Educational Articles: Article nr. 2 – **3rd Part**

The sensors

The function of a Co-ordinate Measuring Machine (CMM) is the acquisition of information on the measurand; generally under form of Cartesian co-ordinate values.
The devices utilised to explore the part in order to generate such information are the "***Sensors***"; as underlined in the 1st article one of the four fundamental components of a CMM.
The sensor technology has gone through a remarkable evolution in the last 25 years; today are therefore available a number of solutions, which allow to solve any application problem.
The difference between sensors, besides the mere metrological characteristics, is due to the physical principle on which they are based.
The first discrimination derives from the method by means of which the sensor allows to gather information on the part to be measured; consequently there are two important families of the devices in question:

1. **"*Tactile*"** sensors.
2. "***Non contact***" sensors, or "***Optoelectronic***" sensors.

As it may be intuitive the difference between the two above mentioned type of sensors is intrinsic in their definition. Those belonging to the first category allow the data acquisition by getting in physical contact with the part; those of the second type permit the same function without touching the measurand.
In the family of tactile sensors it is necessary to distinguish:

a. "***Rigid***" sensors.
b. "***Point to point***" sensors.
c. "***Continuous***" sensors.

While, as far as the non contacting sensors are concerned, a differentiation has to be made between:

d. "***1D***" sensors.
e. "***2D***" sensors.
f. "***3D***" sensors.

In the next paragraphs a description of the previously mentioned devices will be given; nevertheless it is necessary to clarify right now some of the fundamental aspects concerning the two categories of sensors, those tactile and those non contact[1].
The non contacting sensors have been made available in relatively recent times with respect to the rather consolidated tactile technology. Essentially the non contact sensors have been developed to satisfy two well defined needs:

The measurement of parts made with very soft materials where even the negligible pressure applied by the tactile sensor may damage the part surface and make the measurement impossible[2].
To increase the productivity of the CMM thanks to the very high data acquisition speed of non contacting sensors.

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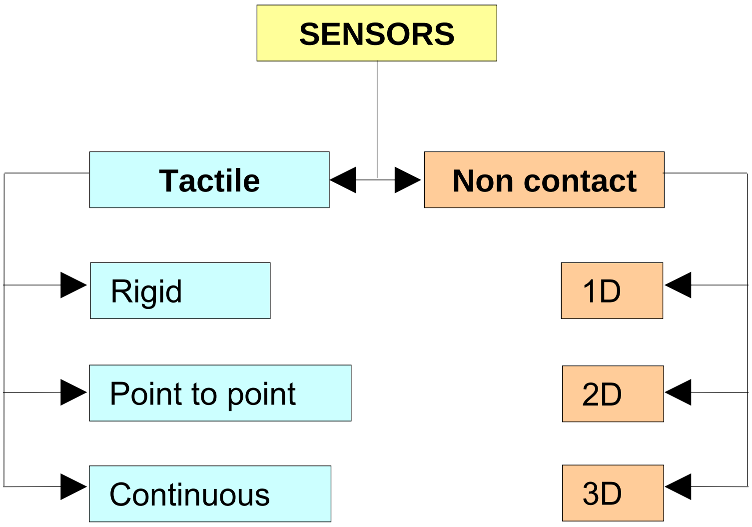
(1) The non contact sensor for co-ordinate measuring machine made their first appearance on the market in the first half of the eighties.
(2) It has been rather recently developed, a tactile sensor based on the control of the resonance of the sensing tip, which allow to apply on the part to be measured a rather small force (2÷3mg) thus allowing the inspection of flexible and soft materials in tactile mode.



1 – Families and type of sensors

The above described needs are met by the modern non contact sensors which, nonetheless, still have some limitations if compared with conventional tactile devices. Major limitations as of today are the following:

- Generally lower metrological performance
- Sensitivity to the surface conditions of the part (finishing, roughness, colour, etc.)
- Sensitivity to the ambient illumination conditions
- Scarce deep reach capabilities
- Lack of international reference standards[3]

It is therefore necessary, in the choice of a sensor, to proceed by successive analysis based on the application needs and on the characteristics of the devices available on the market (and on the compatibility of the sensor with the concerned CMM).

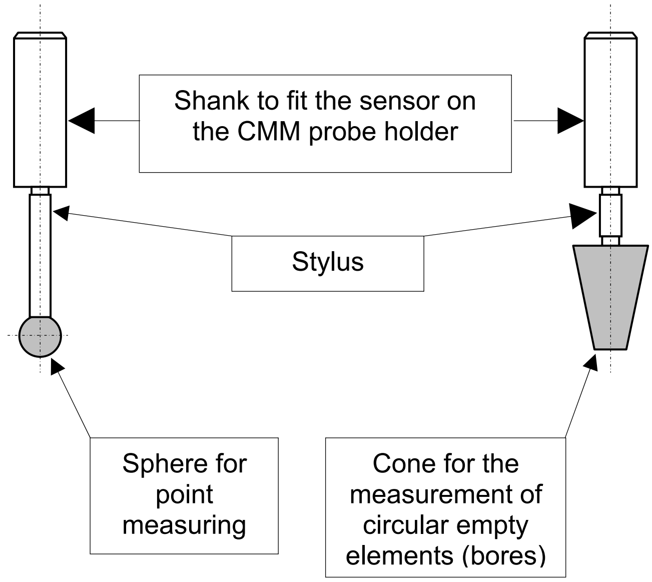
***Table 1** – General characteristics of sensors*

CHARACTERISTIC	**TACTILE**	**NON CONTACT**
Sensitivity to the surface conditions of the part	Scarce	High
Sensitivity to the hardness and flexibility of the part	High	None
Sensitivity to the illumination condition of the environment	None	High
Data acquisition speed	Medium	Very high
Deep reach capability	High	Very low
Need for a third rotational axis	none	Yes for certain type of sensors

(3) Concerning this subject it has to be underlined that OSIS (Optical Sensor Interface Standard), a Committee constituted by the majority of co-ordinate measuring machine manufacturers and sensor makers, is operative since about four years now. Objective of the three Working Groups of OSIS is to generate a standard proposal for: mechanical and electrical interface of a given sensor and a given CMM; data exchange between CMM and sensor; evaluation of the metrological performance of the sensor both stand alone and combined with CMM.
*Further information about OSIS and on the progresses of its works can be found on the web site of **ia.cmm**, the International Association of Co-ordinate measuring Machine Manufacturers (www.iacmm.org).*

The rigid sensors

Heritage of a co-ordinate measuring machine of the past, the rigid sensors have practically disappeared; we mention them here for historical reasons. The sensors in question (for which the definition "*Touch finger*" would be more appropriate) are constituted by a shaft for the fitting of the touch finger in the CMM probe holder which has on the opposite extremity either a sphere or a cone.



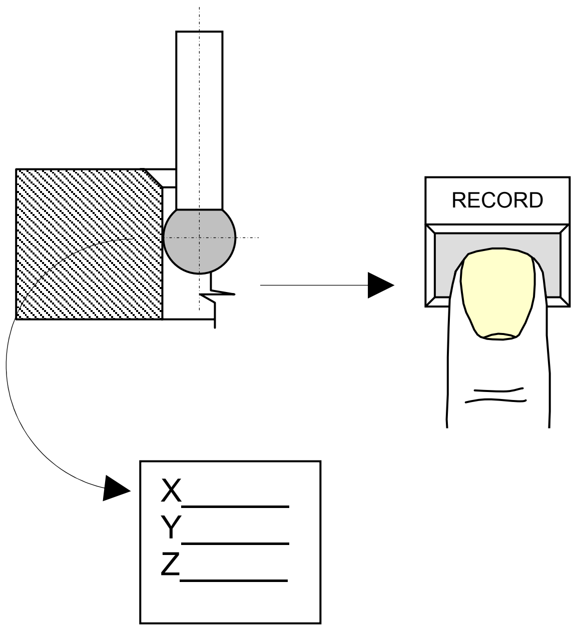
2 – Examples of rigid sensors

To utilise a spherical rigid sensors the user manually brings the sphere in physical contact with the point to be measured then, acting on a record key (or pedal), enables the recording of the co-ordinates of the centre of the sphere of the sensor which, deducted or added of the sphere radius, will represent the co-ordinates of the measured point.

Using the same principle the conical rigid sensor is manually driven inside the bore of which it is necessary to measure the centre co-ordinates. The cone will self centre in the bore itself and the position of the cone centre (which obviously coincides with the bore centre) will be recorded.

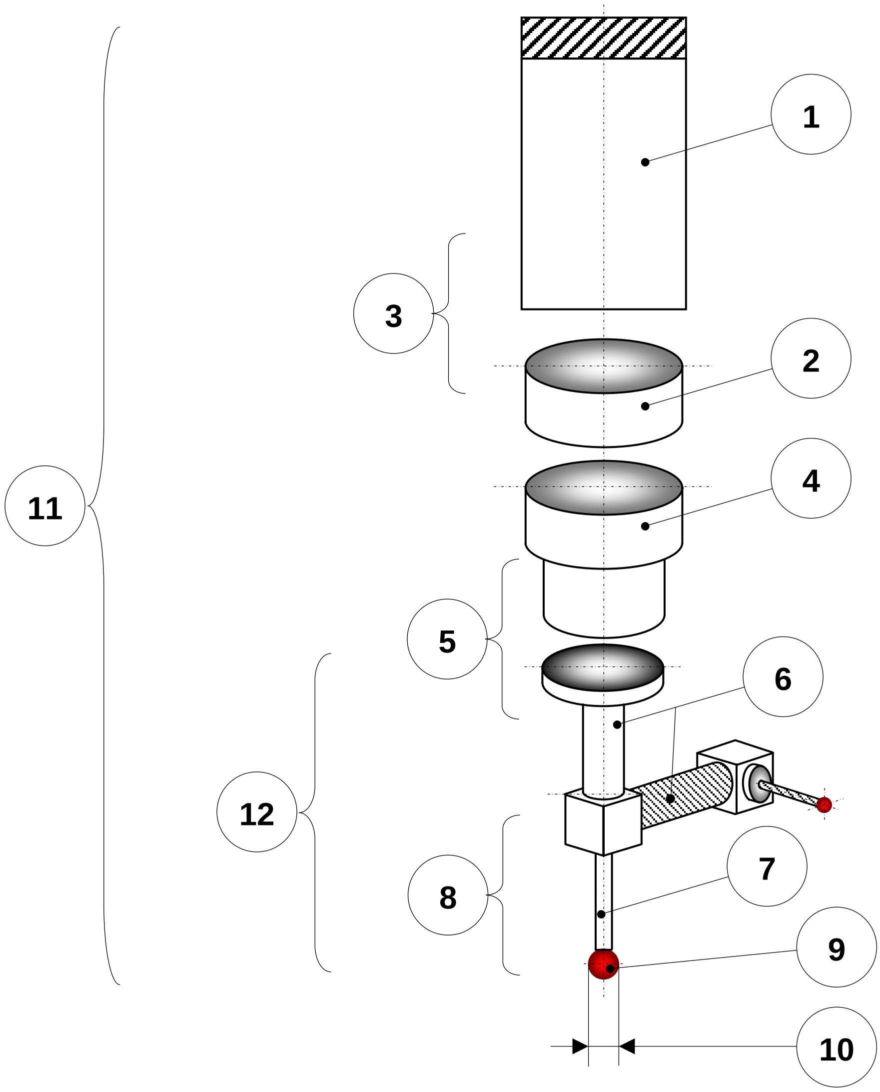
It goes without saying that rigid sensors are built in different shape and dimensions depending on the feature to be measured.

Even if the use of rigid sensors has been practically abandoned, the simplicity of the concept on which these devices are based allowed to a generation of CMM users of approaching the measuring machine in a gradual and user friendly mode. As of today the use of these mechanical sensors is limited to few, rather specific, applications.



3 – Point measurement by means of a spherical rigid sensors

Characteristic elements of a generic, tactile probing system
The scope of a CMM kinematics is to bring the sensory element in an adequate position, with respect to the part to be measured, in order to allow the sensor to probe the necessary points. For this purpose the sensor is fitted in a special mechanism (probe holder) located in the lower part of the machine spindle; this mechanism represents both mechanical and electrical interface. The locking device on the machine spindle may be fixed or articulated, depending on the applications.
In the figure 4 the characteristics of a "***fixed***", generic tactile probing system, as defined by ISO 10360-1, are described.



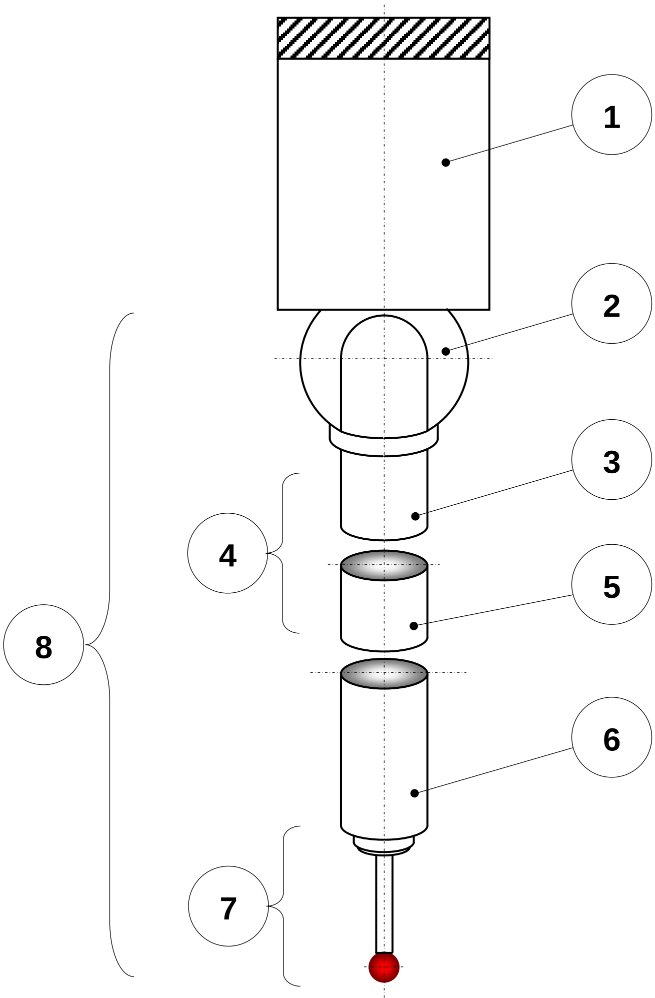
4 – Characteristic elements of a generic, tactile, fixed probing system

Legend:

1......: Co-ordinate measuring machine ram (or spindle).
2......: Probe extension.

3......: Probe changing system.
4......: Probe.
5......: Stylus changing system.
6......: Stylus extension.
7......: Stylus shaft.
8......: Stylus.
9......: Stylus tip.
10....: Tip diameter.
11....: Generic, fixed probing system.
12....: Stylus system (composed of stylus system components).

As it may be noticed in figure 4, the stylus orientation in the space is given by the relative orientation of the stylus shaft with relation to the main body of the probing system; this is characteristic of a fixed probing system. In an "***articulated***" probing system (figure 5) the orientation of the stylus is given, either step wise or continuously, by electrical actuators located in the articulation system or, for larger devices, inside the ram.



5 *– Characteristic elements of a generic, tactile, articulated probing system*

Legend:

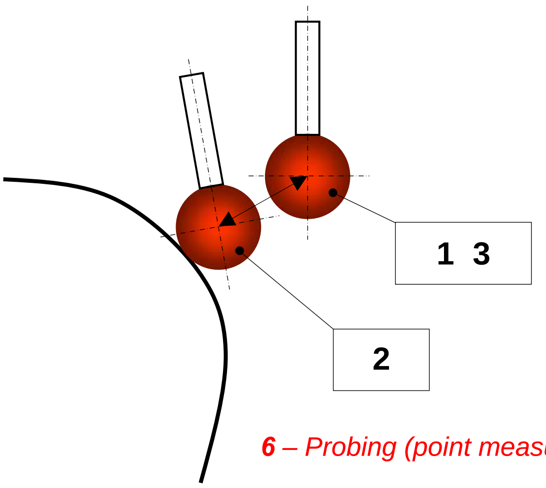
1......: Co-ordinate measuring machine ram (or spindle).

2......: Articulation system.
3......: Probe extension.
4......: Probe changing system.
5......: Probe.
6......: Stylus extension.
7......: Stylus.
8......: Generic, articulated probing system.

As underlined in the previous articles, the co-ordinate measuring machine is capable of determining, with extreme accuracy, the position in the space of points lying on the surface of the part to be measured; this operation can be executed utilising either "***Point to Point***" or "***Continuous***" sensors. The choice between the two approaches is made on the basis of the application needs, available sensors and of the type of data handling and control system.

Point to point, on the fly, measurement

The point to point measurement represents a fast ideal solution for the measurement of features of which it is necessary to define Dimension and Position. It is also possible to determine, with point to point sensors, the Form status of a given feature; even though Form analysis is better and more efficiently carried out with a continuous sensor.
The point to point type of measurement allows the determination of the position of points by bringing in physical contact the tip of the sensors with the part and then retracting.



6 – Probing (point measurement) sequence

Legend:

1......: Starting point.
2......: Point probing.
3......: Disengagement position after point probing.

Point to point measurement (also said "on the fly") used to be rather fast if compared with continuous measurement; it must however be noticed that, in the last years, extremely rapid continuous sensors have been developed[4]. The versatility, speed and relatively low price of the type of the sensors in question, have made of these devices the most diffused in the world of co-ordinate measuring machines. Once again it has to be said that the choice of the type of sensor must be made after a detailed analysis of the application.

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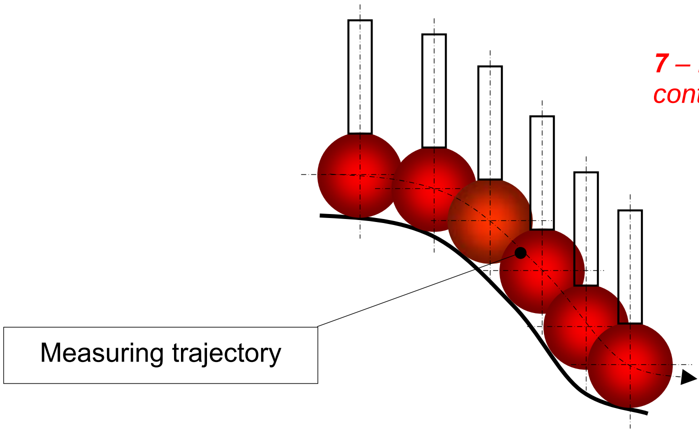
(4) *In current times extremely high speed continuous sensors have been developed and very recently introduced on the market.*

Continuous measurement

While in the point to point measurement the sensor gets in contact with the part to be measured in the moment of point probing only, in continuous measurement the sensor remains in contact with the part, following its profile and measuring points according to pre-determined laws in a single measuring path.

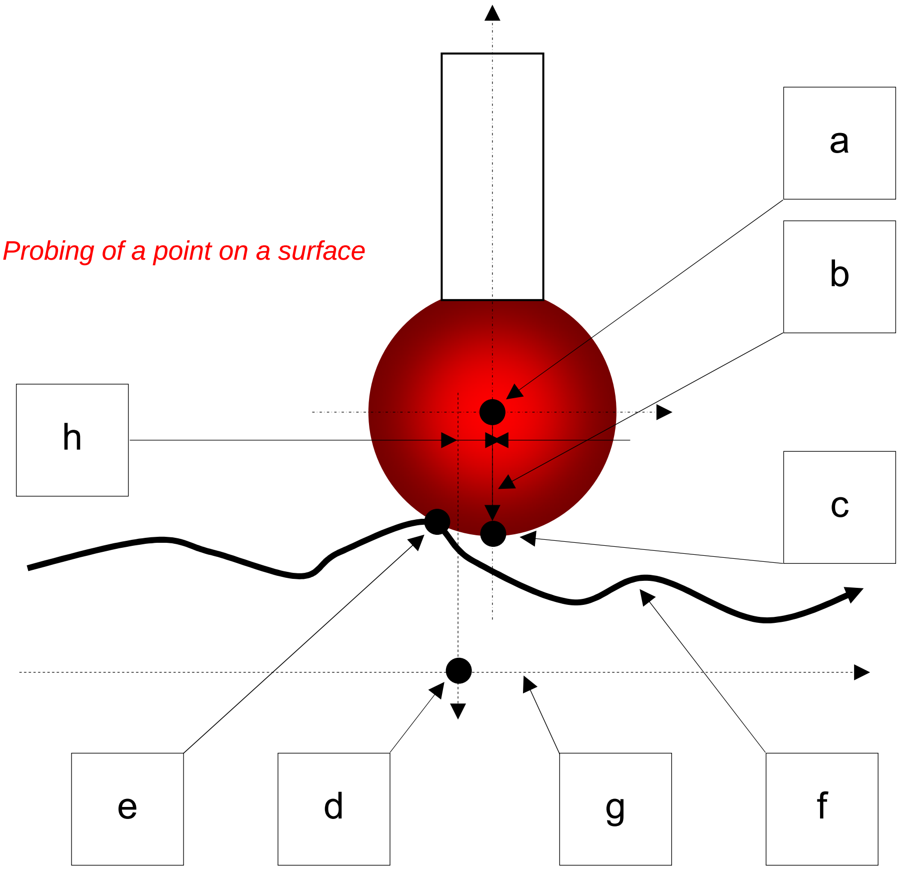


7 – Probing sequence in continuous measurement

Generally very accurate and relatively larger than point to point, the continuous sensors, thanks to their capacity of following a profile and determining the relevant spatial co-ordinates, in an almost continuous mode, can supply very complete information on the form of the measured feature.

In figure 8 it may be noticed what happens during the probing of a point on the surface of a geometric element of a given part of production.

8 – Probing of a point on a surface



Legend:

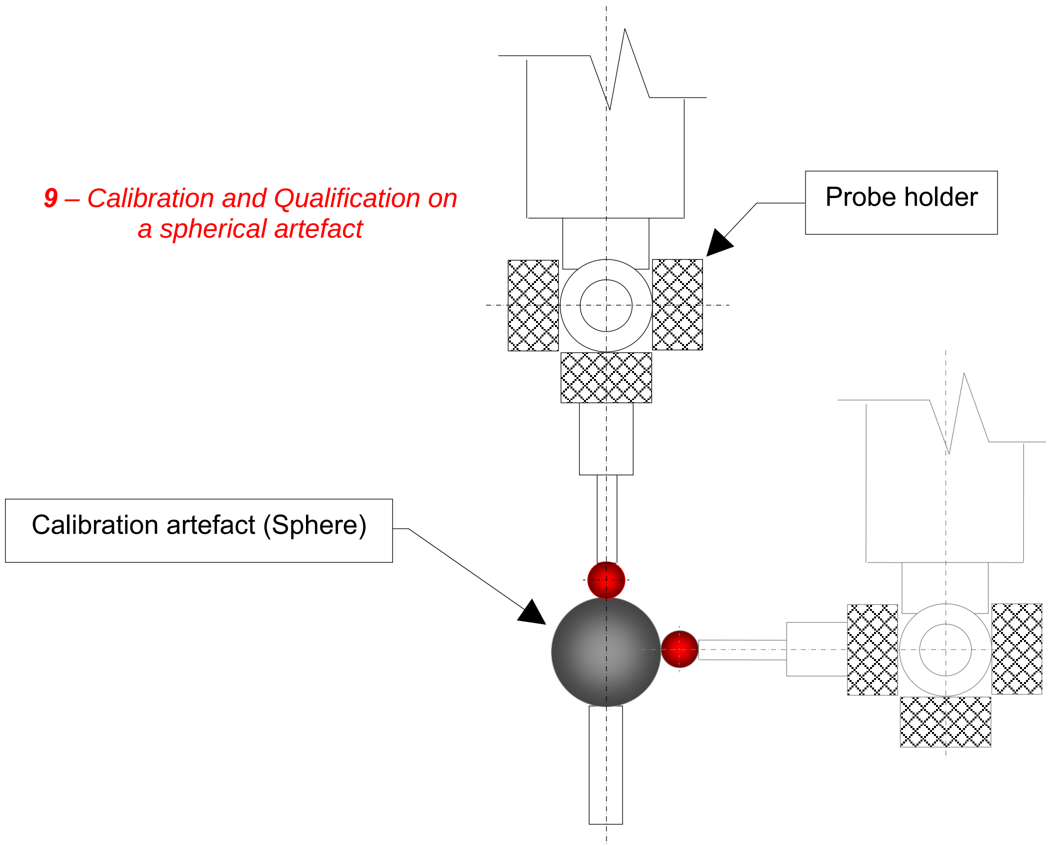
a......: Indicated measured point
b .....: Tip correction vector
c......: Corrected measured point
d .....: Target contact point
e......: Actual contact point
f ......: Real feature
g .....: Nominal feature
h .....: Position error

It has to be mentioned that continuous sensors may also be utilised in order to measure discrete points even if this is not the ideal way of using them.

Calibration and Qualification

Calibration and Qualification are two fundamental activities in the management of sensors and of the entire measuring cycle.
The “***Calibration***” of a generally spherical artefact of very high form accuracy is the first step of the procedure that make possible, during the execution of a measuring cycle, to change the sensor attitude or the sensor itself always obtaining coherent readings.
The calibration consists in the identification of diameter and of the position of the centre of the spherical artefact with respect to the origins of the CMM reference system; this is carried out by means of a sensor generally positioned in –Z attitude. Once the calibration of the sphere has been carried out the “***Qualification***” of the sensor can be executed. By measuring the previously calibrated artefact the offsets of the centre of the stylus tip are automatically determined.

9 – Calibration and Qualification on a spherical artefact



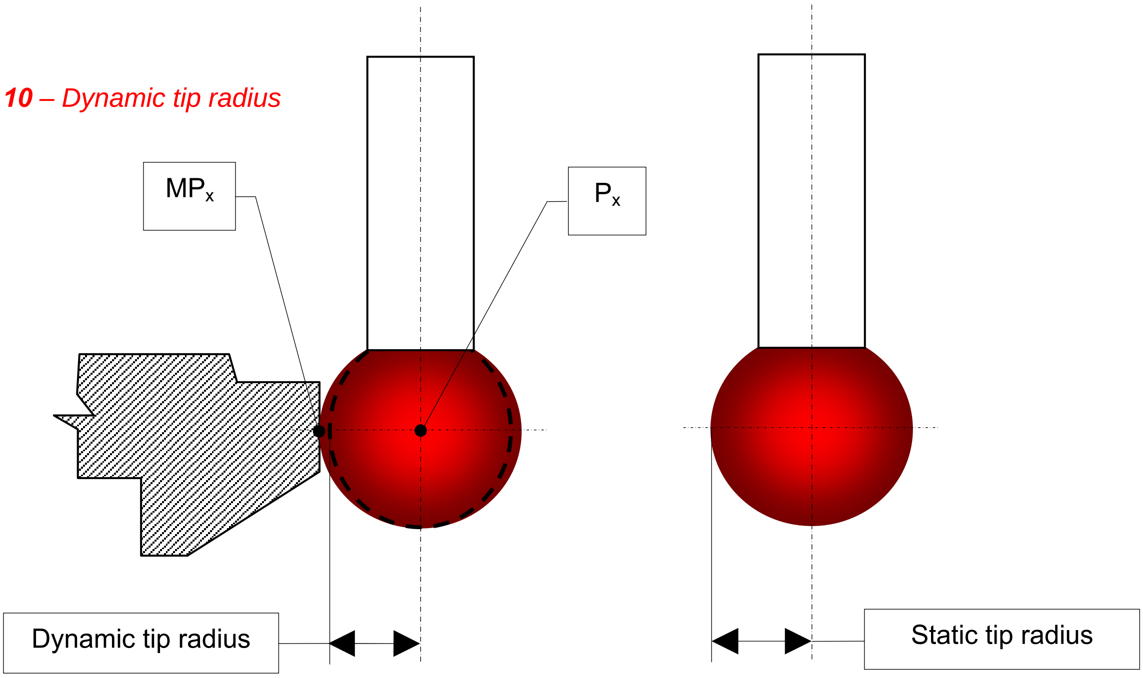
Once the above mentioned operations have been carried out, it will be possible to sequentially use any qualified sensor during a measuring cycle and the offsets will be automatically updated in order to obtain coherent measuring results, as if the cycle itself would have been executed with a single sensor in a single attitude.
Modern CMM provide automatic calibration and Qualification procedures.

Calibration and Qualification have an important impact on the reliability of measuring results; therefore they must be correctly executed according to metrology criteria.

Dynamic tip radius

During the qualification of a sensor with a given tip also the "***Dynamic stylus tip radius***" is determined. The stylus tip obviously has its own diameter that may be statically determined even with great accuracy; nevertheless the measurements with a CMM occur in dynamic mode. Therefore the tip radius, that is utilised to compute the actual value of the measured point, has to be dynamically determined considering all the parameters that modify its original true dimension such as mechanical and electrical phenomena.
The dynamic tip radius is smaller than the static tip radius. It is consequently extremely important to use the same operating conditions both during tip radius determination procedure and measuring cycle execution.

10 – Dynamic tip radius



$MP_x = P_x +$ Dynamic tip radius

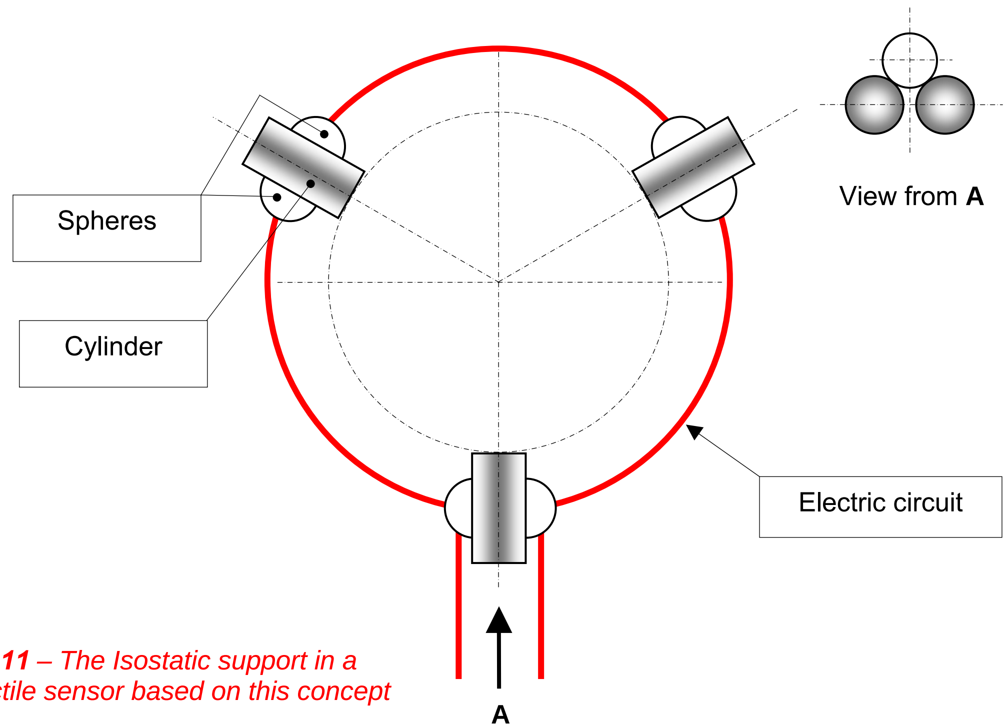
Since not perfect measurement can be made in nature, even the most accurate calibration and qualification procedure will generate small errors due to the uncertainty of the determined parametres and the repeatability of the system during the procedures themselves.
Nevertheless, if calibration and qualification procedures are carried out correctly, these residual errors will not affect the declared metrology performance of the Co-ordinate Measuring Machine.

Point to point tactile sensors
The most diffused tactile sensors for point to point measurement can be divided in three main categories, namely those:

a. Based on "***Isostatic support***" concept.
b. Based on "***Piezoelectric Isostatic support***" concept.
c. Based on "***Strain gauge***" concept.

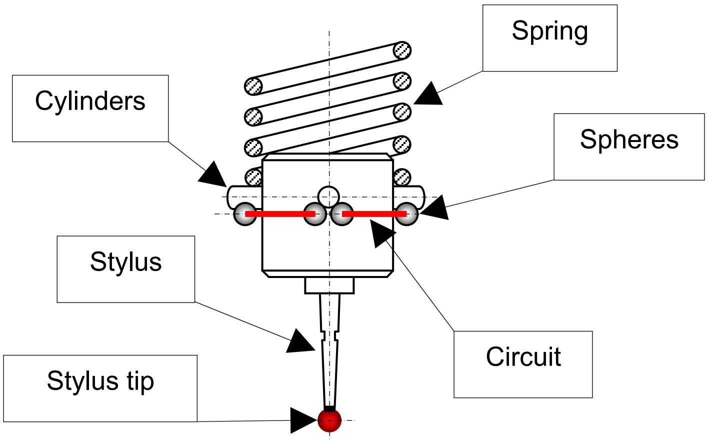
Each of the above mentioned sensors has its own cost and functional characteristics and represents the ideal solution for a given application. These sensors are also referred to as "***Trigger probes***" in so far as they generate an electrical signal when they get in physical contact with the part to be measured. In correspondence with this electrical signal the coordinates of the stylus tip centre are automatically frozen and recorded by the CMM system.

Tactile sensor based on Isostatic support mechanism
This kind of point to point sensor is the simplest and more diffused; devices of this type have been, for many years, the only electronic probes available on Co-ordinate Measuring Machines.
These sensors are based on a mechanism in which three pairs of contacts are kept closed by means of the force generated by a spring. The three contacts constitute an Isostatic support, very repeatable in positioning.
The contacts are constituted by three cylinders located on the same plane at 120° from each other and physically connected with the stylus of the sensor. In resting conditions the three above mentioned cylinders are supported by three pair of spheres also located on the same plane at 120° from each other and fitted on the sensor body.



11 – The Isostatic support in a tactile sensor based on this concept

As already pointed out the three cylinders are located on the shaft on which it is fitted the stylus; the three series of spheres are connected trough an electrical circuit. As it may be noticed in figure 12, the mechanism in question is idle when the stylus is not displaced from its resting position; in this case the circuit is closed and no signal is generated by the sensor.

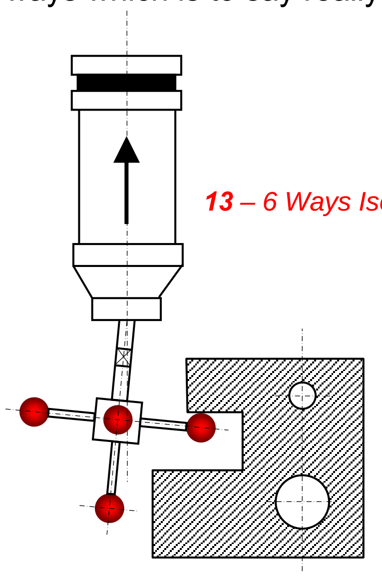


12 – Isostatic support tactile sensor: functioning principle

As soon as the sensor comes in physical contact with the surface of the part to be measured:

a. The force that tries to displace the sensor from its resting position grows. At this point the spring still keeps the contact closed. Nevertheless the force of contact balances the force of the spring itself.
b. Just before that the balance between the forces is reached, the force of contact between part and sensor causes a slight displacement of the stylus and the contact is opened.
c. At this point a signal is generated that allows the recording of the co-ordinates of the sphere centre at the moment of contacting the part surface. The point has been measured.
d. The CMM starts to decelerate, while the spring preloaded mechanism follows the machine movement with a slight over-travel.
e. Finally the machine retracts and the Isostatic support assumes its resting position in an extremely repeatable mode, ready to measure more points.

The sensors in question can be either 5 ways, namely able to measure in any direction but not along a pulling vector or 6 ways which is to say really omni-directional (figure 13).



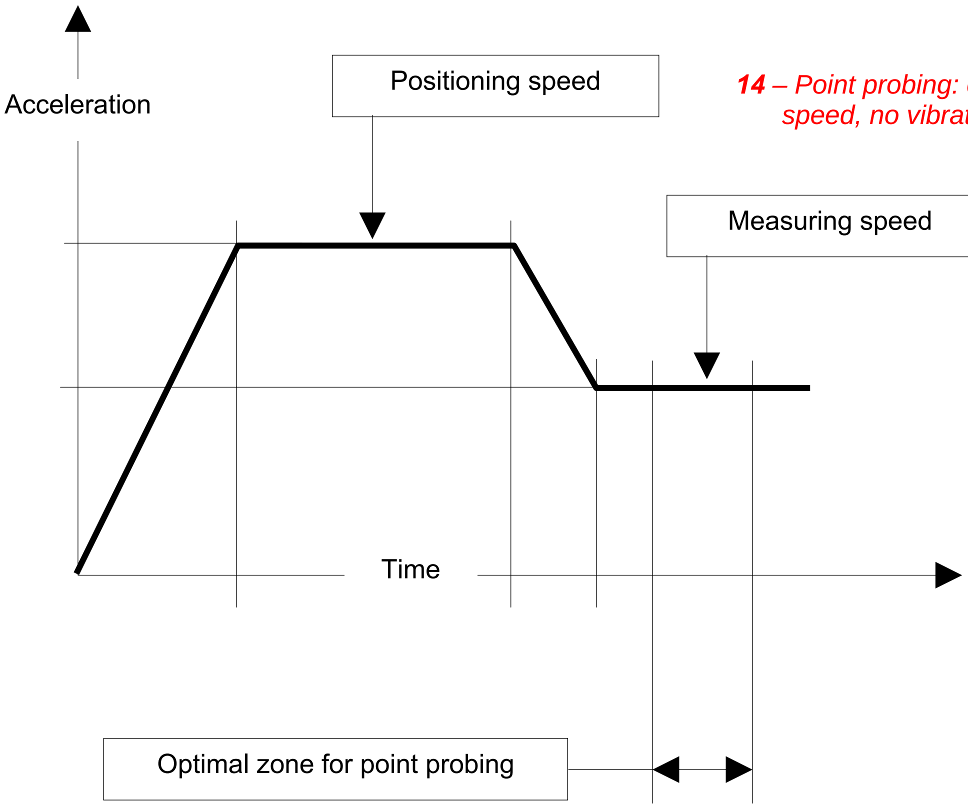
13 – 6 Ways Isostatic sensor

The sensor stylus is evidently interchangeable, this in order to substitute it in case of damage but also, and very important, to allow to choose the best device (dimensionally and morphologically) to cope with a specific application.

The sensors styli are generally made of stainless steel, nevertheless, for special applications; it is not rare to see styli built in either ceramic or carbon fibre. This in order to reduce weight, obtain good reactions to thermal environment conditions, etc... The stylus sphere is generally made of synthetic ruby or ceramic.
The length of the stylus is a critical parameter that may affect the reliability of measuring results.
As any object to which mechanical stress is applied, when the sensor is brought in touch with the part it is subject to elastic deformations; in this case deflections. The magnitude of the deformation may vary on the basis of different parameters such as:

Stylus length.
Stylus material.
Speed.
Etc.

It is therefore recommended never to use styli longer than what strictly necessary and built of a material with the best compromise between low weight and rigidity.
The point to point sensors for on the fly measurement allow rather high operating speed; it is however necessary to operate within certain dynamic conditions in order to exploit at the very best the metrological characteristics of the sensor itself.
The point probing has to be done without accelerating, namely at constant speed, and in absence of vibrations.

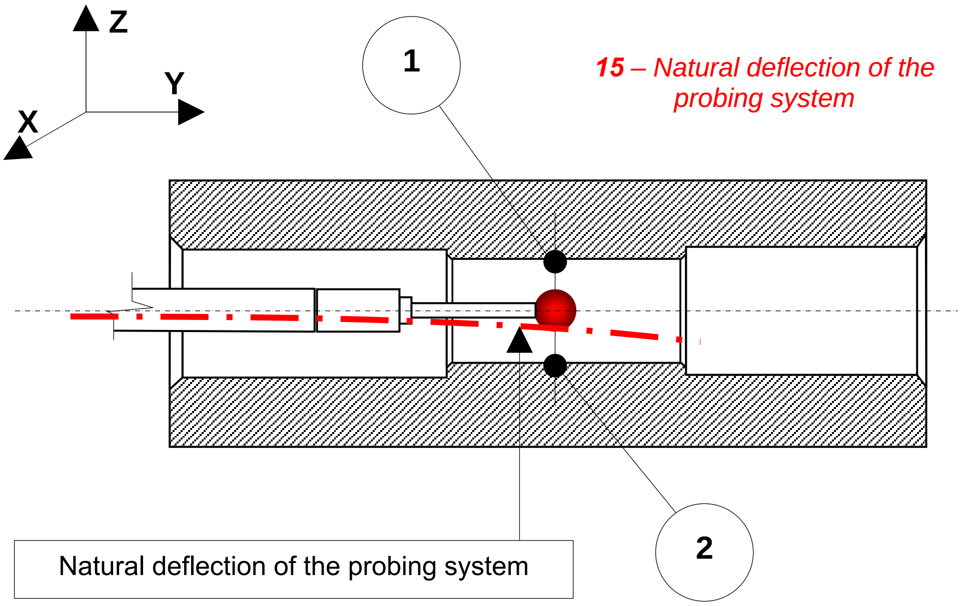


***14** – Point probing: constant speed, no vibrations*

As it can be noticed in figure 14, the correct movement for point probing consists of:

1. Acceleration ramp to reach the maximum positioning speed.
2. Approaching trajectory to the point to be probed at constant positioning speed.
3. Deceleration ramp to reach measuring speed.
4. Point probing at constant measuring speed.

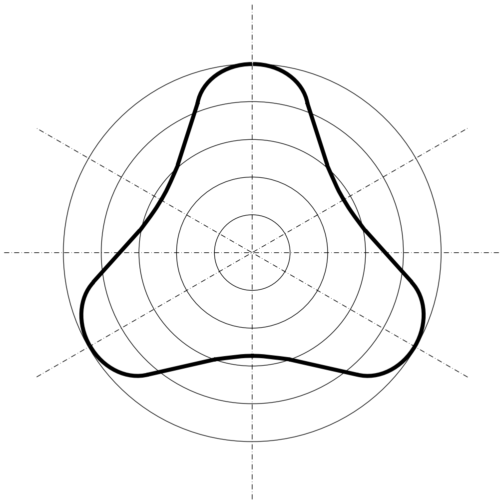
In the case of features which require a deep reach to be measured, extension bars will have to be used. As said it is very important to use the shortest possible extensions, considering that the overall deflection of the probing system is also function of the sensor attitude in the Cartesian space; a sensor fitted with its longitudinal axis in the XY plane will be naturally bent by the force of gravity. Therefore, the longer is the stylus, or the extension, the poorest is the rigidity the higher is the risk of producing non repeatable dynamic deformations, thus generating unreliable readings.



***15** – Natural deflection of the probing system*

With reference to figure 15 it is rather obvious that, while probing point 2 the natural deflection will be partially recovered, while, when probing point 1 the deformation will increase.

Also to be considered in any Isostatic support based system is "***Anisotropy***"[5]; for this reason the force necessary to open the contact of the sensor are different depending on the direction of the approach to the point to be measured with respect to the position of the support itself. Force will be higher in correspondence of the sphere and cylinders, lower in between.

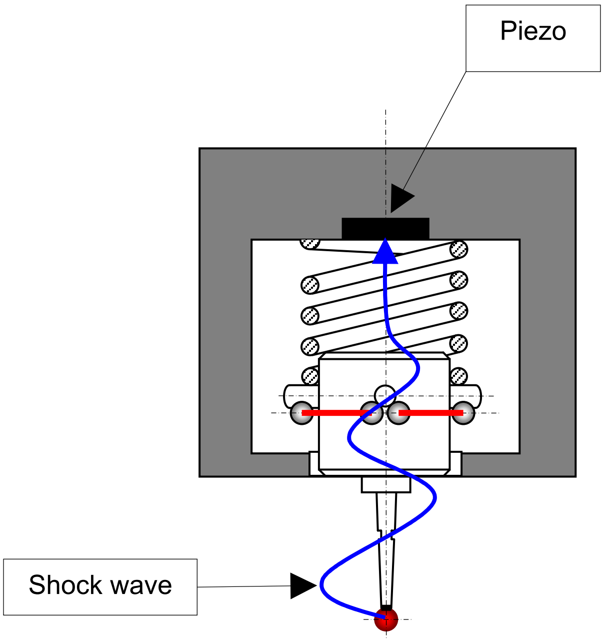


***16** – Diagram of anisotropy in an isostatic support sensor*

[5] *Anisotropy, the contrary of Isotropy, is the property of depending on the direction. For example, the radiation of an antenna can be non isotropic if the generated field varies with the direction of irradiation.*

Piezoelectric tactile sensor based on Isostatic support mechanism

A "***Piezoelectric***" [6] sensor may detect the shock wave generated by the contact of the stylus tip with the part to be measured.



17 – Piezoelectric Isostatic support tactile sensor: functioning principle

The main characteristics of this type of sensor are as follows:

a. Very good metrological characteristics even with rather long styli[7].
b. Possibility of probing points along all directions (6 ways).
c. Possibility of being fitted directly in the CMM spindle.
d. High precision.

Regardless of the interesting properties, the type of sensor in question is not as diffused as those mentioned in the previous point. It has however to be underlined that the electromechanical Isostatic support sensors have been conceived and marketed in the early seventies; the piezoelectric sensors are of a much recent conception.

Strain gauge point to point sensors

The point to point "***Strain Gauge***"[8] sensors utilise a different sensory technology with respect to those previously described, even though the Isostatic support is still present to guarantee the sensor position and generate extra travel. These sensors are capable of detecting the force of contact of the stylus with the part in the three directions. The output is then processed by the electronic of the sensor which detects when the resulting force vector exceeds a given threshold. When the threshold level is reached, the signal of point probing is automatically generated. With respect to the electro mechanic point to point sensors, the strain gauge ones generate the signal with a force of contact with the part remarkably lower; this allows a minor deflection of the stylus and much reduced extra

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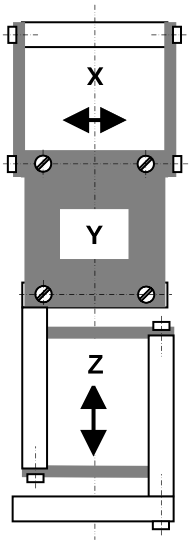
(6) Phenomenon discovered by Pierre and Jacques Curie in 1880 in the quartz and Rochelle salt. This phenomenon for which an electric potential is present on certain faces of a crystal when the latter is subject to mechanical pressure, is called "Piezoelectricity" (from the Greek "piezein" = press). As opposite, when an electric field is applied to certain faces of a crystal, the crystal itself is subject to a mechanical deformation.

(7) Very important characteristic if compared with those of the sensor of the type described in the previous point.

(8) Device in which the electrical resistance varies in proportion to the amount of strain placed on it.

travel. It has to be finally observed that these kinds of sensors are Isotropic, namely they have the same force of contact in all directions. Generally the electronic for signal processing is built in the sensor.
Because of the high sensitivity of these devices, the output must be filtered to avoid spurious points generated, not by the contact with the part, but induced by vibrations of the measuring system.
A further positive characteristic of strain gauge sensors is to allow the use of rather long styli. It is however recommended, with any kind of sensor, to use styli built of material with very good vibration dumping coefficient and low weight.

Continuous tactile sensors / Scanning Sensors
The continuous tactile sensors have represented the most sophisticated form of sensory utilised on Co-ordinate Measuring Machines for many years. As already pointed out, in point to point mode the sensor comes in touch with the part only at the point probing moment; in continuous scanning the sensor remains in touch with the component following its profile and gathering points, according to pre-determined laws, in the course of a single measuring path.
The type of sensor in question is utilised both for "***Digitising***"[9] and "***Gauging"*** operations.
These kinds of devices may be divided in two categories, namely: "***Active***" and "***Passive***".
The active sensor constitutes a real CMM within the CMM itself. These devices use active force generation, in other words, during the measuring scanning path the sensor itself controls the force of contact with the part; this avoids influences caused by probe deflection, for example. Also, modern sensors of the type in question are equipped with an automatic weight balance system to compensate for the different probe weights. The passive sensors, simpler mechanisms, are capable of detecting the deflection of the stylus by means of a passive spring mechanism. The point probing is generated by the movement of the CMM which causes the stylus displacement from its resting position; the most common mechanism is based on three couples of springs fitted as a parallelogram, which allow to the relevant axis the measuring movement which is detected by a transducer.
While the active sensors are always fitted in –Z, the passive sensors can be fitted on a swivelling probe holder and can be positioned in thousands of different positions.
These kinds of sensors, which can also be used for discrete point measurement, represent the ideal solution for the determination of the form status of a given geometric element. The strokes of these heads are, generally speaking, shorter than the point to point devices.



18 *– Schematics of the principle of a blade spring mechanism for continuous sensors*

(9) See 1st Education article "Use and scopes of the Co-ordinate Measuring Machine" (www.iacmm.org)

It must however be underlined that in the recent years miniaturised and sophisticated tactile continuous sensors have been developed. The availability of accurate micro components allowed realising devices of remarkable small dimensions and metrological characteristics.

Non Contacting sensors

The non contacting sensors are based on optoelectronic techniques. These types of sensors allow measuring an object without getting in physical contact with the same. The use of optoelectronic technology in Dimensional Metrology does not represent a novelty per se. Since more than a decade artificial vision techniques are applied, with success, for determined measuring application.

Considering the evolutions of which tactile sensors have been subject during the last quarter of a century, it may be asked for which reason the non contacting measuring technology has arisen such a strong interest and constitutes a primary research objective for many industries of the sector.

The reasons are essentially three, namely:

a. **The dimensions of the part to be measured**: when the object to be dimensionally inspected is very small (constituted by surfaces of few mm^2) it is impossible to access its features even with a stylus of reduced size. As a consequence the impossibility of utilising tactile technology and the need for an alternative approach.
b. **The measuring speed of non contacting sensors**: the automation level reached by the manufacturing process, combined with the need of producing parts of always better accuracy, have generated the need of increasing the sampling rate, often directly in the manufacturing line. Because of these reasons a high measuring speed is needed.
c. **The material of which the part to be measured is built**: in certain industrial sectors the produced part are built of extremely soft material. Even the very light force applied by a tactile sensor would deform the surface of the part making useless the measuring operation. In other cases, for instance on "*clay*"[10] models, the light pressure generated by the sensor on the part surface would even damage the part itself; once again the impossibility of using the tactile technology and the need for an alternative approach.

Summarising the non contact measuring technology allows:

- To measure very small sized parts otherwise not measurable.
- To obtain a higher measuring speed than that of a tactile sensor[11].
- To measure very soft material parts otherwise not measurable.

The application of non contacting techniques on very small parts is carried out on particular machines not really similar to the canonical Co-ordinate Measuring Machines subject of our articles.

The tactile sensor technology has reached a remarkable level of standardisation both in terms of utilised physical principles and manufacturing. The situation is rather different as far as the optoelectronic sensors are concerned; this is due to a series of reasons such as:

- Lack of concerning international standards.
- Typology of the offer which make the costs of integration of the sensor with the CMM still rather high.

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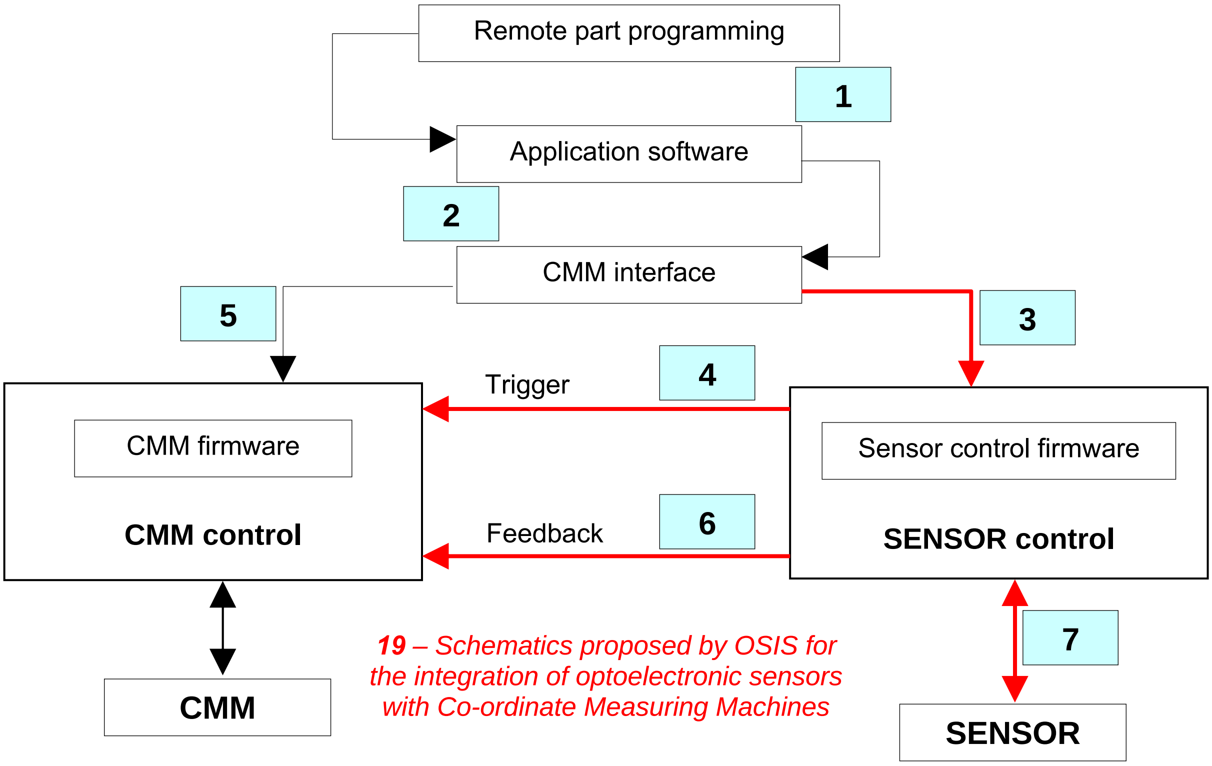
(10) Firm, fine grained earth, plastic when wet used in model making.
(11) This statement can not be generalised and it is true with given non contacting sensors only in determined applications.

As already pointed out (see note [(2)] page 3) the OSIS Committee has initiated, with its three Working Groups, a series of activities with the objective of generating standardisation proposals concerning the following subjects:

Mechanical and electrical interfacing of the non contacting sensor with the CMM.
Software interfacing of the non contacting sensor with the CMM.
Metrological performance testing and relevant procedures.

In figure 20 it is possible to observe the integration concept developed and proposed by OSIS.
With reference to figure 20 it can be noticed that:

1. The interfaces represented with red coloured arrows are of OSIS interest.
2. The interfaces represented with black coloured arrows are not of OSIS pertinence.
3. The interface "**1**": is utilised for the transfer of measuring part programs from a remote part programming station. OSIS recommends the use of DMIS as a standard at this level of interface. Any further definition at this level is not within the scopes of OSIS.
4. The interface "**2**": located between the application software and the CMM interface, separates that part of software which depends on the specific CMM hardware (e.g. drivers, transducers, thermal compensations, sensors, etc.) from the hardware independent software. Because of this reason the application software could also be supplied by other supplier than the CMM one. OSIS recommend the use of I++ / DME[12] as a standard for this interface. There is a strong commitment between OSIS Working Group 2 and I++ / DME to utilise common definition and of mutually tune the standardisation activities on the basis of each other developments.



19 – Schematics proposed by OSIS for the integration of optoelectronic sensors with Co-ordinate Measuring Machines

(12) I++/DME is an interface that allows to run a dimensional inspection part program on different co-ordinate measuring machines, independently from the brand, provided that this standard is supported by the specific CMM.

5. Interface "**3**": the interface of the CMM and the sensor control firmware are the main actors for the integration of an optoelectronic sensor data with a CMM. The definition of this level is consequently one of the main scopes of OSIS Working Group 2. The objective is to group in the sensor control firmware all the specific functionality of the sensor itself. One part of the CMM software realises the bi-directional communication between the CMM itself and the sensor firmware.
6. Interface "**4**": the only scope of this interface is to electrically generate the signal of data acquisition for the CMM (freeze and evaluate current co-ordinates) and for the sensor (acquire and pre-process the measuring data of the sensor itself). The sensor is always the only source of generation of the signal in question.
7. Interface "**5**": by means of this interface the communication between the CMM software interface and CMM control firmware is realised. This interface is therefore specific of the CMM and, consequently, does not fall within the competence of OSIS Working Group 2.
8. Interface "**6**": during the continuous scanning the CMM needs information concerning the part surface in order to maintain an adequate trajectory. Obviously the position information must be available to the control in real time. Since the data exchange with interface "**3**" is not necessarily real time, the exchange of large amount of measuring data may slow down the communication, therefore the interface "**6**" is delegated the "almost" real time feedback task. The feedback data, because of the relatively low accuracy, must not be assumed as measuring result.
9. Interface "**7**": as interface "**5**" this interface is normally a communication line specific of a given sensor and relevant control. In multisensor system different sensing devices must physically share the communication line on the basis of OSIS Working Group 1 specifications. Obviously exception made for multiarm CMM with on sensor per front.

Many different non contacting sensors are available on the market having different metrological performance and based on different principle of physics. It has been therefore one of the first tasks of OSIS to propose a sensor classification matrix to make simple and secure the identification of the sensor characteristics. In the following table is illustrated a summary of the classification matrix proposed by OSIS. It has however to be considered that being the work in progress this matrix may be subject to variations.

Table 2 – *OSIS proposal for a sensor classification matrix*

Characteristic	**Type**	**Classification criteria**	**Description**
Sensor Movement	A	Trigger	Dynamic data acquisition
	B	Static	Static data acquisition
Output	1	Point with 1 degree of freedom	1 Co-ordinate: **r** or **s** or **t**
	2	Point with 2 degrees of freedom	2 Co-ordinates: **rs** or **st** or **rt**
	3	Point with three degrees of freedom	3 Co-ordinates: **r**,**s** and **t**
	4	Multiple points with 1 degree of freedom	Multiple **r** or **s** or **t**
	5	Multiple points with 2 degrees of freedom	Multiple **rs** or **st** or **rt**
	6	Multiple points with 3 degrees of freedom	Cloud of points (multiple **r**,**s** and **t**)
Type of data acquisition	I	Simultaneous data acquisition	Points acquired simultaneously
	II	Sequential continuous	More points are detected in a

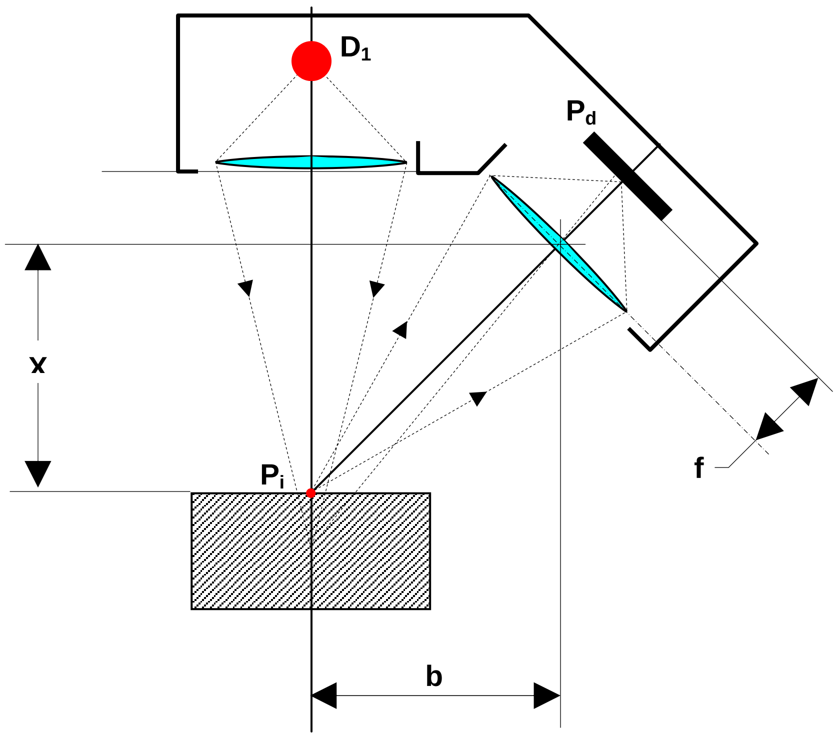
			fast sequence during a single working stroke
	III	Sequential point to point	Detection of a single point each working stroke
Type of output	YES	May generate, at sensor level, output concerning geometric elements	May generate output relevant to elements such as circles, slots, etc.
	NOT	The negation of the above	The negation of the above

The triangulation principle

It is a principle rather often used in non contacting sensors. In the course of time it has been subject to many improvements, mostly due to the evolution of components; this principle is however still valid and it is at the basis of many sensors today on the market.

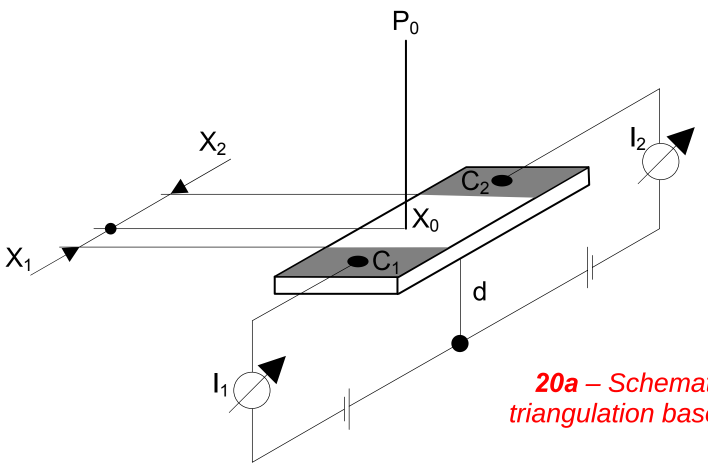
The triangulation sensors work on diffused light. In the schematic example of figure "*20*", the laser beam generated by the diode "D_1" is conveyed to the surface of the part to be measured on which it generates the point "P_1". The resulting light is then conveyed to the photodiode "P_d" of extended surface of high homogeneity semiconductor.

Evidently the scope of the exercise is to detect, with the best possible accuracy, the distance "X".



***20** – Schematics of the principle of a triangulation based non contacting sensor*

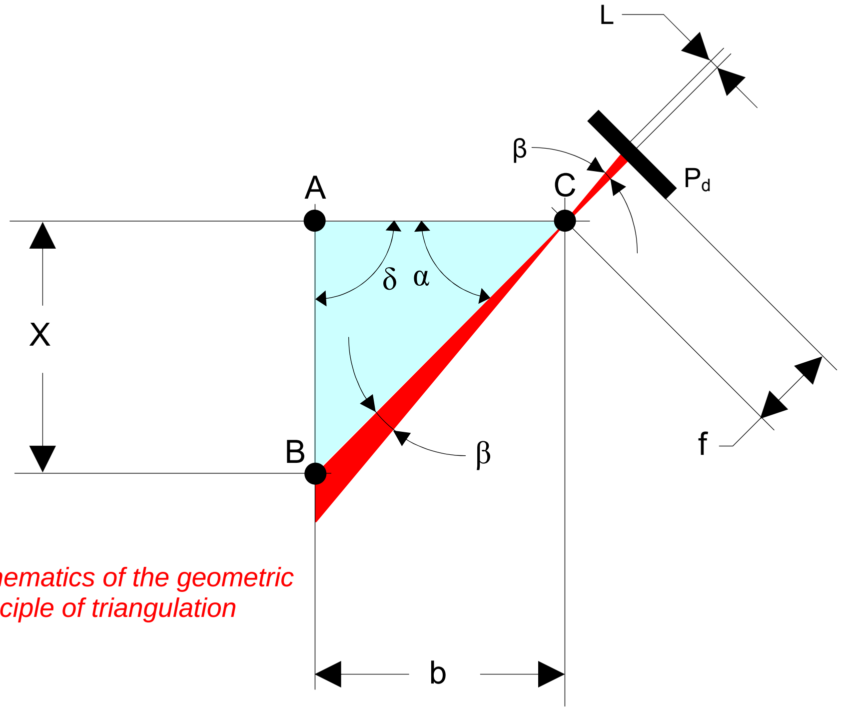
It may be noticed in figure "*20a*" that when "P_0" hits the photodiode in "X_0" the latter generate a current. The current, through "X_1" and "X_2", flows to the electrodes "C" and "C_1" and close the circuit through "d".



***20a** – Schematics of the principle of a triangulation based non contacting sensor*

The sum of the currents “I_1” and “I_2” is function of the distances “X_1” and “X_2”. Theoretically it should be a linear function, in the reality it is not so because of the non complete homogeneity of the photodiode. The value of the currents “I_1” and “I_2” is not only function of “X_0” but also of “P_0” intensity. The analogue signal of the photodiode is then amplified, filtered and deprived of the influence of “P_0” intensity.

After the analogue / digital conversion each single sensor is compensated for linearity errors by means of its firmware.



***21** – Schematics of the geometric principle of triangulation*

From a geometric point of view the triangulation principle is rather simple, with reference to figure “*21*”, it can be notice that:

1. AB= X (to be determined)
2. AC= b (known)
3. δ= 90°
4. α= 45°

Therefore:

5. $$\frac{X}{B} = tg(\alpha - \beta)$$

6. $X = b\,tg(\alpha - \beta)$

7. $$X = \frac{(tg\alpha - tg\beta)}{(1 + tg\alpha tg\beta)} = \frac{(1 - tg\beta)}{(1 + tg\beta)}$$

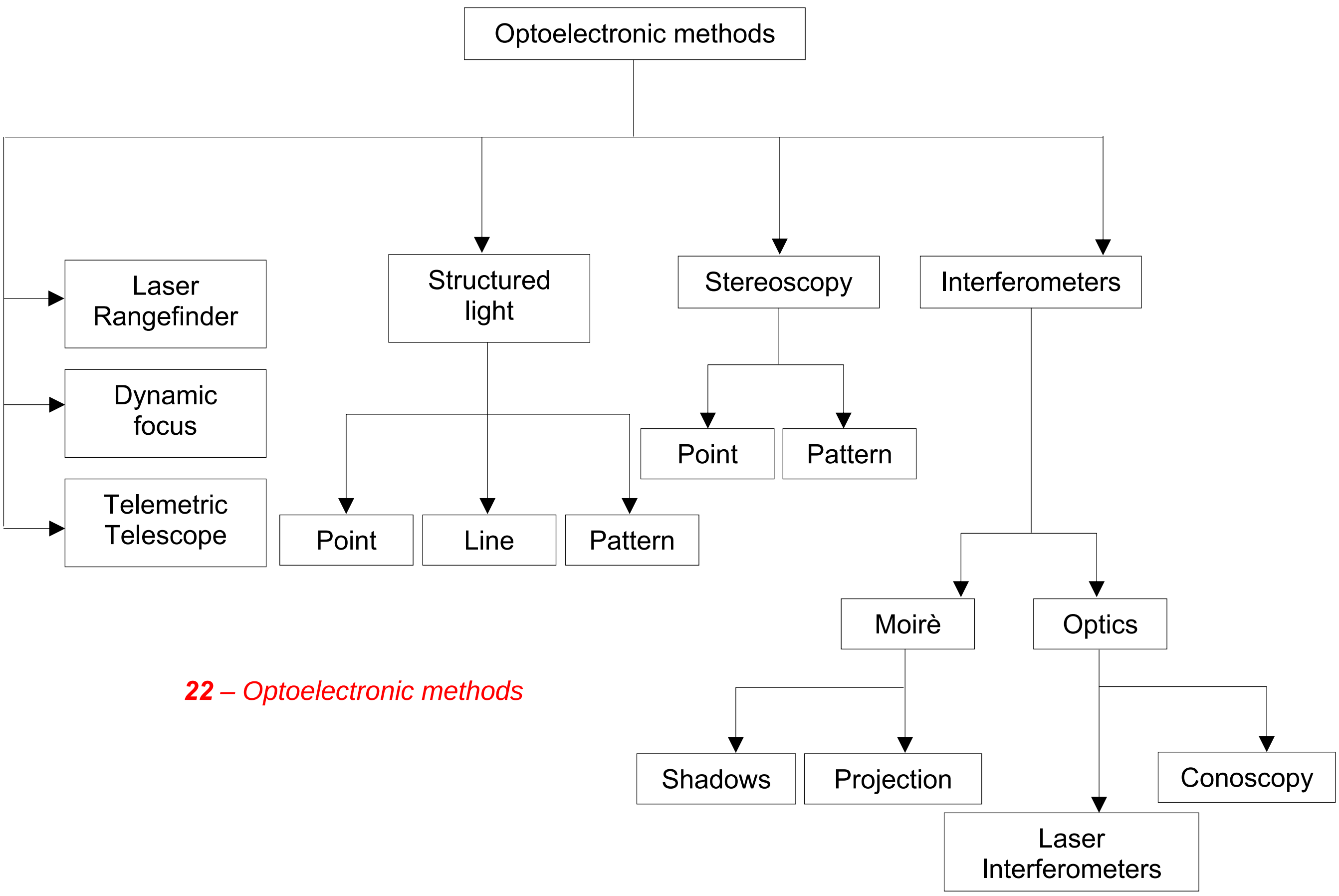
8. $$tg\beta = \frac{L}{f}$$

9. $$X = \frac{1 - \frac{L}{f}}{1 + \frac{L}{f}}$$

Therefore:

10. $$X = \frac{f - L}{f + L}$$

The non contacting sensor technology can be based on many different principles; in this article only the basics have been described as a general overview on the subject. Figure "*22*" describes how wide can be the application of optoelectronic in non contacting sensors.
In the next **ia.cmm** Educational Articles a more detailed analysis of these emerging techniques will be carried out.



***22** – Optoelectronic methods*

NOTE FOR THE READER:
This article has exclusively a basic educational objective. The scope of the above is to supply general information on sensor techniques; ia.cmm Member Companies either produce or make available a wide variety of sensors which allow the solution of any kind of CMM applications.

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