verlag moderne industrie

Multisensor Coordinate Metrology

Measurement of Form, Size, and Location in Production and Quality Control

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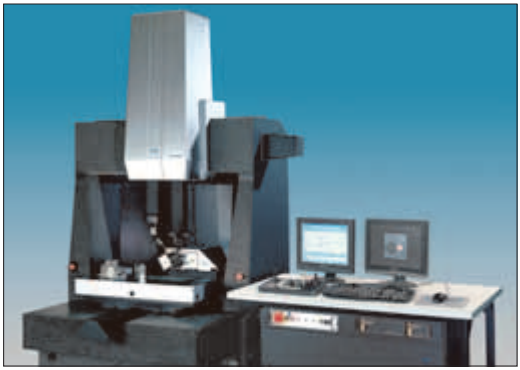

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Sensors for Coordinate Measuring Machines

The sensors of a coordinate measuring machine are used to pick up the primary signal from the workpiece. They are designed using mechanical and, in some cases, opto-electronic and software components of varying complexity. The sensors must be selected on the basis of the conditions on and near the workpiece, the touch sensitivity of the object, the size of the features to be measured, the requirements of the measurement plan and the number of measured points. Thus, the selection of the sensor or sensors basically depends on the measuring task at hand.

Coordinate measuring machines can be equipped with tactile or optical trigger and measuring (usually called dynamic or scanning) sensors (Fig. 6). *Trigger sensors* only produce a trigger signal after detecting a measuring point. This causes the measuring system of each machine axis to be read out, determining the coordinates of the point in space. Movement in the axes is absolutely essential in order to determine the coordinates of an object point (dynamic measurement principle). *Measuring sensors* have an internal measuring range of up to several millimeters. An object point is determined by superimposing the measured values of the sensor over the coordinates read out by the measuring machine. It is thus possible to determine a point even when the coordinate measuring machine is standing still (static measurement principle), as long as the magnitude of the object point is located within the measuring range of the sensor.

Touch trigger sensors require dynamic principle of measurement

Measuring sensors permit static principle of measurement

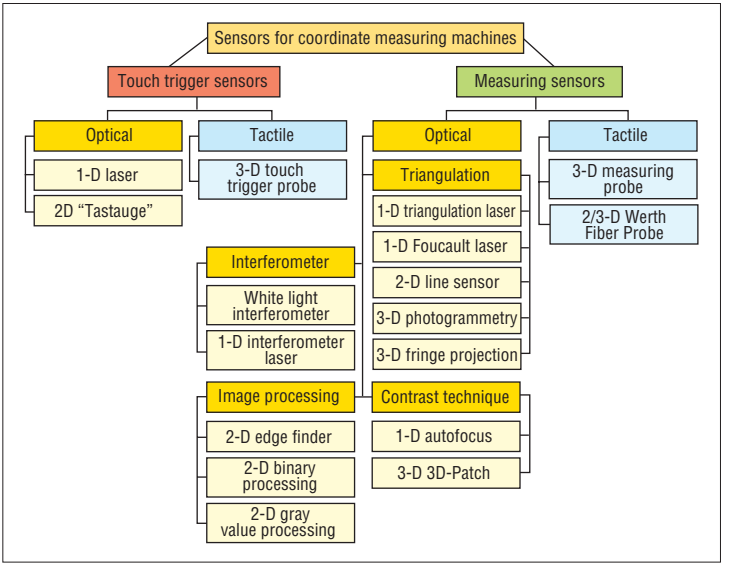


Fig. 6: Sensors for coordinate measuring machines classified by principle of operation: For the sake of descriptiveness, contrast techniques basically allocated to triangulation processes are listed separately.

Another important criterion for differentiating between sensors is the physical principle of transmission of the primary signal. In this regard, the sensors commonly used today can be divided into two groups – optical and tactile. The location information of a measured point is transmitted to an *optical sensor* by light in such a way that it can be used to determine the corresponding coordinates. In the case of a *tactile sensor,* this information is generated by touching the workpiece with a probing element, which in most cases is a stylus tip.

One-, two- and three-dimensional sensors

Another important application-specific feature is the number of dimensions of the sensor. This factor determines whether the sensor can pick up information in one, two or three coordinate axes. For sensors with less than three degrees of probing freedom, the remaining coordinates are determined from the previously measured position of the sensor probing point

within the machine coordinate system. However, this approach restricts the system's applicability in connection with complex, three-dimensional objects (e.g. a 1-D laser cannot measure the cylindrical form of a bore or an X-Y touch probe cannot measure the flatness of a plane in the Z-direction).

Visual Sensors

Visual sensors replace the human eye

The term "visual sensor" denotes all sensors which, similar to the human eye, pick up at least a two-dimensional image of the object being measured. The intensity distribution of this optical image is detected and evaluated by a sensor.
For many decades the *human eye* was the only visual "sensor" available for optical coordinate measuring instruments such as measuring microscopes and measuring projectors. Subjective error sources influencing measurements of this type include parallax (oblique sighting) and faulty measurement of bright-dark transitions on edges due to the logarithmic light sen-

Fig. 7:
"I still can't see anything." (Cartoon by Manfred Pühn)

sitivity of the human eye. The results of such measurements therefore basically depend on the operator (Fig. 7) and are comparable only to a limited degree. The maximum measuring speed is also limited.

Visual probing

Because of all of its drawbacks, visual probing represents the last possible alternative for modern image processing systems. It is used in cases where the object structures to be measured show poor visibility and the geometric features can only be probed intuitively. Assuming that the human eye can resolve several tenths of a millimeter when sighting with a reticle, a final resolution of several microns can be attained by using this technique, for example, in conjunction with a 100X optical magnification.

Optical Edge Sensor, Tastauge

The Tastauge or "Probing Eye" is a touch trigger sensor for optical measuring projectors. A thin glass fiber picks up the light signal in the beam path of the projector and guides it to a photomultiplier (see Fig. 3c). When an object is moved through the beam path, each edge produces a bright-dark or a dark-bright transition. Whenever an edge transition is detected based on an electronic threshold value technique, the coordinates of the measuring axis are read out. Important here is correct determination of the threshold value based on calibrated standards. This occurs automatically in modern measuring systems.

Transmitted-light measurement with the Werth Tastauge

In practice, use of the Tastauge is limited to measurements performed according to the transmitted-light technique and in two or two-and-one-half dimensions (2-D or $2^1/_2$-D). $2^1/_2$-D means that an adjustment (but no measurement) is possible in the third axis. Low contrast values such as those characteristic of reflected light may result in measuring errors,

since the spot-shaped sensor permits hardly any strategies for differentiating between contamination, surface interference, and genuine probing features.

Image Processing Sensor

Today, image processing sensors are commonly used as visual sensors (Fig. 8). The object is imaged onto a matrix camera by the lens. The camera electronics convert the optical signal to a digital image, which is then used to calculate the measured points in an evaluation computer equipped with the corresponding image processing software. The performance of such sensors is heavily influenced by several individual components including the illumination, the lens system, the sensor chip, the electronics and the computing algorithms [3].

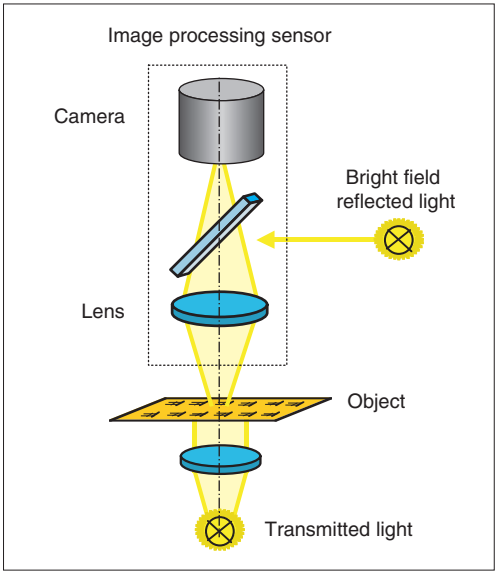


Fig. 8: Basic design of an image processing sensor with transmitted-light and reflected-light illumination

Telecentric lens systems are precise

The lowest measuring uncertainty can be achieved using telecentric lens systems. The advantage of telecentrics is that the lateral magnification remains constant when the working distance is altered within the telecentric range, thus preventing errors of dimension. This is especially important when working with lower magnifications. The best quality can be attained using telecentric lenses with a fixed magnification.

From an applications standpoint, it makes sense to combine high and low magnifications. This is especially true in cases where features with less precise tolerances should be measured in one image quickly and in addition, high-precision measurement of closely toleranced features in small image fields should also be possible or the positions of the elements to be measured must still be better located after coarse positioning (of the workpiece) on the measuring machine. Using telecentric lenses with a fixed lateral magnification, this can be achieved in two different ways. The first way is simply to change the lens. This can be done automatically (for example, with a revolving lens changer). The main problem here is the high repeatability required for a lens change. This approach thus has a negative effect on the measuring uncertainty. Since only two different magnifications are required in most cases, the simplest approach is to switch back and forth between two different image processing sensors of varying magnification.

Zoom lens systems are flexible

The greatest flexibility can be achieved using a zoom lens system (Fig. 9). Due to the positioning movement of the optical components in the lens, slight losses of accuracy can be expected. However, such losses should be negligible in modern systems.

Werth zoom

Linear guides are used in the Werth Zoom to en-

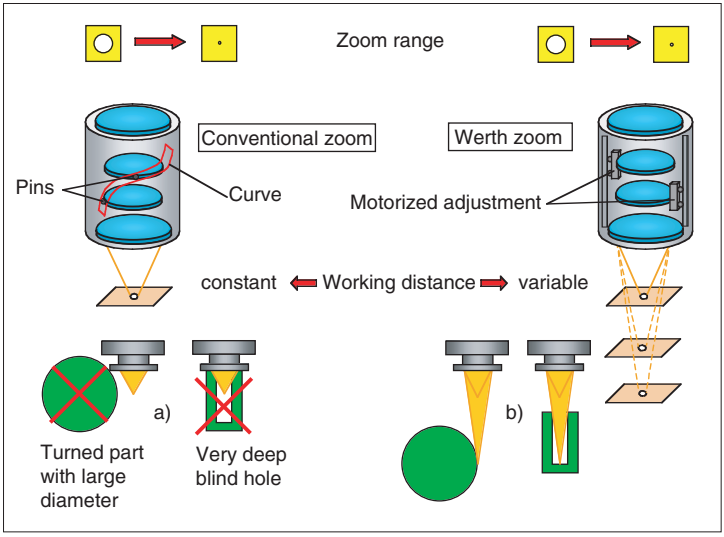


Fig. 9:
Werth zoom with adjustable magnification and variable working distance in comparison to conventional zoom optics;
a) Collision with rotationally symmetrical parts and deep bores
b) Collision prevented

sure high positioning repeatability. The movements of the lens packages required for the zooming processes are motorized. This design enables a 1X to 10X magnification and working distances ranging from 30 mm to a maximum of 250 mm. Optimization between the measuring range of the sensor and the measuring uncertainty can thus be attained (via magnification). Regardless of this, the working distance can be adapted to the specific requirements of the workpiece (to prevent collision problems).

Today, digitization of images is usually achieved using CCD cameras in conjunction with PC components suitable for image acquisition (framegrabber boards, firewire interfaces, etc.). The chief advantage offered by the CCD camera over the competing CMOS chip lies in its high metrological quality. For example, the very linear relationship between the light intensity input signal and the digital out-

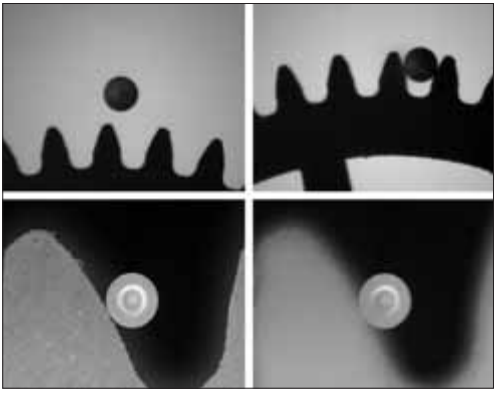


Fig. 25: Top: Self-centering measurement of gearwheels with the Werth Fiber Probe in the transmitted light mode, diameter of stylus sphere 180 µm Bottom: Measurement of flank angle in luminous mode

Self-centering measurement

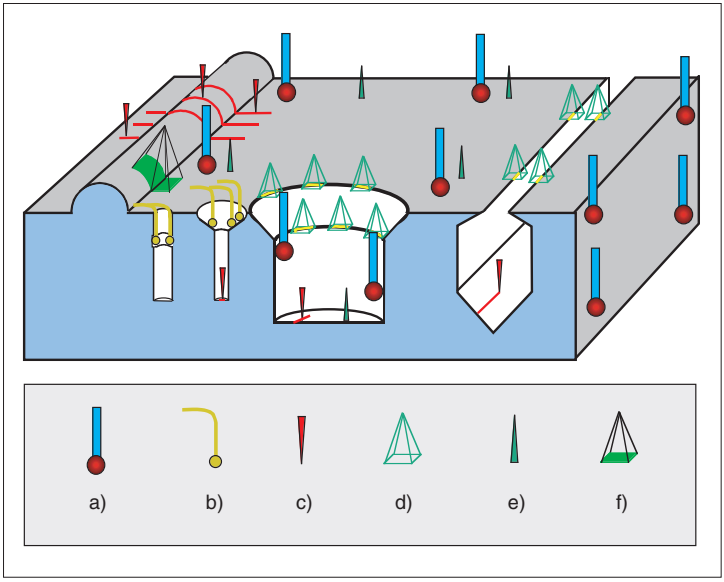
fiber probe (Fig. 25). A calibrated sphere is positioned in a tooth space to determine the pitch errors of a gear. The position of the sphere on the gearwheel results from the value measured by the fiber probe (position of the sphere in the image field) and the coordinates of the coordinate measuring machine. Values such as the dimension over two balls or the pitch of the gearwheel can then be determined based on several positions measured in different tooth spaces. The profile can be measured by probing the tooth flanks.

After the image processing sensor, the fiber probe is one of the most accurate sensors now available for multisensor coordinate measuring machines due to its unique method of operation.

Multisensor Technology

Multisensor technology combines all advantages

Multisensor coordinate measuring machines use a combination of several of the sensors described above. The properties of these sensors usually depend on their various primary applications (Fig. 26). Regarding applications, their distinguishing characteristics include the size



of the object features they can probe, the type of object features they can probe (edge, surface), and their suitability for rapidly acquiring large numbers of measured points (scanning). In order to perform complex measuring jobs, it is usually necessary to use several different sensors for a single measuring run.

Fig. 26: Multisensor technology: typical applications of different sensors;
a) Mechanical stylus
b) Werth Fiber Probe
c) Laser
d) Image processing
e) Autofocus
f) 3D-Patch

The Company behind this Book

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Werth Messtechnik GmbH celebrated the 50th anniversary of its founding in 2001. Innovations characterized by quality and precision form the foundation of this company's successful development. Following its introduction in 1955, the first profile projector in desk design set ergonomic standards. During the late 1960s, digitization provided measuring projectors with the functionality of a coordinate measuring machine. The Werth Tastauge optical edge sensor, which represented the first glass fiber sensor for measuring projectors, was introduced in 1977. This principle has established itself worldwide as an accepted means of performing measurements in transmitted light. In 1980, the first optical CNC coordinate measuring machine was also introduced by Werth Messtechnik.

The development of multisensor coordinate metrology began at the end of the 1980s. One such machine featuring integrated image processing and laser sensors, the INSPECTOR®, was introduced in 1987. With the introduction of the VIDEO-CHECK® line in 1992, the cornerstone was laid for continued successful growth of the company. The early integration of personal computer technology and a strictly modular concept permitted maximum performance at acceptable prices. Today Werth Messtechnik is by far Europe's biggest supplier of optical and multisensor coordinate metrology products.

The integration of linear drive technology in coordinate measuring machines and sensor developments such as the Werth Fiber Probe and the Werth Zoom justify Werth Messtechnik's claim to worldwide technical leadership in this market segment. Modern developments in the area of software such as BestFit, Tolerance-Fit® or WinWerth® Autoelement further enhance this image.

The two-figure growth rates characterizing the company's expansion during the past decade have also led to the establishment of a highly motivated team. 150 employees in Germany supported by sales and service centers in all major industrial countries guarantee that Werth Messtechnik will continue to provide its customers with state-of-the-art coordinate metrology products of top quality and excellent service in the future as well.