the operator control. The motion is controlled by joystick or similar devices. The collisions between the probe and the part are reduced by low-power stepping motor and friction clutches.

CMM with *direct computer control* (*DCC*) operates just like a CNC machine tool. It is power driven and the movements of the coordinate axes are controlled by a dedicated computer under program control. Various data processing is performed by the computer and it also keeps record of the measurements made during inspection. DCC CMM requires a part programming facility.

SAQ 4

(a) Describe the advantages of using CMMs over conventional inspection methods.

(b) Enlist the applications where CMMs become an important device.

Activity I

Find literature about Image Acquisition and Digitization and their application in contact less inspection methods.

2.5 SUMMARY

This unit dealt with details on inspection fundamentals and their relationship with meeting quality standard prescribed by the customers. Enough focus has been given on different types of inspection procedure, and accuracy, mainly to highlight the importance of automated inspection, which has potential to minimize the lead time and cost. Co-ordinate measuring machine and related techniques are also discussed in this unit to signify the growing environment of computer application in contact inspection techniques.

2.6 KEY WORDS

Inspection : Inspection can be defined as the activity to examine the products, its components, sub-assemblies, or materials out of which it is made, and to determine whether they adhere to design specifications.

Automated Inspection : Automated inspection is defined as the automation of one or more steps involved in the inspection procedure.

On-line Inspection : If the task of inspection is done as the parts are manufactured, then it is called an online inspection.

Off-line Inspection : When the inspection equipment is usually dedicated and does not make any physical contact with machine tools, it is called off-line inspection. Inspection is done away from the manufacturing.

Coordinate Measuring Machine : A coordinate measuring machine is an electromechanical system designed to perform coordinate metrology.

Type I Errors : Type I error occur when a good lot is rejected and is called producers risk.

Type II Errors : Type II error occurs when a bad lot is accepted and is called consumers risk.