

MODERN 3D MEASUREMENT SYSTEMS

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ABSTRACT

In many cases, planar measurement or the individual measurement of part dimensions using classic measuring instruments (caliper, micrometer, comparator, etc.) are no longer sufficient. This creates the need for spatial measurements, in which the part is analyzed and measured in a three-dimensional measurement system. High measurement accuracy and increased flexibility in measuring objects of various sizes and complex configurations, combined with the possibility of automatically determining the relationships between the various geometric elements of the parts to be measured, make coordinate measuring machines (CMM) powerful tools for controlling manufacturing processes.

KEYWORDS: 3D Measurement, Coordinate measuring, Controlling manufacturing process, CAQ, CAI, CAT, Coordinate Measuring Machine.

1. INTRODUCTION

The basic principle of coordinate measuring technology is the movement of the probe along the machined surfaces. The measurement information is collected point by point, and the desired value of the dimension is established by software processing, based on the coordinates of the points where the determinations were made.

In the 1950s, the first coordinate measuring machine was developed. It was called the universal measuring machine. The machine's probe was moved by the operator to different measuring points and the dimensional information was given by a set of vernier scales. The measured values were recorded manually and the desired dimensions were determined by calculation.

The computer was introduced as a component of the three-dimensional measurement system in the early 1970s, receiving measurement data from a sensor. With the help of an appropriate software program, this data was transformed into useful information for the three-dimensional measurement process, as well as for compensating for errors introduced by the machine structure. Direct Computer Control,

meaning control of the machine by the computer without human operator intervention on the quality of the recorded data, was achieved in the mid-1970s.

Today, coordinate measuring machines are equipped with numerical control systems and automatic probe change devices, providing flexibility, precision, and productivity in the three-dimensional measurement of complex surfaces.

The advantages of coordinate measurements are multiple, and some parts can only be measured with these systems.

Among the most important advantages we can mention:

- ✓ CMM measures the size, shape, and position of all possible geometric elements, something that no other known instrument can do;

- ✓ Most measurement times are reduced to a fraction of the times previously required;

- ✓ Flexible adaptation to changing part sizes;

- ✓ They are universally usable for a wide range of parts;

- ✓ CMM is more reliable in the measurement process than most measuring instruments;

- ✓ They can replace single-purpose gauges and measuring devices.

2. COORDINATE MEASURING MACHINES

Coordinate measuring machines are used for precise measurement ($0.5\text{-}2.5\mu\text{m}$) of the dimensions of a part or of most geometric deviations.

From a constructive point of view, there are several types of machines:

-Universal coordinate measuring machines, having (figure 1):

- a) console construction;
- b) single-column construction;
- c) two-column construction;
- d) four-column construction;

- Special coordinate measuring machines:

- a) with scanning devices;
- b) gear measuring machines

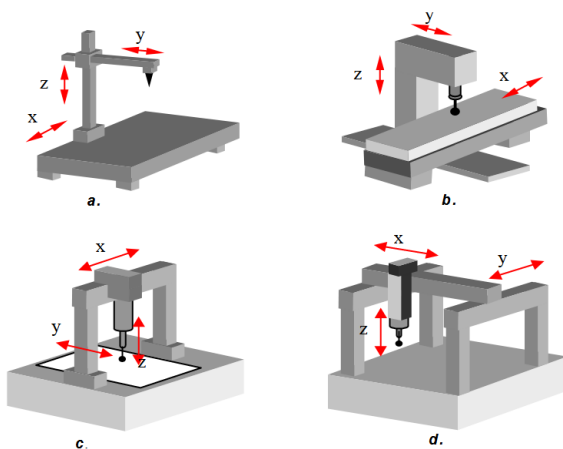


Fig. 1 Coordinate measuring machines; Construction variants

As component parts of a coordinate measuring machine, the following are distinguished:

1. The machine frame supports all other fixed or mobile elements of the machine. It is a welded or cast construction that must satisfy severe conditions of resistance, rigidity, and dynamic stability. Usually, it is provided to support it on vibration-isolating supports or a vibration isolator is included in its construction;
2. The base plate, serving as a fixed mass and as a carrier of the guideways, is made of a natural rock such as basalt (also known as diabase). Natural rocks offer a number of advantages, the most important of which are:
 - Dimensional and shape stability over time (the material is naturally aged);
 - Low expansion coefficient;
 - The material is non-magnetic and does not conduct electricity;
 - Low density, comparable to that of aluminum;
 - Corrosion resistance;
 - Good mechanical machinability for the finishing operation;

3. The column, portal, and bridges are made as welded or cast structures, requiring special technologies for processing the guideways, and for ensuring the dimensional and shape stability of the structure during the operation of the device;

4. The guides used in the construction of measuring machines must mainly meet three requirements: flatness, straightness, and resistance;

Stylus

5. The probe of the measuring head is cylindrical with a ruby sphere at the top. This sphere must have a material dimension, but for the measurement, only the dimensions of the center of the sphere need to be taken into account.

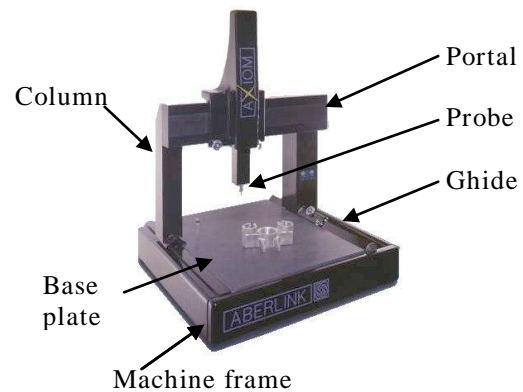


Fig. 2 Main components of a coordinate measuring machine

Portable coordinate measuring machines are different from traditional ones, being most commonly found in the form of articulated arms. These machines can have six or seven axes of rotation with rotary encoders replacing linear axes.

Articulated arms (Figure 3) are lightweight, typically less than 10 kg, and can be transported and used almost anywhere.



Fig. 3 Articulated arms

Portable measuring machines in this range are manually operated, and the measurement accuracy is generally lower than that of a traditional coordinate measuring machine.

Non-repetitive applications, such as reverse engineering or dimensional inspection of large parts, are ideal for portable machines.

Additionally, if the parts are too large, heavy, or need to be inspected while still in the fixture where the manufacturing process was performed, bringing a portable machine to the processing area is often the only solution.

3. THE MEASUREMENT SOFTWARE

The measurement software for the coordinate measuring machine must be a modular structure, easily configured. Its most important modules are:

1. Measurement and verification module

This is structured around an acquisition function that allows the measurement of simple geometric elements. When the measurement is performed, the user can check the tolerances of one or more surfaces.

2. Statistical module

This module offers the possibility of performing a statistical analysis based on the results obtained with the measurement and verification module and which are stored by the computing system. The results of the analysis can be used for statistical control of production.

3. Geometric and thermal correction module

On the three axes of the machine, at the level of the three guides, five deviations can appear (two for translation and three for rotation). Three deviations from the perpendicularity of the axes and three deviations caused by linearity errors of the readers can be added. The 21 deviations must be corrected. The principle of correction consists of measuring these 21 deviations at different points on a 50 mm x 50 mm area using a set of gauges. The recorded values are entered into a multidimensional matrix. When a point comes into contact with the probe, the software interpolates, based on the data in the matrix, the corrections to be made on the three axes. Thermal expansions can also affect the measurement results. In this case, the software takes into account a set of data provided by temperature probes.

4. Curved Surface Module

The verification of curved surfaces is performed point by point by comparing the coordinates of the measured points with a set of values from the computer-aided design stage - CAD.

5. Scanning module

Three-dimensional scanning is possible on coordinate measuring machines with numerical control. There are several types of scanning:

- planar scanning;
- three-dimensional scanning;
- fixed probe scanning.

6. CAD-CAQ link module

This module establishes the link between computer-aided design (CAD) and computer-aided quality control (CAQ).

4. THE ROLE OF SOFTWARE APPLICATIONS IN 3D-MEASUREMENT

Computers and software applications are indispensable in industrial activities.

Quality products are obtained at minimal cost only if the design, manufacture, control, and testing of products are done in a fully integrated system. Such a system cannot exist without the use of computers and software applications.

In modern manufacturing, companies use specialized software in each work point or department, which leads to the possibility of integrating the entire flow of activities.

The result of this integration is increased efficiency, high flexibility, and better competitiveness in the market.

One of the software used in 3D measurement is **Computer Aided Inspection-CAI**.

CAI is a software tool that helps quality engineers, operators, or product inspectors (Technical Quality Control) in determining the degree of agreement between the required quality and that resulting from the manufacturing process.

The purpose of CAI is to facilitate the evaluation of the quality of parts and products in the shortest possible time.

CAI was implemented in production for the first time in 1971 for the evaluation of tools.

The most widely used CAI software is SixSigma, which is based on statistical evaluation (it was developed by Motorola).

The idea is that if you measure the manufactured parts in real time, you can correctly evaluate the problems that influence the technological process and thus intervene to eliminate disturbing factors and obtain products with zero defects.

To perform the control, measurements are made using two methods:

- Contact measurements;
- Non-contact measurements.

There are two methods of non-contact measurement:

- 3D scanning systems;

- Optical laser measurement systems (laser trackers).

Another software used in 3D measurement is **Computer Integrated Testing – CAT**.

CAT is used to evaluate the quality of parts or products. CAT is used to verify that parts, subassemblies, assemblies, or products are of the specified quality (are within the parameters required by the specification). The parameters or test criteria for CAT are often derived from CAE (Computer-aided technological design).

CAT is basically a computerized testing tool (Figure 4), which works with a standardized methodology and is used to prepare preliminary test documentation.

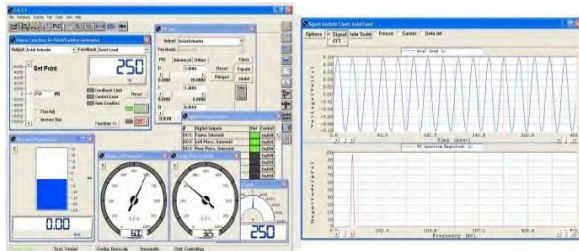


Fig. 4 CAT Interface

Designing a CAT system requires a step-by-step procedure:

1. The critical variables of the process to be tested are selected;
2. The appropriate monitoring and analysis equipment/sensors are selected and placed;
3. The monitoring and analysis instruments are calibrated to a reference system to ensure that the selected process variables can be controlled;
4. Product testing begins;

The equipment to be tested is controlled with CAI software.

For example, in an automatic gear durability test stand:

- The gears are loaded with: angular velocity, working load, lubrication conditions, operating temperature, etc.
- The CAI software of the equipment to be tested returns the values.

In the classical conception, all these test conditions are performed by humans.

5. TRENDS AND PERSPECTIVES IN 3D MEASUREMENT

Placing three-dimensional measuring equipment as close as possible to the place where the processing is carried out is a trend in order to achieve real-time 3D measurements and control. However, a number of issues must be taken into account, such as: thermal compensation, high speeds of data acquisition and processing, and optimization of the control

and measurement software, so that the use of the equipment does not affect its accuracy and sensitivity.

Other trends can also be exemplified, such as: Artificial intelligence helps to quickly process large data sets (point clouds) and make automated "pass/fail" decisions.

High-resolution blue light/laser 3D scanners offer micron-level accuracy, making them essential for industries such as aerospace and automotive, even for parts with glossy or complex surfaces.

Industrial Computed Tomography (CT) continues to expand, allowing the measurement of complex internal structures of parts (e.g.: cooling channels) without destroying them.

Recently, automatic pre-alignment and fast processing have been increasingly used.

Thus, modern software, such as PolyWorks Inspector 2025 or ZEISS INSPECT, introduces functions for automatic pre-alignment of scans in the CAD coordinate system, drastically reducing the inspection preparation time.

3D scanning is used to create accurate digital replicas of physical parts, facilitating automated comparison to the original design and predictive maintenance (Digital Twins).

6. CONCLUSIONS

Three-dimensional (3D) measurement has undergone an accelerated evolution, moving from a final inspection tool to an essential, real-time integrated component in modern manufacturing and reverse engineering processes. 3D technologies (laser scanning, structured light, computed tomography) are defined by automation, high precision, and integration with AI. Although high-precision systems remain expensive, technologies are becoming more accessible, and investments are focused on reducing inspection times.

In conclusion, today's 3D measurement focuses on speed, robotic integration, and intelligent analytics, transforming quality control from a passive process into an active one that optimizes manufacturing.

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