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Área Académica de Ingeniería Mecatrónica



Graduation Project

**“Development of a Measuring Program for Single Parts of an Electronic Stability Control
Using a Coordinate Measuring Machine”**

Continental Teves AG & Co. oHG

**Informe de Proyecto de Graduación para optar por el título de Ingeniero en Mecatrónica
con el grado académico de Licenciatura**

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October 14th, 2016

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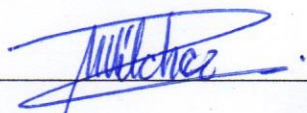
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Abstract

The project was carried out in the Quality Control Department of Continental AG located in Frankfurt am Main, Germany. Continental developed a braking system called MK 100[®], which makes it possible to install ABS/ESC in all vehicle categories. In the manufacturing process, there are many factors that can affect the dimensions of the geometric features of the product, so it is necessary to establish a method for identifying that these features lay within the defined tolerance values.

The main goal of the project is to develop a measuring program for the valve block of the electronic stability control module. The measuring program is developed using a coordinate measuring machine that measures all the specified geometric features defined in the technical drawing of the workpiece. At the end, the software generates a report that shows all the measured and calculated geometric features and they are compared with the nominal values. Each of the features has a range of accepted values and the report indicates if the values are in the tolerance zone or out of it.

This document describes all the important concepts regarding coordinate metrology that is necessary for developing the measurement protocol and understanding the results of the measurement report. It also contains a description of all the important steps when developing a measurement strategy and the way the coordinate measuring machine Leitz PMM 866 is programmed using the Quindos 7 software.

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1. Introduction and Background

This chapter includes an overview of the problem, the definition of it, and based on this, the objectives that the project should accomplish. The overview talks in a general way about the problem and reasons that support the implementation of the project and names the technologies used for this purpose. The problem statement defines the most important factors to take in consideration when developing the project and summarizes it. Then, the general objective defines the main goal of the project and the specific objectives set the specific aims that should be carried up through the development of the project. This part of the work is the base of the project because helps to understand the problem by giving an introduction and background of it, what should be accomplished, and factors to take in account when developing it.

1.1. Overview

Continental has developed a braking system called MK 100[®], which makes it possible to install ABS/ESC in all vehicle categories. It is a modular product family that makes scalability possible. The MK 100's range of functions can be scaled to suit many functionalities and levels of performance depending on the vehicle's requirements. This family of braking systems can be adapted from a motorcycle ABS system, with or without an integral braking function, up to high-end solutions with extremely powerful, low-pulsation pump variants with a high level of running smoothness. The MK100 electronic stability control also benefits, from precise, comfortable and gentle control interventions. The range of safety and assistance functions, which depending on what the vehicle manufacturer wants, can be incorporated into the MK100 ESC.

In the manufacturing process, several factors can generate defects on the produced units, so it is necessary to establish a method or procedure to verify if the products are within the established parameters. In the process of manufacturing, several units should be tested to measure the accuracy and precision of the required dimensional tolerances and parameters. Then, the results of these tests can be analyzed to determine if modifications should be done on the manufacturing process. These tests should be performed frequently because the machines are disarranged through manufacturing and because external factors may affect the process. For this reason, it is very important to have an efficient measuring process for the specified unit. Nevertheless, to test all the produced units would be very expensive for the company, so in most

cases some units are extracted from the production line and tested. Then, through a statistic analysis, it is possible to determine if there is a problem in the manufacturing process.

There are several methods and technologies available for measuring the dimensional characteristics of products. The most known and used methods are: optical trackers or comparators, microscope measuring, computed tomography (CT), and coordinate measuring machines (CMM). For the development of the project, it is necessary to use a CMM for programming a measuring protocol to test the geometric features of the workpiece and compare them with the nominal values specified on the technical drawings. The measuring test has the goal of detecting defects in the characteristics of the products to determine if it is necessary to make modifications in the production line.

1.2. Problem Statement

1.2.1. General Concept

The MK 100 braking system represents a new dimension in integrability and installation space and weight. Modern braking systems must satisfy drivers' desire for more safety, comfort, and assistance functions and at the same time satisfy the industry demands for weight reduction in order to reduce fuel consumption. Regarding installation space and weight its dimensions have been reduced in a 20 percent compared with the older generation of brake systems. In the process of manufacturing these modules, it is extremely important to maintain a high standard quality because brakes have a direct impact on safety issues. In addition, it is very important for the company to meet the national and international standards in the automotive industry. These are the main reasons why the manufacturing process must fulfill all stated norms and regulations, to obtain a reliable and safe product. Thus, the department of precision testing is a very important part of the complete manufacturing process, because it determines if the products comply with the established quality standards.

It is necessary to develop a measuring program for the valve block of the electronic stability control in which all contained geometrical characteristics are analyzed. For this, it is necessary to choose which machine or machines are better to carry out the tests and to program this machine to do it in an efficient way. It is essential to analyze which fundamental characteristics of the block like the kind of tolerances and desired precision to decide which

equipment and procedures are better for the process. Then, the project is centered in establishing a protocol to measure the dimensional characteristics of the valve block. Each one of the parts of the valve block has different requirements regarding form and location tolerances and surface parameters that have to be fulfilled. Because of this, it is necessary to develop a program to measure the dimensional characteristics of the single parts and based on those measurements, lead the decisions that have to be made in the industrial process. Programmed machines normally carry out this process of verifying tolerances because they can accomplish results within a reasonable period of time and with high accuracy. The developed method has to be fast and accurate enough to analyze all the characteristics of the block so modifications to the manufacturing process can be made on time and when necessary.

1.2.2. Synthesis

It is required to develop a measuring program for the valve block of the electronic stability control to verify that the product complies with the established parameters and to make decisions regarding the manufacturing process based on the analysis of measurement results.

1.3. Objectives

1.3.1. General Objective

Develop a measuring program for initial sample parts of the electronic stability control to create a measurement protocol with all required dimensional results.

1.3.2. Specific Objectives

- Acquisition of knowledge regarding control of inspection, measuring and test equipment.
- Research the functionality of an ESC and specifically the valve block.
- Study the necessary specifications, norms (internal and external) and mechanical drawings of the unit.
- Learn how to use the measuring equipment with all kind of forms, locations, dimensions, and the associated evaluations.

- Document all the information regarding the measuring protocol and programming of the machine.

This section summarizes the most important aspects taken in account to develop the project and serve as an introduction and gives a background about the problem which is very important for the development of the work. The named technologies are later analyzed to determine which option is the best for the solution of the problem and more details of the process are given in the theoretical framework. The most important aspect of this section is that the main objective is defined and the specific objectives that work as a checklist of goals that must be carried up for the development of the measuring protocol.

2. Theoretical Framework

This section contains all the theoretical concepts necessary to understand the process of developing a measuring protocol and serves to guide and determine how the process should be made. It is divided in several subsections: quality control and metrology, geometric dimensioning and tolerancing, coordinate measuring machines, coordinate metrology, MK 100 braking system, and the Project Background. The first subsection explains the importance of quality control processes in the industry which the project is about. Several concepts are explained which are important for understanding the results of a measuring protocol and the aims of it. Geometric dimensioning and tolerancing is important for the project, because it explains the meaning of the symbols used on the technical drawings and the measuring of each of the geometric features of the valve block which is the main goal of the project. It also helps understand the information which usually goes in a measuring report of a manufactured part.

The subsection of CMMs explains the main concepts of this technology which is the one used in the project for creating the measuring protocol. It explains important factors regarding the environment of the machine to work appropriately, and the functioning which must be taken in account to develop the program that controls the machine. Coordinate metrology clarifies all the theoretical and practical aspects of a measuring process, which are necessary to write the program that measures the workpiece. The next subsection clarifies some details about the braking system, which is important for the project because helps understand the functionality of each of the parts of the valve block, and are taken in account when developing the program. The last subsection which is the project background details the state of the problem before the project execution and the main contributions of it.

2.1. Quality Control and Metrology

Quality control in manufacturing processes is almost a uniform goal throughout industry, which implies a degree of excellence that makes a product superior to others in the performance of its intended functions. It involves a series of procedures intended to ensure that the manufactured product complies with a set of criteria and meets the established design requirements. To implement an effective quality control program, it is necessary to decide the specific standards the product must meet. For this process, it is necessary to collect data, analyze

it, and report it to the management personnel. After these actions are carried out, corrective actions must be taken to ensure that the product complies with the quality standards established by the company.

To achieve a cost effective quality control it is essential a combination of both product inspection and statistical evaluation of inspection results. To achieve this goal, statistical process control is widely used in manufacturing companies to attain continual improvement. “To effect improvements in control and capability, common and special causes of variation must be identified and the process modified accordingly; then the cycle begins again, as more data are gathered, interpreted, and used as the basis for action” (Statistical Process Control: Reference Manual, 1992, p.21). Then, this process has three important stages: collection of data, control, and analysis and improvement. Commonly, cause and effect diagrams are used to determine the root problem that causes defects on manufactured products, an example is shown in Figure 2.1.

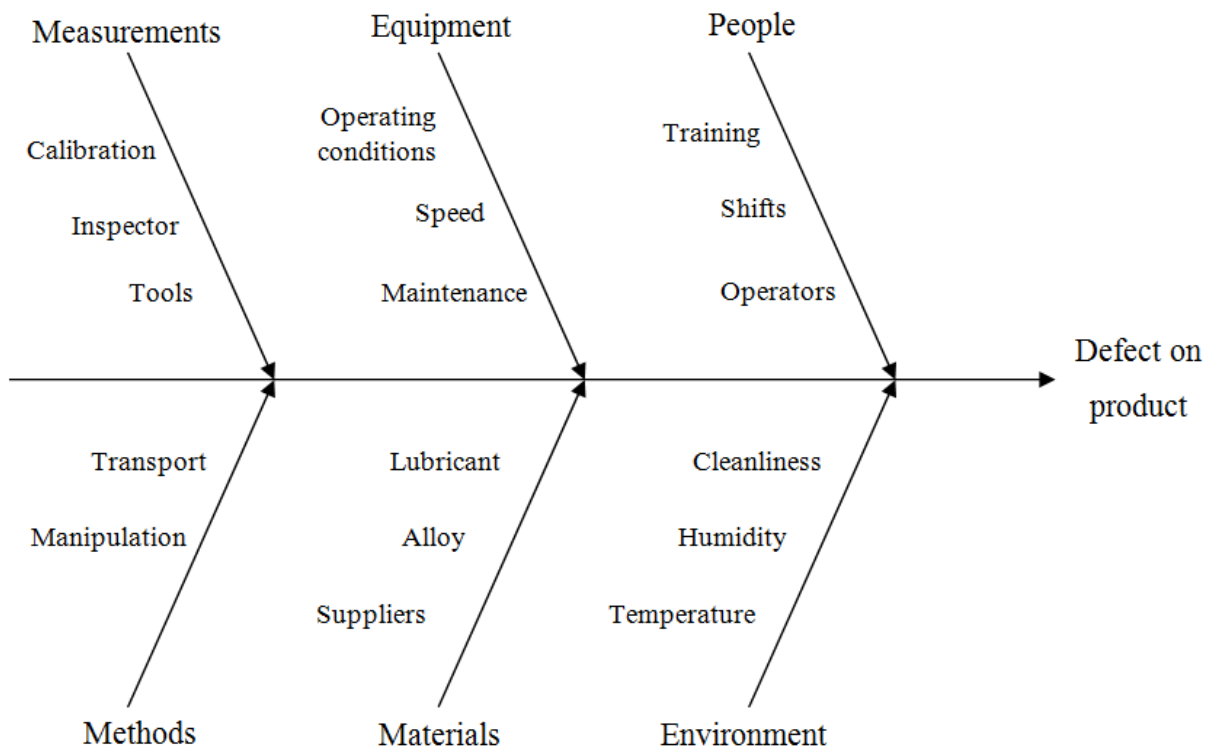


Figure 2.1. Cause and effect diagram used in manufacturing processes.

Several kinds of tests are widely used in the industry for the evaluation of incoming and outgoing products to maintain a desired level of quality. Coordinate metrology is an important part of the quality control process as it is important for obtaining information about products, regarding dimensional characteristics, and to determine whether the products comply with the established parameters. Systematic measurement with known uncertainty is extremely important to assure quality control and is one of the foundations of technology and science. Using quality control enables a company to improve its manufacturing process through a series of benefits that are listed in Table 2.1.

Table 2.1. Benefits of quality control. Taken from (Measurement Technologies in Quality Control Purposes, 2014)

Internal benefits	External benefits
Reduce costs	Increase customer satisfaction
Increase profitability	Ensure product specifications
Decrease reject rates/costs	Increase products average quality
Increase customer retention	Appropriate intangibles

Metrology is defined by the International Bureau of Weights and Measurements (2012) as “the science of measurement and its application”, and “includes all theoretical and practical aspects of measurement, whatever the measurement uncertainty and field of application”. A fundamental role of metrology and calibration process is to determine the accuracy or uncertainty of measurements. This can be achieved by establishing the characteristics of measuring systems and equipment limitations.

2.1.1. Important terms

2.1.1.1. Error in Measurement

The error in a measurement is the difference between the measured value and the true value of the measured quantity. Errors can be classified into two categories:

- Random errors: these errors are accidental in nature, and they fluctuate in a way that cannot be predicted. Some sources of this type of errors are hysteresis, ambient influences and variations in the measured object.
- Systematic errors: those which are not usually detected by repetition of measurements, such as an error resulting from faulty calibration or a defect in contact configuration of an internal measuring system.

It is important to analyze the sources of error for attaining the necessary knowledge of achieved accuracy. There are many error sources in measuring systems, according to (Borror, 2009) they can be classified into three large groups:

1. Process environment
2. Equipment limitation
3. Operator fallibility

These three factors constitute an interrelated system for the measuring process and is shown in Figure 2.2.

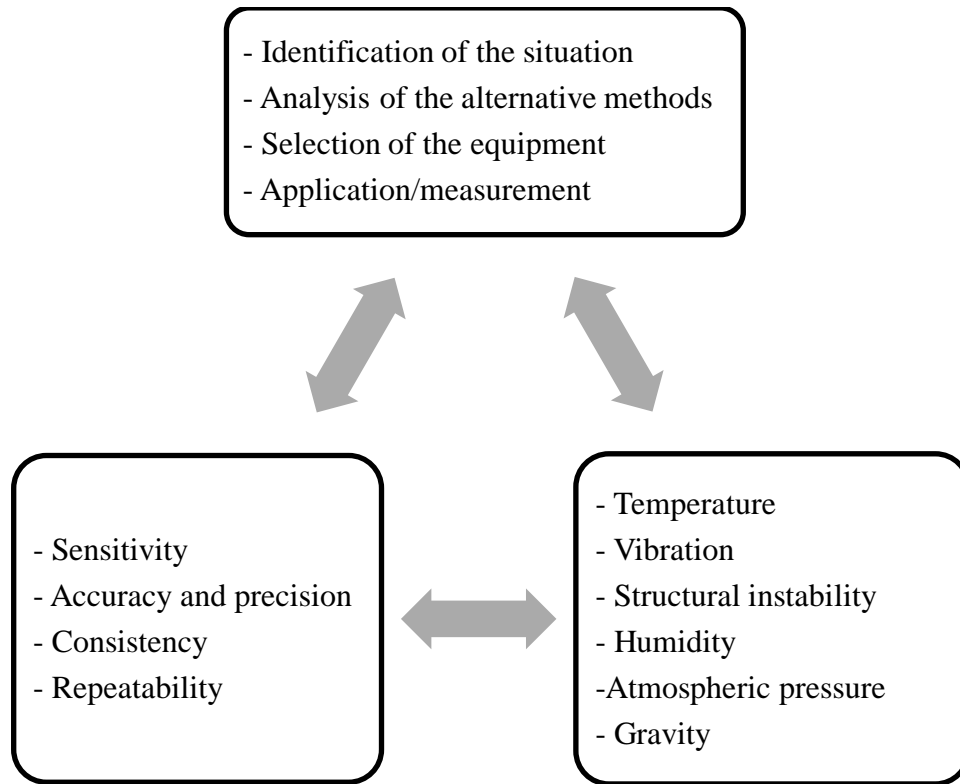


Figure 2.2. Factors affecting the measuring process. Taken from (Borror, 2009)

The requirement of any measuring instrument is that it should be able to represent as accurately as possible the dimension that it is measuring. For this, it is necessary that the measurement instrument itself, has a high degree of inherent accuracy.

2.1.1.2. *Measurement Precision, Trueness, and Accuracy*

Precision refers to the dispersion of measurements the less the measurement data is scattered, the more precise is the equipment. It can be defined as “closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions“ (International Vocabulary of Metrology, 2012).

Measurement trueness is defined as “closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value” (International Vocabulary of Metrology, 2012). It gives information on the difference between the mean of the measured values and the real value of the dimension. This means, the closer the

mean value of the measurements to the nominal value, better the trueness of the measuring equipment.

Measurement accuracy can be defined as the “closeness of agreement between a measured quantity value and a true quantity value of a measurand” (International Vocabulary of Metrology, 2012). As it can be observed in Figure 2.3 the accuracy of a system is a combination of its precision and trueness.

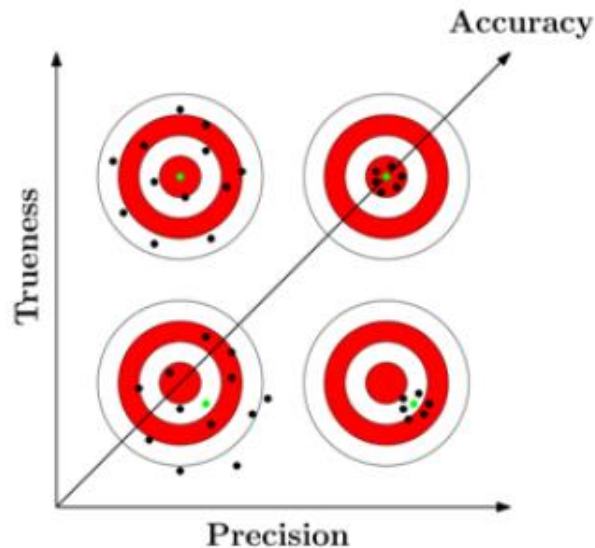


Figure 2.3. Relation between measurement trueness, precision, and accuracy. Taken from (Measurement Technologies in Quality Control Purposes, 2014)

2.1.1.3. Measurement Traceability and Uncertainty

Traceability is defined as the “property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty” (International Vocabulary of Metrology, 2012). This ensures that a measurement result or the value of a standard is related to references at the higher levels. Every measurement intended to be reliable should have a traceability chain to the corresponding definition of the SI unit. The metrological traceability chain is “the sequence of measurement standards and calibrations that is used to relate a measurement result to a reference” (International Vocabulary of Metrology, 2012). Figure 2.4 show the representation of the traceability chain.

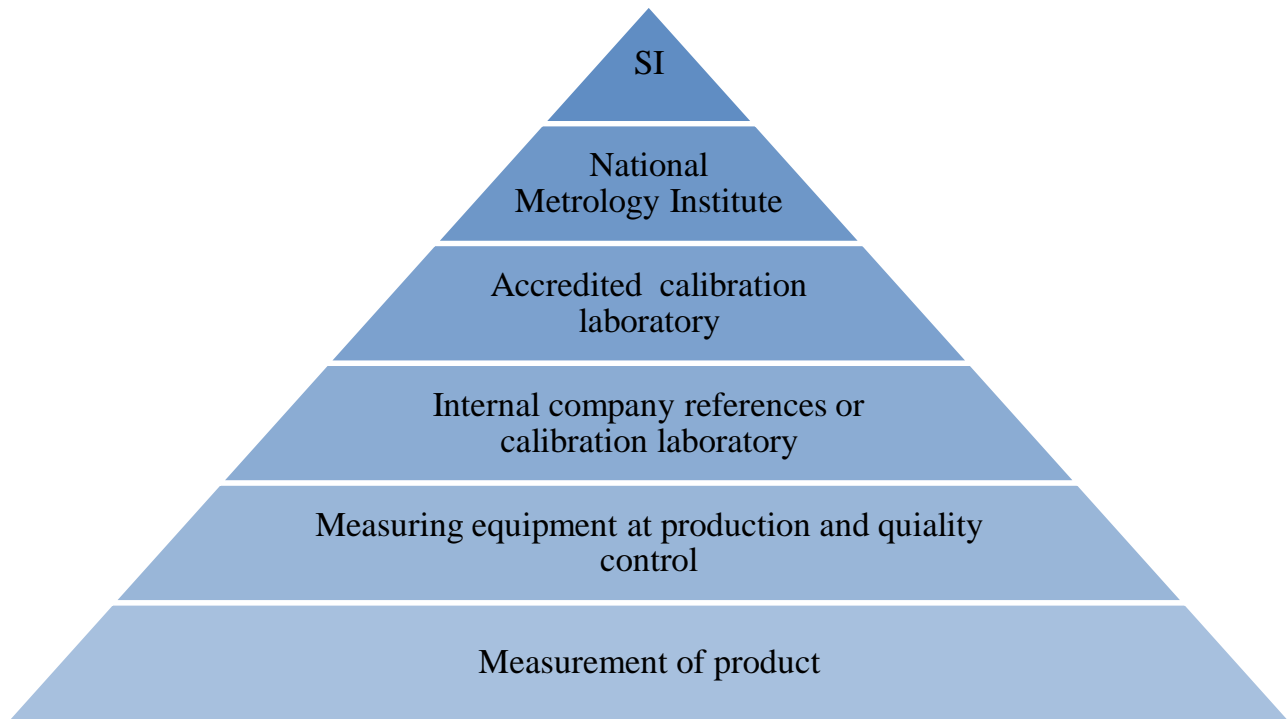


Figure 2.4. Representation of traceability chain.

Uncertainty is defined as a “non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used” (International Vocabulary of Metrology, 2012). It is described as the doubt of the validity of a measurement value. A measurement never gives the real value, but it is the best estimation of it. In this way, a measurement is only complete when a statement of the associated uncertainty accompanies it. Figure 2.5 shows some of the sources of uncertainty in a measurement.

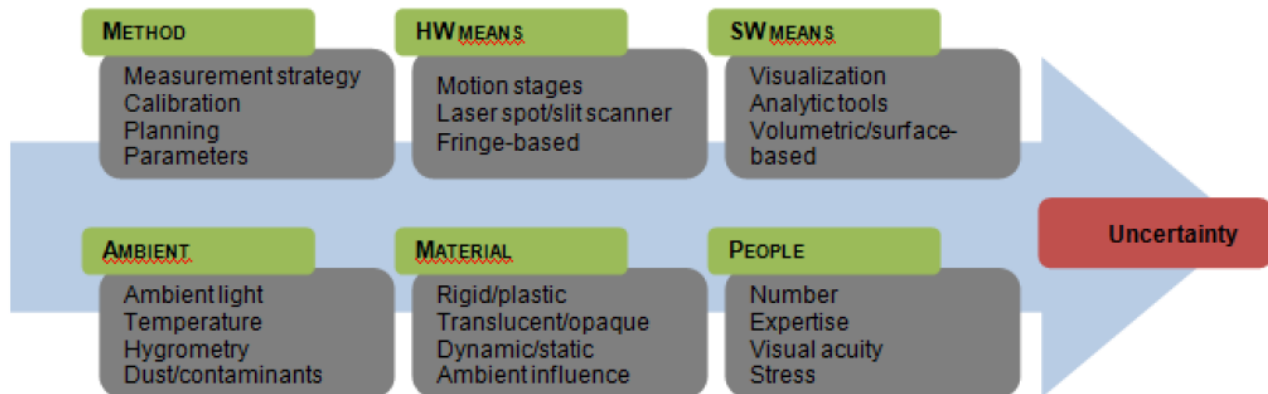


Figure 2.5. Representation of main sources of uncertainty. Taken from (Measurement Technologies in Quality Control Purposes, 2014)

2.1.1.4. Calibration

Calibration is defined as an “operation that, under specified conditions, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties” (International Vocabulary of Metrology, 2012). It also refers to the discipline necessary to control measuring systems to assure their functioning within prescribed accuracy objectives. The result of a calibration process is a certificate usually containing a table where measurements by the instrument are compared to reference values. According to Borror (2009), the general calibration provisions for a measuring system include:

1. Acceptance calibration of a new system.
2. Periodic calibration of the system in use or when placed in use after storage.
3. Availability of standards traceable to the national standard for the unit of measure under consideration.

2.2. Geometric Dimensioning and Tolerancing

Geometric dimensioning and tolerancing refers to system used for defining and communicating engineering tolerances using a symbolic language on mechanical drawings and

CAD generated models. This system is used to define explicitly nominal geometry and its allowable variations in manufactured objects. It gives an indication to the manufacturing department and machines of the degree of accuracy and precision required for each controlled featured on the object. The system is used to define nominal geometry of parts and assemblies, allowable variation in form and location of individual features, and the allowable variation between these features.

When applied to objects that are part of assemblies, this system is used to make sure that all the components can fit together. This principle is based on the Form-Fit-Function concept, which states that an object with specific dimensional characteristics needs to have compatible dimensions to interact with other objects and perform a specific function. “Dimensional control of objects guarantees that the forms will fit well together and create the function that the product is designed for” (Measurement Technologies in Quality Control Purposes, 2014).

2.2.1. Tolerances

An actual part dimensions never complies exactly with the nominal value which it was designed for, because manufacturing processes cannot assure perfect dimensions. Part dimensions have a functional range, this means that for a certain range of values, the quality and therefore the function of the part will not be affected. Tolerances are defined as the permissible limits of variations in dimensions of a geometrical feature, and are usually specified to allow imperfections on the part without compromising performance. Geometrical tolerances are often expressed in the form of a plus/minus interval, and adapted to each feature depending on the type of industry, material and level of accuracy of manufacturing processes and machines. Then, an analysis of the measured value of a geometric feature, leads to the validation or rejection of the conformity of the specific dimension.

2.2.2. Tolerance Zones

Depending on the element that needs to be controlled, it can involve different types of tolerance zones. For location tolerances, it is necessary to define a datum that indicates the exact location of the tolerance zone. Tolerances are usually applied directly on the features of a part,

rather than just on one-size dimensions. Depending on the feature to be tolerances and the way in which it is dimensioned, the tolerance zone is one of the following:

- The area within a circle
- The area between two concentric circles
- The area between two parallel, straight lines
- The area between two equidistant lines
- The space between two parallel planes
- The space between two equidistant surfaces
- The space within a cylinder
- The space between two coaxial cylinders
- The space within a parallelepiped

In the case of cylindricity applied to a cylinder, the tolerance zone consists of two concentric cylinders of which the difference in diameters equals the value specified, as observed in Figure 2.6.

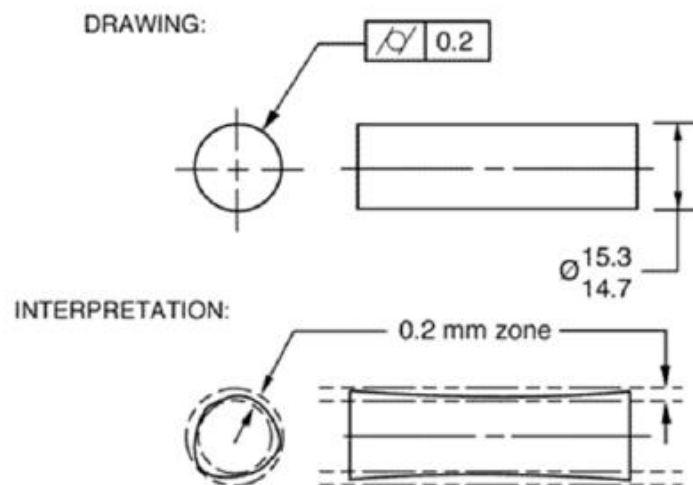


Figure 2.6. Representation of tolerance zone of a cylindricity tolerance. Taken from (Measurement Technologies in Quality Control Purposes, 2014)

Depending on the combination of the controlled and datum feature, the tolerance shape can change. “For instance, the perpendicularity between two planes leads to a linear tolerance zone. In this case, the tolerance zone is defined as an envelope within two parallel planes that is spaced using the distance specified by the tolerance and perfectly perpendicular to the datum(s) reference” (Measurement Technologies in Quality Control Purposes, 2014). Another example is when perpendicularity between an axis and a plane is used, and it leads to a cylindrical tolerance zone. The cylinder has the diameter specified by the tolerance and has to be perpendicular to the plane. In all possible situations, the measured features must fit within the established tolerance zones to meet the requirements.

2.2.3. Validation of the Conformity Zone

Measured results have to confirm or reject the conformity of a part’s dimension. In summary, a measurement that is inside the specified values is valid, whereas a measurement outside the tolerance limits is invalid. Nevertheless, the uncertainty of a measurement device has a strong effect on the validation of the dimension. Figure 2.7 shows the three possible situations when measuring a dimension and what decision can be taken.

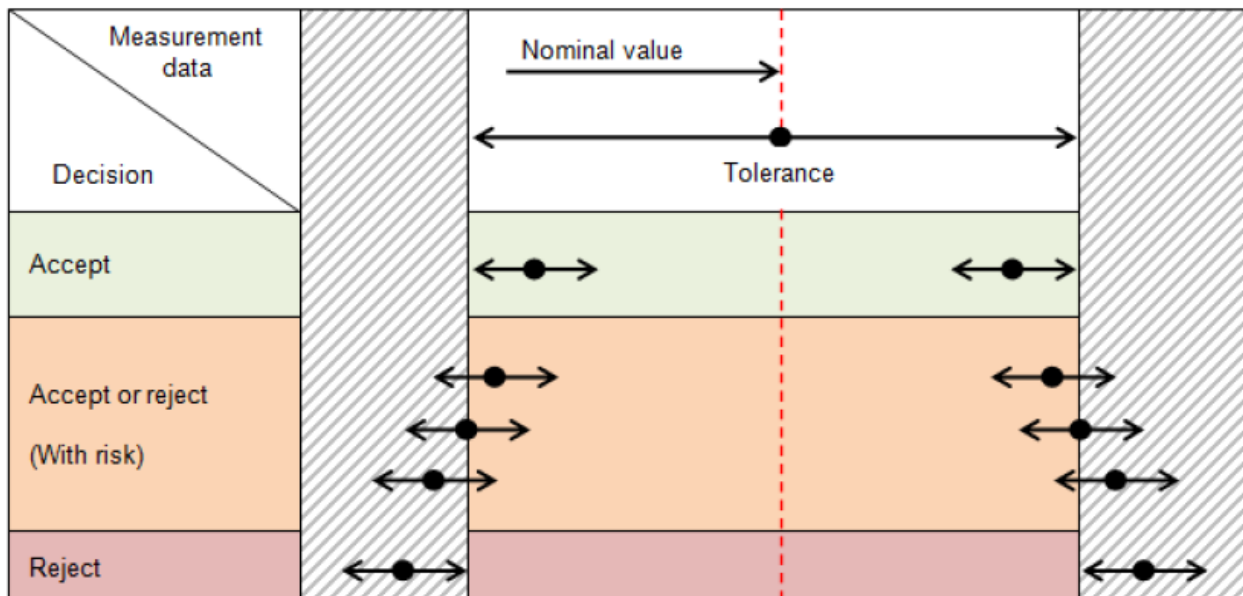


Figure 2.7. Decision in validation of measurements. Taken from (Measurement Technologies in Quality Control Purposes, 2014)

2.2.4. Datum and Datum Features

“A datum is a virtual ideal plane, line, point, or axis that is established from the physical features of a real part that has an important functional relation with the function of the entity being controlled” (Measurement Technologies in Quality Control Purposes, 2014). These physical features are generally represented on 2D drawings by a capital letter and a datum feature triangle and are referenced to within feature control frames as observed in Figure 2.8. in the case of a flat surface, the corresponding datum would be the perfect flat surface on which the surface of the object is in contact with. The main purpose of using datums, is to improve the repeatability of inspections since the features of a manufactured part are never perfect. This is why datums are used to define the coordinate system used to carry out measurements on a workpiece. The use of datums allows a specific alignment between the data and the reference object, which is usually a 3D CAD model, and makes it possible to compare both objects.

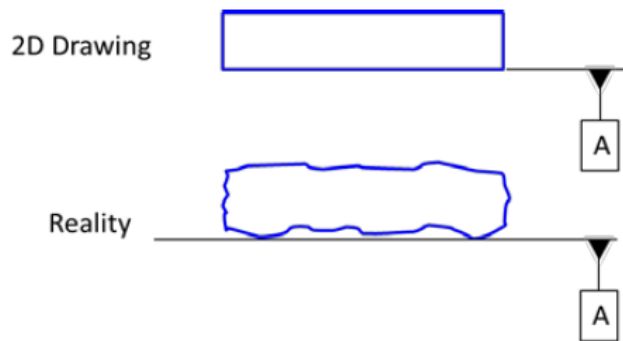










Figure 2.8. Representation of a datum feature in a technical drawing. Taken from (Measurement Technologies in Quality Control Purposes, 2014)

Six degrees of freedom (three rotations and three translations) must be constrained so an alignment between the reference object and the data can be performed. The primary datum is the most important one in the process of alignment, because it constrains more degrees of freedom. The remaining degrees are blocked by the remaining datums, where the secondary datum is in the same way more influential than the tertiary datum.

2.2.5. Categories of Tolerances and Symbols

Tolerances are usually given in a feature control frame on a 2D drawing with an arrow indicating on which feature it is applied. The datum(s) used by a tolerance should always be defined on the same drawing. The different geometric requirements can be expressed in five main tolerance groups which are form, profile, orientation, location, and run out tolerances. Each one of the categories aims to control specific geometric elements on a part. Table 2.2 shows the different types of tolerances, their symbols and a description of each type of tolerance. The german term for each type of the geometric features is shown between parentheses.

Table 2.2. Categories and symbols of tolerances. Taken from (Measurement Technologies in Quality Control Purposes, 2014)

	Geometric Features	Symbol	Description
Form	Straightness (Geradheit)		The condition in which an axis is a straight line (or, in the case of a centerplane, each line element is a straight line).
	Flatness (Ebenheit)		The condition of a surface having all of its elements in one plane.
	Roundness (Rundheit)		The condition in which all points of a surface of revolution, at any section perpendicular to a common axis, are equidistant from that axis .
	Cylindricity (Zylindrizität)		The condition of a surface of revolution in which all points of the surface are equidistant from a common axis.
Profile	Profile of a line (Linienprofil)		A geometric tolerance that limits the amount of errors for line elements relative to their true profile.
	Profile of a surface (Flächenprofil)		A geometric tolerance that limits the amount of errors a surface can have relative to its true profile.
Orientation	Perpendicularity (Rechtwinkligkeit)		The condition that results when a surface, axis, or center plane is exactly 90° to a datum.
	Angularity (Neigung)		The condition of a surface, centerplane, or axis being exactly at a specified angle.

	Parallelism (Parallelität)		The condition that results when a surface, axis, or centerplane is exactly parallel to a datum.
Location	Symmetry (Symmetrie)		The condition in which the median points of all opposed elements of two or more feature surfaces are congruent with the axis or centerplane of a datum feature.
	Position (Position)		The zone within which the axis or centerplane of a feature is permitted to vary from a true (theoretically exact) position.
	Concentricity/ Coaxiality (Konzentrizität/ Koaxialität)		The condition in which the median points of all diametrically opposed elements of a cylinder (or a surface of revolution) are congruent with the axis of a datum feature.
Run-out	Radial run-out (Rundlauf)		A composite control that affects the form, orientation, and location of the circular elements of a part feature relative to a datum axis.
	Total run-out (Gesamtlauf)		A composite control affecting the form, orientation, and location of all surface elements of a diameter (or surface) relative to a datum axis.

In Figure 2.9 shows an example of a location tolerance which states the axis of the tolerance bore shall be contained within a cylinder of diameter 0.02, the axis of which is in theoretically exact position with respect to the surfaces A and B.

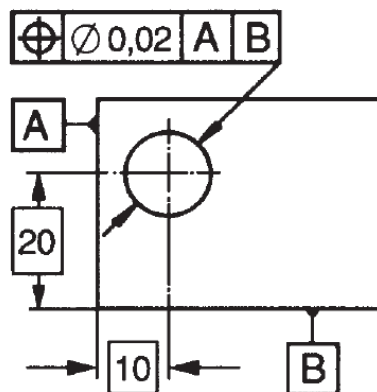


Figure 2.9. Example of a feature control frame using three datums. Taken from

2.3. Coordinate Measuring Machines

“Recent innovations about the development of more advanced inspection devices have revolutionized the industry as the inspection process has become extremely more accurate and efficient” (Flack, 2014). This makes it possible to use quality control in a wide range of applications. Environment conditions and measurement requirements in which the product is inspected vary a lot, and this leads to completely different approaches to inspection techniques.

CMMs were first introduced in the early 1960’s and worked as manual measuring devices; this first technology was based on three-axes machining tools where the tool was replaced by a sensing probe. The sensors that were usually employed were hard probes which made contact with the measured surface, and the center coordinates of the probe were shown on a display which was recorded by an operator. The problem of this method was the limited accuracy and repeatability, besides it was very time consuming and with the chance of user errors. In the 1970’s there were some big advances in coordinate metrology technology and the first CMMs which satisfy nowadays definition were built. After these first CMMs, touch trigger contact probes were developed which overcame the disadvantages of hard probes, and made possible the automation of the process of making contact. Measurement accuracy reached a new level due to the introduction of 3D measuring probe systems, and today there are several non-contact probe systems like laser devices or optical sensors that enlarge the range of probe systems which can be used.

“A CMM is a device to measure the spatial coordinates of a point on an object” (Flack, 2014). To determine the x, y, and z coordinates of a point in an object a probing system is moved relatively to the workpiece, so it can be checked. The individual measured points are combined by best-fit algorithms for the measured geometric features (e.g. planes, cylinders, cones, etc). Afterwards, deviations in form, position, orientation and size from the nominal geometry of the object are evaluated and compared with the established tolerances.

2.3.1. Classification of CMMs

There are different configurations for CMMs, each one of the configurations has advantages which make that particular type suitable for certain applications and plays an

important role meeting measurement requirements such as accuracy, size of the workpiece, time, cost and flexibility; they can be classified in 4 primary groups:

- Cantilever
- Bridge
- Gantry
- Horizontal arm

2.3.1.1. *Cantilever*

These types of machines are usually the smallest in size and occupy a minimum of floor space. “The probe is attached to a vertical machine ram (z-axis) moving on a mutually perpendicular overhang beam (y-axis) that moves along a mutually perpendicular rail (x-axis)” (Borror, 2009). This configuration allows a completely unobstructed work area which provides easy operator access, allowing full access to loading, unloading, and inspecting a part that can even be bigger than the table itself. One disadvantage is that the single overhanging beam support for the probe may limit the accuracy of measurements as it does not have a rigid support.

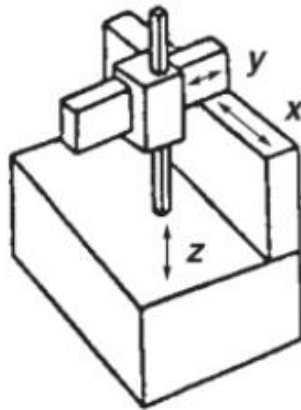


Figure 2.10. Cantilever type CMM. Taken from (Borror, 2009)

2.3.1.2. *Bridge*

These machines are built as moving bridge or table models and are the most popular type of configuration. In these machines “a horizontal beam moves along the x-axis, carrying the

carriage that provides the y-motion. In other configurations, the horizontal beam is rigidly attached to the machine base and the machine table moves along the x-axis” (Borror, 2009). The double-sided support of this type of CMM provides more rigid construction which in turn provides better accuracy. However, accessibility to the work area is limited by the bridge itself and it cannot measure parts larger than the clearance of the bridge.

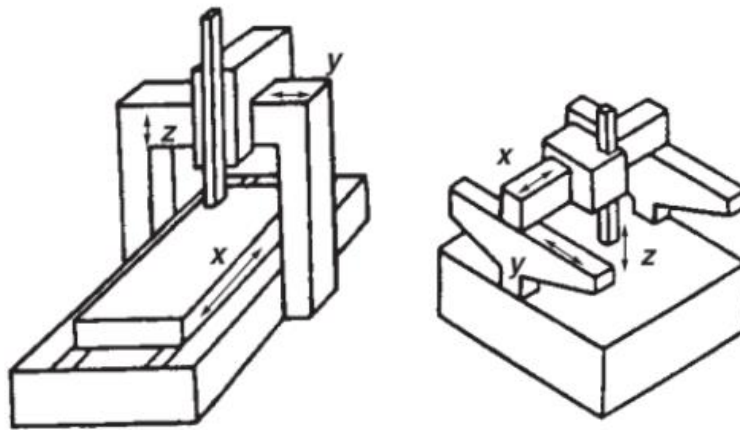


Figure 2.11. Bridge type CMM. Taken from (Borror, 2009)

2.3.1.3. Gantry

Gantry CMMs are usually the largest ones available on the market and are usually made according to customer needs. It can be used for measuring big objects such as airplane wings, automobile bodies, ship propellers, etc. This type of machine “comprises a vertical ram (z-axis) moving vertically relative to a horizontal beam (x-axis), which in turn moves along two rails (y-axis) mounted on the floor” (Borror, 2009). The accessibility to the work area can be limited by the columns on which the rail of the cross beam are mounted, but it can be designed so there is enough space for the objects to be measured. The parts to be measured are usually not placed in the machine, instead the focus lies on a foundation of the machine base which should be isolated from the building's foundation.

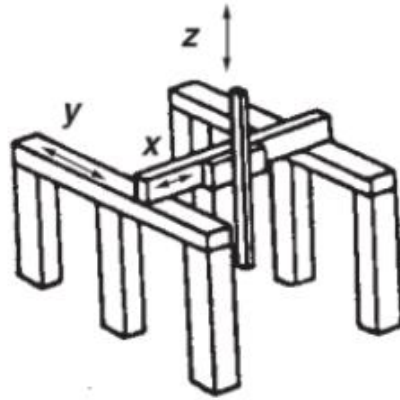


Figure 2.12. Gantry type CMM. Taken from (Borror, 2009)

2.3.1.4. Horizontal Arm

“Horizontal-arm configuration features a horizontal probe ram (z-axis) moving horizontally relative to a column (y-axis), which moves in a mutually perpendicular motion (x-axis) along the machine base” (Borror, 2009). For some applications a horizontal access might be desirable for example for parts which are machined on horizontal machining centers. They have very good accessibility to the working area from all sides and substantially less restricted to part sizes being measured.

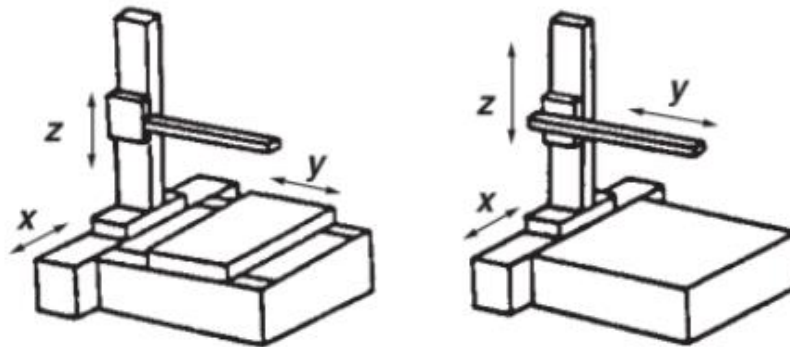


Figure 2.13. Horizontal arm type CMM. Taken from (Borror, 2009)

2.3.2. CMM Components

A coordinate measuring machine consists of four major functional components that can be differently developed depending on the configuration of the machine, and the type of probe and level of automation. The main parts of a CMM can be observed in Figure 2.14, and listed below:

- Machine structure
- Linear measurement transducers
- Probing system
- Computer hardware and software

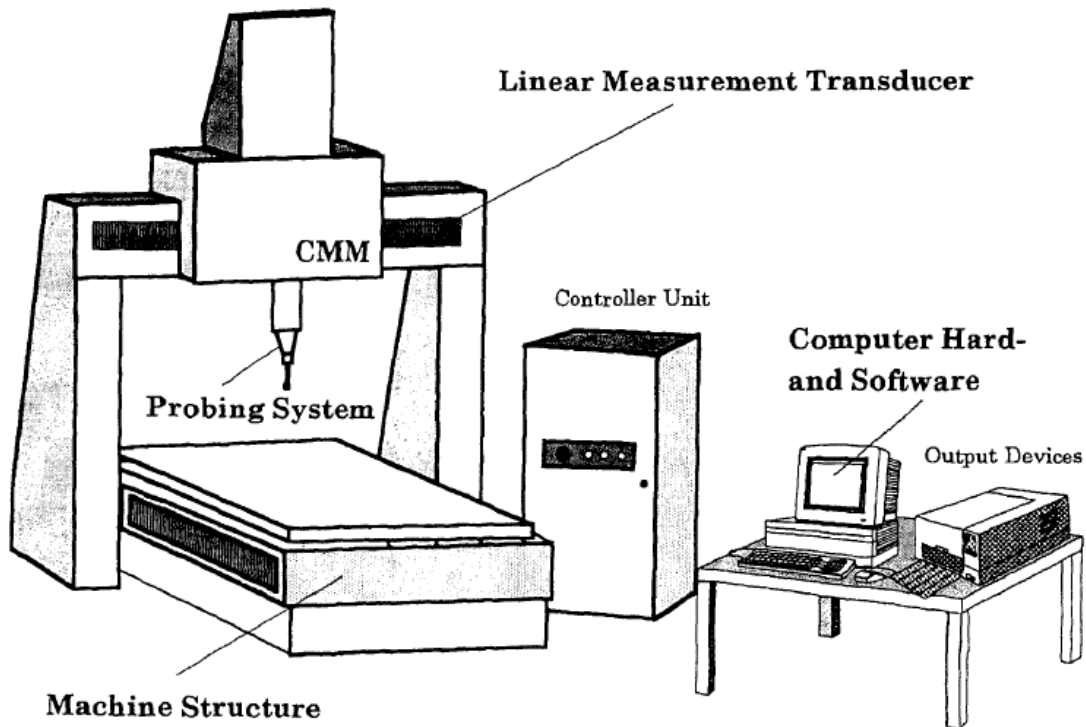


Figure 2.14. Components of a CMM. Taken from (Mantel, 1993)

2.3.2.1. Machine Structure

The machine structure is the physical base with three perpendicular axes of travel. This structure has to accomplish some requirements so the machine can assure good accuracy results through time. It must have a rigid construction so unintentional movement between components

is minimized and the material must ensure thermal stability so machine deformation due to thermal expansion is minimized. Also, it is important that the structure is not affected by mechanical vibrations, has good damping characteristics, and long-time stability.

The bearings must have the lowest friction possible, high linearity, and short-periodical positioning deviations. This, because bearings employed on CMMs have a direct effect on the accuracy of the machine because of their impact on every motion along its axes.

DC motors are commonly used in most of the CMMs to drive the axes. These motors power a friction wheel with a friction rod, to transform the revolving motion of the motor into linear motion along the axes. The power transmissions enable high acceleration and deceleration in a short period of time and guarantee high positioning accuracy.

2.3.2.2. *Linear Measurement Transducers*

Linear measurement transducers are mounted at the three perpendicular traveling axes of a coordinate measuring machine. The function of the transducers is to provide information about the reference coordinate system or machine coordinate system. They consist of a scale and an encoder system, and used to provide position feedback.

2.3.2.3. *Probing Systems*

This part of the CMM is in charge of probing a series of point in the workpiece surface. Probing systems are commonly classified in two big groups based on the type of measurement which can be contact or contactless. The function of this component is to identify a coordinate point on the surface of the measured object. The type of probe system installed on a CMM determines its capability and application based on specific requirements. The different types of probes in which contact and non-contact probing systems are subdivided are shown in Figure 2.15.

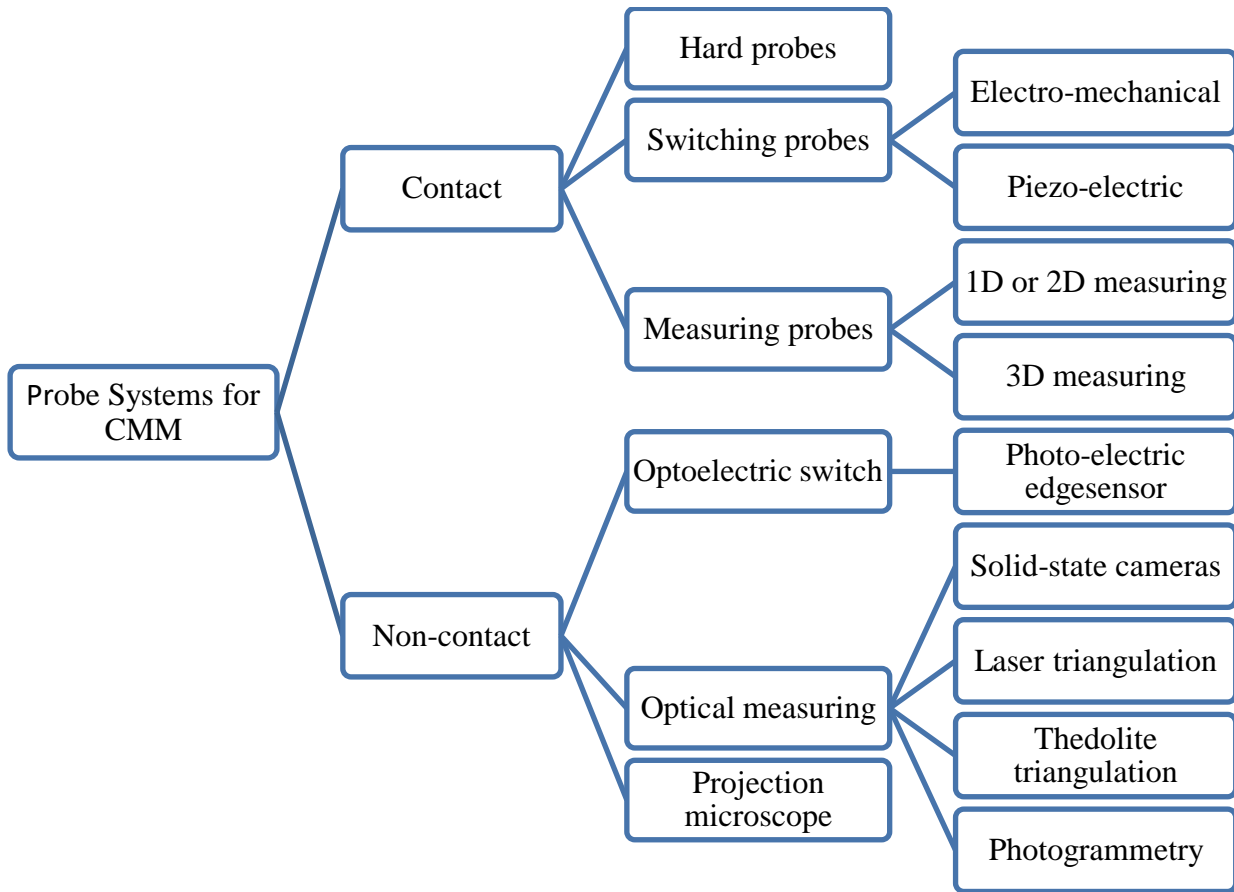


Figure 2.15. Probe systems for CMMs.

2.3.2.4. Computer Hardware and Software

The versatility of a CMM is determined partly by the computer hardware and the applied software. The primary function of the computer is to facilitate the measuring process and to provide the user the measurement data in a clear and useful format. The software used for CMMs can be divided into four categories regarding their function:

- **CMM core software:** The CMM core software is the minimum software needed for the machine to run. It performs tasks such as calibration, feature construction, and coordinate system configuration.
- **Programming software:** This part of the software is used to facilitate the job to the user. It assists in the programming task of the CMM by providing a user interface which facilitates and provides important information when programming the CMM.

- Post inspection software: This part of the software deals with the manipulation and representation of the obtained results during the probing process. It performs tasks such as calculation of data fitting and evaluation, statistical analysis, and graphical representation of errors.
- Reverse engineering software: This part of the software is used to define the geometry of a measured object by calculations performed with the recollected data.

The computer has to accomplish diverse tasks and the software enables the system to achieve its potential. According to Mantel (1993), there are five major tasks the computer has to accomplish:

- Control the machine motion: point to point, straight line, scanning, etc.
- Align the part: reference coordinate system, part coordinate system.
- Make corrections: radius compensation, stylus deformation, temperature, etc.
- Calculate: substitute elements, intersects, functions, transformations, etc.
- Evaluate: nominal-actual evaluations, test reporting, statistics, etc.

2.3.3. Factors Affecting CMM Performance

The errors that lead to a lower level of performance are mostly of systematic rather than of random nature. To obtain a high level of performance it is essential that the user chooses the appropriate machine for the specified requirements. Also, it is important that machine is located in a suitable environment and operated by well trained machine operators. Figure 2.16 summarizes all the possible types of factors that can affect the performance of the machine, these factors can be classified into three main groups:

1. Environment
2. Machine
3. Operation

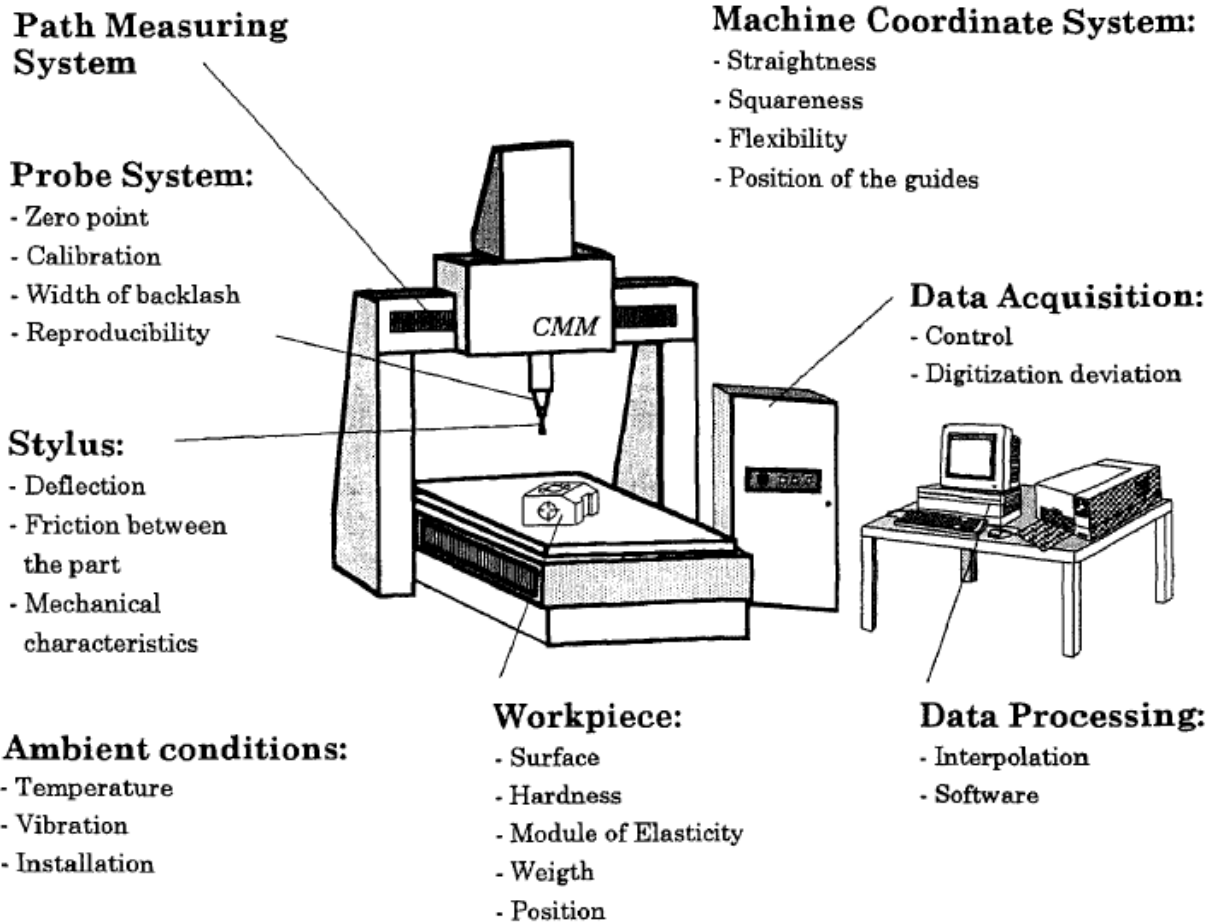


Figure 2.16. Factors influencing the machine performance. Taken from (Mantel, 1993)

2.3.3.1. Environmental Factors

Environmental factors are very critical for the correct performance of CMMs and it is always essential that the user provides a suitable environment at the installation site. Usually, CMM manufacturers provide guidelines including environmental conditions such as temperature and humidity ranges under which the manufacturers guarantee the specified performance of the machine. The most important factors related to the environmental conditions are:

- **Temperature:** it is the most important of the environmental factors because it affects the whole machine structure, especially the orientation and shape of the guide elements and scales, which deform according to the temperature they are exposed to. Deviations from the reference temperature specified by the machine manufacturer

may result in length variations of the CMM scales and of the workpiece, thus leading to a loss in measuring accuracy. Therefore it is very important that the ambient temperature lies within a specified temperature range which is often specified by the manufacturer.

- **Vibration:** vibrations caused by external sources are transmitted via the support surface to the machine and can result in a relative motion of the machine components. This motions which can be interrupted or continuous have a detrimental effect on measuring results, as they may cause excessive deviations during the measurement process. Thus, it is recommended to select a proper location for the machine or by using shock absorbing base elements.
- **Airborne particles:** all kind of air transported particles such as dirt, dust, oil and grease may affect machine performance and result in accelerated wear of the machine and its subassemblies. These particles can deposit on the scales and can result in misreading of the position and reduction of the gap between the scale and the encoder, which can also lead to damage of the optical measuring transducers. Although normally there are no formal standards for airborne particles, special attention should be taken and preventive maintenance to clean the guide ways along with the scales and encoders. Moisture, in the form of humidity can also affect the machine performance by swelling up the machine table and guide ways and may result in corrosion of other subassemblies. Limit values for the relative humidity are usually specified by the manufacturer and they should be strictly followed by the user to have an optimal operation of the machine.

2.3.3.2. *Machine Factors*

“A very critical factor is the deviation of the machine's reference coordinate system from a mathematically ideal coordinate system” (Mantel, 1993). This deviation can be caused by deficiencies in the form and orientation of the guides of the machine and may result from the fact that the moving subassemblies execute translational movement perpendicular to the transverse direction and rotation movements with a low angle of rotation. The influence on the machine is dependent upon the machine configuration and can vary greatly dependent on the position within the machine’s work envelope. However arithmetic corrections of the reference coordinate system

can be performed easily to correct this kind of errors. These corrections are made by measuring the motion of the CMM along its axes. These measurements are usually done using a laser interferometer with a certain step width and the measurement results are then stored in the computer so that each measured point is corrected according to an ideal reference coordinate system. Deformations and natural oscillations of the machine structure also affect the accuracy and result in measuring deviations. This deformations and oscillations are usually caused by the large acceleration and deceleration forces occurring during the measurement process, and also are dependant of the type of probing system. For example, when using contact probe systems the used stylus adds uncertainty even after it is calibrated due to the probe deflection and deformation of the contact element.

2.3.3.3. Operation Factors

This kind of degrading factors are the ones that are caused during the operation of the machine. For example, the power supply can have an effect over the repeatability and performance on the machine, when it is subject to changes in voltage and frequency. If a CMM is equipped with air bearing, the air supply of the machine can degrade the performance and also decrease the useful lifetime of the machine. Both electrical power and limit values of the air supply need to be specified by the manufacturer so it is possible to make the arrangements to obtain optimal results. Other factors related to the workpiece can affect measurements, for example surface roughness, form, hardness, and others. These can have a great effect over the accuracy of results and most be taken in account when programming the measurement strategy. Expected form variations of the surface and the material of the workpiece are also important, thus an appropriate probing system and probing should be chosen.

The operator or the measurement planner can influence the performance of the machine in various ways; it is an important factor as it has the responsibility of analyzing the measuring task, choosing the stylus configurations, probing forces and probing directions, the part coordinate system, the approximation method, etc. All these factors for which the operator is responsible for can have a great effect over the accuracy of results, thus it is important that the measurement planner has a good training and experience in the programming of the measurement strategies.

2.4. Coordinate Metrology

The science of metrology includes all theoretical and practical aspects of measurement, which applied to the industry is used to determine whether the characteristics of a products complies with the desired values. “The basic function of coordinate metrology consists of the measurement of the actual shape of a workpiece, its comparison with the desired shape, and the evaluation of the metrological information, such as size, form, location and orientation” (Bosch, 1995, p.40). For this procedure, coordinate measuring machines are used which measure the spatial coordinates of a point located in an object.

2.4.1. *Description of the Object Shape*

The object shape of an industrial part or part surface is built by the sum of all its partial boundary area. There are three concepts of shape which are defined as follows:

- Nominal shape: it is the geometrical ideal shape of the object to measure; it is given by the dimensions established on the mechanical drawing of the piece or derived of the numeric data from a CAD system. This object is composed of individual geometric elements.
- Actual shape: it is the real shape of the manufactured object, and generally contains extensive deviations from the nominal shape which are a product of manufacturing tolerances.
- Substitute shape: it is the shape which is built by ideal geometric elements from individual measured points on the surface of the manufactured object. These geometric elements which represent the actual geometrical parts are used to evaluate the accuracy through a comparison with the geometrical elements of the nominal shape.

Figure 2.17 illustrates the differences between the different types of objects and the process by which they are obtained.

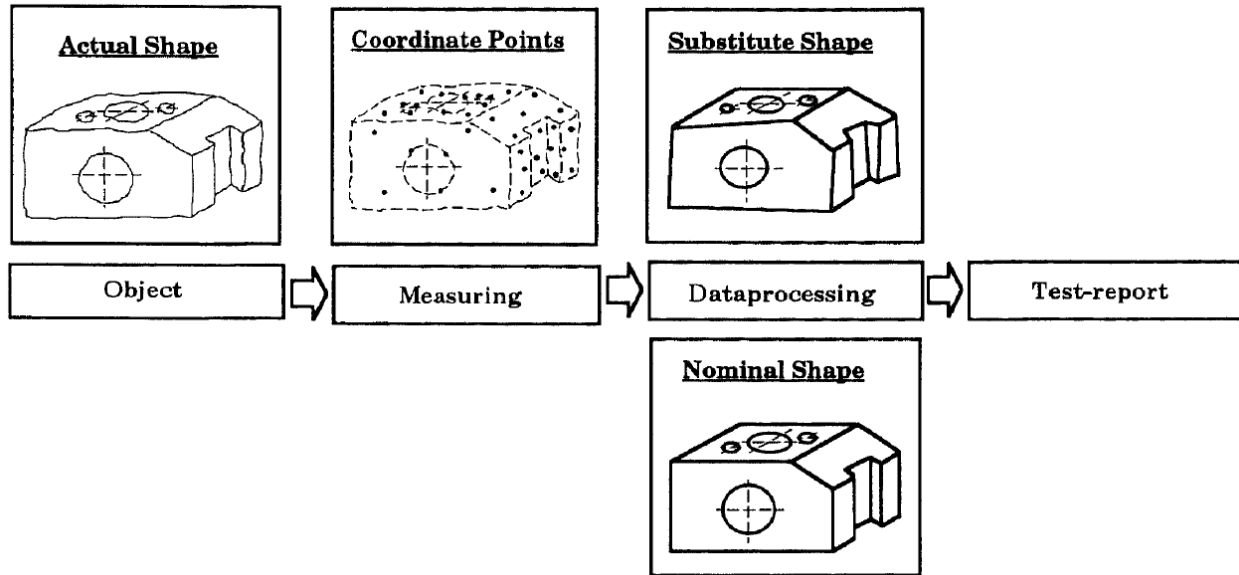


Figure 2.17. Difference between the types of objects. Taken from (Mantel, 1993)

2.4.2. *The Principle of Coordinate Measuring Technique*

The measuring process of an object is done by registering points based on a coordinate system with a probe. After the points are registered, a substitute shape is created by computation of associated features from the probed points. The numeric model of the part is a substitute or a representation of the real part, and consists of basic geometric elements. The calculation of these geometric elements is based only in the probed points and the area in between these points which is not measured is not taken into consideration for the calculation. For this computing process a minimum number of measured points is required, and as more points are taken, better can be the calculation of the fitting element using mathematical approximation methods. To evaluate the dimensional accuracy of a part, the substitute shape is compared with the ideal model or nominal shape.





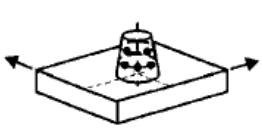
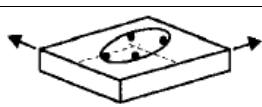
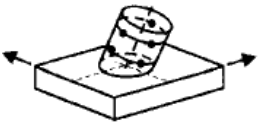
2.4.3. *Mathematical Fundamentals*

2.4.3.1. *Geometric Elements*

Most of the industrial parts are described as the summation of a few geometrical elements, and to solve measuring tasks by coordinate measuring it is required to calculate the geometric

features based on the probed points from the real part. If the actual shape was geometrically ideal, it would be enough to calculate the substitute elements with only the minimum number of points, which is equivalent to the degrees of freedom of the geometric element. A metrological minimum number of points and their distribution over the element is suggested for the calculation of such elements, as observed in Table 2.3, which is an extract from BS 7172 (Guide to assessment of position, size, and departure from nominal form of geometric features).

Table 2.3. Minimum Number of Points in Coordinate Measuring Technique. Taken from (Flack, 2014)

Geometric elements		Mathematical Minimum Number	Metrological Minimum Number
	Straight line	2	5
	Plane	3	9 (Approximately three lines of three)
	Circle	3	7 (To detect up to six lobes)
	Sphere	4	9 (Approximately three circles of three in three parallel planes)
	Cone	6	12 (Circles in four parallel planes for information on straightness) 15 (Five points on each circle for information on roundness)
	Ellipse	4	12
	Cylinder	5	12 (Circles in four parallel planes for information on straightness) 15 (Five points on each circle for information on roundness)

Manufactured parts are not geometrically ideal, therefore the minimum number of points is not sufficient to describe the actual element and often a low number of probing points involve considerable drawbacks which can be observed in Figure 2.18. Some of these drawbacks are that the substitute shape fails to represent the actual shape of a manufactured part and measurement results may vary if probing points are displaced on the probed surface with inherent form errors.

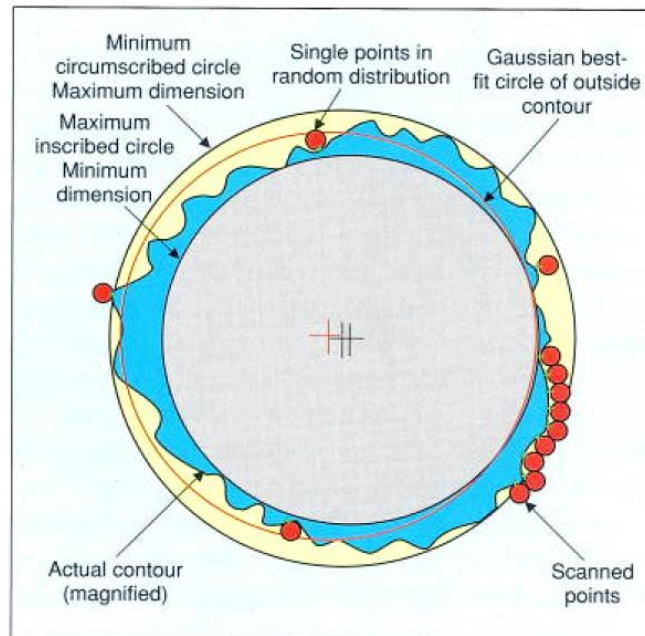


Figure 2.18. Low number of probing points in a workpiece. Taken from (Neumann, 2000)

Generally, as more points are probed to calculate the substitute shape, the better the representation is. It is impractical to take a large number of points because of the time and resources it takes, and after a certain number of probed points, the accuracy reaches a threshold. In addition, only continuous contact scanning measurement guarantees reproducible practical dimensions.

2.4.3.2. *Mathematical Approximation Techniques*

Mathematical approximation techniques are applied to calculate an approximated ideal element from the measured points. There are different techniques that can be applied and each of

these applied to the same group of probed points can yield a different result. Each technique should be selected based on the specific characteristics of the measured part, taking in account that some information about the actual shape will be lost after an approximation method is used, this can be observed with an example in Figure 2.19.

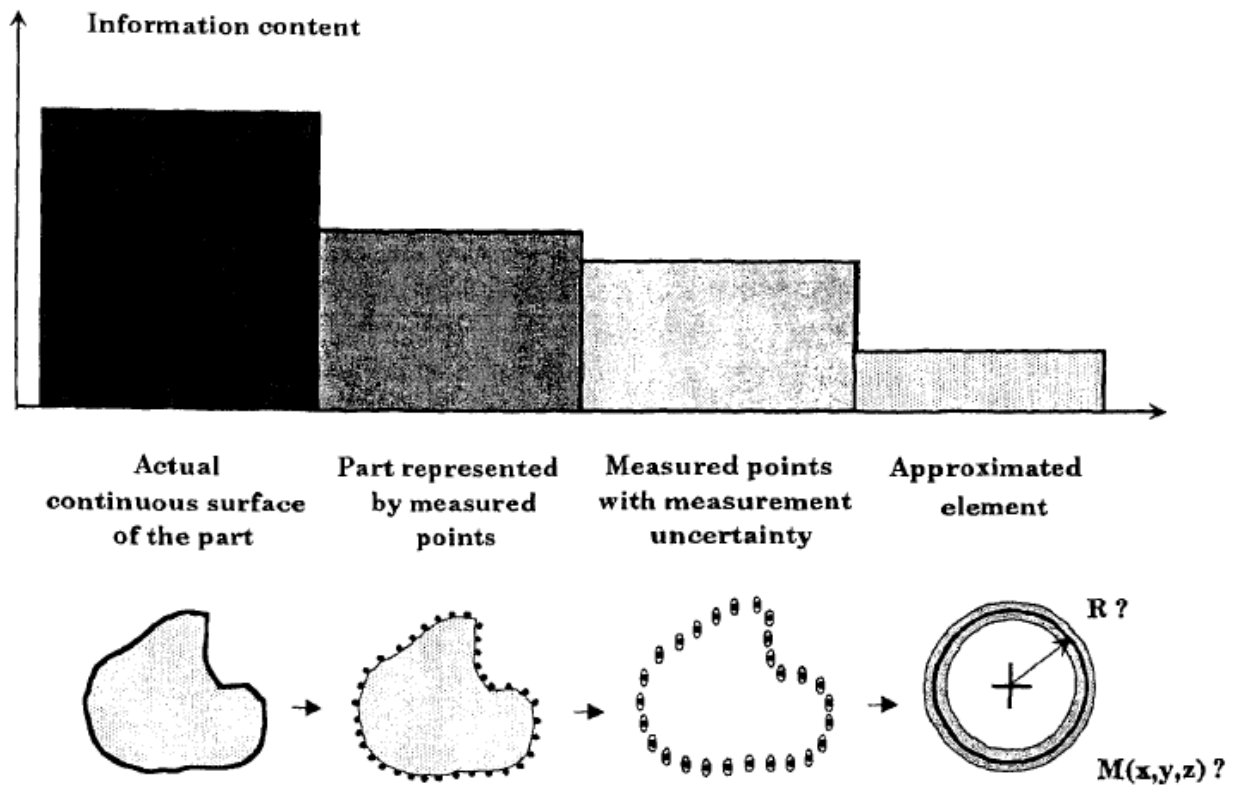


Figure 2.19. Loss of information after applying an approximation method. Taken from (Mantel, 1993)

There are four approximation or standard best-fit methods that are commonly used in the coordinate measuring technique and are summarized in Table 2.4.

Table 2.4. Characteristics of standard approximation methods. Figures taken from (Mantel, 1993)

Method	Illustration with form error magnified	Computation	Application
Gaussian		Minimizes the squared distances of all points to the mean element, assigning the points equal statistical weights.	Classical method. Suitable for geometrical features without major form errors.
Minimum circumscribed circle		Largest possible element which lies fully inside all measured points.	Useful for fitting dimensions. Applied to evaluate the largest inside diameter of a bore hole for a system of fit.
Maximum circumscribed circle		Smallest element possible that includes all measured points.	Useful for fitting dimensions. Applied to evaluate the diameter of a shaft for a system of fit.
Chebyshev		It calculates the mean diameter according to the criterion: least radial difference between the centric minimum and maximum circles.	Standards for calculating the form deviation according to minimum conditions.

2.4.3.3. Coordinate Systems

By using coordinate measuring technique an object is measured by probing several points on its surface. For establishing the location of points, a measured point has to be related to a reference system, which is called coordinate system. The CMM's linear transducers, which are mounted to the axes of travel exemplify such a reference system and is known as the machine coordinate system.

The measured objects cannot be exactly aligned to the machine coordinate system, and therefore the exact location of the object has to be determined in the machine's work envelope before measurements can be made. On coordinate measuring machines, the part alignment in its work envelope is done mathematically by a computer, and for this process the machine measures a few geometrical elements on the workpiece, usually datum features identified in drawings or technical documents of the workpiece. The mathematical alignment of the object is one of the most important advantages of CMMs compared to conventional measurement devices, where the part alignment takes place by using mechanical fixtures. Mechanical fixtures are often complex and very expensive, with manufacturing tolerances itself that contribute to the uncertainty of measurements over the object. By aligning the object, a part related reference system is created called part coordinate system. This coordinate system is related to the machine coordinate system, and is represented by the following mathematical equation:

$$\vec{X}_{part} = \mathfrak{R} * \vec{X}_{machine} + \vec{T}$$

\mathfrak{R} : matrix of rotation

\vec{T} : translation vector

The mathematical alignment of the part can usually be done in several ways by measuring various geometric elements in the object. The alignment of the part is a very important step of the measuring process, and has to be done very carefully with full knowledge of the underlying principles. In general, errors made in the part alignment process influence directly the measured results. There is not a general rule for aligning an object, therefore the method and elements used for the alignment are often defined for each specific object. For prismatic objects, the international standard ISO 5459 and the German standard DIN 32 880 recommend the Three-Plane-Method. In this method, the element with the tightest manufacturing tolerances should be chosen as the normal vector of the primary plane, which is the element that levels the part and gives the main direction of the coordinate system. The secondary direction is perpendicular to the main direction and is a result of the intersection of the secondary and primary plane. Finally, the origin of the part coordinate system is the intersection of all the three defined planes. This method is illustrated in Figure 2.20.

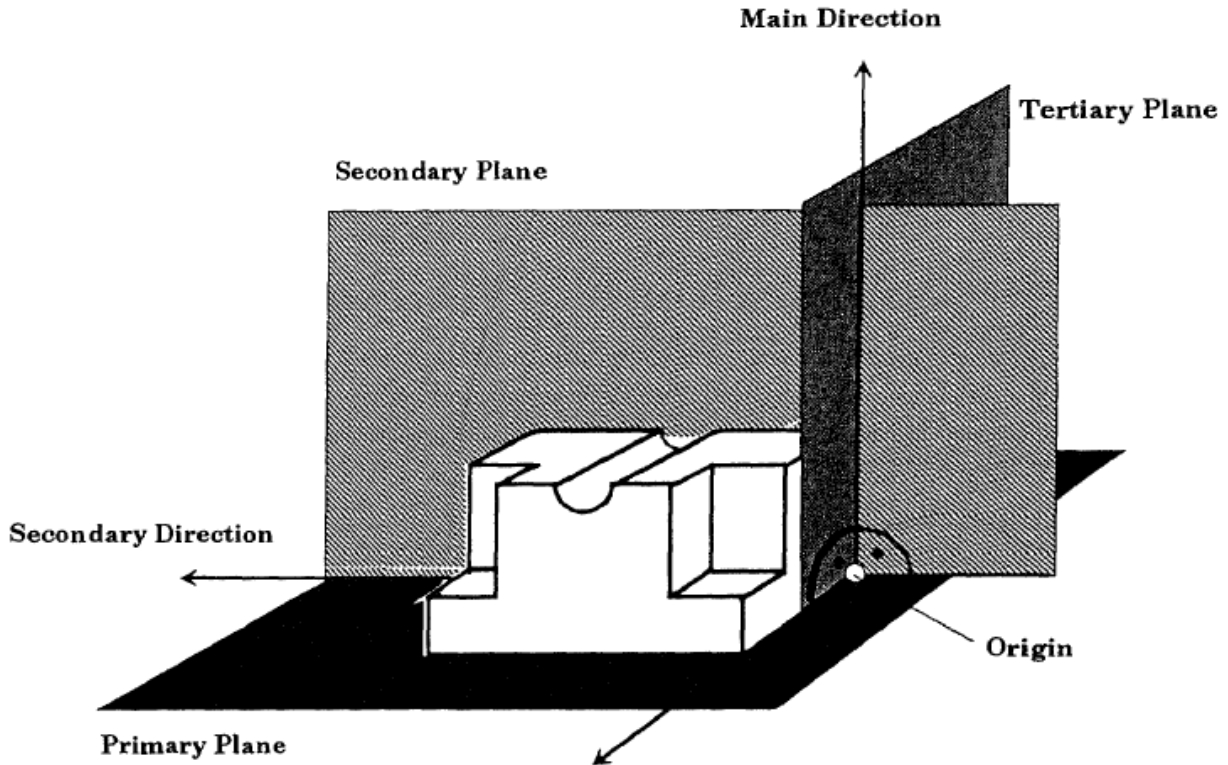
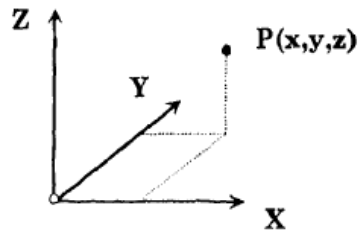


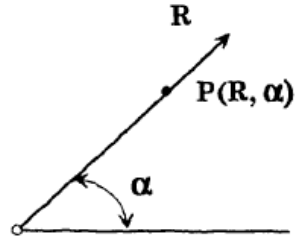
Figure 2.20. Three-Plane-Method to create a part coordinate system. Taken from (Mantel, 1993)

For the previously described process, a three-dimensional Cartesian coordinate system was assumed. This type of coordinate system, where all the three directions are perpendicular, is the type of coordinate system which is most commonly used in measurements using CMMs. This is due to the fact that the machine structure itself is built most often like such a coordinate system. Nevertheless, in coordinate measuring technique, there are other coordinate systems which might be useful in specific applications. Also, the transformation from one type of coordinate system to another can be done by using mathematical equations. The four types of coordinate systems are the following and can be observed in Figure 2.21.

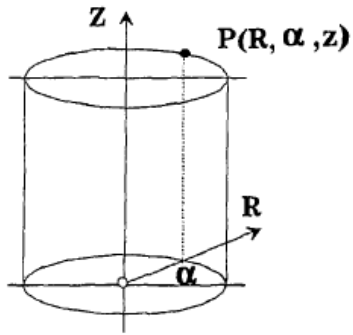
- Cartesian Coordinate System (2D and 3D)
- Polar Coordinate System (2D)
- Cylindrical Coordinate System (3D)
- Spherical Coordinate System (3D)



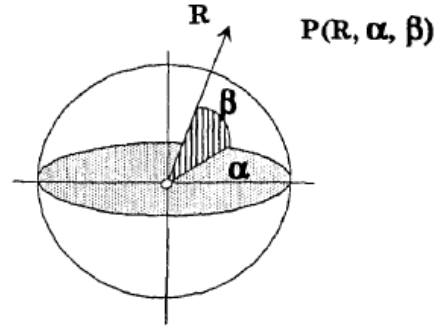
Cartesian Coordinate System



Polar Coordinate System



Cylindrical Coordinate System



Spherical Coordinate System

Figure 2.21. Types of coordinate systems. Taken from (Mantel, 1993)

2.5. MK 100 Braking System

2.5.1. Definition of a ESC

An electronic stability control (ESC), also known as electronic stability program (ESP) is a system that improves a vehicle's stability by the process of detection and reduction of loss of traction. "ESC augments vehicle directional stability by applying and adjusting the vehicle brake torques individually to induce a correcting yaw moment to the vehicle" (Electronic Stability Control Systems, 2007). The ESC prevents critical vehicle states from developing, this is why it is considered one of the most important active safe systems on a vehicle. The system is constantly evaluating the data from the wheel speed sensors, the steering angle sensor, the yaw rate, and lateral acceleration sensor and compares the driver's input to the actual behavior of the vehicle. If an unstable state is detected, for instance as the result of a sudden direction change, ESC responds in milliseconds and stabilizes the vehicle through wheel-specific brake intervention and adjustment of the engine torque (Facts & Figures, 2015). The ESC provides traction and anti-skid support when there is a loss of control of the vehicle, this occurs in cases of oversteering and understeering. Oversteering occurs when the vehicle turns more sharply than intended and continues to turn beyond the driver's steering input because. Understeering occurs when the vehicle turns less than the driver's steering input as a consequence of insufficient traction.

The ESC acts when the car threatens to oversteer by braking the outer wheels of the car. Generally, most of the force goes to the front of the wheel, where wheel slip is set to about a 50%. The increase in wheel slip reduces the lateral forces and gives rise to a counter torque which compensates the yawing torque. The effect of the ESC when the car is going to oversteer can be observed in Figure 2.22.

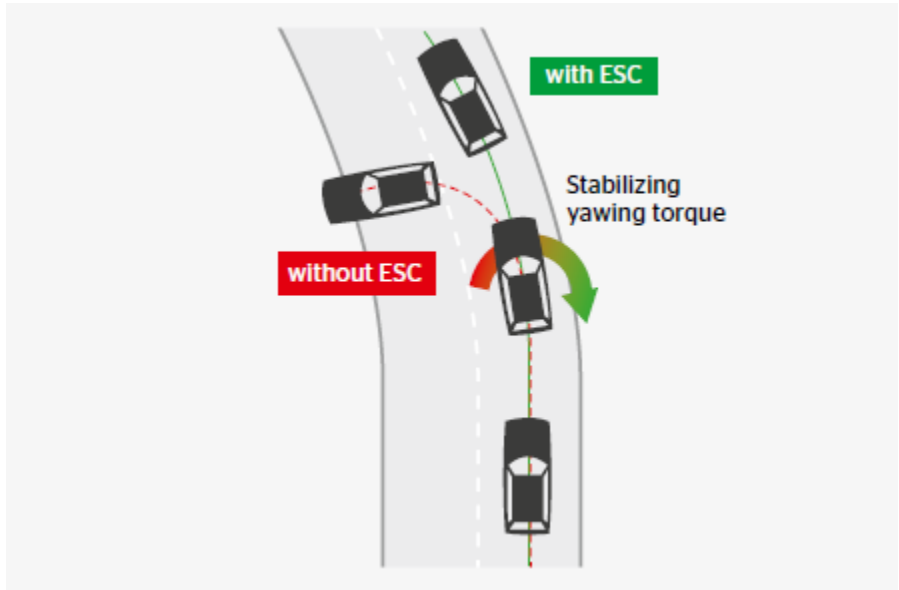


Figure 2.22. Stabilization when oversteering. Taken from (Facts & Figures, 2015)

ESC also intervenes when the vehicle is going to understeer and tries to drift straight ahead in a curve. In this situation, ESC brakes the inside wheel of the car by applying the largest brake force to the rear wheel. The effect of ESC when the vehicle threatens to understeer can be observed in Figure 2.23.

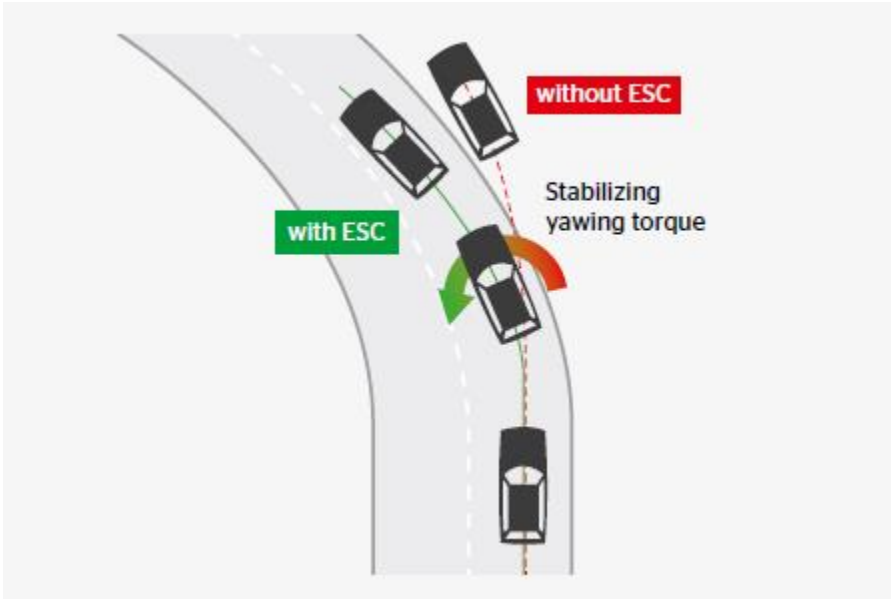


Figure 2.23. Stabilization when understeering. Taken from (Facts & Figures, 2015)

2.5.2. Characteristics of the MK 100 System

The MK 100 system uses the ESC pump for brake boosting to avoid the increase in the pedal force of the brake during the event of brake fade, and also to support the driver when there is temporarily a low engine vacuum. The MK 100 is based on a modular product family and makes it possible to be scaled to different applications: from motorcycle ABS to high-end solutions. Dimensions and weight of this module were reduced in a 30 percent compared to the later generations of ESC systems. In the Figure 2.24 the MK 100 developed by Continental AG can be observed, in the figure all the parts all already assembled.



Figure 2.24. MK 100 system. Taken from (Facts & Figures, 2015)

2.5.2.1. Parts of the ESC

The six main components of an ESC system are: wheel speed sensors, a control module, a steering angle sensor, a yaw rate sensor, an accelerometer, and the hydraulic modulator.

- Valve block / valve housing
 - NO Valve: it is a stainless and open magnet valve, which is used in the HCU. It has the function of opening and closing the hydraulic circuit in quick succession and blocking or allowing the pressure/flow volume to pass from the TMC to the brake caliper.

- NC Valve: it is a seamless and closed magnet valve. It opens and closes the hydraulic circuit in rapid succession in order to shut off and pass the pressure/volume flow from the brake caliper to the low-pressure accumulator.
- Electrical Shuttle Valve (ESV): it is an electromagnetically switched 2/2-way valve which is crimped into the hydraulic control unit (HCU) of an ESC system. Under normal operation, the ESV separates the pump intake side from the TMC so that the brake system can perform the ABS functions. The valve is equipped with a two stage tappet/seat system so that it retains its full functionality even when pressurized.
- Separate Valve (SV): the valve is a seamless open valve. Its task is to block the hydraulic connection between pump and TMC during a control Intervention. So only due to the pumping regulation/function and without any brake actuation the pressure in the wheel brakes can be built up.
- Electric motor and pump: it is a permanent-magnet direct current motor which is screwed or caulked onto a radial piston pump via the face-side bearing flange. The reciprocating movement of the pump pistons is generated via the eccentric motor shaft. In combination with the pump, the motor represents the hydraulic energy supply system for ABS/TCS/ESP control.
- LPA: serves as a buffer for temporary volume flow peaks. It accommodates the brake fluid removed from the wheel brakes to reduce the braking pressure. The brake fluid stored in the low-pressure accumulator is returned to the TMC by means of the pump.
- Pressure-suction valve unit: The pump suction valve / pressure retention valve is a spring-loaded ball valve. In the event of ESC control, the pump suction valve opens in response to the vacuum in the pump working space and sucks brake fluid through appropriate suction lines without pressure. The valve is closed by the valve spring in response to the pressure conditions in the working space. The useful delivery stroke of the pump starts after the pump suction valve has been closed.
- Pressure Sensor: measures the pressure and the temperature of the brake fluid in the electronic brake systems.

2.6. Project Background

The production of MK 100 series braking system started in 2011, which made possible to install ABS/ESC in all vehicle categories. Since the production started, the quality control department has developed measuring protocols for all the braking systems of this product family. Nevertheless, there is a wide range of products from this family for all the different types of vehicles in the market and models usually change because of continuous improvement in the design of the product. There are many available MK 100 models depending on the car class, and each one of them is different; there is also a MK 100 family product for motorcycles. in Figure 2.25 it can be observed the different types of ABS and ESC braking systems for different car categories.

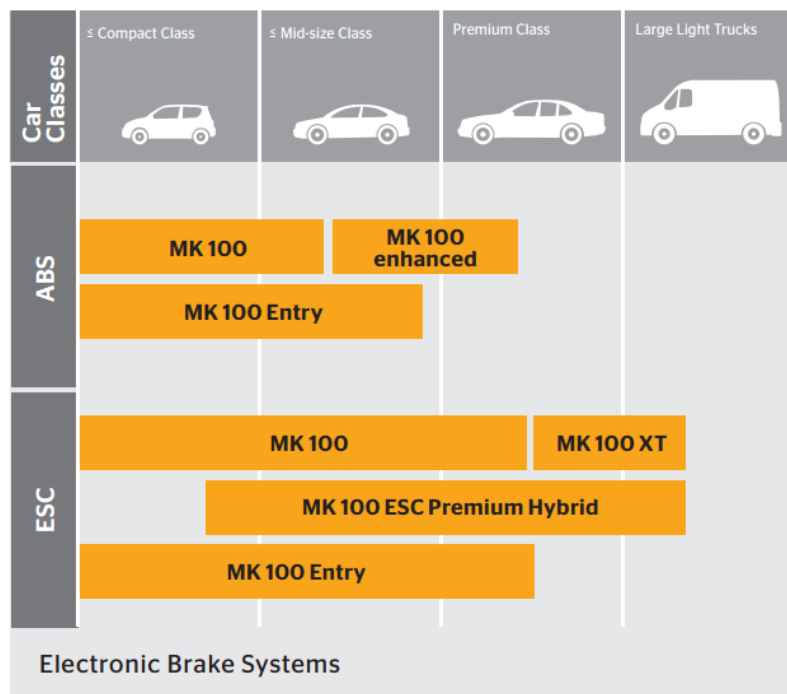


Figure 2.25. MK 100 models for different car classes.

In the manufacturing process, defects are always present on the produced units, so the quality control department has to assure that the causes of these problems are identified and take actions to comply with the established quality standards. The measuring protocol developed corresponds to a new MK 100 model and the specific part of it is called “valve support MK 100 ESC standard 10.0206-3064.1” which contains modifications compared to previous models. A

measuring protocol was not developed for this specific model and to assure quality standards, the department needed to make an inspection for all the dimensional features of the valve block. The chosen equipment to perform the tests was introduced to the department in 2015, which was acquired because of better performance and accuracy compared to older machines used for this purpose. The department already has a program where other products can be tested such as MK 20/25/30, MK 60, MK C1, and other models as observed in Figure A.3.8.1 of Appendix A.3 which corresponds to the main menu of the platform. Also, there are other programs for variations of the MK 100 depending on the model, but for the assigned model there was not a measuring protocol before the implementation of the project. Regarding the program for calibrating the styli, the department already had a program that does this process for all the available styli.

The most important contribution of the project is to generate a measuring protocol for the valve support MK 100 ESC standard 10.0206-3064.1 using the Quindos 7 software and integrating it to the existing platform. The creation of this measuring protocol includes the choice of styli for the probing, and other aspects such as the workpiece holding method and orientation. Also, to create a user manual with all the important steps, from calibration to the inspection of the product using images of how the valve block should be positioned and which actions the user should follow. The process of calibrating is also included in the project but the department already has a program that calibrates all the types of styli available in the department. Nevertheless, it is necessary to include this part in the work as it is a basic part of the effective implementation and functioning of a measuring program. For the programming of the machine, the technical drawing of the product was used which contains all the geometric features to be evaluated. It was also necessary to perform tests over less complex objects to learn how to effectively program the machine different types of forms, locations and dimensions. This was needed to generate an appropriate measuring and probing strategy which requires experience from the programmer.

3. Solution Description

The solution description includes two fundamental parts that are the measurement strategy and the programming of the machine. The measurement strategy explains each of the steps followed for developing the measuring protocol. This subsection explains the basic planning for carrying up the inspection of the valve block. Contains general information about the tools that the machine is going to use for performing the test, and also factors to take in account for developing the probing strategy which is one of the most important parts of the project. This section summarizes the most important aspects because the process of developing a probing strategy is very extensive and explaining the whole process would be impractical for the work.

The second subsection explains how the measuring test was programmed in the machine using the tools of the software called Quindos 7. It includes the explanation of basic commands used for the setup of the machine, the definition of the coordinate system which is one of the most relevant factors when programming a measuring protocol, and the commands used for measuring each of the geometrical features. It also contains secondary commands which are useful for performing more complex measurements of the features of the valve block, and are necessary for performing the process of tolerance evaluation.

3.1. Measurement Strategy

The objective of using a coordinate measuring machine is to sample points from a manufactured part to extract the geometric features from the sample part and then obtain and evaluate the deviation between the produced part and the geometric model. The Figure 3.1 represents the relation between the inspection and verification process, and the different elements present in this procedure.

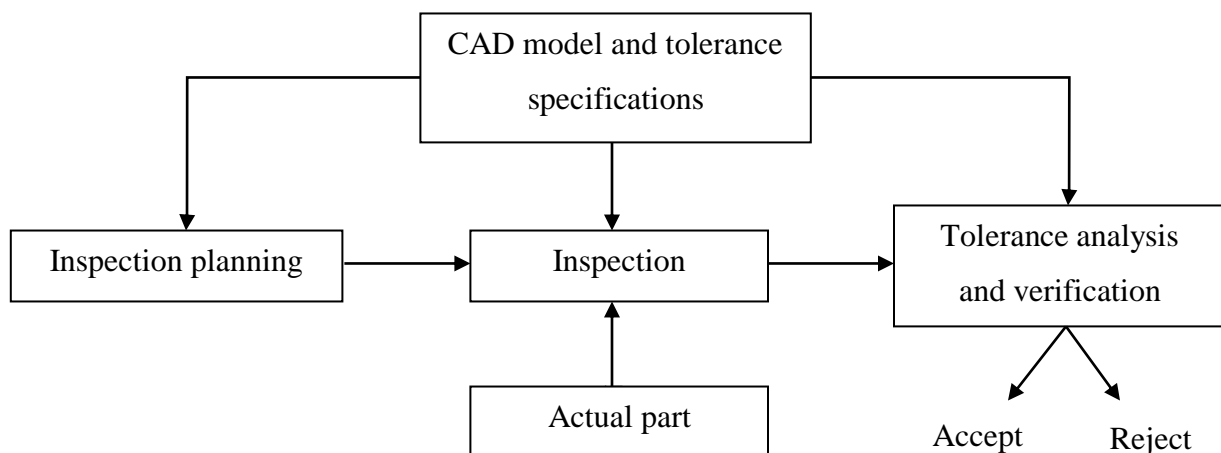


Figure 3.1. Inspection planning and verification process.

The ISO 10360 standards detail the acceptance, verification tests and temporary checks required to determine whether the CMM performs to the manufacturer's stated error. However, even if these tests are applied, it is not possible to make a statement about the length measurement capability. Therefore, the length measurement uncertainty derived from a limited sample of measurements cannot be considered representative of all the possible length measurement tasks. Thus, it is important to develop task-related measuring strategies for each measurement undertaken that will give the appropriate level of confidence in the results.

The sampling strategy for a CMM inspection process is under the control of the user whereas the accuracy is determined by the machine and the software. Nowadays machines are capable of very high accuracy measurements, but the inspection quality and confidence in the result depends also of the measurement strategies. The selection of a correct measuring strategy demands skill, experience and attention to detail by the user. Therefore, it is important to identify the uncertainties inherent in the use of CMMs and strategies that will provide confidence in the results.

“In contrast with simple, single-purpose measuring instruments, CMMs are able to measure a wide range of geometrical parameters. For each of these parameters the user may adopt any of a number of measurement strategies” (Flack, 2014). These strategies include the selection of a specific probe and stylus configuration, the number of probed points and other parameters such as direction and speed of approach of the probe.

The general measurement strategy can be divided into several steps which should be followed in the subsequent order:

- 1) Selection of the features to be measured.
- 2) Definition of the datum feature(s).
- 3) Selection of the workpiece orientation.
- 4) Selection of the workpiece holding method.
- 5) Stylus system qualification.
- 6) Definition of probing strategy.
- 7) Programming of the CMM.

3.1.1. Selection of the Features to be Measured

Generally, the production and functionality requirements determine which features require measurements. There are some cases in which the features to be measured cannot be probed using the CMM due to several reasons:

- Accessibility problems.
- Impractical to measure.
- Could be more cost effective to measure them using other equipment.

In the valve block all the specified features on the mechanical drawing must be measured, and their respective form and location tolerances. Every of the measured characteristics are compared with their nominal values and also their form and location tolerances.

3.1.2. Definition of the Datum Features

The datum of a drawing is a reference surface, plane, axis, or point which is used to define geometric features on a part and their form and location tolerances. In this case it is not necessary to define the datums as they are already specified on the mechanical drawings of the valve block. The reference datums are P and Q which are used to define the Y and Z axis and the surface S which normal defines the X+ axis. These are the first references used to define the coordinate system used to measure the geometric features. The other datums are V and Z which are used as a reference to measure the geometric characteristics on the back of the valve block.

3.1.3. Selection of the Workpiece Orientation

The next step is to choose the orientation of the workpiece within the measurement volume of the CMM. The most important consideration is to ensure that all surfaces and geometric features are accessible for probing. It is important to choose a strategy of measurement where a single set up of the workpiece is needed or the least number of set ups possible. If more than one set up is chosen there is the possibility of operator error degrading the measurement process and reducing the confidence in the obtained results. In this case, two setups were chosen: the first one has the surface with least features on the bottom where it is fixed with the fixture; the

second one has this surface on top of the workpiece. With the first setup it is possible to measure the majority of the geometric features present in the technical drawing, and with the second set up, the rest of the features.

3.1.4. Selection of the Workpiece Holding Method

For the holding method of the part, an adjustable holding kit is used with which it is possible to hold up to 8 pieces. This type of clamp is useful for small parts and specifically for prismatic ones. With the selected clamping method it is easy to place the workpiece so the surfaces of it are parallel to the coordinate system of the machine, making easier the alignment of the piece. It is important that when placing and fitting the workpiece it is tight enough so that the part does not move.

3.1.5. Choice of Styli and Qualification

The choice of the stylus to be used in the measurement strategy and also the stylus system qualification is a very important process of the whole measurement process.

3.1.5.1. Choice of Styli

When choosing the styli used for the measuring process there are several factors to be considered in advance. For example, the stylus tip diameter should be as large as possible, because with larger balls surface finish has less effect on the measurement gaining more flexibility due to the ball/stem clearance. The largest diameter to be used is determined by the smallest diameter bore to be measured in the workpiece. Several styli can be chosen depending on the requirements and the characteristics of the part. For the measurement of the geometrical features of the valve block, the probes shown in Table 3.1 were chosen. These specific probes were chosen because of the diameter of the stylus tip which and also because of the length of the stylus which has to be taken in account regarding the working area of the machine and the position of the pieces in the measuring table. The first number is used to describe the position on the rack, the second number is used to define the specific model of the stylus, and the last one defines the probe-pin that is going to be used for the measurement. The configuration and numeration of the

styli or probe-pin when programming the machine can be observed in Figure 3.2, this number corresponds to the last number on the code used for specifying the probe-pin used for the measurement.

Table 3.1. Probes used for the measurement process.

Probe number	Stylus code	Stylus head diameter (mm)
21x	211	1,5
	212	1,5
	213	1,5
	214	1,5
	215	1,5
33x	331	1
41x	411	3
	412	5
	413	3
	414	5
51x	515	3

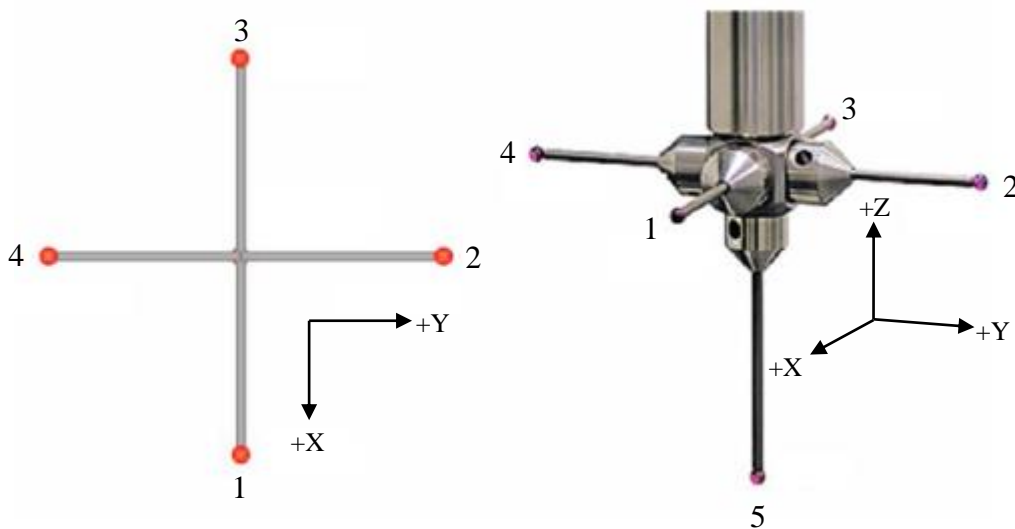


Figure 3.2. Probe configuration and numeration.

3.1.5.2. Stylus System Qualification

The stylus system qualification must be undertaken for every combination of stylus and probe bodies to be used during the inspection process of the workpiece. The stylus tip is usually qualified using a reference sphere as shown in Figure 3.3, the process of stylus qualification should be undertaken under the same conditions as those under which the workpiece will be measured. Ideally, the same direction and speed of approach should be the same for both qualification artifact and workpiece as these parameters have an effect over precision and accuracy.

During the qualification process, the probe stylus is driven perpendicularly onto the surface of the reference sphere in several planes. Careful qualification improves the accuracy of measurements. Increasing the number of points during the qualification process will result in a more effective stylus tip diameter calculation.

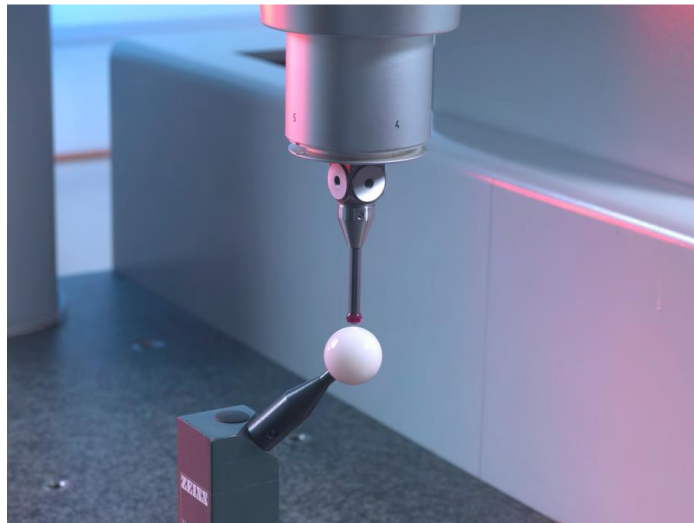


Figure 3.3. Example of CMM stylus qualification of a spherical tipped stylus using a reference sphere. Taken from (Flack, 2014)

3.1.6. Definition of Probing Strategy

An important factor when defining a measurement program, is the selection of number and the distribution of contact points on the workpiece that are a combination of standard geometric features. The selection of the number of nominal points on a geometrical feature such

as a circle depends on the size of the circle, and also the grade of tolerance. For a higher accuracy when obtaining the form of a circle, more probing points are used, but the problem is that this takes more time and it must be cost-effective. For example, in the Table 2.3 the minimum number of probing points is shown for the most important geometric forms, but it is not useful to use the minimum number of points because the accuracy level is lower. For choosing the number of points should take in account the nature of the machining process and the intended function of the workpiece. The distribution of probing points should normally aim for a uniform coverage of the feature being measured so that the software provides a more accurate representation of the geometric feature. However, sometimes it would be necessary to use a not so regular distribution of points for avoiding systematic or periodic deformations that are a result of a machining process.

3.2. Programming of CMM

3.2.1. Programming Method

There are four types of techniques for programming a coordinate measuring machine:

1. **Manual operation:** this technique is carried out by controlling the machine probe head to touch the workpiece at the specified points. Then, the encoders of the machine determine the locations of the probed points. This method is actually not very useful as it requires a lot of time and it is not an automated process.
2. **Teaching mode:** the part inspection steps are carried out manually by driving the probe using the control drive and measuring the object's surface. During the probing process, the machine records these steps in an inspection program, so once the program is complete, it can be recalled at any time to perform the part inspection repeating the recorded procedure.
3. **Offline programming:** with this technique it is not necessary that the machine is connected to the computer in which the inspection plan is programmed. The workpiece design data and the CMM planner's experience are used to generate the inspection plan, which is translated into the machine language.
4. **Automatic planning and program generation:** in this method, the CMM inspection plan and programming are automatically generated based on the CAD model of the workpiece. This process includes some calculations for inspection points allocation, points grouping and clustering, probe orientations, and collision-free optimum probe path planning.

For the programming of the inspection plan, the offline programming was chosen because in this way, the programmer can specify the measurement of all the geometric features. With this technique, it is possible to determine each step of the measuring program and there is more control over the desired steps than with the automatic planning. Manual operation and teaching mode takes a lot of time for such a complex piece as the valve block.

The used communication interface is called I++ DME which is a standard for connecting devices in quality assurance. I++ is an acronym for Inspection_plusplus, inspired by the name of the programming language C++. DME means Dimensional Measuring Equipment and is the generic term for different types of gauges, for example: coordinate measuring machines, form

testers, camshafts and crankshafts measuring machines, and special machines. The interface is designed to break the link between the machine and its associated software. For a given application, the ideal machine/software combination can be used.

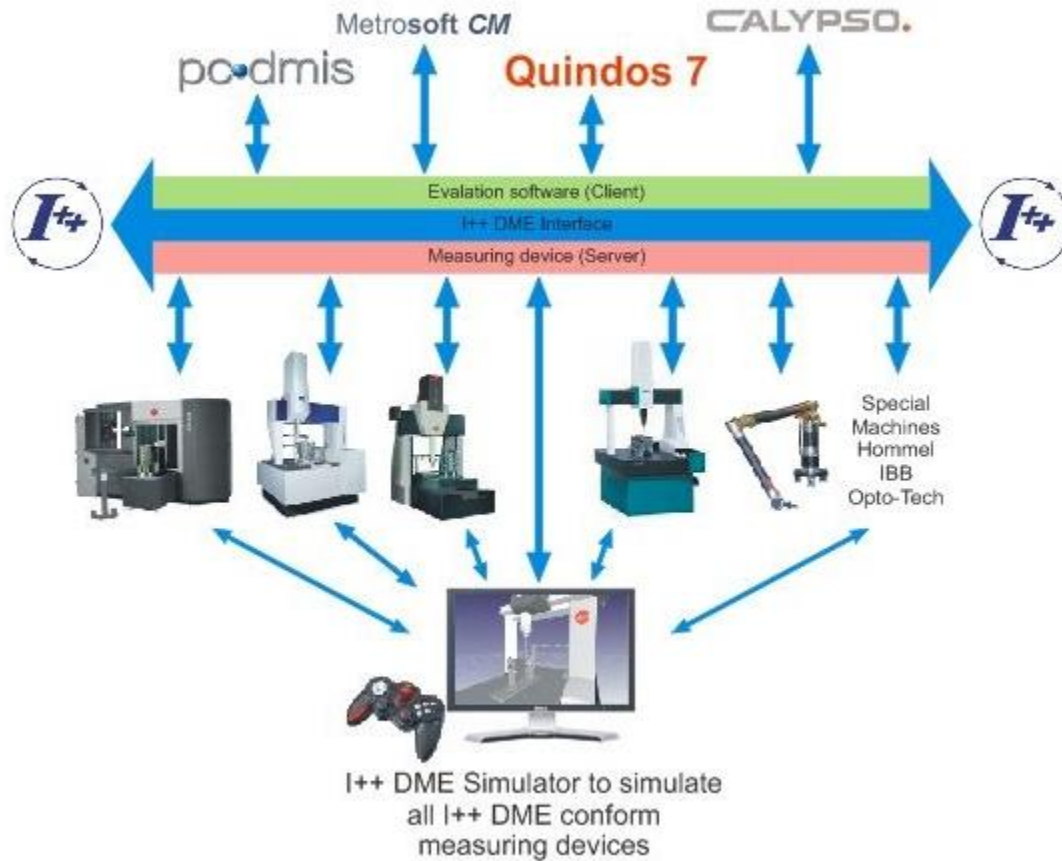


Figure 3.4. I++ communication interface. Taken from (Quindos 7 Manual)

The concept of the I++ DME interface makes a clear differentiation between the machine functions (Hardware) and the metrology software functions:

- The hardware side (server) of the machine manufacturer:
 - Control of the machine
 - Calibration of the tools
 - Compensation of any systematic errors
 - Control of peripheral equipment, such as tool changers, articulating heads and rotary tables

- The software side (client) of the software vendor :
 - Measuring strategy
 - Measuring sequence
 - Evaluations
 - Reporting

The software in coordinate metrology is modularized, there are some programs used for archiving and evaluating the measured values, the measurement process planning and control, and for data exchange with external processing systems. Quindos 7 is the name of the software used for the programming of the coordinate measuring machine Leitz PMM 866. For the offline programming of the measurement plan there are two basic ways in which the commands can be given. One way of programming is to use directly the commands into the main command buffer as shown in Figure 3.5.

```

Main Command Buffer |
Mainlp
SET          (NAM=Language, RVL=0, SVL=en, GRP=0)

STOP
ShowPicAndText (PIC=Spannung_1, WAI=Y)
!-----
DSBSYS      (NAM=GFONLY)
ENBSYS      (NAM=CMDICO)
USECMM      (NAM=GDBCMM:SAVE$CMM)
USEPRB      (NAM=PRB(413))

SET          (NAM=DFLT$TOL, RVL=.15)
!-----
START        (WKP=MK100, PRQ=Grafik, TOP=N, EDT=Y, TEI=N)
!-----
! WICHTIGE ABFRAGE, MUSS AUSGEFÜHRT WERDEN
!-----
INQYESNO    (CHS=~JA_NEIN, MSG=KAN_JA_NEIN, RED=N)
TESTSTR     (NAM=JA_NEIN, ST1=~JA_NEIN, ST2=Y)
!-----
MEPNTX      (NAM=PU_X, CSY=KO_REF, MOD=NOE, DEL=YY)
MEPNTY      (NAM=PU_Y, CSY=KO_REF, MOD=NOE, DEL=YY)

```

Figure 3.5. Main command buffer used for entering commands.

Another way of programming is using the graphic interface with icons as shown in Figure 3.6, which is easier as it is possible to create complete measuring programs without knowing in detail all the commands or instructions. Also both of the methods can be combined depending on the knowledge and ability of the programmer. The selected icon is double-clicked with the mouse, and the associated input mask opens, in which some fields must be provided with the necessary information. The given statements are directly transferred into the main command buffer.

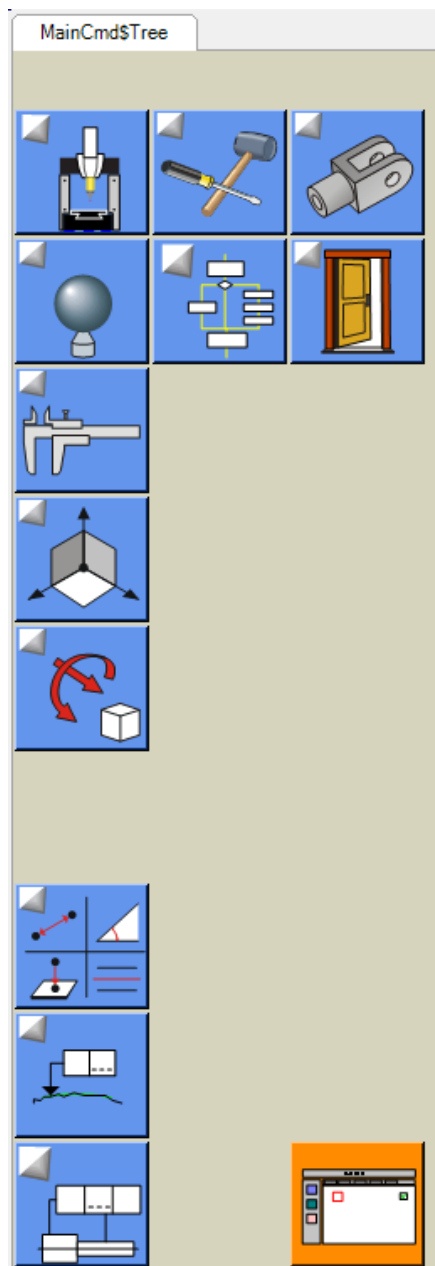


Figure 3.6. Tab page containing Quindos 7 commands displayed as icons.

3.2.2. *Probing Strategy*

This section describes the commands used to measure and obtain the geometrical features from the surface of the workpiece. It also contains the explanation of important commands used in the program to calculate geometric features or to change the configuration of the CMM.

3.2.2.1. *Basic Programming Commands*

Initialize New Part Measuring Program

The new measuring program is initialized using the menu item File - New, the icon New on the general icon bar or the command CNCINI.

Menu item “File – New”

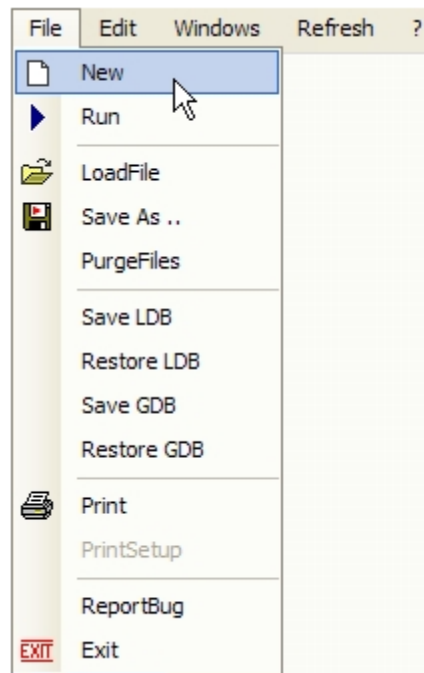


Figure 3.7. Menu item for creating new file.

Icon "New" on the general icon bar

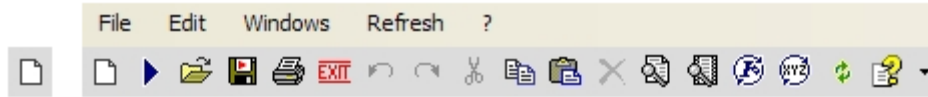


Figure 3.8. Icon on general bar for creating a new file.

Start Program

Once the important parameters defined the program can start, this is done by using the command START. The command initializes the data for the header and expression of the workpiece name which is the basis for the naming of the measuring program.

A screenshot of a software dialog box titled "Start program (CNC-run)". The dialog contains several input fields and checkboxes. A large "START" button is prominently displayed in the center-left. The fields include: "Name of the workpiece" (dropdown menu with "MK100" selected), "Name of printer format" (dropdown menu with "Grafik" selected), "Reset part temperature?" (radio buttons for "Yes", "Initialize", and "No", with "No" selected), and "Control character" (text input field). At the bottom, there are three rows of three input fields each, labeled: "Serial number", "Customer", "Article number"; "Production machine", "Production date", "Production time"; and "Inspector", "Department", "Order".

Figure 3.9. Start program command dialog.

Interrupt Execution of Instructions

To interrupt the execution of instructions the command STOP is used. This command is usually used at the end of the measuring program or when necessary to interrupt the program.

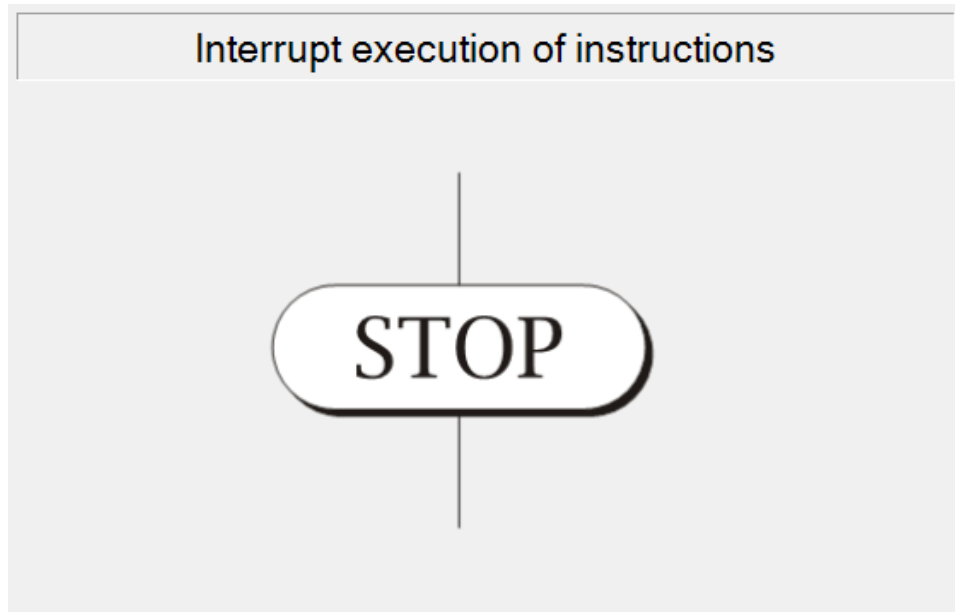


Figure 3.10. Stop command dialog.

3.2.2.2. Machine Related Commands

Select Machine Parameters

First the command USECMM is given to select the machine parameters to be used. This command defines some parameters such as positioning speed, probing force, scan speed, etc. This parameters should be previously defined with the command DFNCMM which is used to create a parameter set.

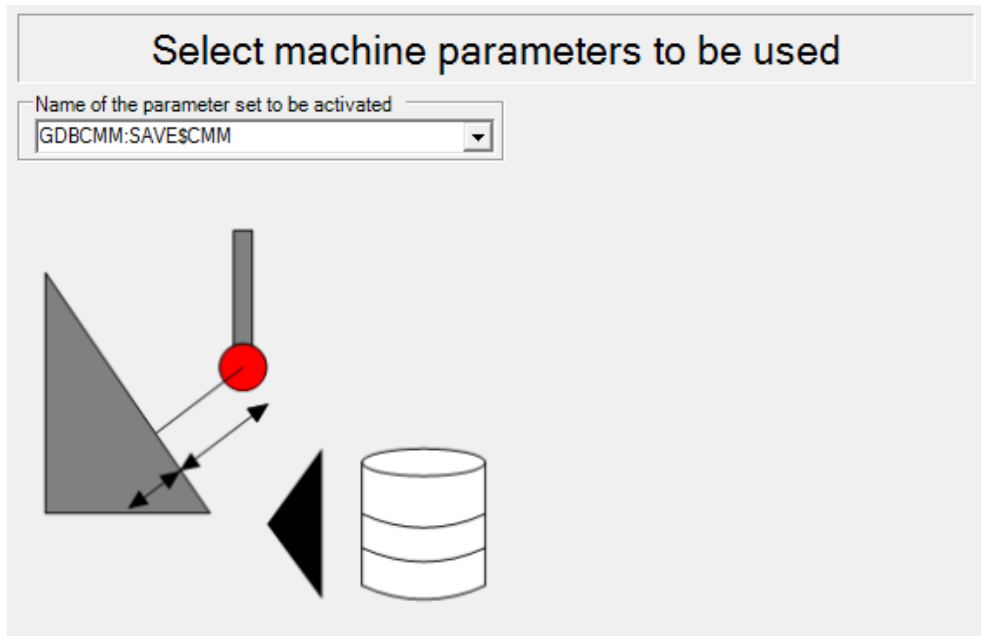


Figure 3.11. Select machine parameters command dialog.

Put Probe/Sensor in Probechanger

The command PUTPRB is used to return the probe or probe cluster to the assigned magazine position. For this procedure the magazine coordinate system must have been defined and the probe changer enabled

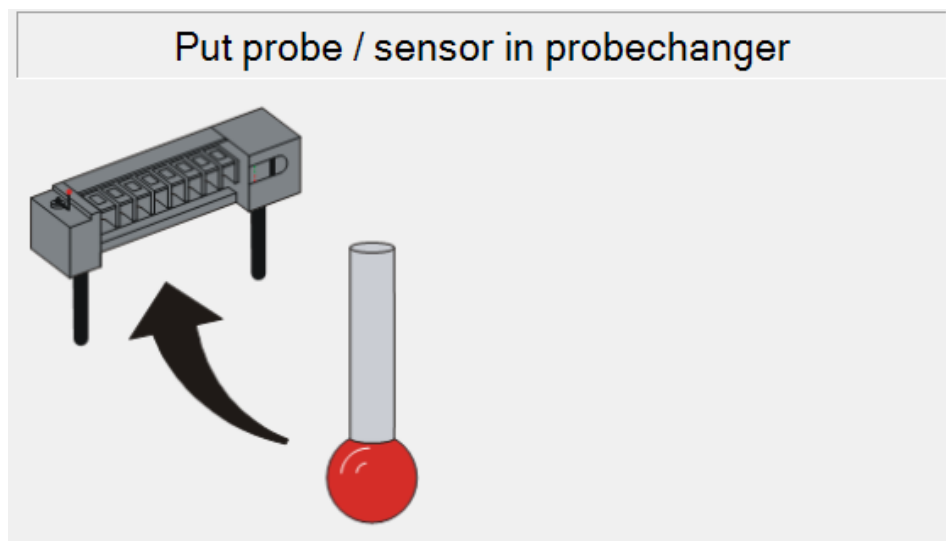


Figure 3.12. Put probe in probechanger command dialog.

Select Tool/Sensor

The command USEPRB is used to activate a probe-pin. The probe-pin related data, established during the probe calibration are sent to the CMM electronics. This information is used to correct all probing points for pin deflection, pin position, etc. The activated probe remains active until a new probe-pin is activated by means of the command USEPRB or a measuring command using another probe-pin.

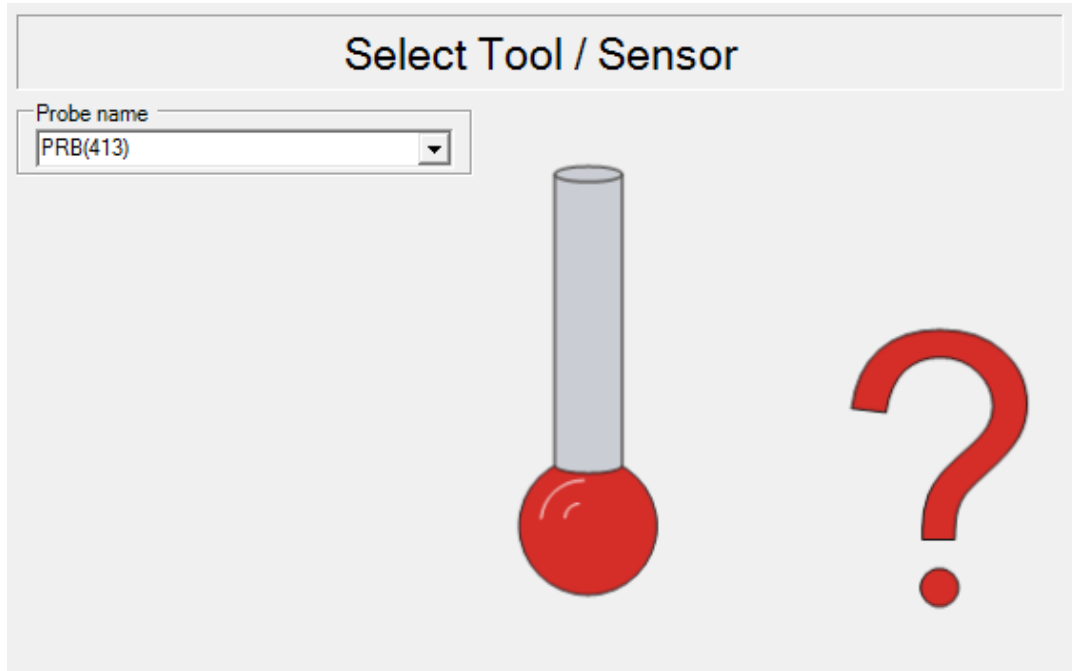


Figure 3.13. Select probe or sensor command dialog.

Move CMM

This command is used to move the CMM to a target position, independent from a measuring command.

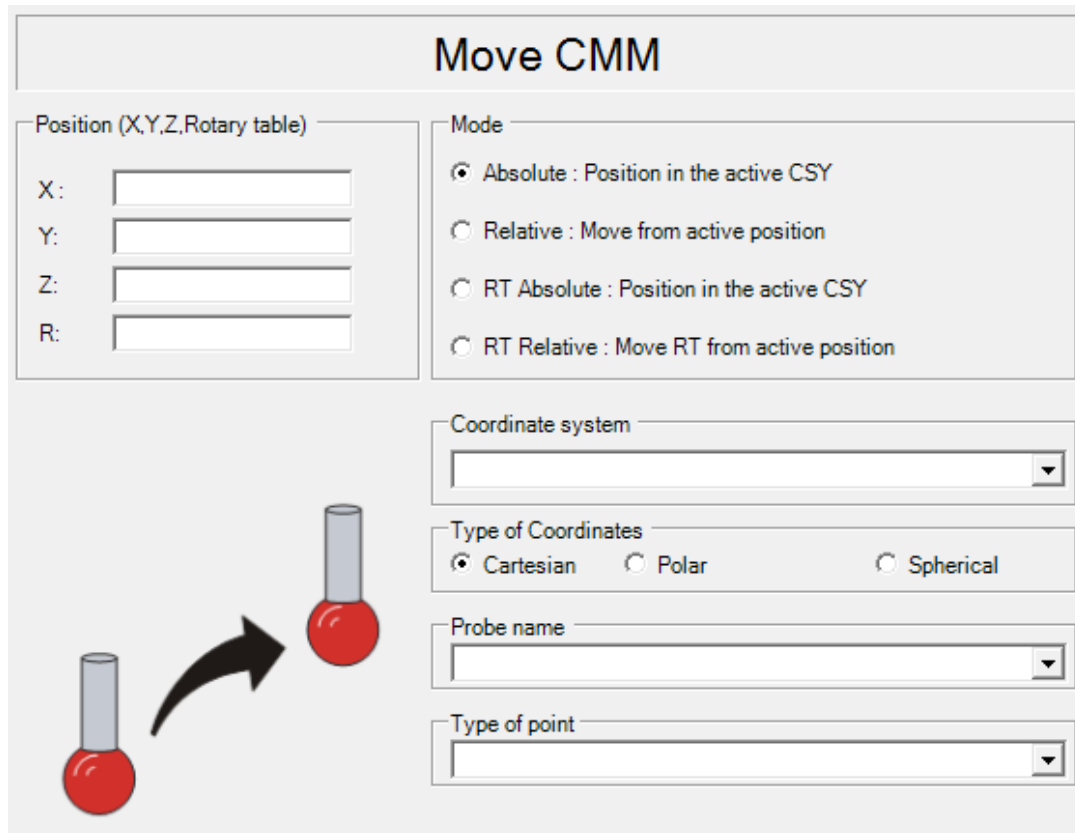


Figure 3.14. Move CMM command dialog.

3.2.2.3. *Alignment and Transformation*

Definition of Coordinate System

The coordinate measuring machine has a coordinate system which is given by its moving axes. To perform the measurements the coordinates related to the part are needed. Therefore, it is necessary to define a part coordinate system which is also called alignment.

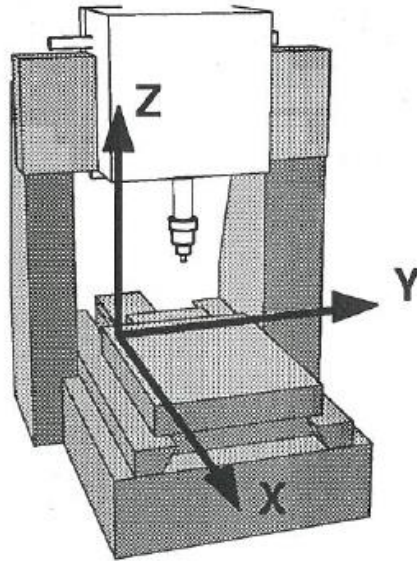


Figure 3.15. Machine coordinate system of the Leitz PMM 866. Taken from (Quindos 7 Manual)

The location and orientation of the part coordinate system is taken from the mechanical drawing of the workpiece, which is derived from the specified datums. The part coordinate system is used to generate the nominal measuring points and the nominal dimensions for evaluations.

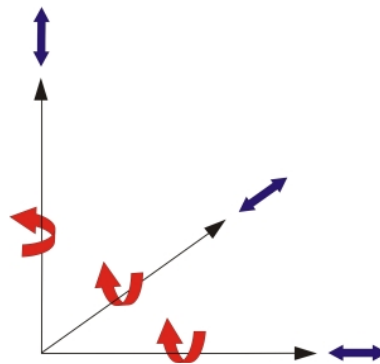


Figure 3.16. Degrees of freedom of a coordinate system. Taken from (Quindos 7 Manual)

A coordinate system has six degrees of freedom in space. These are the shifts along the X, Y, and Z axes and the rotations about these axes. To build a coordinate system at a given point on the part, these degrees of freedom must be locked which is achieved by measuring geometric elements. Two of the measured elements must provide a direction for coordinate axes

Building a part coordinate system is one of the first steps when creating a measuring program. This is defined from already existing elements by using the command BLDCSY. There are two methods in which the part alignment can be done:

- Build coordinate system with a plane, an axis, and a point.
- Build coordinate system with three planes.

Figure 3.17 is used as an example to show how the part coordinate system can be defined with both methods.

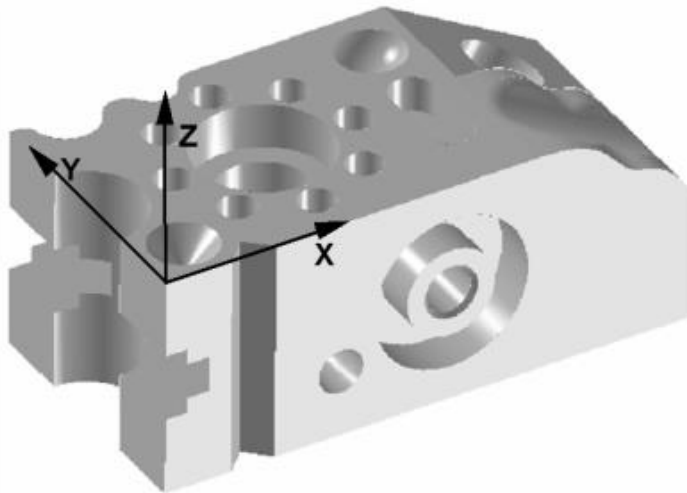


Figure 3.17. Example of a part coordinate system in a workpiece. Taken from (Quindos 7 Manual)

Build coordinate system with plane, axis, point

To define the part coordinate system three elements must be measured: a plane, an axis, and a point as observed in Figure 3.16. The normal of the plane PLA_1 defines the spatial orientation and the positive Z axis of the new coordinate system. The direction of the axis AXI_1 defines the plane orientation and the positive X axis of the new coordinate system.

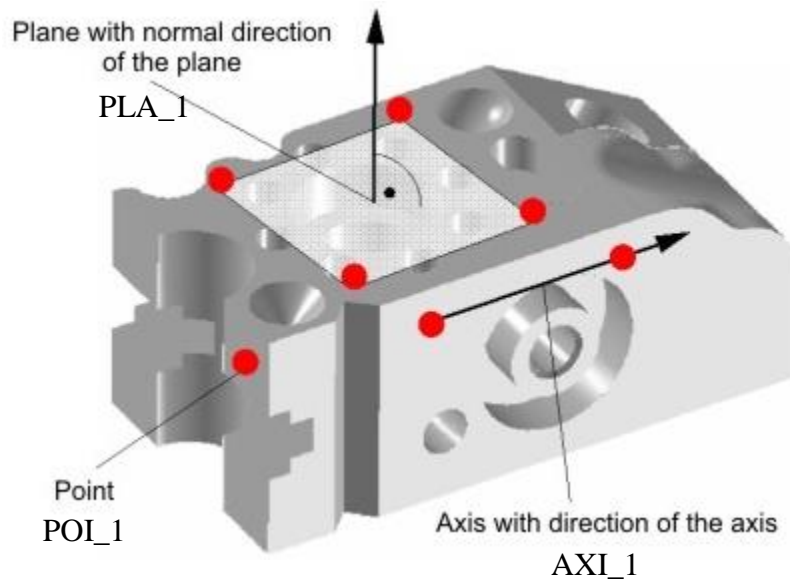


Figure 3.18. Part coordinate system defined using a plane, an axis, and a point. Taken from (Quindos 7 Manual)

The elements for spatial and planar alignment must contain direction information to define two of the coordinate system axes. The third axis will automatically complete a right-hand coordinate system (orthogonal to the directions defined by the first ones). The origin of the new coordinate system is defined by the point POI_1 in the X axis, the center of gravity of the axis AXI_1 in the Y axis, and the center of gravity of the plane PLA_1 in the Z axis. The command dialog can be observed in Figure 3.19.

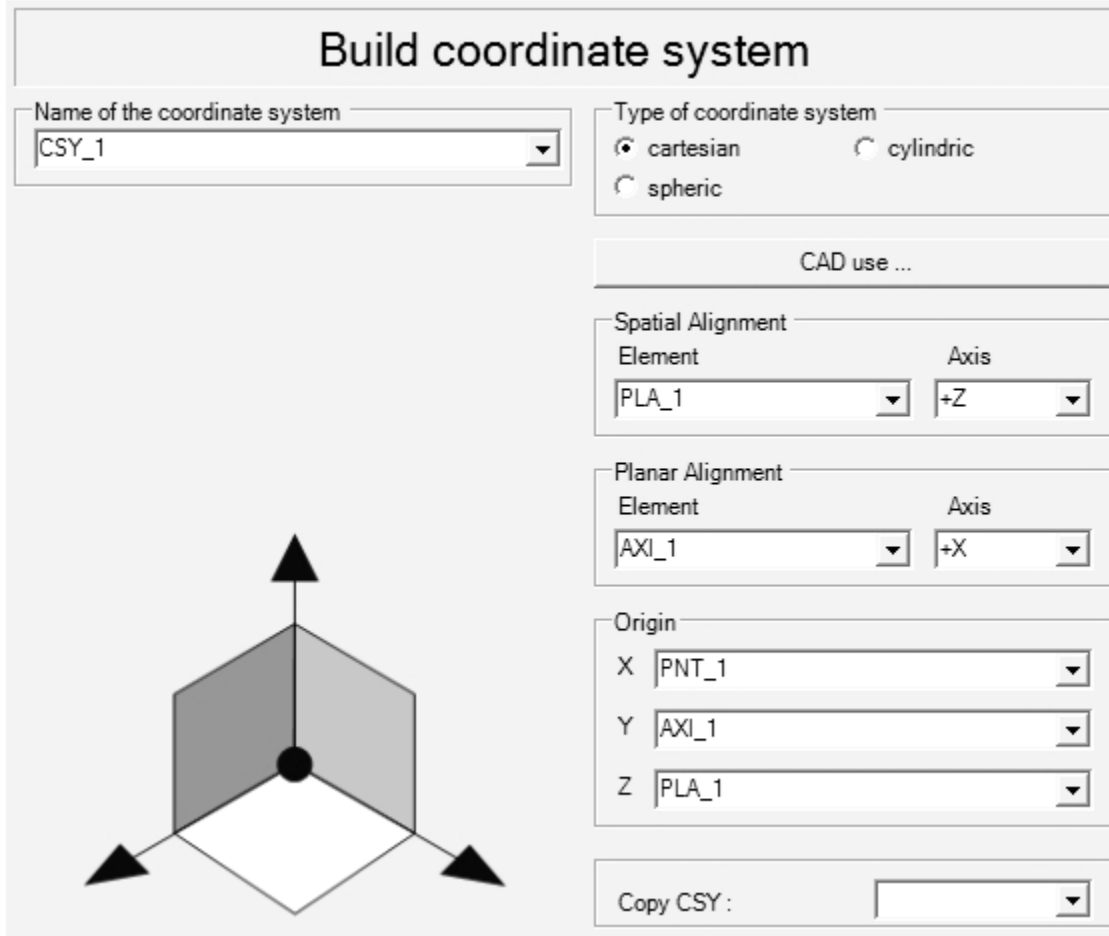


Figure 3.19. Build coordinate system command dialog.

Build coordinate system with three planes

To define de part coordinate system three planes must be measured as observed in Figure 3.20.

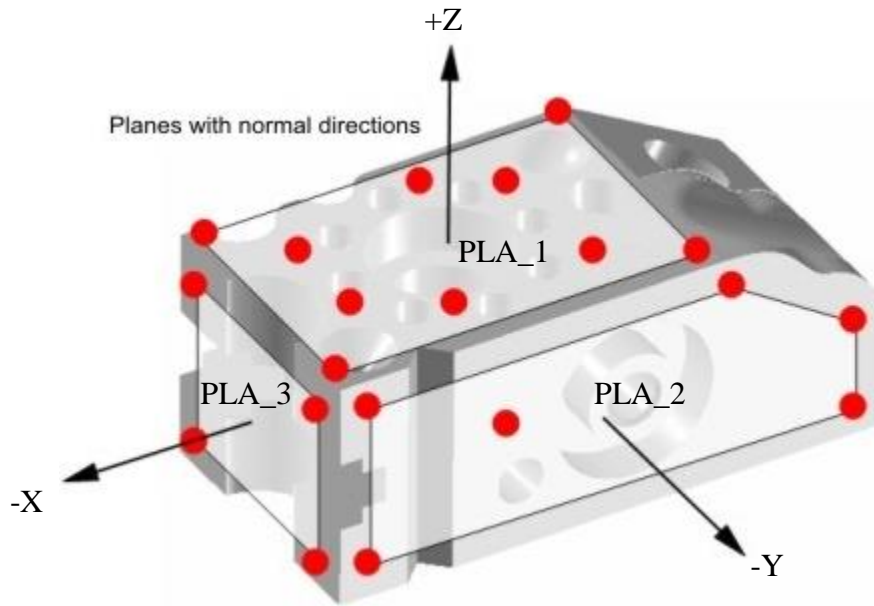


Figure 3.20. Part coordinate system defined using three planes. Taken from (Quindos 7 Manual)

The normal of the plane PLA_1 defines the spatial orientation and the positive Z axis of the new coordinate system and the normal of the plane PLA_2 defines the planar orientation and the negative Y axis of the new coordinate system. The command dialog for this instruction can be observed in Figure 3.21.

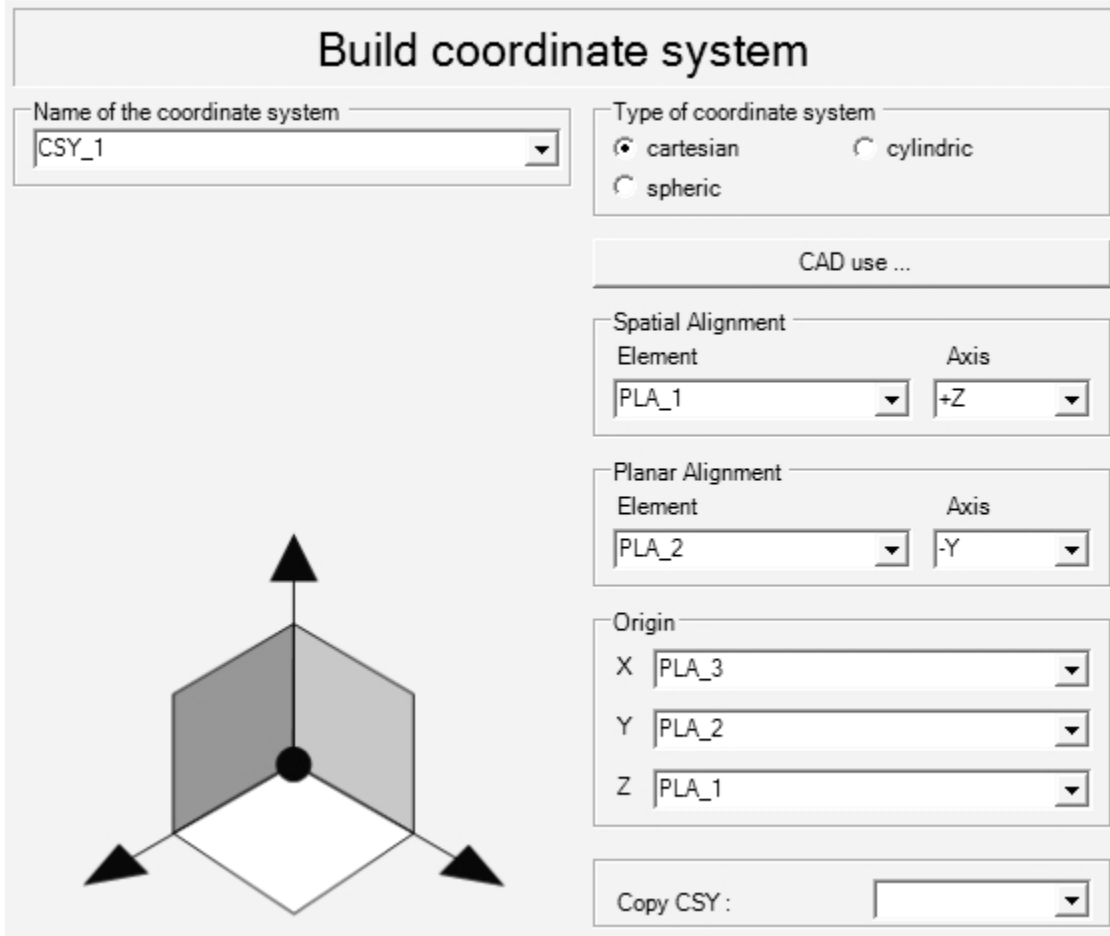


Figure 3.21. Build coordinate system command dialog.

Generally, the program does not use a unique coordinate system because the geometric features have different references. Several coordinate systems can be defined according to the measuring points and their reference in the mechanical drawing.

Choosing a Coordinate System

After defining a coordinate system, the use of a specific coordinate system must be given to the machine by the use of the command USECSY. It is necessary to indicate which reference system is going to be used, because in a single program several coordinate systems can be defined. The command sends the translation vector and the rotation matrix of the coordinate system to be activated to the CMM electronics. From this point forward, all points received from

the CMM will be in the newly activated coordinate system. In the command dialog showed in Figure 3.22 only the name of the coordinate system is necessary as an input.

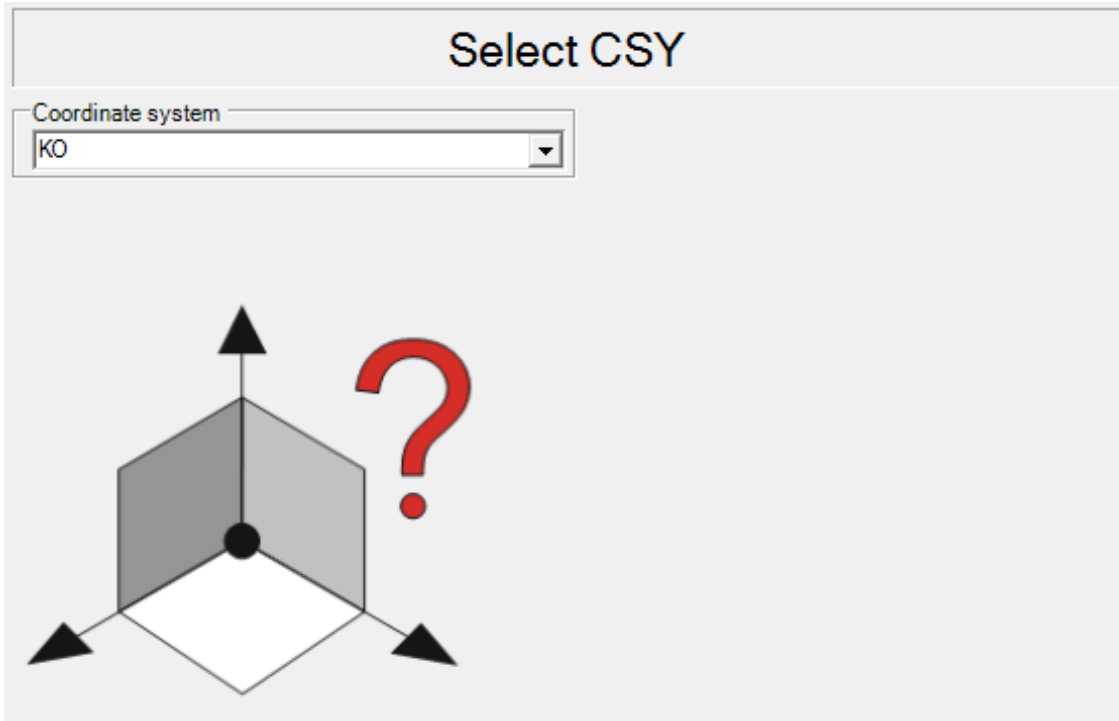


Figure 3.22. Use coordinate system command dialog.

Build a Transformation

To define a transformation the command BLDTRA is used. This transformation can be used to transform objects (elements, coordinate systems, etc.), which is used to translate or rotate the given object. During the execution of a transformation, at first translations is executed and then the rotation. The input data includes the name of the transformation, the shift in every axis, the rotary axis and the angle of rotation. To apply this transformation to an object another command needs to be used depending on the type of object. To transform a geometric element, the command TRAELE is used and for a coordinate system TRACSY.

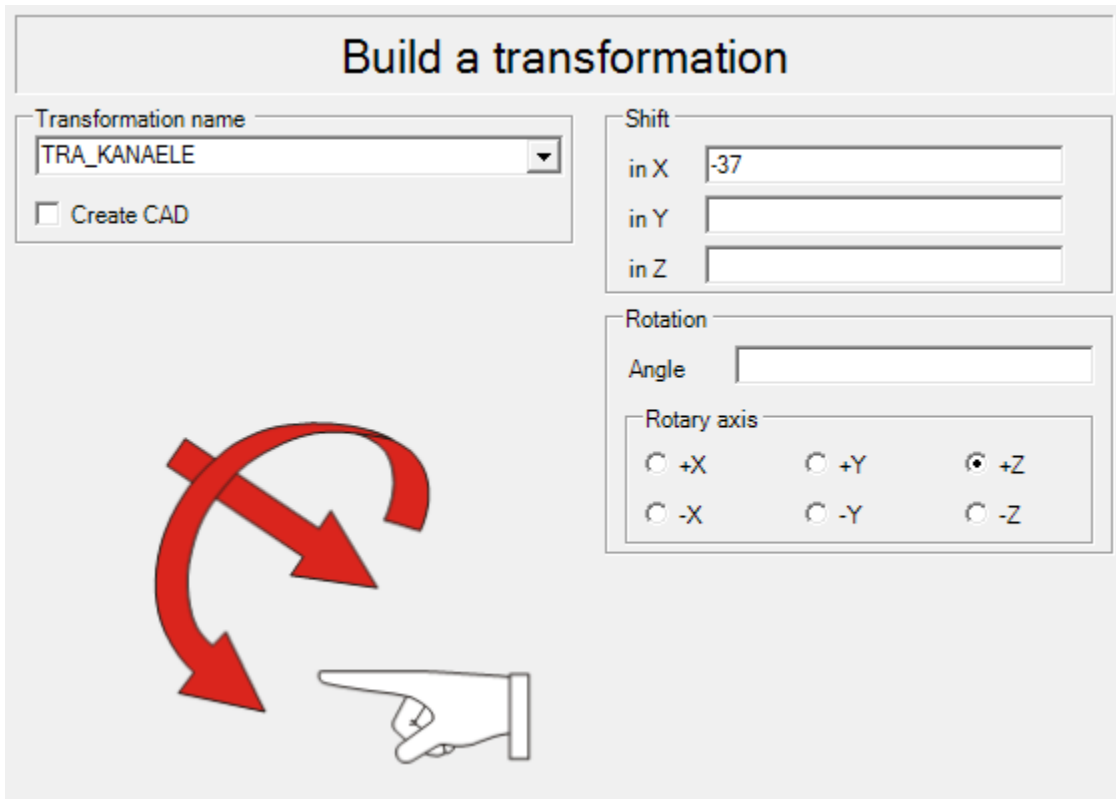


Figure 3.23. Build a transformation command dialog.

Transform Element

With the command TRAELE elements can be transformed in two different ways:

- Transformation of the element into another coordinate system.
- Transformation (translation and/or rotation) of the given element within a coordinate system.

To apply the transformation, the name of a previously defined transformation or the name of the coordinate system in which the object will be transformed must be given (defined with BLDTRA). The command dialog where the information is given for the transformation is shown in Figure 3.24.

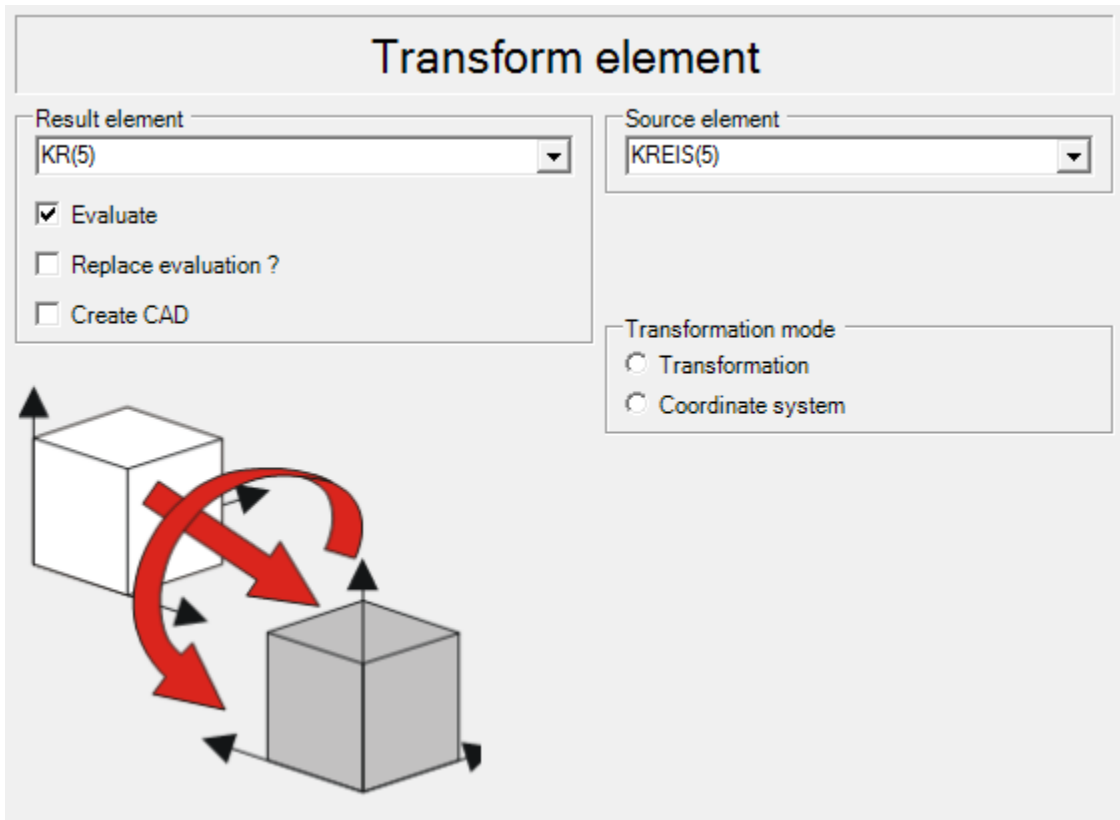


Figure 3.24. Transform element command dialog.

Transform Coordinate System

With the command TRCSY a coordinate system is shifted and rotated. In the same case as the transformation of an element, the name of a previously defined transformation must be given (defined with BLDTRA).

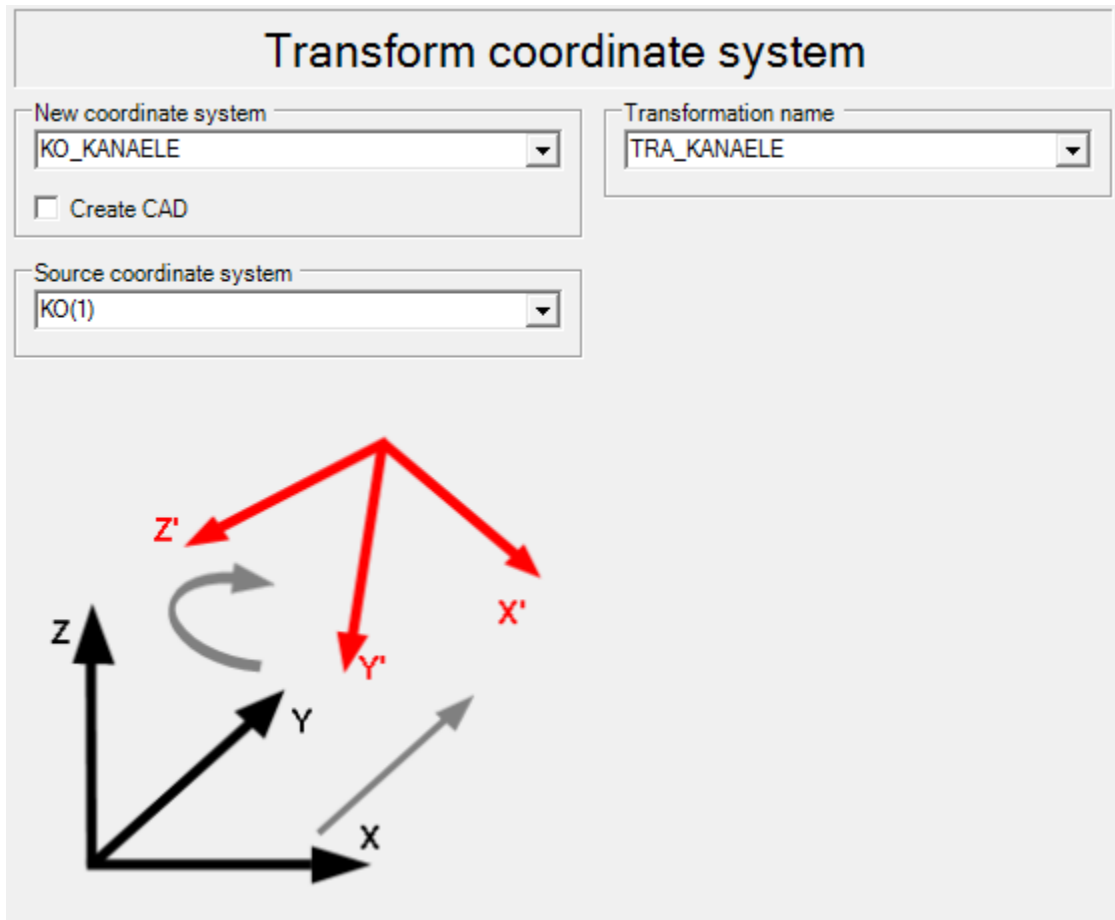


Figure 3.25. Transform coordinate system command dialog.

3.2.2.4. *Measurement and Manipulation of the Standard Geometric Elements*

In coordinate metrology, as explained before, part surfaces are measured and represented as geometric elements. The dimensions, form and position of the elements are calculated from probing points and for the calculation of each element a minimum number of points is required as stated in Table 2.3. The probing points (PRB) are recorded by manually hitting the part or by generating nominal points. Each probing point is defined by its coordinates and the probing direction. The coordinate values of these points describe the contact points on the part surface. The probing direction is the normal direction of the part surface in this point. The next basic type of points is the clearance position (CLP). Clearance positions are control points to move the machine without collision. From the recorded measuring points which are a statistical sample of the entire surface, the software calculates an ideal assigned element. If more than the minimum number of probing points has been recorded the assigned element is fitted into the measuring

points using the Gaussian method. Each time an element is measured the recorded and calculated data are saved as element in the local database (LDB).

An element is a complex data type which contains all data of a geometric element, which includes:

- 1- Nominal element: data that is used during calculation and evaluation.
- 2- Actual element: the assigned element calculated from the probed points.
- 3- Nominal points: list of nominal points used to measure the element.
- 4- Actual points: list of actual measured points.
- 5- Evaluations: features to be evaluated of the element, includes tolerances.

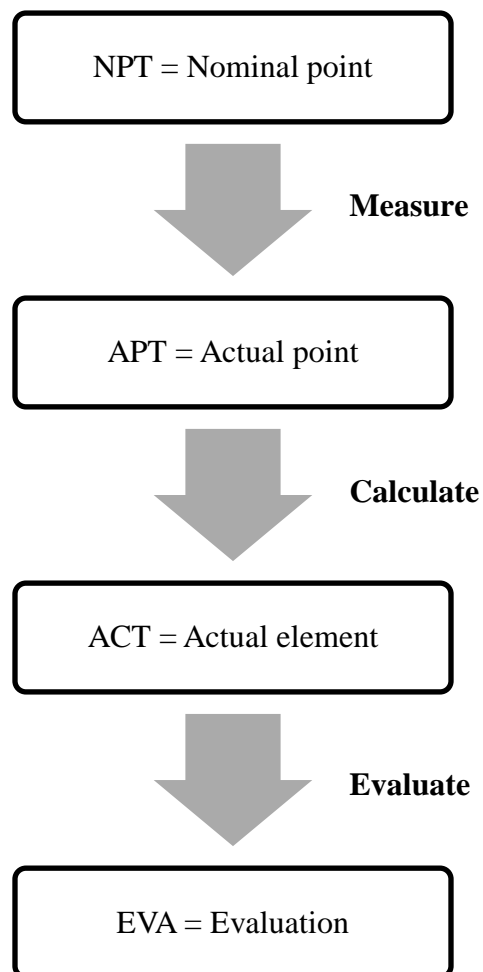


Figure 3.26. Object type element.

Measure Point

The command MEPNT is used to measure a point which has to be measured with a minimum of one probing. Projection and direction of the probe radius correction can be selected. The point can be measured in each of the axis (X, Y, Z).

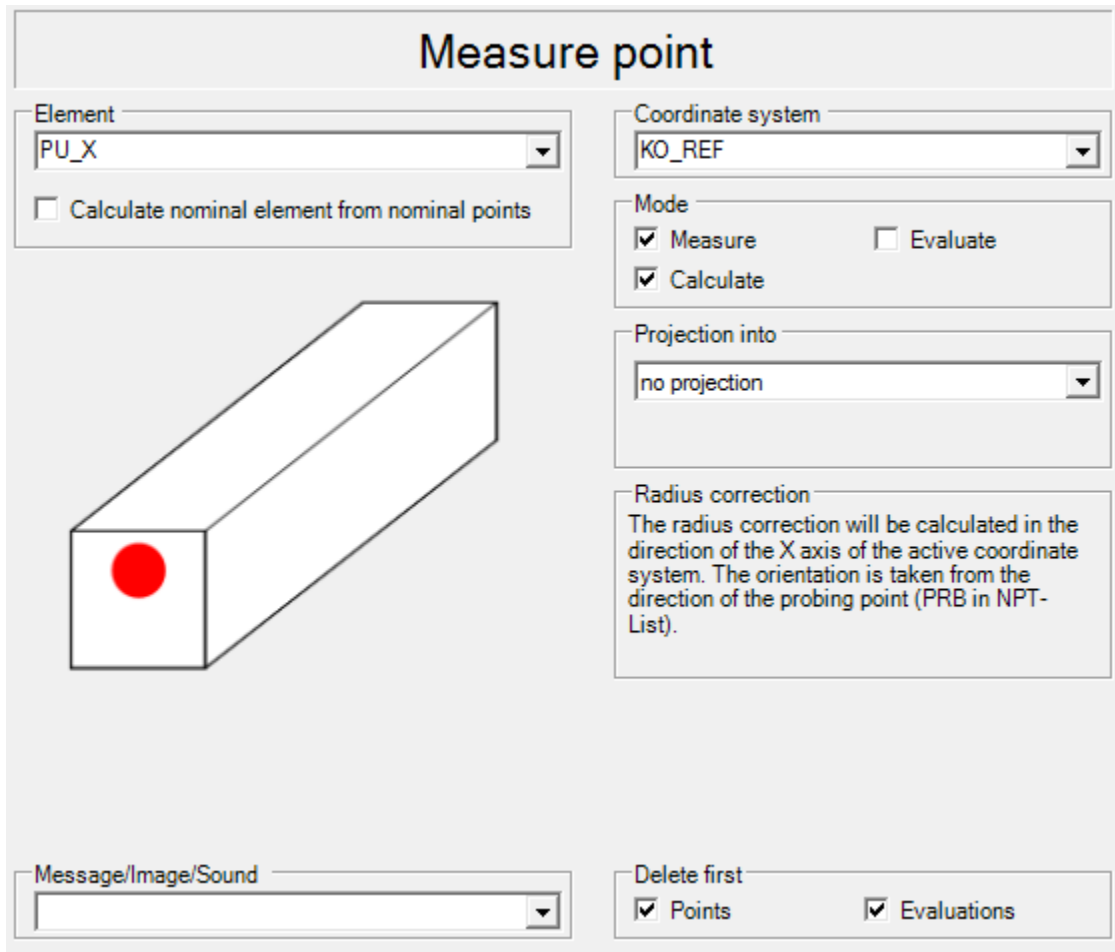


Figure 3.27. Measure point command dialog.

Generate Nominal Points of a Straight Line

The command GENAXI is used to generate nominal points on an axis. The coordinates of the first and second point are needed to calculate the axis. Also the number of points to be generated between the first and last point are needed, which by default is two points.

Generate nominal points of a straight line


Name of axis <input type="text" value="AXI_Y_S1"/> <input checked="" type="checkbox"/> Delete existing points	Coordinate system <input type="text" value="KO"/> Probing direction <input type="text" value="KO.\$ZDI"/>
Coordinates of first point X <input type="text" value="2.7"/> Y <input type="text" value="43.6"/> Z <input type="text" value="-23"/>	
Coordinates for last point X <input type="text" value="2.7"/> Y <input type="text" value="36.4"/> Z <input type="text" value="-23"/>	
Number of points <input type="text" value="6"/>	Clearance point distance <input type="text"/>
	Rotary table position <input type="text"/>

Figure 3.28. Generate nominal points of a straight line command dialog.

Measure Axis

For measuring an axis the command MEAXI is used. The axis has to be measured with a minimum of two probing. The projection and also the direction of the probe radius is selectable by the user.

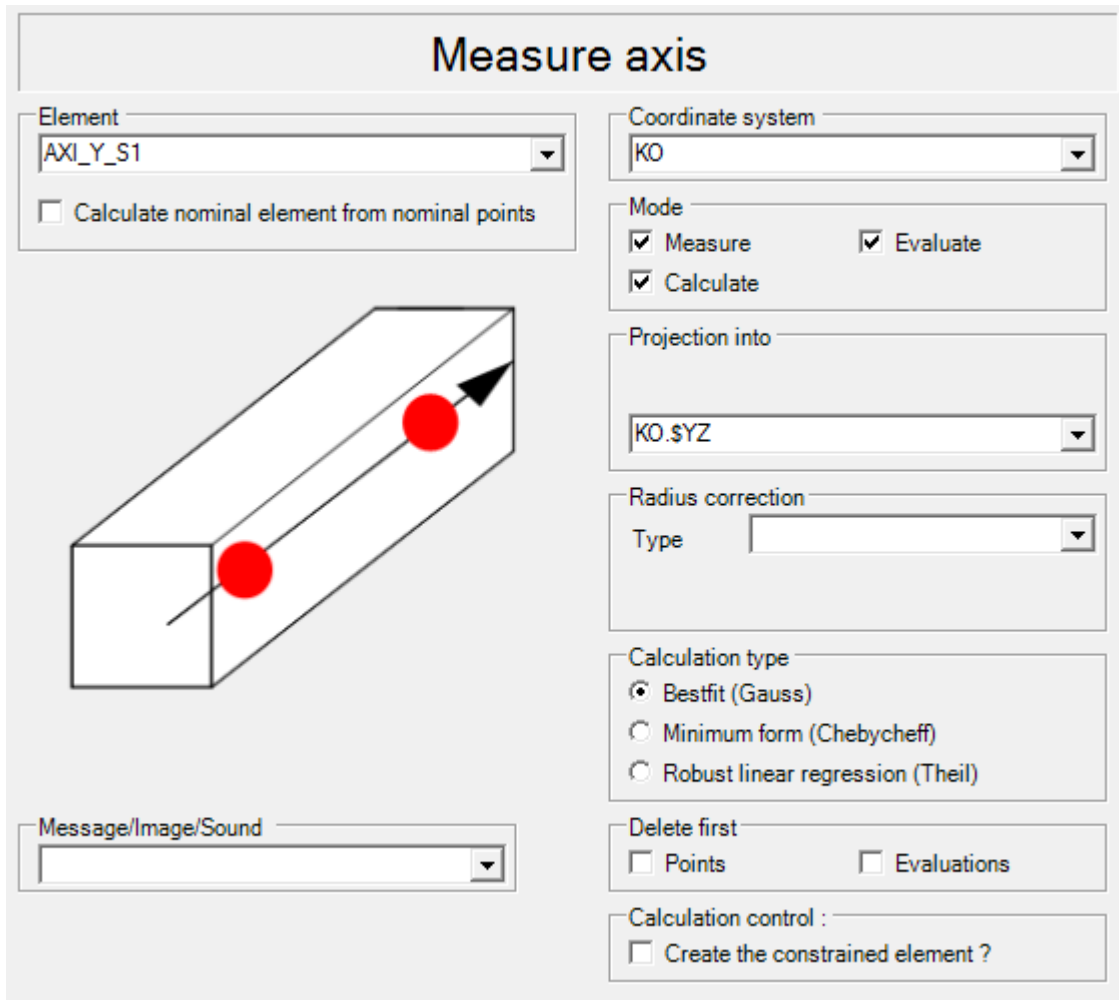


Figure 3.29. Measure axis command dialog.

Generate Nominal Points on a Plane

The GENPLA command generates nominal points on a plane. The element with the generated nominal points (NPT) must be measured with the command MEPLA. The location of the points must be specified so that the lines from point 1 to 2 and from points 2 to 3 are parallel to the coordinate axes. Otherwise a parallelogram is going to be generated, as observed on Figure 3.30.

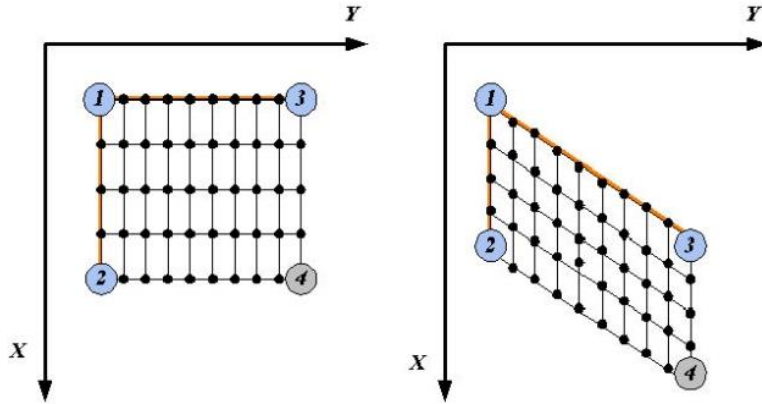


Figure 3.30. Location of points when measuring a plane. Taken from (Quindos 7 Manual)

Generate nominal points on plane

Name of plane

Delete existing points

Coordinate system

coordinate 1. point(P1)

X

Y

Z

coordinate 2. point(P2)

X

Y

Z

Plane normal direction

positiv negativ

coordinate 3. point(P3)

X

Y

Z

Number of points from P1 to P2

Clearance point distance

Nb. of points from P1 to P3

probing vector

Rotary table position

Figure 3.31. Generate nominal points on a plane command dialog.

Measure Plane

With the command MEPLA the geometrical element plane is measured. The measurement of a plane can be used to measure the position, orientation and form of a plane surface as well as for a coordinate system datum.

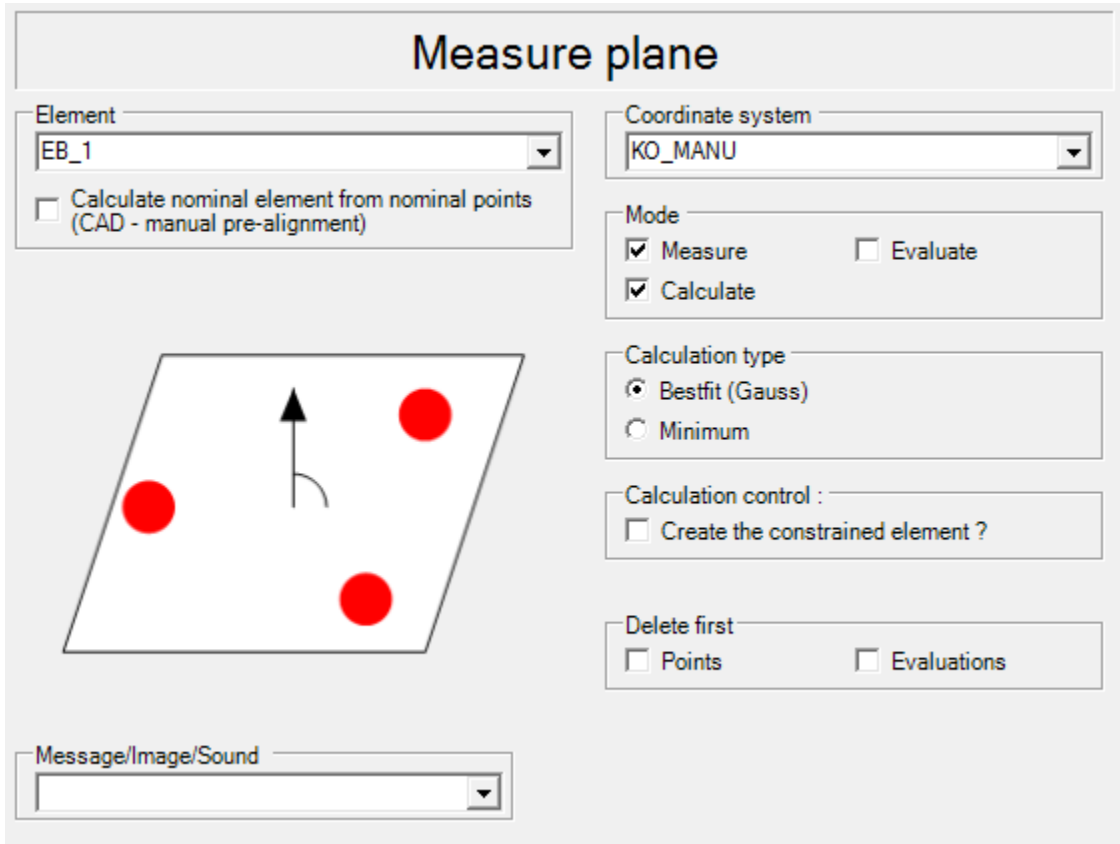


Figure 3.32. Measure plane command dialog.

After recording the probing points a plane is calculated using the selected fitting algorithm. The plane normal is always rectangular to the plane. It is important to take in account that the number and distribution of the probing points has an influence on the position of the center of gravity as well as the normal direction. A good probing strategy is to distribute the probing points equally so the center of gravity is close to the center of the plane as observed in Figure 3.33.

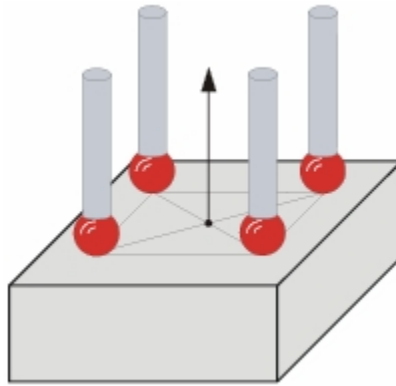


Figure 3.33. Probing points equally distributed over a plane surface. Taken from (Quindos 7 Manual)

Generate Nominal Points on Circle

The GENCIR command generates nominal points on a circle. The element generated with the nominal points must be measured with the command MECIR.

Generate nominal points on circle

Name of circle

Delete existing points

Coordinate system

Center coordinate of circle

X

Y

Z

Measuring plane
 XY YZ ZX

Circle type
 Internal External
 positiv negativ

Circle diameter

Get position from CAD

Number of points

Clearance point distance

Rotary table position

Rotary table offset

Slot width

Start angle of arc

End angle of arc

Figure 3.34. Generate circle command dialog.

Measure Circle

With the command MECIR the geometrical element circle is measured and it can be projected onto a freely selectable plane. Given as standard evaluation are the coordinates X, Y, Z of the centre of the circle as well as the radius and the diameter.

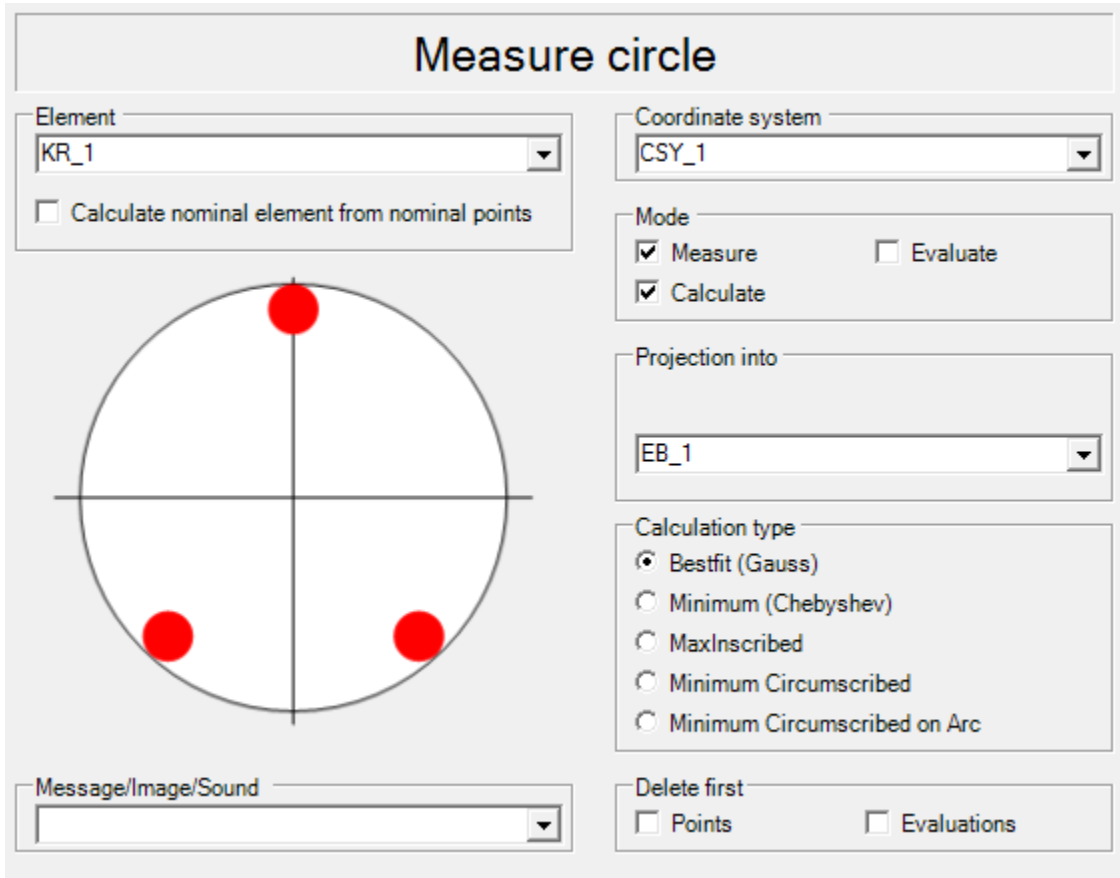


Figure 3.35. Measure circle command dialog.

Generate Nominal Points on a Cylinder

The command GENCYL generates nominal points on a cylinder. The points created with this command must be measured with the MECYL command.

Generate nominal points on cylinder

Name of cylinder

Delete existing points

Coordinate system

Center in X

Center in Y

Center in Z

Diameter

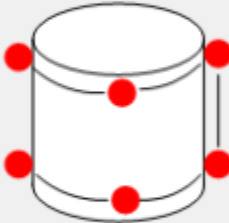
Length

Get info from CAD

Number of measuring planes

Number of points

Clearance point distance



Measuring plane
 XY YZ ZX

Cylinder type
 Internal External

Slot width

Offset from end of cylinder

Rotary table position

Rotary table offset

Start angle of arc

End angle of arc

Figure 3.36. Generate nominal points on a cylinder command dialog.

Generate Nominal Points on a Cone

For generating nominal points on a cone, the GENCON command is used.

Generate Nominal Points on Cone

Name of cone

Delete existing points

Coordinate system

Center coordinate of cone

X

Y

Z


Cone axis direction

+X +Y +Z

-X -Y -Z

Cone type

Internal External



Cone diameter at X,Y,Z

Cone angle

Slot width

Cone length

Offset from end of cone

Start angle of arc

Number of measuring planes

Clearance point distance

End angle of arc

Number of points to be gen.

Rotary table position

Figure 3.37. Generate nominal points on a cone command dialog.

Shift Actual Points along a Cone Surface

The command ADJCON is used to project all actual points of an element along the cone surface into the planar section defined by the reference diameter.

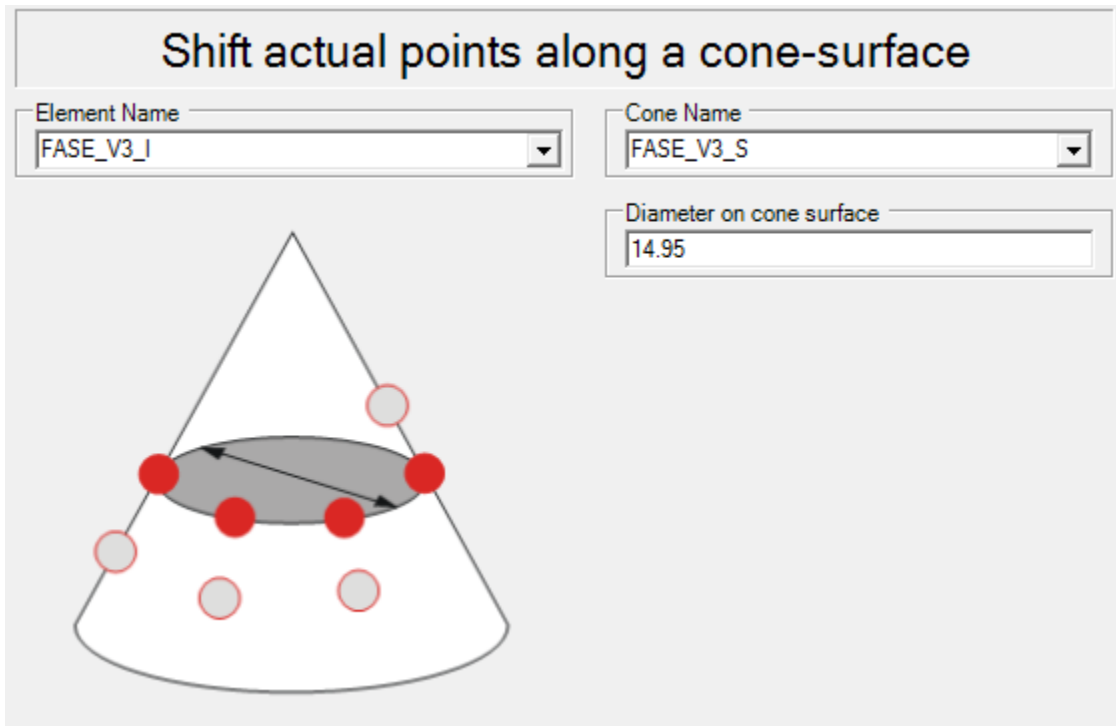


Figure 3.38. Shift actual points along a cone surface command dialog.

Screw Nominal Points

The command SCREWNPT can be used to transform circular point patterns into helical patterns for the measurement of screw threads. For the command to function correctly the points must be equally spaced in a circular pattern which lies in a plane parallel to one of the coordinate system planes.

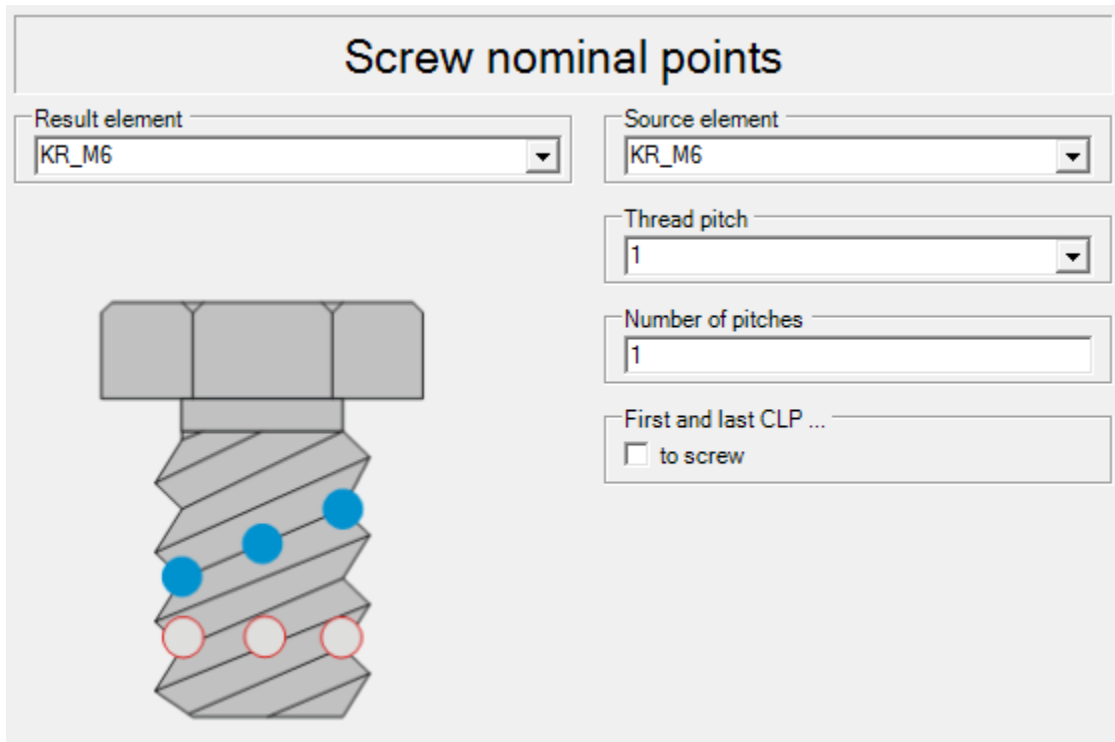


Figure 3.39. Screw nominal points command dialog.

3.2.2.5. Connecting Elements

Calculate Cylinder from Measured Circles

There are two different ways in which cylinders can be measured using the Quindos 7 software: by calculating a cylinder from multiple coaxial measured circles (BLDCYL) or by using the command MECYL. Nevertheless, it is preferred to measure a cylinder by calculating it from measured circles because of the calculation of the form error axis which is usually used for evaluating a form or location tolerance or used as reference.

To calculate the cylinder it is necessary to collect all measuring points of all circles and then compute the cylinder without the need to measuring them again, for this process generally different circles with 3 or 4 points are measured (this value also depends on the size of the cylinder). For a correct calculation the direction must be known approximately. During a teach-in this is derived from the position of the probings according to the different probing strategies. During generation it is taken from the nominal values entered before.

Example taken from the actual program:

1) Measurement of different circles in the cylinder (3 circles inside the bore)

```
GENCIR      (NAM=KR_Q_1, XCO=-5.8, YCO=0, ZCO=0, DIA=26, NPT=9, PLA=YZ, INO=I,  
PDI=3, CSY=CSY(1), ZVL=8+5.8)
```

```
MECIR      (NAM=KR_Q_1, CSY=CSY(1))
```

```
GENCIR      (NAM=KR_Q_2, XCO=-3.85, YCO=0, ZCO=0, DIA=26, NPT=9, PLA=YZ,  
INO=I, PDI=3, CSY=CSY(1), ZVL=8+3.85)
```

```
MECIR      (NAM=KR_Q_2, CSY=CSY(1))
```

```
GENCIR      (NAM=KR_Q_3, XCO=-1.9, YCO=0, ZCO=0, DIA=26, NPT=9, PLA=YZ, INO=I,  
PDI=3, CSY=CSY(1), ZVL=8+1.9)
```

```
MECIR      (NAM=KR_Q_3, CSY=CSY(1))
```

2) Collection of the circles into the cylinder

```
COLAPT      (NAM=ZYL(1), CSY=CSY(1), PTS=(KR_Q_1,KR_Q_2,KR_Q_3))
```

3) Generation of the nominal points for the cylinder

```
GENCYL      (NAM=ZYL(1), XCO=-5.8, YCO=0, ZCO=0, DIA=26, NPT=27, PLA=YZ,  
INO=I, PDI=3, CSY=CSY(1), LEN=4.8, NPL=3, ZVL=8)
```

4) Calculation of the cylinder

```
BLDCYL      (NAM=ZYL(1), CSY=CSY(1), RAD=3, INO=I, CTY=IM)
```

Then, the best fitted cylinder is calculated by using the measured points.

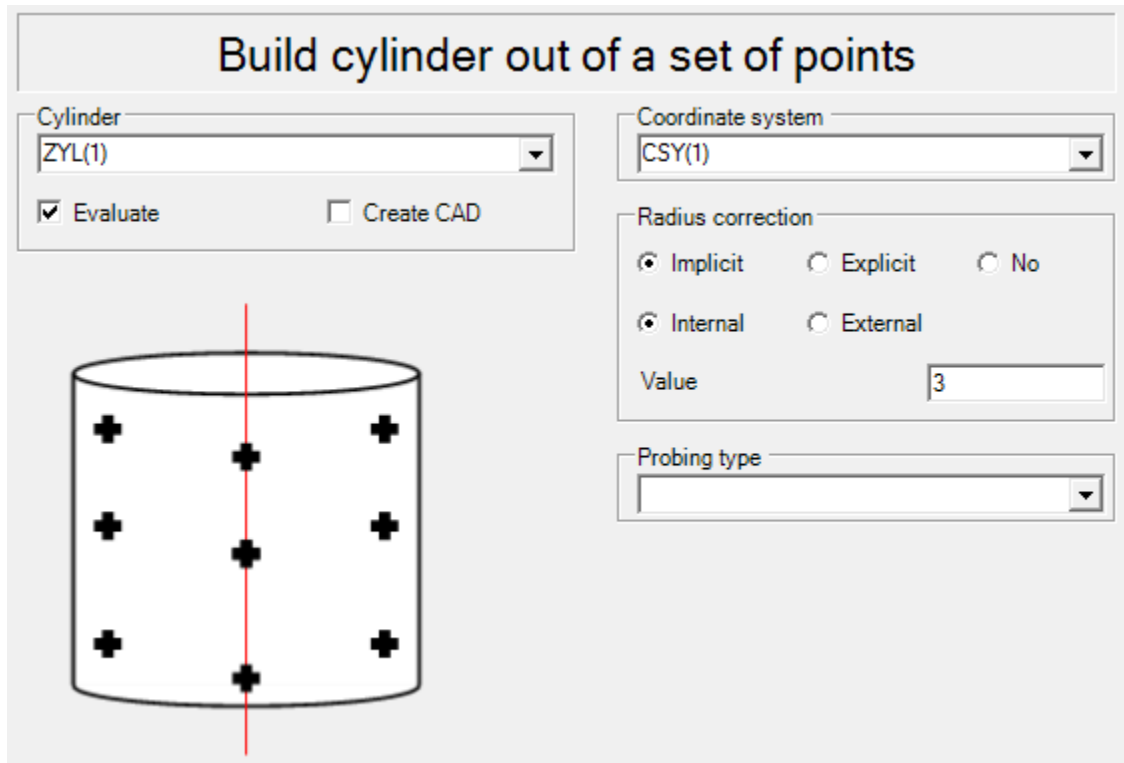


Figure 3.40. Build cylinder out of a set of points command dialog.

Collect Measured Points

With the command COLAPT actual points of one or more elements can be collected with the objective of building a geometric element out of the collected points. These measured elements can be measured in different coordinate systems, the points will then be transformed into one common coordinate system. This command is used in order to build elements out of a selection of actual points, for example: axes, cones, cylinders, planes, and other geometric elements.

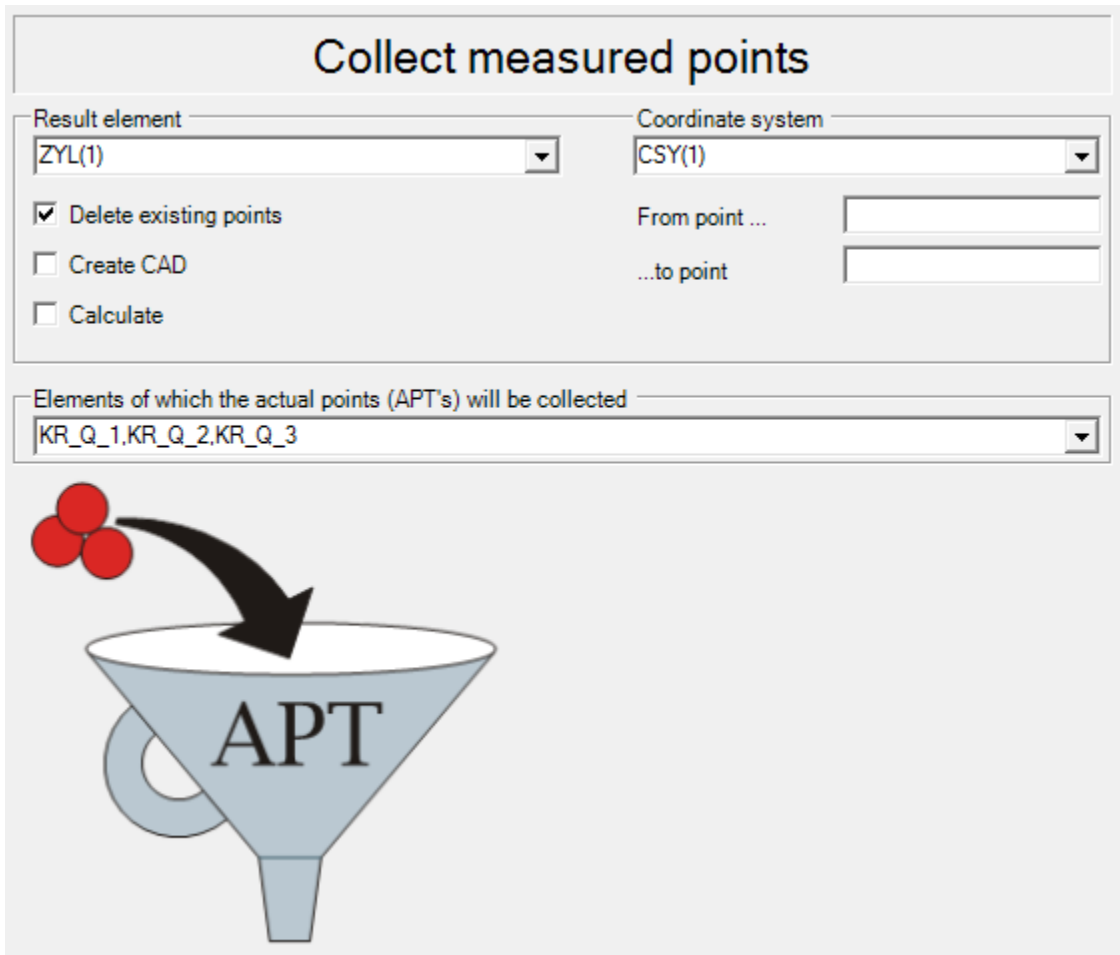


Figure 3.41. Collect measured points command dialog.

Collect Actual Points

With the command COLPTS calculated points of elements (circle center points, plane's point of gravity, etc) are collected. These elements could have been measured in different coordinate systems, later they are transformed into a common coordinate system. The main difference between the COLAPT and COLPTS commands is that the first one uses actual points (APTs) and COLPTS uses actual elements (ACTs). This command is used before using any BLDxxx commands.

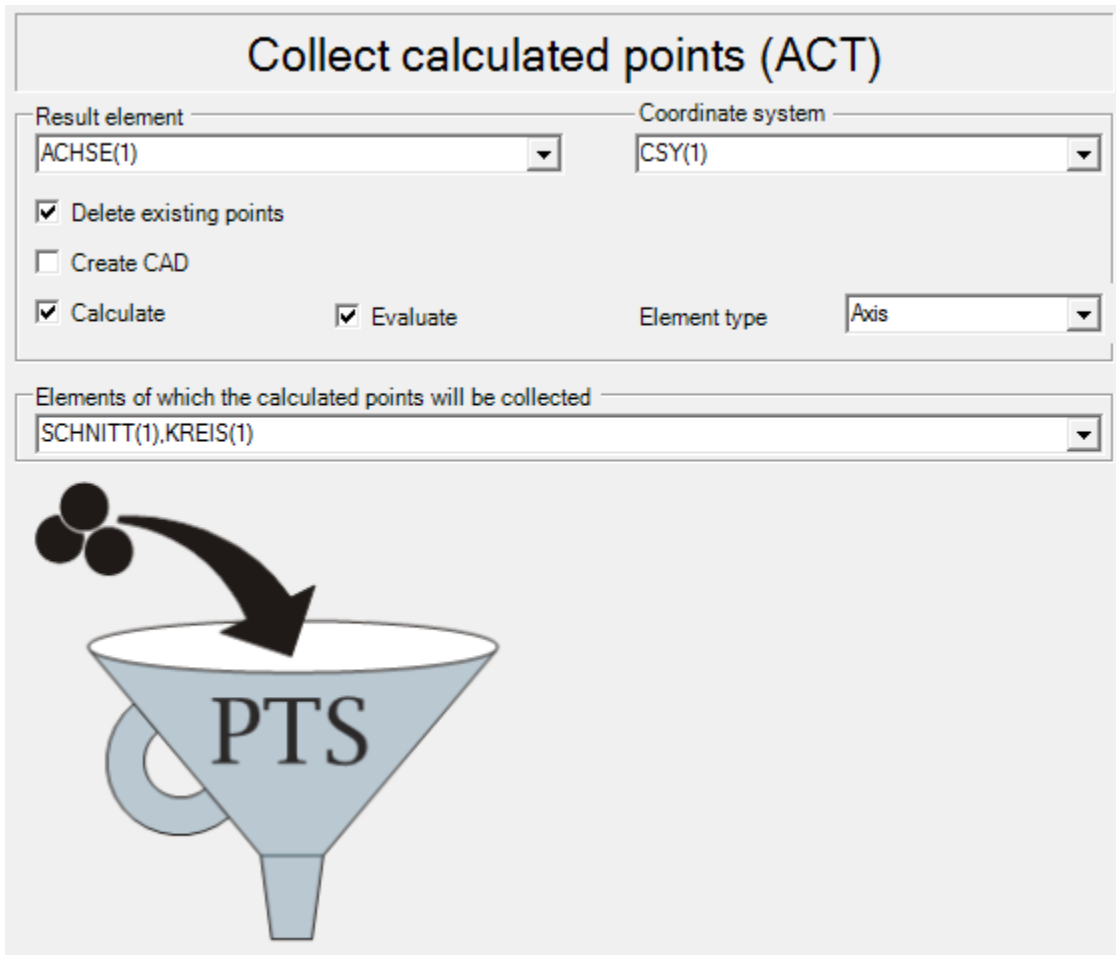


Figure 3.42. Collect actual points command dialog.

Distance between Two Points

To calculate the distance between two points for example center points or measured points, the command DIPNTPNT is used. Given as a standard evaluation is the spatial distance between the elements, as well as the single axis components of this distance relative to the coordinate system.

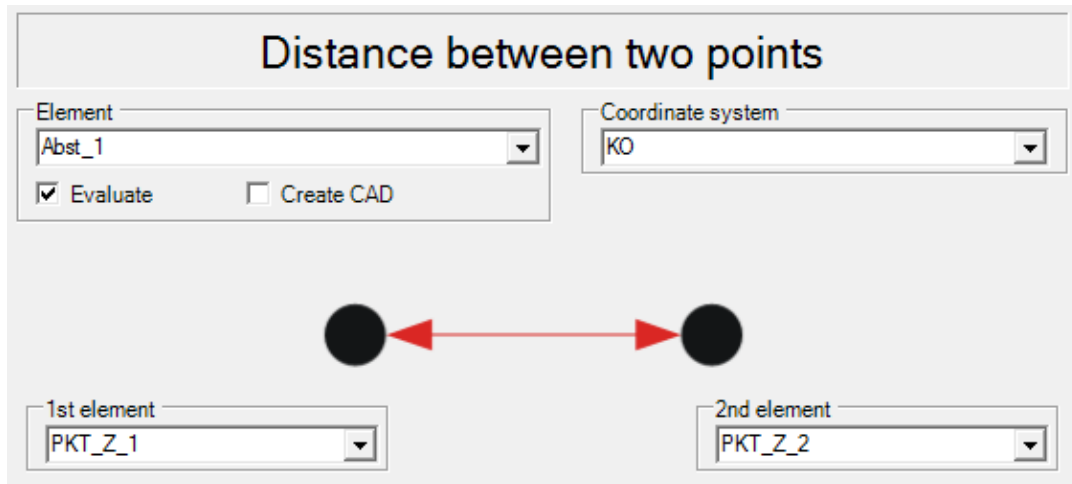


Figure 3.43. Distance between two points command dialog.

Intersection Point

With the command INTPNT (Intersection Point) elements are connected to one or more intersection points. Given as standard evaluation are the coordinates X, Y, Z of the intersection point.

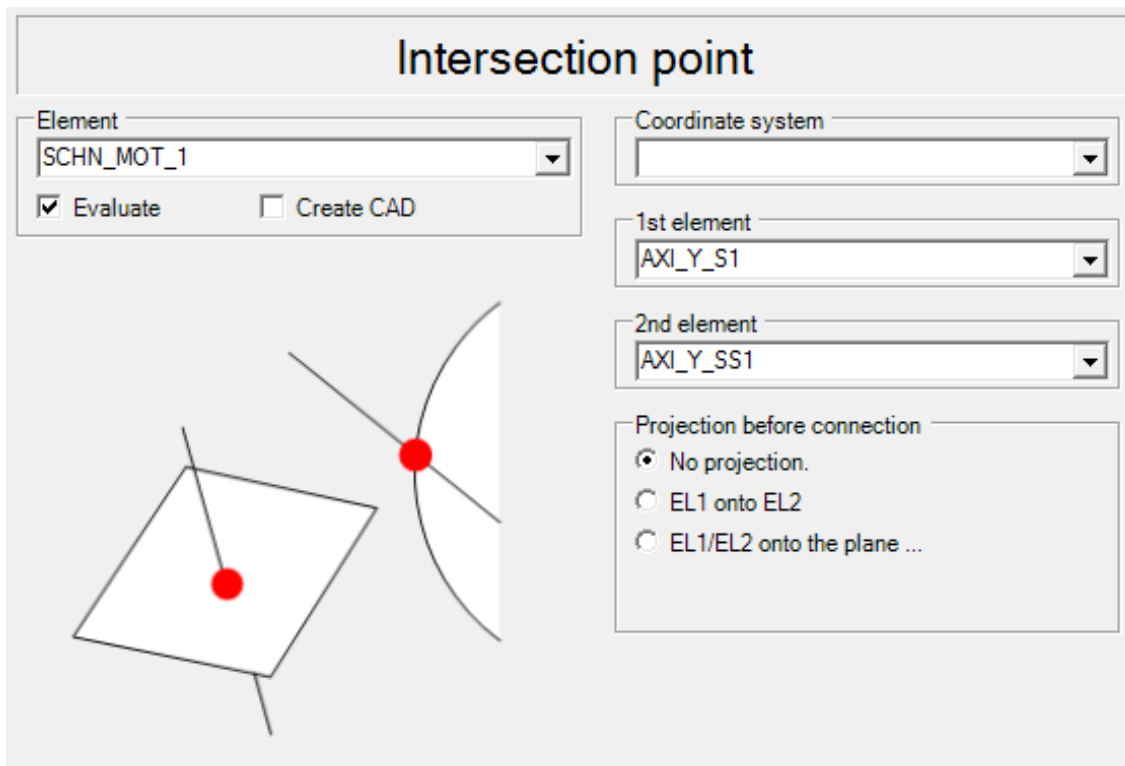


Figure 3.44. Intersection point command dialog.

Symmetry Point

The command SYMPNT (Symmetry point) calculates the symmetry point between two points. This point is defined as the point, which lies in space, equidistant from the two given points EL1 and EL2. Given as standard evaluation are the coordinates X, Y, Z of the calculated symmetry point.

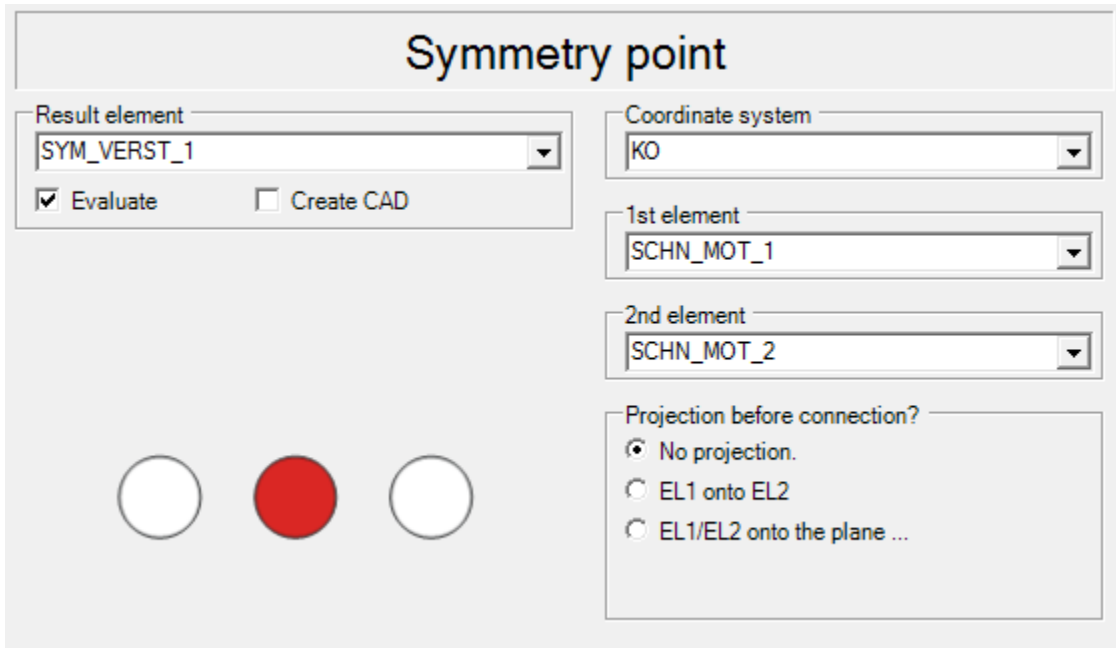


Figure 3.45. Symmetry point command dialog.

Intersection Point between Axis and Surface

With the command INAXISRF the intersection of an axis and an element-surface is calculated. Given as standard-evaluation are the coordinates X, Y, Z of the intersection point(s).

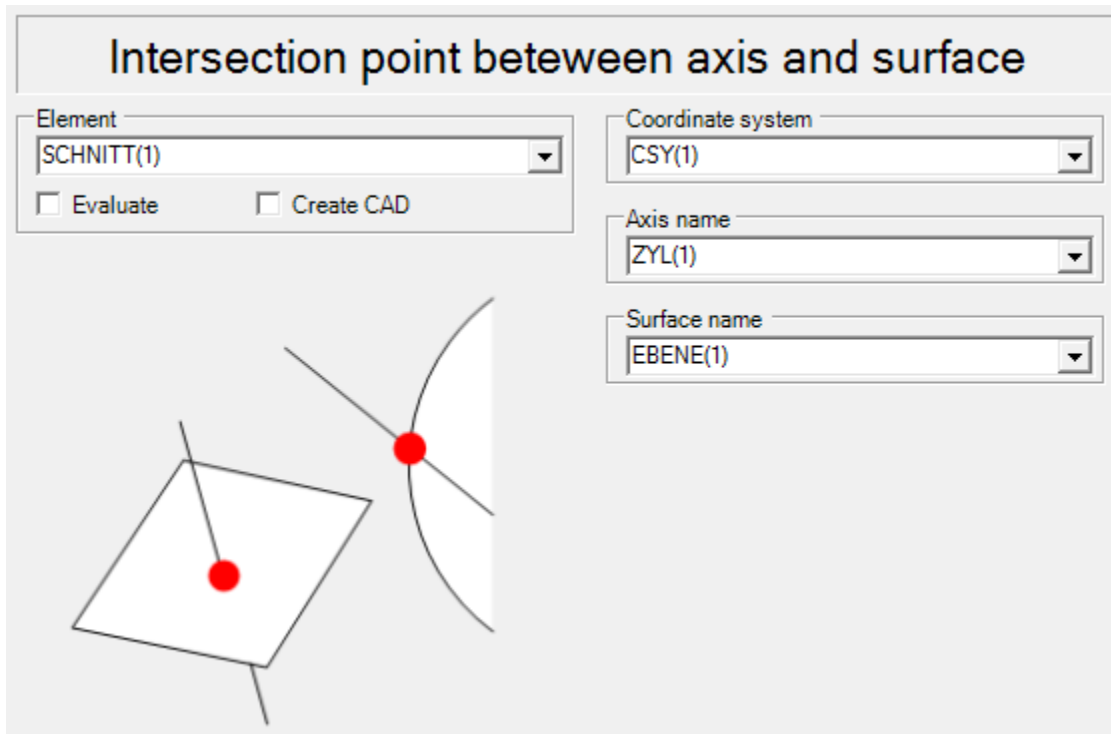


Figure 3.46. Intersection point between axis and surface.

3.2.2.6. Form and Position Tolerances

ISO 1101 Squareness (Perpendicularity)

The command SQRNES evaluates the squareness or perpendicularity of an axis or plane in accordance with ISO R1101. The result of this evaluation is an element (ISO-Element) containing the result of the ISO evaluation.

Table 3.2. Possible combinations for the evaluation of perpendicularity. Taken from (Quindos 7 Manual)

Measured element	Reference element	Tolerance element
Axis	Axis	Band of parallel planes
Axis	Plane	Cylindric, Band of parallel planes, box
Plane	Axis	Band of parallel planes
Plane	Plane	Band of parallel planes

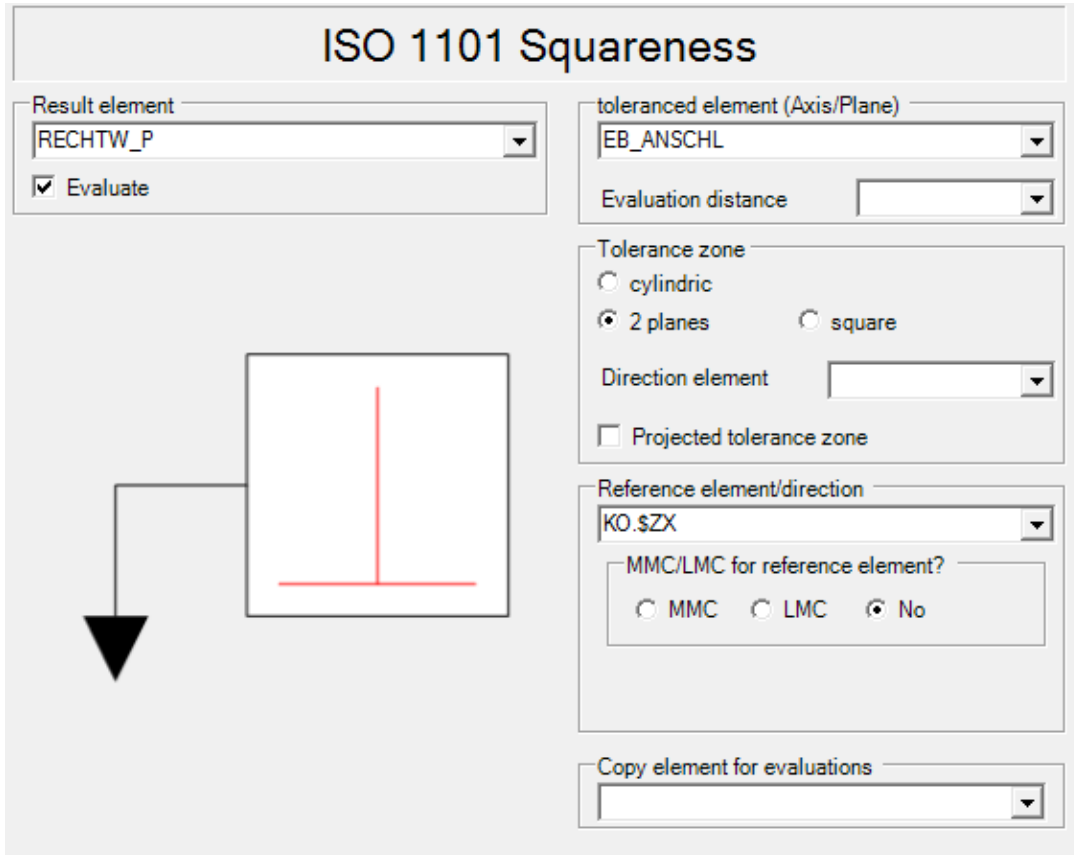


Figure 3.47. Squareness command dialog.

ISO 1101 Symmetry

The command SYMTY evaluates the symmetry of elements (point, axis, or plane) in accordance with ISO R1101. A plane of symmetry is calculated between the planes DT1 and DT2 and used as reference plane to determine the deviation of the object. The result of the symmetry evaluation is twice the distance between the object and the reference plane.

Table 3.3. Possible combinations for the evaluation of symmetry. Taken from (Quindos 7 Manual)

Measured element	Reference element 1	Reference element 2	Tolerance element
Point	Plane	Plane	Band of parallel planes
Axis	Plane	Plane	Band of parallel planes
Plane	Plane	Plane	Band of parallel planes

ISO 1101 Symmetry

Result element

Evaluate

Name of a plane,axis or point

1st reference plane / axis

2nd reference plane / axis

Axis

Projection plane

Projected tolerance zone

Reference

Min Max.

Copy element for evaluations

Figure 3.48. Symmetry command dialog.

ISO 1101 Parallelism

The command PARALL evaluates the parallelism of an axis or plane in accordance with ISO R1101. The result of this evaluation is an element (ISO-Element) containing the result of the ISO evaluation.

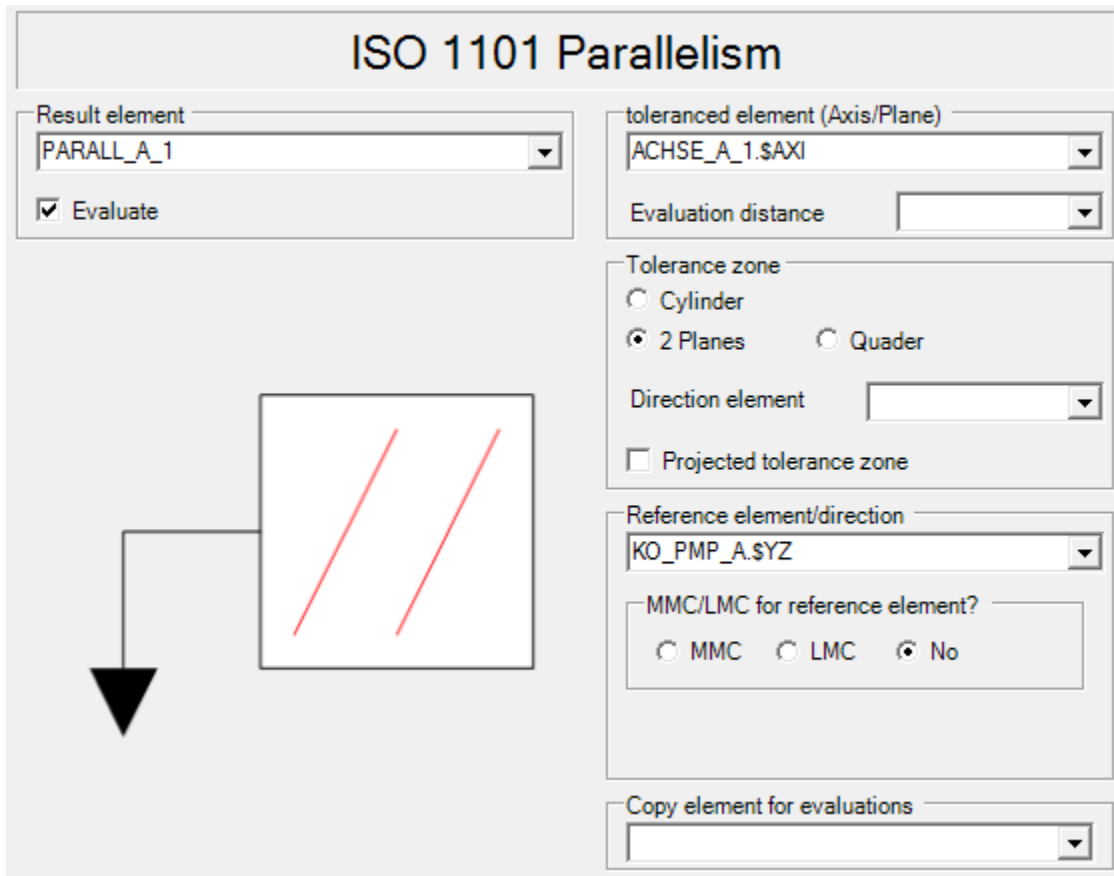


Table 3.4. Possible combinations for the evaluation of parallelism. Taken from (Quindos 7 Manual)

Measured element	Reference element	Tolerance element
Axis	Axis	Band of parallel planes, Cylinder, Quader
Axis	Plane	Band of parallel planes
Plane	Axis	Band of parallel planes
Plane	Plane	Band of parallel planes

ISO 1101 Position

The command POSITN calculates the position of a point, axis or plane in accordance with ISO R1101. The result of this evaluation is an element (ISO-Element) containing the result of the ISO evaluation.

ISO 1101 Position in YZ plane

Result element ▼

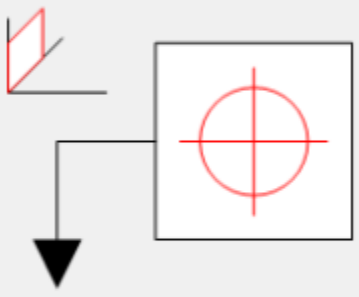
Evaluate

Name of the axis or plane ▼

Type of tolerance zone ▼

Type of coordinate system
 cartesian cart.@ 0 polar

Distance from the zero point in the active
rcv
Y
Z
 Consider sign of nominals



Entry to HRC:QSTPGRP ▼
 Group ELE for qs-STAT?

Copy element for evaluations ▼

Figure 3.49. Position command dialog.

ISO 1101 Radial Run-out

The command RADRUN evaluates the radial runout of a circle in accordance with ISO R1101. The result of this evaluation is an element (ISO-Element) containing the result of the ISO evaluation. The actual points are projected into a plane whose direction is defined by the reference axis.

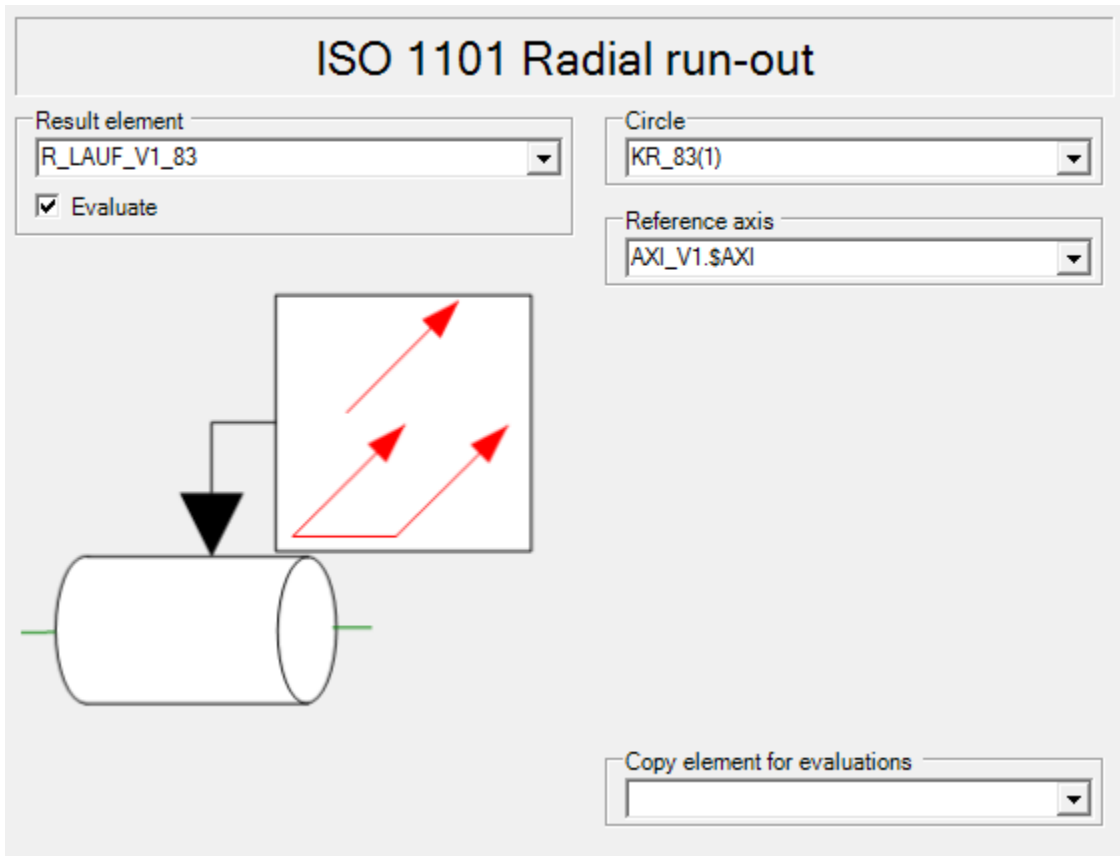


Figure 3.50. Radial run-out command dialog.

ISO 1101 Axial Run-out

The AXIRUN command (Axial Run-out) evaluates the axial runout of a surface (circular probings) according to ISO R1101. The result of this evaluation is an element (ISO element) which contains the results of the ISO evaluation. The maximum distance of all measured points in direction of the reference axis is determined. Evaluation symbol: AXIRUN

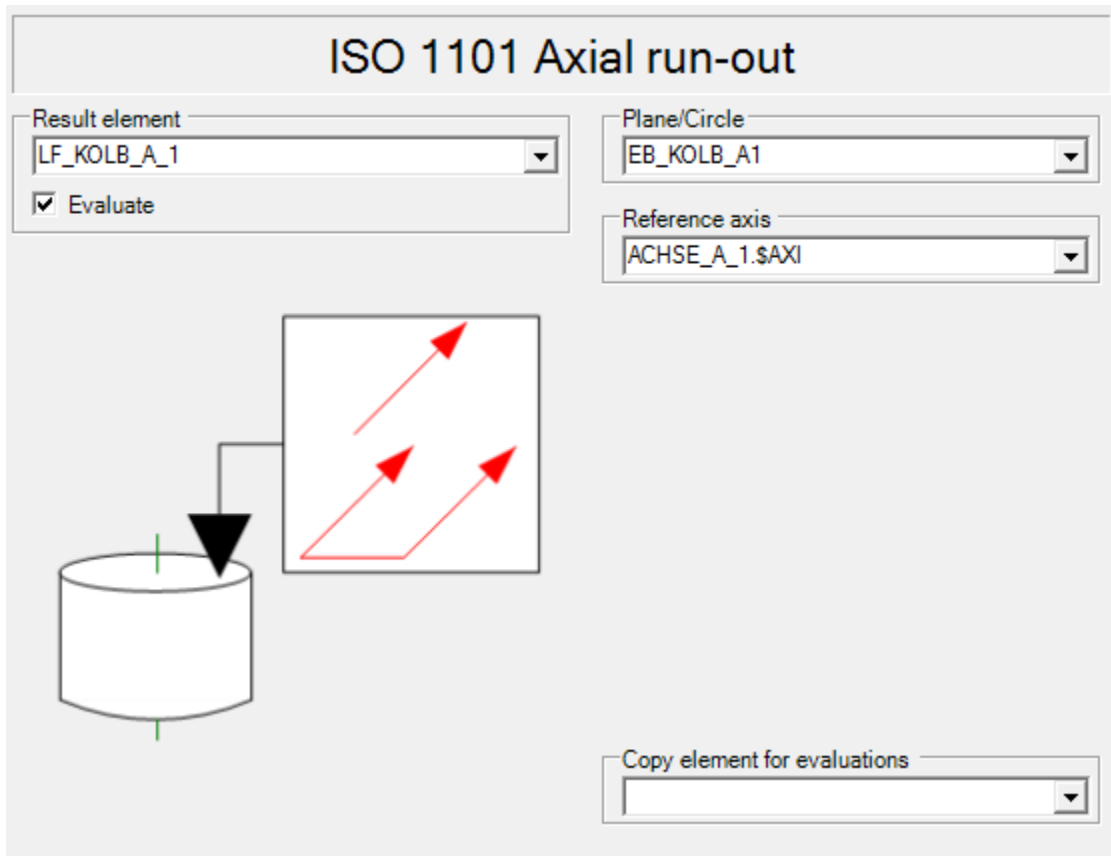


Figure 3.51. Axial run-out command dialog.

ISO 1101 Coaxiality/Concentricity

The command COAXTY calculates the coaxiality/concentricity of an axis or point to a reference axis or point in accordance with ISO R1101. The result of this evaluation is an element (ISO-Element) containing the result of the ISO evaluation.

Table 3.5. Possible combinations for the evaluation of coaxiality. Taken from (Quindos 7 Manual)

Measured element	Reference element	Tolerance element
Point	Point	Circle
Point	Axis	Circle
Axis	Axis	Cylinder

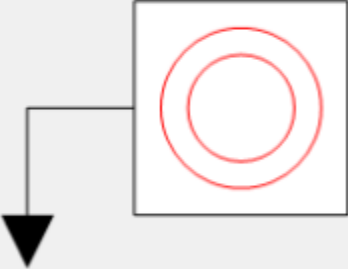
ISO 1101 Coaxiality/Concentricity

Result element
 Evaluate

Name of the axis or point

Name of the reference element
 MMC/LMC for reference element?
 MMC LMC No

Projection plane



Projected tolerance zone
 Reference Min Max.

Copy element for evaluations

Figure 3.52. Coaxiality/Concentricity command dialog.

3.2.3. Program Planning

Dimensional inspection of parts and subassemblies costs money to the company and can contribute tremendously to the total manufacturing cost of the product. It is of extremely importance to plan the measurement process effectively, to reduce time of inspection and thus the costs of it. For the measurement planning there are three important elements needed, the mechanical drawing of the workpiece, the inspection request where the inspection features are specified, and the physical part itself. The measurement task analysis describes the necessary geometric elements and the sequence in which they are measured.

3.2.3.1. *Basics for the Operation*

Homing Machine

The command AUTZER is used as an automatic procedure that sends the measuring device to its zero position. This instruction should be executed every time after switching the machine on or prior to any stylus qualification process. With this command the X- and Y- counters are set to zero, and the Z- counter is set according to the Z- range of the measuring device. This defined homing of the measuring device is a condition for the correct use of all automatic correction procedures such as scale error correction, angle correction, temperature compensation, etc. It is important to verify that the machine can move from the current position to the home position without collision.

Probe Qualification

Determining the size characteristics for each stylus by using a calibration standard or qualification artifact is the primary goal of the process of qualification. They affect the calculation of the position of the probing points with the workpiece surface relative to the probe. To be able to calculate the correct position of the stylus, the location of the probing head must be additionally specified. The determination of this relative position of the probing head is the secondary objective of calibration. For the probe qualification it is important to verify that all of the probes that are going to be calibrated are mechanically mounted on the rack. To perform the probe qualification process some general steps must be executed:

1. Define the calibration sphere: the command DfnArtefact is used to specify the diameter and position/orientation of the qualification sphere to be used by the machine. A name must be given to the qualification artifact and parameters such as sphere diameter, shaft diameter at sphere, and azimuth and elevation angle must be given. In Figure 3.53 an example is shown where the parameters are the ones of the qualification sphere for the Leitz PMM 866 machine which data can be obtained from the calibration certificate.

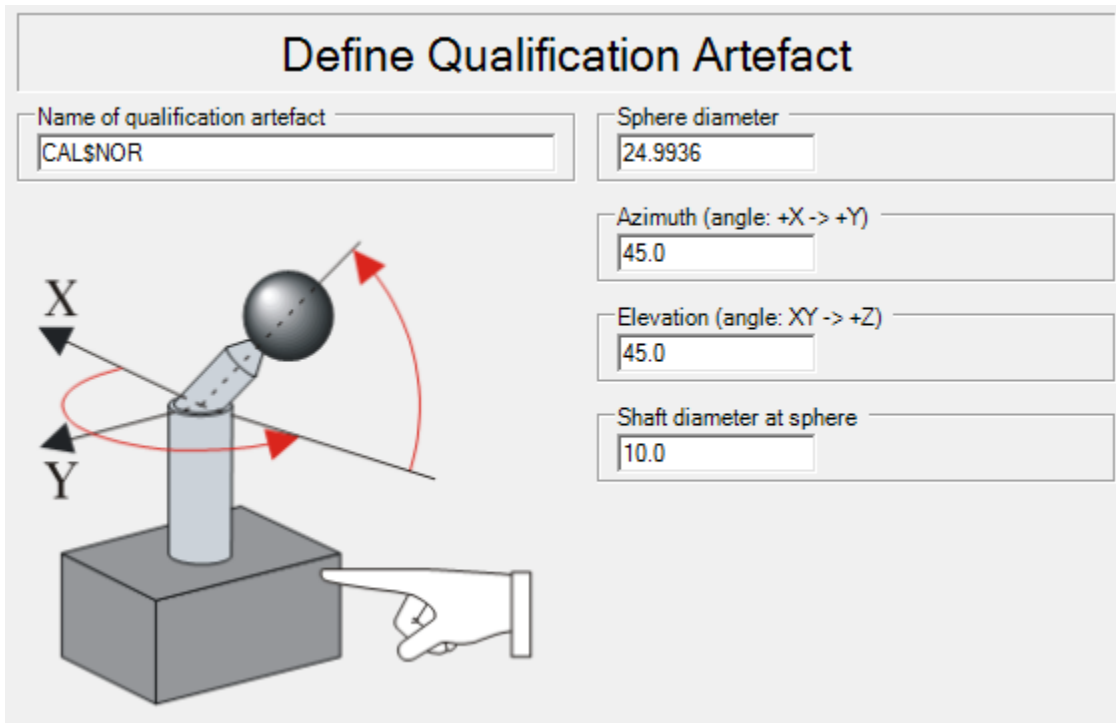


Figure 3.53. Define qualification artifact command dialog.

2. Activate an existing calibration sphere: when multiple spheres have been defined, the command UseArtefact is used to select one of the calibration spheres. The command dialog is shown in Figure 3.54 and the only input is the name of the qualification sphere which was saved in the database.

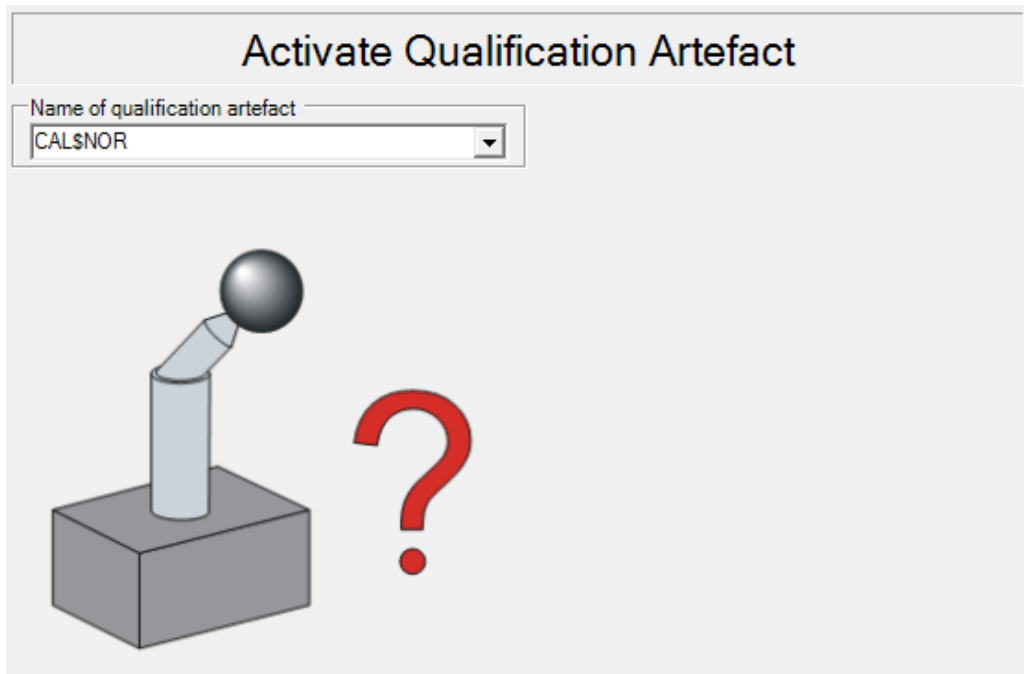



Figure 3.54. Activate qualification artifact command dialog.


3. Set probe to qualify: then it is necessary to choose which probe-pin is going to be calibrated. This is done by using the command USEPRB which indicates which one of the probes is going to be calibrated.
4. Calibrate reference probe: the process of calibration of the probe is done by using the command QualifyTool. When using this command the tool name must be given specifying which probe-pin is going to be calibrated, also the name of the artifact used to calibrate the probe-pin, the magazine position, the head type, the sensor type, and the diameter of the head. First, the user must enter a clearance position above and a probing point on the pole of the qualification sphere, then the rest of the process is automatic. In the Figure 3.55, it can be observed the calibration command dialog for the PRB211.

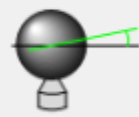
Qualify Tool

Tool name	PRB(211) ▼	Name of Artefact	CAL\$NOR ▼
Magazin Position	2	Head Type	Without Wrist ▼
<input type="checkbox"/> Delete existing points		Sensor Type	Leitz LSP S1 ▼
<input checked="" type="checkbox"/> Define Shaft Direction		Elevation XY --> Z	0
		Azimuth +X --> +Y	0

Sphere probe	Disk probe	Cylinder probe
--------------	------------	----------------







Probe diameter	1.500
Angle restriction	

Additional scanning qualification
 Qualify as reference probe

CMM parameter set (optional)	▼
------------------------------	---

Figure 3.55. Qualify tool command dialog.

3.2.3.2. Main Program

At the beginning of the measuring program, some basic commands are used to initialize the configuration of the machine, and an image is printed on screen which shows the way in which the valve block should be positioned using the fixture of the machine.

Then, the command ENBSYS (NAM=CMDICO) is entered which means it enables the system parameter CMDICO which is used to define the probing point using its coordinates and

the probing direction. The coordinate values given refer to the surface of the workpiece. As a rule, the direction of the normal probing direction is determined by the connecting line between the last point and the probing point. For PMM measuring machines the direction of the normal may also be derived from the DVM values (probe head inclination during probing).

Then the command USECMM is used to activate a set of user defined measuring machine parameters. For the Leitz PMM 866 these parameters are already defined and are saved in the global database (GDB) with the name SAVE\$CMM, which are shown in Figure 3.56.

Machine parameters

<div style="border: 1px solid gray; padding: 5px; margin-bottom: 5px;"> <p>Move Parameter</p> <p>Speed X-Axis <input style="width: 80%;" type="text" value="10"/></p> <p>Speed Y-Axis <input style="width: 80%;" type="text" value="10"/></p> <p>Speed Z-Axis <input style="width: 80%;" type="text" value="10"/></p> <p>Speed Rotary Table <input style="width: 80%;" type="text" value="20"/></p> <p>Accuracy <input style="width: 80%;" type="text" value="0.1"/></p> </div> <div style="border: 1px solid gray; padding: 5px;"> <p>Scanning parameter</p> <p>Scan Mode <input style="width: 80%;" type="text" value="SCA"/></p> <p>Scan Type <input style="width: 80%;" type="text" value="PLA"/></p> <p>Scan Speed <input style="width: 80%;" type="text" value="1"/></p> <p>Scan accuracy <input style="width: 80%;" type="text" value="0.1"/></p> <p>Point density <input style="width: 80%;" type="text" value="4"/></p> <p>Scanning Offset <input style="width: 80%;" type="text" value="0"/></p> <p>Scanning Limit <input style="width: 80%;" type="text" value="0"/></p> </div>	<div style="border: 1px solid gray; padding: 5px; margin-bottom: 5px;"> <p>Probing parameter</p> <p>Speed <input style="width: 80%;" type="text" value="0.3"/></p> <p>Probing Offset <input style="width: 80%;" type="text" value="0.1"/></p> <p>Search distance <input style="width: 80%;" type="text" value="10"/></p> <p>Control <input style="width: 80%;" type="text" value="DFL"/></p> </div> <div style="border: 1px solid gray; padding: 5px;"> <p>Lower force <input style="width: 80%;" type="text" value="0.1"/></p> <p>Trigger force <input style="width: 80%;" type="text" value="0.2"/></p> <p>Upper force <input style="width: 80%;" type="text" value="0.4"/></p> <p>Max. force <input style="width: 80%;" type="text" value="0.5"/></p> <p>Min. No. of data <input style="width: 80%;" type="text" value="7"/></p> <p>Divisor for retract speed <input style="width: 80%;" type="text" value="50"/></p> <p>Retract dist. in Step mode <input style="width: 80%;" type="text" value="-1"/></p> <p>Retract dist. in scanning <input style="width: 80%;" type="text" value="0"/></p> </div>						
<div style="border: 1px solid gray; padding: 5px;"> <p>Auxiliary parameter</p> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%;">b <input style="width: 80%;" type="text" value="0"/></td> <td style="width: 50%;">g <input style="width: 80%;" type="text" value="0"/></td> </tr> <tr> <td>c <input style="width: 80%;" type="text" value="0"/></td> <td>h <input style="width: 80%;" type="text" value="0"/></td> </tr> <tr> <td>e <input style="width: 80%;" type="text" value="0"/></td> <td>j <input style="width: 80%;" type="text" value="1"/></td> </tr> </table> </div>		b <input style="width: 80%;" type="text" value="0"/>	g <input style="width: 80%;" type="text" value="0"/>	c <input style="width: 80%;" type="text" value="0"/>	h <input style="width: 80%;" type="text" value="0"/>	e <input style="width: 80%;" type="text" value="0"/>	j <input style="width: 80%;" type="text" value="1"/>
b <input style="width: 80%;" type="text" value="0"/>	g <input style="width: 80%;" type="text" value="0"/>						
c <input style="width: 80%;" type="text" value="0"/>	h <input style="width: 80%;" type="text" value="0"/>						
e <input style="width: 80%;" type="text" value="0"/>	j <input style="width: 80%;" type="text" value="1"/>						

Figure 3.56. Machine parameters for the Leitz PMM 866.

Then the command set is used to configure other important settings for the measuring program. In this case the default general tolerance is used (DFLT\$TOL). After initializing the machine, the measuring program is started.

At first, the 413 probe pin is selected because of the position of the valve block which front is measured first and this probe contains the largest pin head diameter and most of the geometric features need a probe in the $-X$ axis direction. To perform a rough alignment of the workpiece so that the machine knows the position of the workpiece, it is necessary to define a first coordinate system as a reference. To create this coordinate system, 3 points must be measured to define it. This is done by using the commands MEPNTX, MEPNTY, MEPNTZ. These points are measured manually using the control panel of the machine. The code for measuring these 3 points in the different axes is shown below and the used coordinate system is KO_REF which parameters are shown in Figure 3.57.

```
MEPNTX      (NAM=PU_X, CSY=KO_REF, MOD=NOE, DEL=YY)
MEPNTY      (NAM=PU_Y, CSY=KO_REF, MOD=NOE, DEL=YY)
MEPNTZ      (NAM=PU_Z, CSY=KO_REF, MOD=NOE, DEL=YY)
BLDCSY      (NAM=KO_MANU, XZE=PU_X, YZE=PU_Y, ZZE=PU_Z)
```

Coordinate System Data			
Type	CAR	Reference System	REFR\$CSY
<input type="checkbox"/> bound to CAD		Direction	ZX XYZ
Translation		Rotation Matrix	
X	-37.878	1	0
Y	-2.854	0	1
Z	123.722	0	0
		0	1

Figure 3.57. Coordinate system data of KO_REF.

Then a point and a plane are measured to carry out a rough alignment of the piece, using as a reference the new coordinate system named KO_MANU.

```
MEPNT          (NAM=PKT_Z, CSY=KO_MANU, MOD=NOE)
MEPLA          (NAM=EB_1, CSY=KO_MANU, MOD=NOE, ITY=GSS)
BLDCSY        (NAM=CSY_1, SPA=EB_1, SDR=X, XZE=EB_1,
YZE=KO_MANU.$ZP, ZZE=PKT_Z)
```

Then, it is necessary to define a new coordinate system that is going to be used to know the average location of the workpiece and to define the coordinate system defined by the datums in the mechanical drawing. For this step, it is necessary to measure some geometric features defined as follows. First, two circles are generated and measured so it is possible to collect the central point of each circumference and generate an axis that goes through the center of both bores, which is carried up by using the command COLPTS. Then this axis called ACHSE_1 is used to define the direction of the Z axis of the workpiece. In the definition of the coordinate system the direction is in Z- as the axis goes from the circle 1 to the circle 2 and it is required to go in the opposite direction.

```
GENCIR        (NAM=KR_1, XCO=-3.5, YCO=-45, ZCO=-41.8, DIA=22,
NPT=4, PLA=YZ, PDI=3, CSY=CSY_1, ZVL=8+3.5)
MECIR         (NAM=KR_1, CSY=CSY_1, PRO=EB_1, MOD=NOE)

GENCIR        (NAM=KR_2, XCO=-11, YCO=-45, ZCO=-67.3, DIA=7,
NPT=6, PLA=YZ, PDI=3, CSY=CSY_1, ZVL=8+11)
MECIR         (NAM=KR_2, CSY=CSY_1, PRO=EB_1, MOD=NOE)

COLPTS        (NAM=ACHSE_1, CSY=CSY_1, ELE=(KR_1,KR_2),
TYP=AXI)
```

```
BLDCSY          (NAM=CSY(1), TYP=CAR, SPA=EB_1, SDR=X,  
PLA=ACHSE_1, PDR=-Z, XZE=EB_1, YZE=KR_1, ZZE=KR_1)
```

After defining the previous coordinate system, it is necessary to perform a more accurate measurement of the geometric features of the workpiece for the definition of the new coordinate system which uses datums P and Q as stated in the mechanical drawings. To perform this task, three circles are generated and measured in the first bore to define the axis that goes through the center of the cylinder. Then, the intersection of the axis and the plane of the surface is calculated which is going to be used as the center point of the coordinate system. Then, the axis that goes through both bores is calculated and the new coordinate system is defined. Once the alignment using the reference datums P and Q is finished, it is possible to measure and evaluate all the geometric tolerances and features that use these references in the mechanical drawing.

After the important geometric features on the front of the piece are measured, the machine changes the probe to 414 to start measuring some characteristics on the side. First, it measures the side A which is the right one and then measures the other side using the probe 412. Once it is finished with these geometric elements on both sides of the valve block, it changes to probe 411, which is useful to measure the elements on the back of the block as the probe is in direction of the +X axis. Before measuring the elements on the back, it is necessary to change the reference coordinate system as these elements use different datums. Because of this, a new alignment of the piece is necessary by using the reference datums V and Z. Then, the machine measures the valves on the back side and other elements. Then, the stylus 21X is used to measure smallest elements as its probe-pins have a 1,5 mm diameter. After this process, the channels are measured by using pins on the bores, so the machine can measure the pin and determine the position. For each of the channels the coordinate system is transformed using the respective inclination of the channels. Once the channels are measured, the valve block must be turned around so that the bottom of the piece is now placed on top. In this way the rest of the channels which were not reachable with the previous placing of the workpiece. For this measuring process, a new alignment is necessary using the datums P and Q to define the new coordinate system.

The most important contribution of this section is to effectively explain the process of the development of the inspection planning and the programming of the coordinate measuring machine used for performing the measuring test. It clarifies the most important parts of the program and inspection and not the whole measuring process, as some parts of it are repetitive because of the similar characteristics of the geometric features. The programming of the machine takes all this concepts and commands to inspect and evaluate each of the geometric features. It summarizes important aspects such as the process of defining a coordinate system, the setup of the machine, probe qualification process, and other machine parameters. It also explains in detail, the process of inspection for each of the geometric features which in brief consists in acquiring the probed points, calculating the geometric elements, and the subsequent evaluation to determine if the feature is within the defined tolerance range.

4. Results and Analysis

This chapter includes an explanation of the results obtained from the program regarding the compliance of the dimensions and geometric features of the workpiece with the established tolerances. The measuring report is presented in German as it is the used language in the department so this chapter includes a table explaining each of the terms used in the report. Also, some evaluations are explained taking examples from a real measuring report and developing each one of the results.

The Appendix A.3 shows the necessary steps to calibrate the machine and to carry out the valve block inspection. The program is integrated into the system, which is used for evaluating other products from the company. As a result of the valve block inspection, a measuring protocol is generated which is analyzed by the production department of the company to determine which actions should be taken if the specified tolerances are not complied. To explain the obtained results, a manufactured block was taken from production to be evaluated and to check that the program works as desired, the results for this piece are shown in Appendix A.4. The table shown on top of the measurement report contains information about the evaluated valve block which in this case is not important as it is used as an example. This information is entered before the piece is measured and contains information about the inspector, department, date and other information which is relevant for the database of the company. The Table 4.1 helps understand the results from the measuring report by indicating the meaning of each of the columns.

Table 4.1. Meaning of the columns in the measuring report.

Number of column	German term	English term	Meaning
1	Text	Text	It indicates the measured geometric by name
2	Ausw. (Auswahl)	Selection	Indicates the type of tolerance (e.g., roundness)
3	Istmaß	Actual value	The measured value of the geometric feature
4	Nennmaß	Nominal value	The nominal value of the geometric feature
5	O. Tol. (Obere Toleranz)	Upper tolerance	The upper limit of the tolerance range
6	U. Tol. (Untere Toleranz)	Lower tolerance	The lower limit of the tolerance range

7	Ist-Soll	Difference	The difference between the nominal and actual value
8	Grafik	Graphic	Visual representation of the measured value between the specified limits

For each of the measured geometric features the report shows each of the values shown in Table 4.1 to analyze if the measured value is in between the established limits defined in the mechanical drawing of the valve block. The graphic indicates the location of the measured value in between the tolerance limits and how close it is to the nominal value. The actual value is represented with a “#” sign, the nominal value with a point and the negative range with “-” and the positive range with “+”. In the measurement report, all the measured values are shown in the table, but it is of real importance the ones, which are out of the tolerance limits because are the ones that indicate there is a problem in the manufacturing process. The actual values which are out of this range have a red arrow to the right of the row where the graphic should be shown.

For an example, the circle two (KREIS (2)) is analyzed to show the meaning of each of the values which is shown in Figure 4.1. The first tolerance that is being evaluated is the roundness (Rundheit) of the circle which has an actual dimension of 0.004. The nominal value is 0.000, the upper tolerance is 0.100, and in this case, there is no lower tolerance. It can be observed that the difference between the measured value and the nominal one is 0.004 that is under the established tolerance range. The graphic shows visually the location of the measured value related to the nominal one. In the case of roundness there is only a positive range of acceptance, this is why only the “+” sign is shown. The actual value is located to the left of the graphic because it is a very small difference compared to the whole tolerance range, indicating it is very close to the nominal value. The second row evaluates the diameter of the measured circle, the third one the position in the Y axis, and the last one the position in the Z axis. When there is no point shown in the graphic, it means the actual value is very close to the nominal value so the difference cannot be observed because of the scale of the graphic. In this example, all of the actual values comply with the established tolerances of the measured geometric feature.

KREIS(2)		CIR					
RUNDHEIT	0.004	0.000	0.100	0.000	0.004	#+++++++	
DM	17.488	17.500	0.100	-0.100	-0.012	---#.++++	
Y	-0.002	0.000	0.250	-0.250	0.002	----#++++	
Z	24.302	24.300	0.250	-0.250	0.002	----#++++	

Figure 4.1. Aalysis of a measured circle. Taken from Appendix A.4.

If the actual dimension is outside the defined limits, a red arrow appears at the end of the row. For example in the page 9 of the report there is a cylinder which does not comply with the tolerance, this example is shown in Figure 4.2. In this case, it can be observed that the measured value was 9.720 and the upper tolerance corresponds to 0.019 so the difference between this upper value and the measured one is shown left to the red arrow.

HUELLZYLINDER							
ZYL_HU_A		CYL					
DM	9.720	9.700	0.019	-0.002	0.020	0.001 ◀	

Figure 4.2. Analysis of a measured cylinder. Taken from Appendix A.4.

This section is important to understand the results obtained by the process of inspection of the different geometric features contained in the valve block. It explains each one of the aspects contained in the measuring report and helps understand the validation of the tolerances. This results were obtained by analyzing one single valve block but for the solution validation, several pieces were tested to verify that the program was functioning correctly. The results are reliable based on the accuracy of the machine which is indicated on the datasheet and by verifying that all the geometric features were measured by comparing the results of the evaluation with a list that contains the features that had to be measured. This results are reliable as long as the environmental conditions are followed and the machine is calibrated according to the manufacturer's specifications. In the next chapter the solution is validated by providing aspects that support the reasons why the use of a coordinate measuring machine is adequate for this specific problem.

5. Solution Analysis and Validation

This chapter explains why the coordinate measuring machine was chosen as the best solution approach compared to other technologies available in the market by analyzing the characteristics of the valve block and the requirements of the system. Regarding the program, it was developed in a process of feedback and continuous improvement to generate a code that was able to measure all the specified geometric features and give the corresponding evaluation of each of the tolerances.

The solution approach was developed taking in account the available technologies for measuring the geometrical features of the product. The most important technologies regarding automation level and accuracy of results are coordinate measuring machines, optical scanners and computed tomography. Depending on the type of workpiece that is going to be measured, one or another technology may result more appropriate. In the case of microscope measuring, it is not appropriate because it allows only 2D measuring and in this case, the workpiece has a lot of features which cannot be evaluated in two dimensions. Besides, it does not allow a high level of automation which is important when having a workpiece with many geometrical features.

Coordinate measuring machines function by reading the input of a touch probe which generates points recording the X, Y and Z coordinates of the target. Then, using mathematic algorithms the geometrical features of the workpiece are generated and compared with the nominal values of the features. This method has the advantage that it is a well-developed technology, widely used in the industry and it can achieve very high levels of accuracy. It has the disadvantage that it has lack of information because it depends on the number of probed points, and increasing the number of probing points increases the duration of the measurement. In the case of an optical scanner, it generally works by the principle of triangulation in which two sensors are used to determine the position of a point over a surface. In this method, the point is located in space by using the projections centers of the sensors and the point in the objects surface which form a triangle, and by triangular relations the position of the measured point can be determined. “The limitation for the optical scanner is a lack of the measurement possibility of internal surfaces (e.g. deep holes and grooves) and lower measuring accuracy than for CMM” (Gapinski, Wieczorowska, Marciniak-Podsadna, Dybala, & Ziolkowskib, 2014). The valve block

has a lot of deep holes and channels, so the optical scanner is not a viable solution because it cannot measure these geometrical features.

The computed tomography works by x-raying an object, and “making the tomographic image consists in the measurement of radiation absorption which penetrates the object” (Gapinski, Wieczorowska, Marciniak-Podsadna, Dybala, & Ziolkowskib, 2014). The scan is made by dividing the volume of the object into small cells and the reconstructed sectional image is a quantitative plot of the linear coefficient of radiation absorption. Then, a cloud of points is obtained which is used to carry out the analysis of the dimensions of the object. This technology has the advantage that can give very accurate results both for external and internal surfaces but the size of the part and also the ability of radiation absorption are important limitations of this type of technology, the Table 5.1 shows the maximum penetrable thickness for some materials.

Table 5.1. Typical maximum penetrable material thicknesses for common industrial materials.

Taken from (De Chiffre, Carmignato, Kruth, Schmitt, & Weckenmann, 2014)

X-ray voltage	130 kV	150 kV	190 kV	225 kV	450 kV
Steel/ceramic	5 mm	<8 mm	<25 mm	<40 mm	<70 mm
Aluminum	<30 mm	<50 mm	<90 mm	<150 mm	<250 mm
Plastic	<90 mm	<130 mm	<200 mm	<250 mm	<450 mm

Computed tomography is used mostly for small objects with complex geometry for example with curved surfaces that are difficult to measure with other technologies. It also has the advantage that it is the only technology capable of measuring non-accessible inner features. When comparing the scanning speed, “contrary to coordinate measuring machines, in CT systems the scanning time is independent from the number of features to be measured on the object” (De Chiffre, Carmignato, Kruth, Schmitt, & Weckenmann, 2014). This fact can be observed by analyzing the Figure 5.1 that shows how the scanning time of an object increases faster with a CMM in comparison to a CT system which performs a scan of the whole piece and the number of features has almost no effect on the scanning speed.

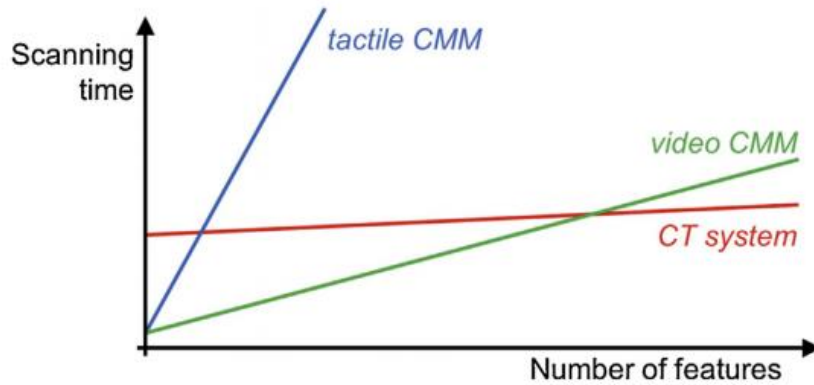


Figure 5.1. Scanning time versus number of features to be measured: schematic comparison of (a) tactile CMM, (b) video CMM and (c) CT system.

One disadvantage of the CT technology is the accuracy level of its measurements, as for other coordinate measurement technologies, in a CT system the uncertainty depends specifically on the measured object and the parameters chosen for the process. Figure 5.2 shows the expanded uncertainty of measurements generated by CT systems in comparison with CMMs.

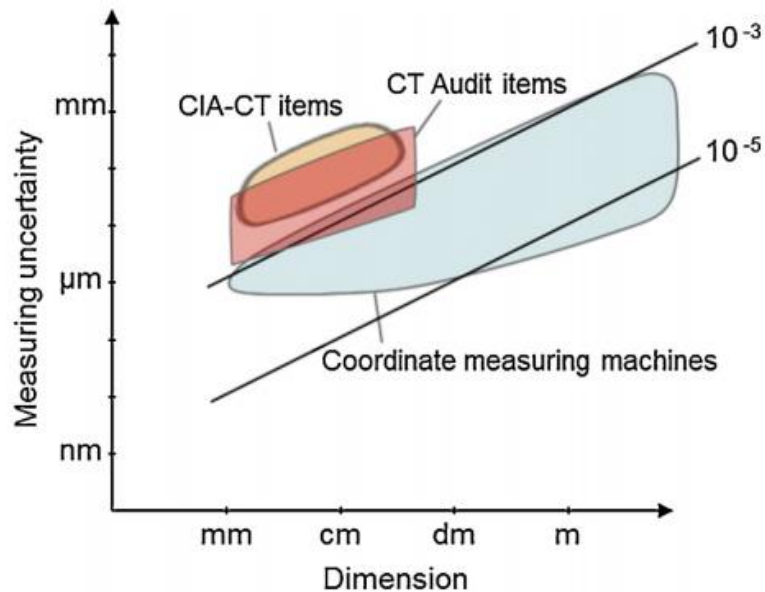


Figure 5.2. Examples of measuring uncertainty on comparison items vs. dimension for CT, compared to general CMM measuring capability. Taken from (De Chiffre, Carmignato, Kruth, Schmitt, & Weckenmann, 2014)

In the case of the valve block it is recommended to use a CMM because it has a simple geometry based on the common geometrical features. In this way, it is easier to program the machine to measure the desired geometrical features depending on the tolerance range of each of the features. It does not have any complex feature or unreachable inner surface that requires a computed tomography. Besides that, taking in account the material of the object that is made from steel, it would require higher voltage in a CT system so that the x-rays can penetrate the material completely because of its ability of radiation absorption which involves higher use of energy. Nevertheless, the most important reason for choosing a CMM is the accuracy, because uncertainty in CT systems is higher than in CMMs as observed in Figure 5.2. The chosen model is a Leitz PMM 866 as it is the available CMM in the department has for this type of measurements and is currently used for similar blocks.

6. Economic Analysis

For the purpose of accounting the monetary costs of performing a measurement protocol for the valve block, this section summarizes the implementation costs of the project. It includes the costs of all the equipment, software and human resources necessary to develop the project.

Table 6.1. Summary of the costs for developing the inspection plan of the valve block.

Detail	Estimated cost (\$)
Leitz PMM 866	180,000.00
Styli	500.00
Fixtures	50.00
Quindos 7 software	10,000.00
Computer	600.00
Human resource	2,925.00
Total	\$194,075.00

The total costs of implementation of the project is around \$194,075.00 considering the most important factors that are equipment and human resource. In this case, the company already had this equipment because it performs many tests to other products that are manufactured in this factory and need the same type of inspections. This makes the project more viable because for the development of it, the resources that the company already has are being used. The only extra costs are the human resources, which have a cost of \$2,925 for the entire project. The economic impact of the project cannot be measured directly as it is part of a quality control process, so it is a necessary step in the manufacturing process to assure quality of the product, which in this case is one of the most important factors of the production process. Nevertheless, the costs are very low because the department already has all the necessary equipment for the evaluation process of the valve block.

7. Conclusions and Recommendations

7.1. Conclusions

- The acquisition of knowledge about the control of inspection, measuring and test equipment was possible through a training process, which was a very important phase for learning the basics of coordinate measuring technique.
- To study the functionality of the ESC and the valve block, which includes the study of the manufacturing process, was very important to know the importance of the geometric features of the workpiece, which was helpful to determine the measurement strategy.
- To thoroughly understand the mechanical drawing was the most important factor to program the CMM, as it was necessary to list all the geometrical features that were going to be evaluated and it includes all the important aspects about the measuring protocol.
- One of the most important factors was to learn how to use the Leitz PMM 866 evaluating all kind of forms, locations, dimensions, for which simple workpieces were used. This training process is very important to develop a measurement protocol as it requires experience to program the machine, so many tests were performed to evaluate results and improve the program.
- The information regarding the process of evaluating one or several valve blocks was documented by creating a user manual that explains all the necessary steps that are necessary to follow. The document also includes an explanation of the development of a measurement strategy that allows someone to understand the programming process.

7.2. Recommendations

- Evaluate the possibility of using other styli for the measuring process to improve the time of the inspection, and reduce the times the tool needs to be changed. This would be beneficial to reduce the time of the measuring process.
- Optimize the program by analyzing the order in which the geometrical features are measured, and determine if a different strategy would be better by taking less time to perform the measurements.
- Evaluate the possible acquisition of a new machine with more accurate measuring and faster speed to improve the measuring process.

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A. Appendixes

A.1. Glossary, Abbreviations, and Symbols

A.1.1. Glossary

Term	Definition
Accreditation	Formal process that assures the quality of organisations and the work they carry out.
Accuracy	Closeness of the agreement between measurement result and true value.
Actual value	Real value of the part (physically).
Bias	The opposite of trueness, as occurs when the indication of a measuring instrument is consistently too high or low.
Calibration	Comparison of an instrument against a more accurate one (or against a reference signal or condition), to find and correct any errors in its measurement results.
Correction	Number added to an instrument reading to correct for a bias.
Datum	A theoretically exact, geometrical feature (e.g. an axis, plane, straight line, etc).
Deviation	The difference between the measured value and the nominal value. It indicates if the measured dimension is in or out the tolerance range and if it is accepted or not.
Error	Deviation from the correct value.
Feature control frame	A rectangular box that is divided into compartments within which the geometric characteristic symbol, tolerance value, modifiers, and datum references are placed.
Measured value	Value acquired with the measuring system.
Metrology	The science of measurement.
Nominal value	Perfect value that the part is supposed to reach according to the drawings or the 3D conception model.
Precision	A measure of the scatter of a number of measured values.
Probe	The device that generates the signal(s) during probing.
Repeatability	Closeness of the agreement between repeated measurements of the same thing carried out in the same place, by the same person, on the same equipment, in the same way, at similar times.
Reproducibility	Closeness of the agreement between measurements of the same thing carried out in different circumstances (e.g. by a different person or a different method, or at a different time).
Resolution	Smallest change in a quantity being measured that

	causes a perceptible change in the corresponding indication
Stylus	A mechanical device consisting of a stylus tip and shaft.
Stylus tip	The physical element that establishes the contact with the workpiece.
Tolerance	Allowance for a specific variation in the size and geometry of a part or range of acceptable values.
Traceability	A measurement is traceable if it can be connected to national or international standards through an unbroken chain of comparisons.
Trueness	Closeness of a measurement to the average of a large set of measurements.
Uncertainty (of measurement)	Quantified doubt about the result of a measurement.

A.1.2. List of Abbreviations

Abbreviation	Meaning
1D	One Dimensional
2D	Two Dimensional
3D	Three Dimensional
ABS	Anti-lock Braking System
ACT	Actual Element
ADAS	Advanced Driver Assistance Systems
APT	Actual Point
CAD	Computer Aided Design
CLP	Clearance Position
CMM	Coordinate Measuring Machine
CNC	Computer Numerical Control
CSY	Coordinate System
CT	Computed Tomography
ESC	Electronic Stability Control
ESV	Electrical Shuttle Valve
EVA	Evaluation
HCU	Hydraulic Control Unit
LDB	Local database
LPA	Low Pressure Accumulator

NC	Normally Closed
NO	Normally Open
NPT	Nominal Point
SI	International System of Units
SV	Separate Valve
TCS	Traction Control System
TMC	Tandem Main Cylinder

A.2. List of Commands in Quindos 7

Command	Function
ADJCON	Shift actual points along a cone-surface
AXIRUN	ISO 1101 Axial run-out
BLDCSY	Build coordinate system
BLDCYL	Build cylinder out of a set of points
BLDTRA	Build a transformation
COAXTY	ISO 1101 Coaxiality /Concentricity
COLAPT	Collect actual points
COLPTS	Collect calculated points (ACT)
CPYOBJ	Copy objects between databases
DELETE	Delete object
DIPNTPNT	Distance between two points
DSBSYS	Disable system functions
EDIT	Edit objects
ENBDMS	Select angle units
ENBSYS	Enable system-parameters
EXCHNG	Convert point types
GENAXI	Generate nominal points of an straight line
GENCIR	Generate nominal points on circle
GENCON	Generate Nominal Points on Cone
GENCYL	Generate nominal points on cylinder
INAXISRF	Intersection point between axis and surface
INPUTSTR	Input string
INTPNT	Intersection point
LOAD	Load program
MEAXI	Measure axis
MECIR	Measure circle
MEPLA	Measure plane
MEPNT	Measure point
MOVCMM	Move CMM
PARALL	ISO 1101 Parallelism

POSITN	ISO 1101 Position
PUTPRB	Put probe / sensor in probechanger
PUTSTR	Put string to record
RADRUN	ISO 1101 Radial run-out
SAVE	Save workpiece data (program)
SCREWNPT	Screw nominal points
SET	Set status variable
SQRNES	ISO 1101 Squareness (Perpendicularity)
START	Start program (CNC-run)
SYMPNT	Symmetry point
SYMTRY	ISO 1101 Symmetry
TEXT	Pass String to Device
TRACSY	Transform coordinate system
TRAELE	Transform element
UNWIND	Unwind
USECMM	Select machine parameters to be used
USECSY	Select CSY
USEPRB	Select tool/sensor

A.3. User Manual

First it is necessary to open the Quindos 7 program and to open the archive that contains the main menu which is shown in Figure A.3.1. In the main menu there are two major sections: *Messen* (Measure) and *Sonstiges* (Others). Under the “Measurement” section, there are several products besides the MK100 valve block that can be inspected by using the Leitz PMM 866. Under the “Others” section there are several options: *Taster kalibrieren* (Calibrate styli), *Taster ablegen* (Store styli), *Programm erstellen* (Create a program), and *Programme auflisten* (List programs). Once the main menu is loaded, it is important to qualify the styli by using the option *Taster kalibrieren* (Calibrate Styli). This step is performed only if the styli have not been calibrated previously.

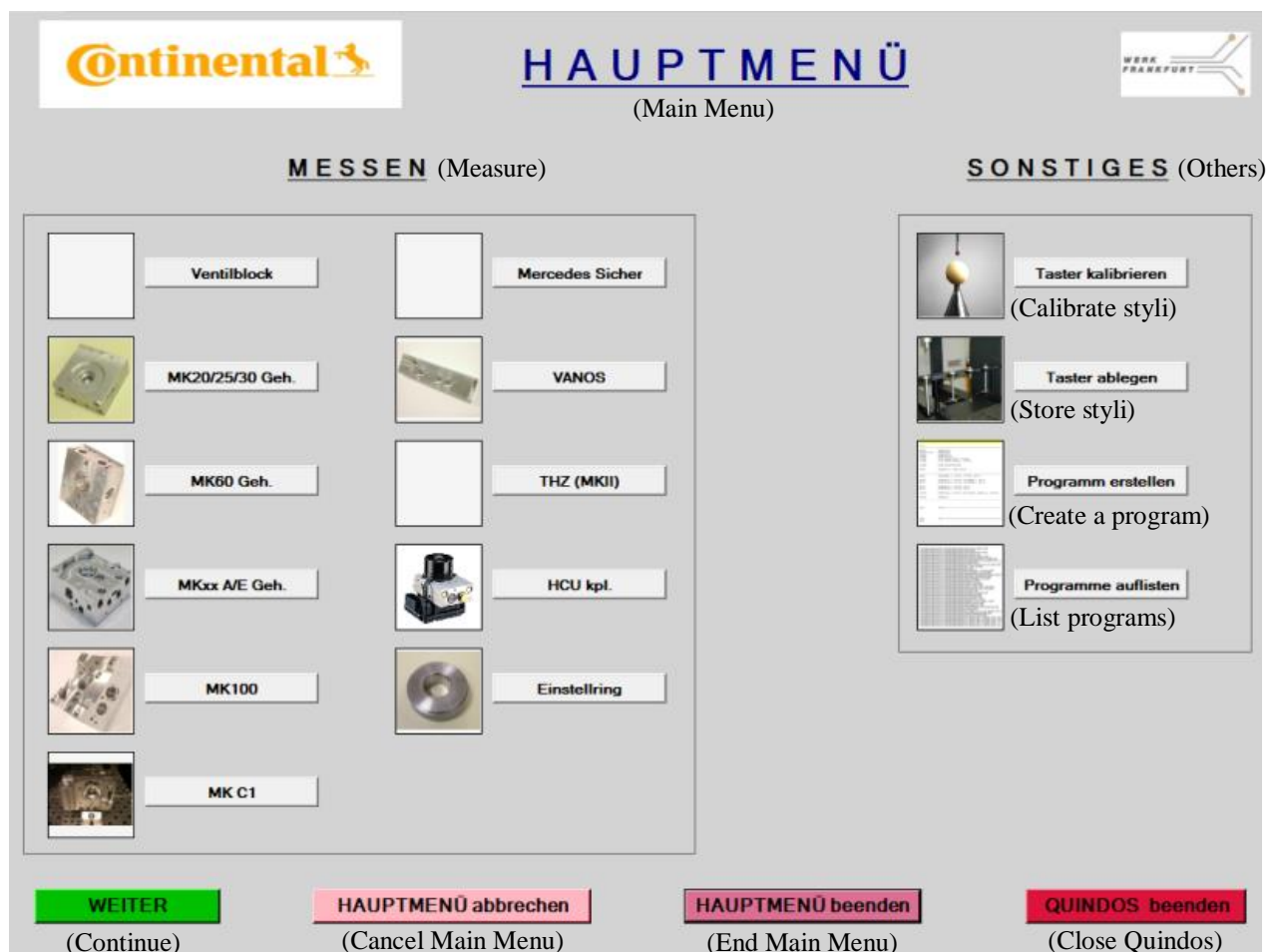


Figure A.3.8.1. Main menu of the program.

Styli Calibration

1. Click on *Taster kalibrieren* under the *Sonstiges* section and then on the green button with the *Weiter* (Continue) label. Once this is done, a new window appears which shows a list of the styli that can be calibrated, as observed in Figure A.3.2. The styli to be calibrated should be chosen depending on the workpiece to be inspected. In the case of the MK100 valve block, the following styli should be calibrated: PRB (21x), PRB (33x), PRB (41x), and PRB (51x). It is important that the specified styli are settled on the exchange bank of the machine in the correct order. The first number of the stylus indicates the position in the exchange bank, and the second number is used indicates the specific model of the stylus. Then it is necessary to click “JA” under the indicated styli and then click on *Weiter*.

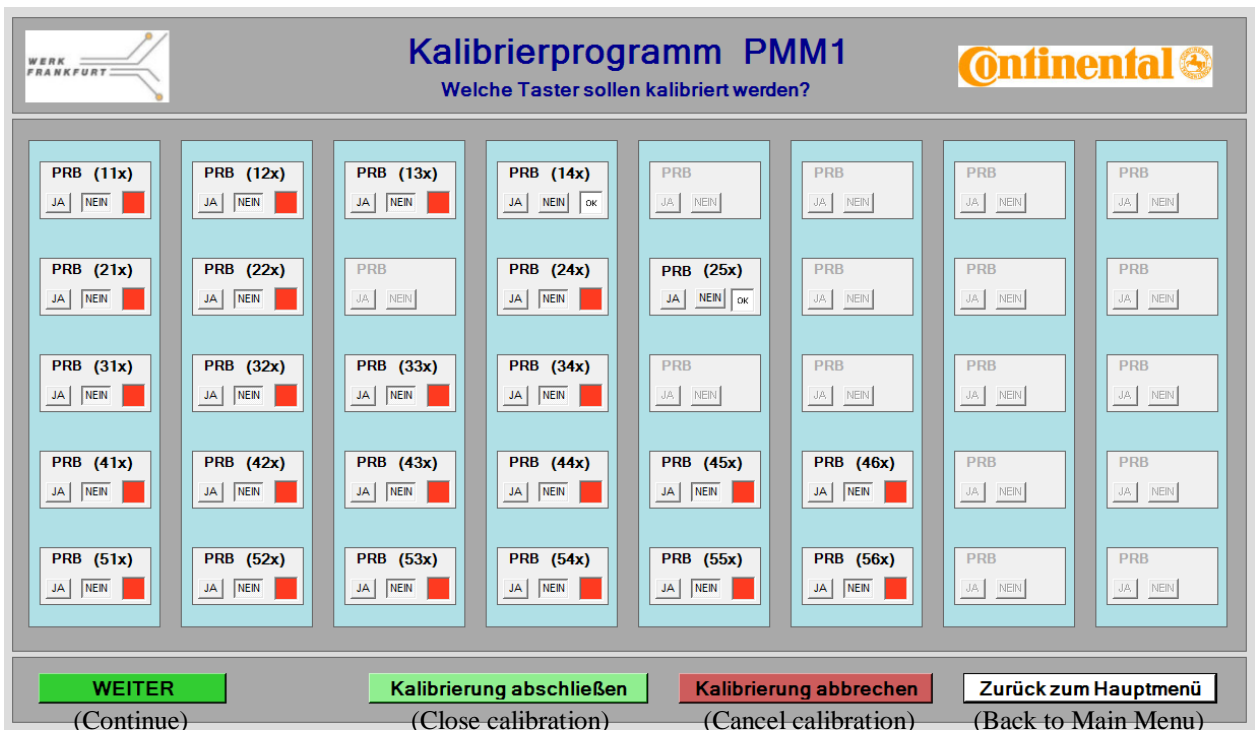


Figure A.3.8.2. Calibration window dialog.

2. Once the styli to calibrate are chosen and the “continue” button is clicked, an image appears (Figure A.3.3) that indicates that the process of calibration is taking place. When something

in the process is wrong, a warning should appear in the screen indicating what kind of error took place.



Figure A.3.8.3. Message indicating that the calibration is running.

Valve Block Inspection

1. Click on *Hauptmenü* (Main Menu). In the main menu, under *Messen* (Measure), choose MK100 and click the green button *Weiter* (Continue). Once this is done, a new window appears which shows the main options regarding the MK100 valve block as shown in Figure A.3.4.



Figure A.3.8.4. Options for the MK100 valve block.

2. In the current window (Figure A.3.5), under *Prüffart* (Type of test) click on *Musterprüfung* (Sample Inspection) and then on *Weiter* (Continue). The probes which are necessary for the measuring process are shown in the lower right corner. It is important to verify that these probes are mounted on the machine rack.

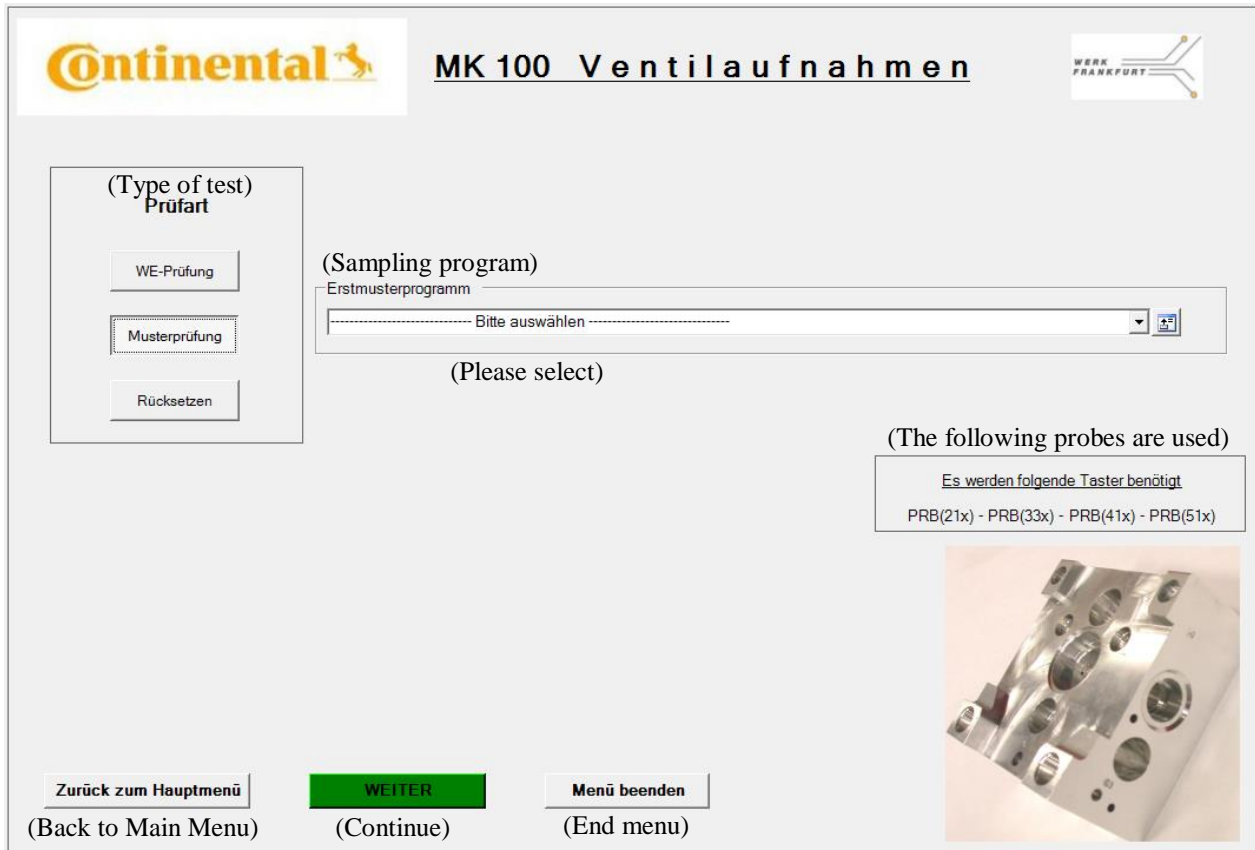


Figure A.3.8.5. Options for the MK100 valve block.

- Once the *Musterprüfung* option is chosen, a new tab appears called *Erstmusterprogramm* (Initial sample program) and the option *Bitte auswählen* (Please select). Then, it is necessary to load the corresponding archive with the program for the MK100 valve block, the name of the archive should be “Erstmuster 10.0206-3064.1” which corresponds to the specific model of the MK100 valve block which is going to be measured. Once the program is loaded, a new window appears with the position and number of valve blocks to be tested as observed in Figure A.3.6.

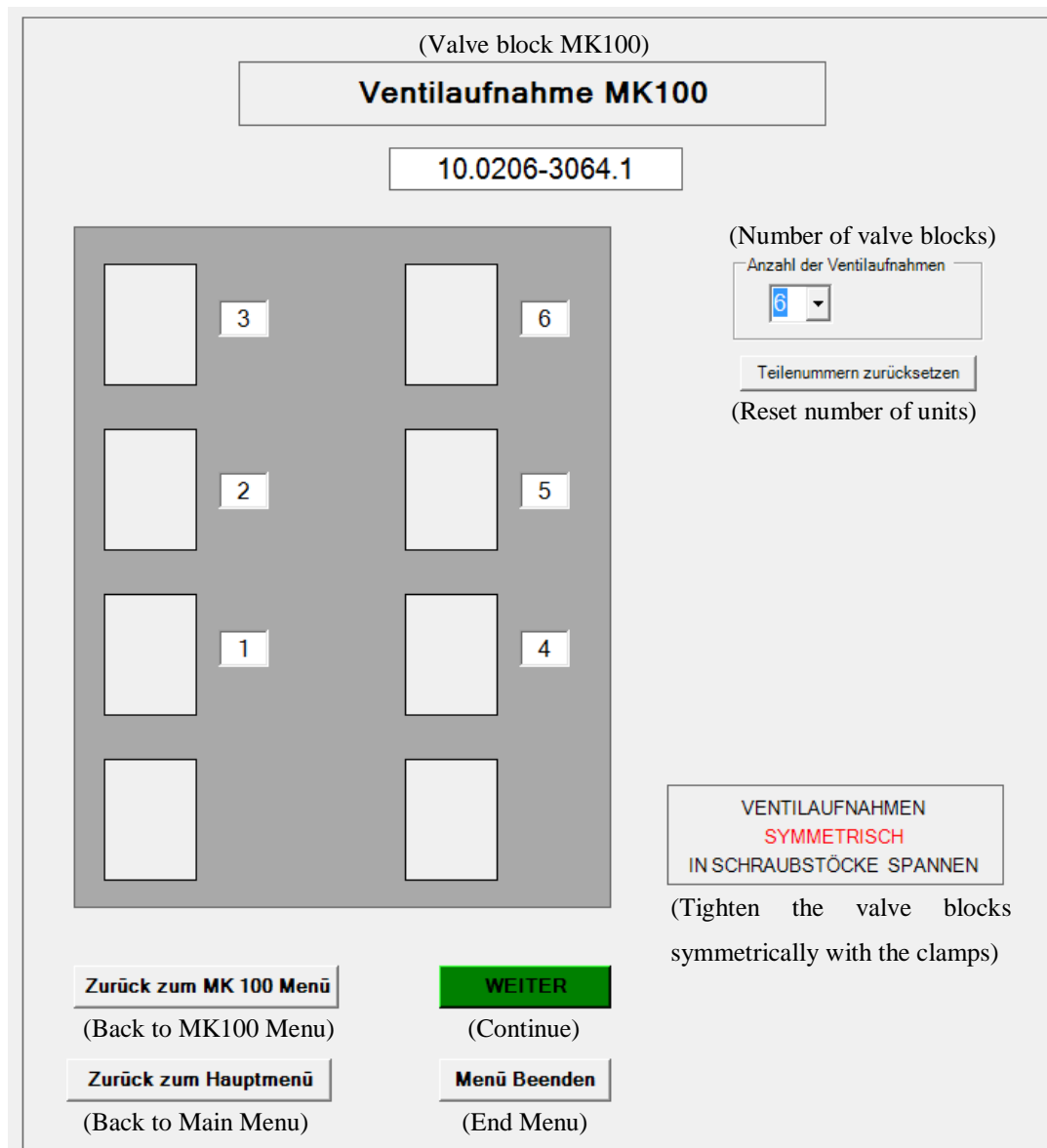


Figure A.3.8.6. Dialog showing position and number of valve blocks.

4. Choose the number of valve blocks that are going to be measured under the option *Anzahl der Ventilaufnahmen* (Number of valve blocks), observe the numbers on the picture to know which number corresponds to each block. Note: the pieces to be measured should be in the positions shown in the image and placed symmetrically. The maximum number of units that can be tested in one run is up to six valve blocks. Once the configuration is set, click on *Weiter*. A new window appears (Figure A.3.7) which requests the specific data of the

measurement protocol, which has to be filled with the corresponding information; this data will be displayed in the results of the measurement report.

Workpiece Characteristic Data	
Messprotokoll (Measurement Report)	
CONTINENTAL Division Chassis Safety	
Bezeichnung (Label) <input type="text" value="Ventilaufnahme (Valve block)"/> Grundzeichn. Nr. (Drawing number) <input type="text"/> Bemerkung (Remark) <input type="text" value="MK100 Kompl.-Prgr."/>	Auftragsnummer (Assignment number) <input type="text"/> Teil-Nummer (Piece number) <input type="text"/> Sachnummer (Article code) <input type="text" value="10.0206-3064.1"/>
Prüfer (Inspector) <input type="text" value="Jorge Castro"/> Fert.-Maschine / AG (Assembly) <input type="text" value="Erstmuster"/>	Abteilung (Department) <input type="text" value="QL FFM C"/> Prüfdatum (Date) <input type="text"/> Messmaschine (Measuring machine) <input type="text" value="KMG PMM1"/>
CNC-Name: <input type="text" value="VEN:VA_ERSTMUSTER_MK100_10_0206_3064_1"/>	

Figure A.3.8.7. Workpiece characteristic data dialog.

- Once the measuring report information is filled click on the green arrow on the left lower corner to continue to the measuring program. A new window opens which shows the report which is going to be generated at the same time as the code is executed. After this, an image appears indicating the correct placement of the valve block using the fixture on the machine, as shown in Figure 6 A.3.8. Once the piece is tighten using the fixture it is important to verify it is correctly aligned and tight so that it does not move when the test is taking place.

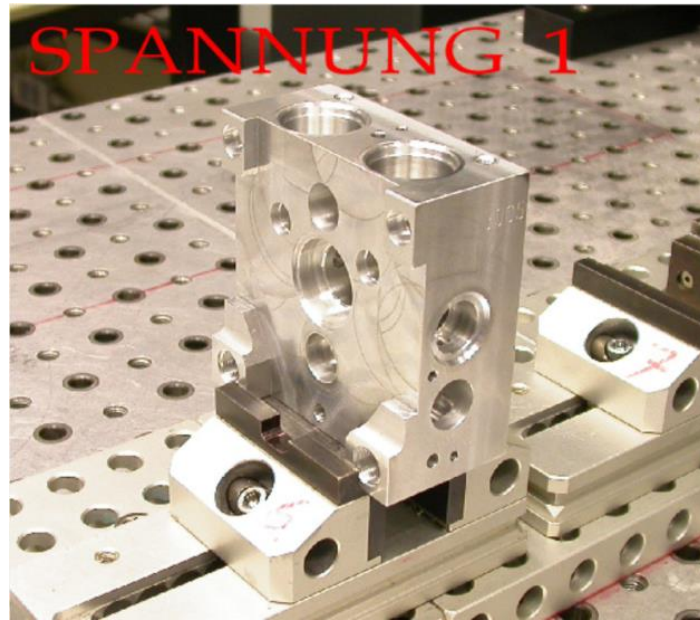


Figure A.3.8.8. Position 1 of the valve block.

6. After the valve block is correctly fitted, click on the green arrow in the lower left corner to continue to the measuring process. Once this is done, the program will ask if only the channels on the valve block should be measured, or the whole piece. If only the channels are going to be measured, then click yes. If the whole piece is going to be measured, then click no.



Figure A.3.8.9. Option for measuring only the channels or the whole piece.

7. Normally, the whole piece should be measured, so the yes button shown in Figure A.3.9 should be clicked. Once this step is finished, it is necessary to measure manually three points on the different axes of the valve block, so the machine can locate the workpiece. This is done by using the control panel of the machine (Figure A.3.11). Each of the points has to be approached slowly and once it is correctly probed, a led flashes in the control panel and makes a beep sound. For probing the surfaces the stylus 413 must be used. First, probe the surface facing the +X axis (red arrow in Figure A.3.10) and confirm with the END button on the control panel. Then, probe the second point on the surface facing the +Y axis (blue arrow in Figure A.3.10) and confirm with the END button. Finally, probe the surface facing the +Z axis on top of the workpiece (yellow arrow in Figure A.3.10) and touch the END button. Once this is done, the machine automatically starts to measure all the geometric features of the valve block.

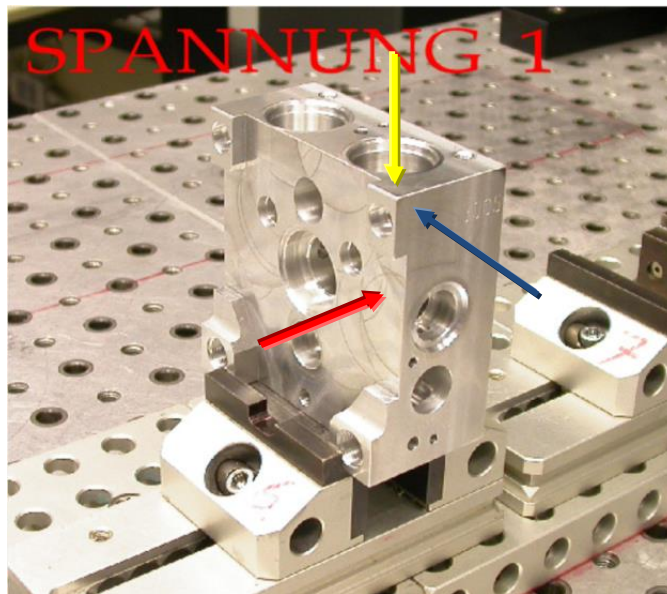


Figure A.3.8.10. Probing points on the workpiece.

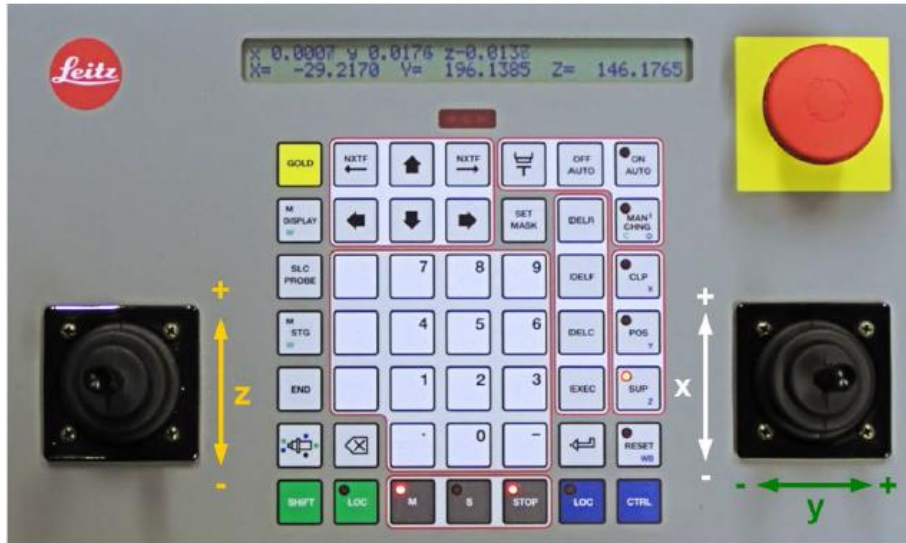


Figure A.3.8.11. Control panel of the Leitz PMM 866. Taken from (Quindos 7 Manual)

8. Once the machine finishes measuring the geometric features of the valve block, a new message is displayed on the screen (Figure A.3.12). The dialog asks if the tilted channels on the valve block are going to be measured. Click the yes button to start the process of measuring the inclination of the channels on the channels on the valve block.

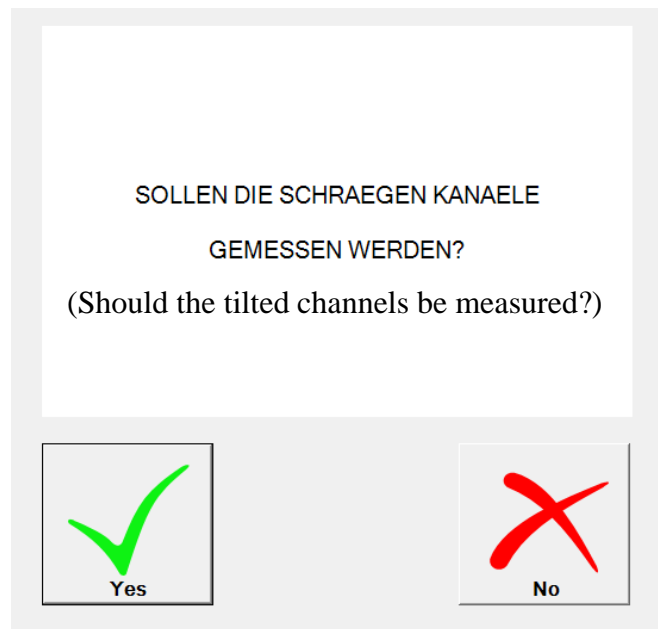
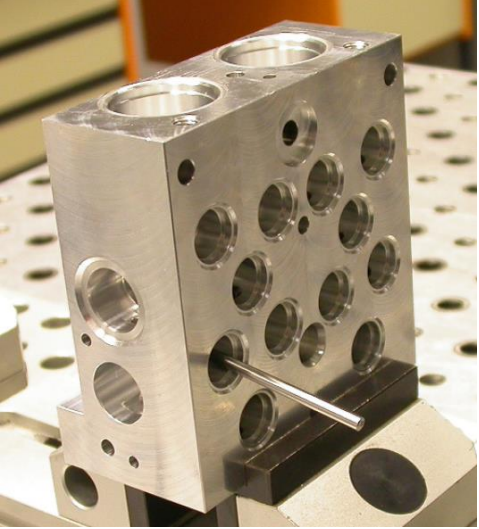
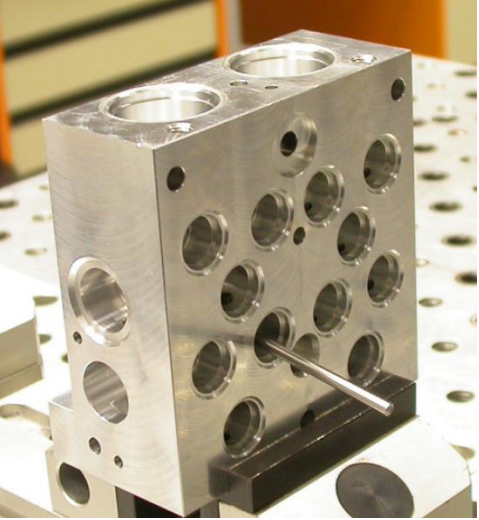
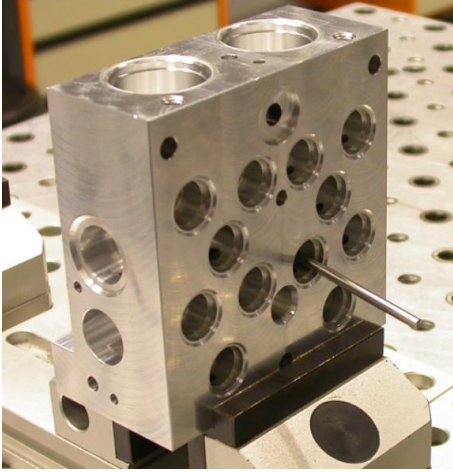
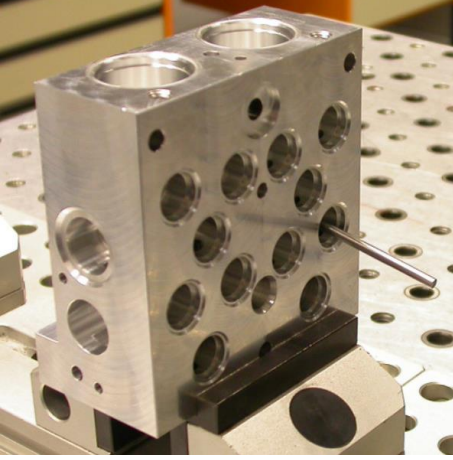
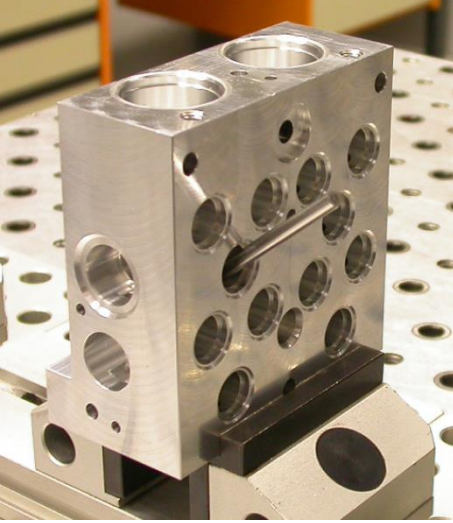


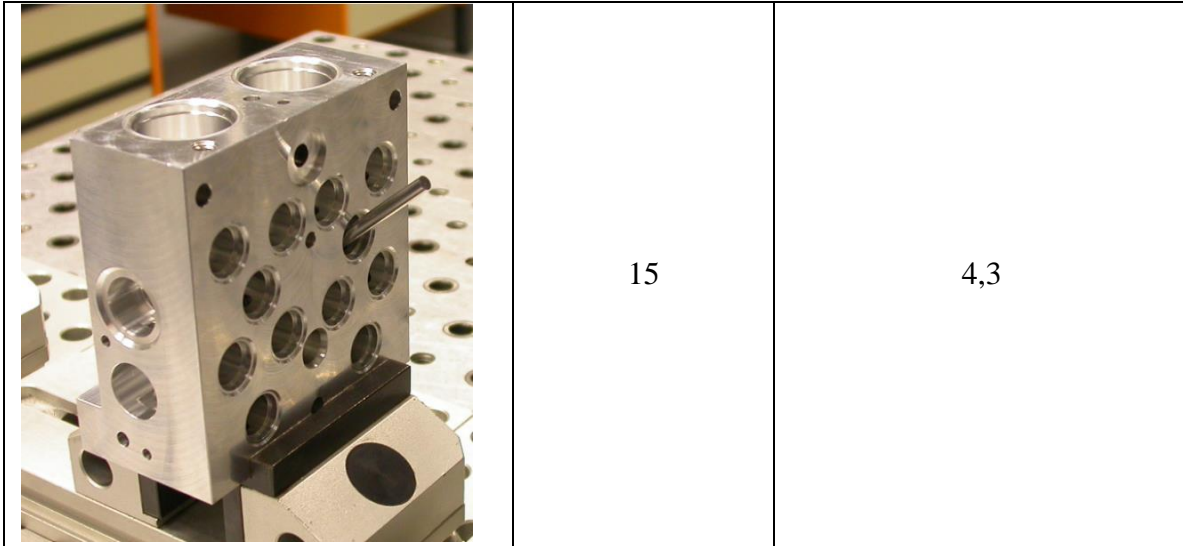
Figure A.3.8.12. Option for measuring the tilted channels.

9. A new dialog appears showing the correct position of the pin gage for testing the position of the channels. In each step the pin gage should be placed as shown in the figure and then the check located in the left lower corner should be clicked to confirm the operation. It is important that the pin gage is firmly fixed into the hole. The nominal size of the pin is given in Table A.3.1 but it is more important that the pin fits firmly into the bore, so a smaller or bigger pin can be used as needed.

Table A.3.8.1. Pin gauges configuration for channels 10 to 15.

Position of the pin gauge	Channel number	Diameter of pin gauge (mm)
	10	3,2
	11	3,2

	<p>12</p>	<p>3,2</p>
	<p>13</p>	<p>3,2</p>
	<p>14</p>	<p>4,3</p>



10. After the process of measuring channels 10 to 15 is finished a new dialog shows up on screen asking if the channels on the bottom of the piece are going to be measured (Figure A.3.13).

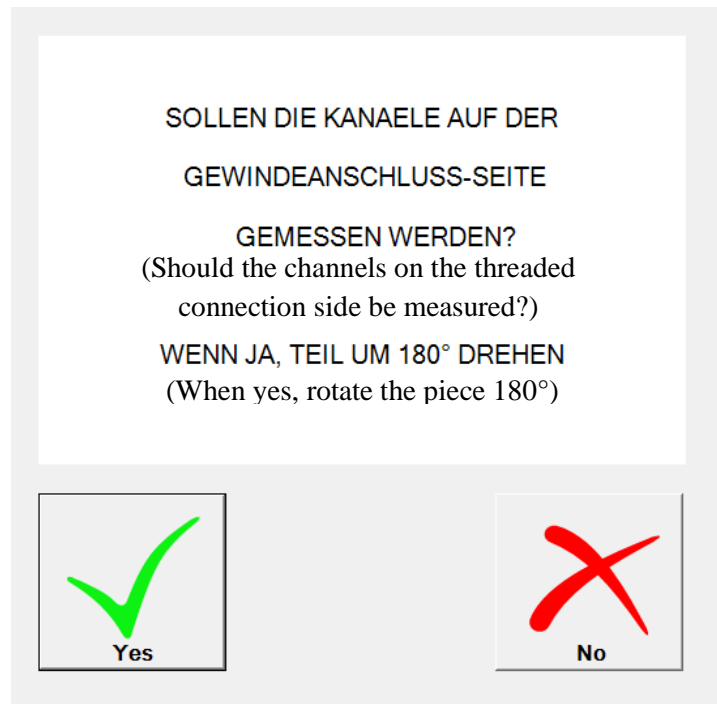


Figure A.3.8.13. Option for measuring the channels on the other side of the valve block (bottom).

11. Click on the yes button and then place the valve block as shown in Figure A.3.14.

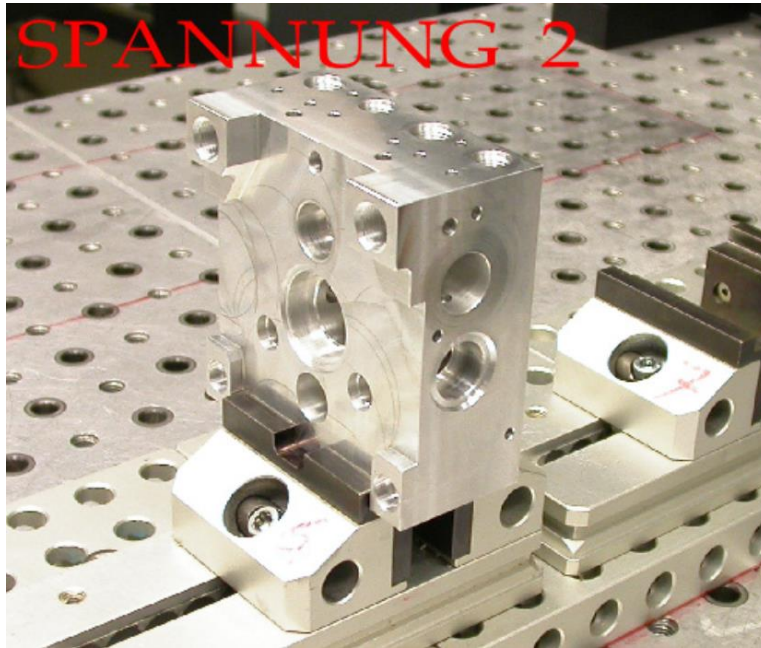
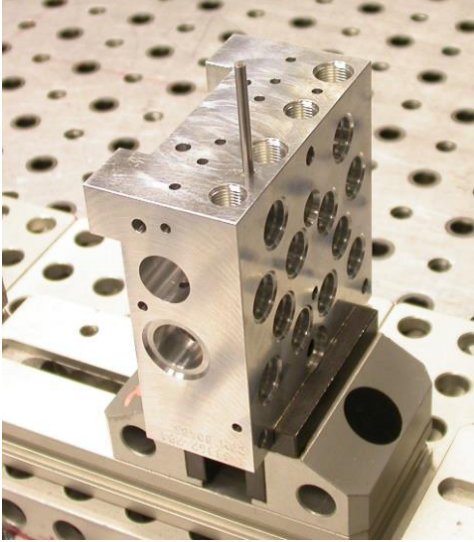
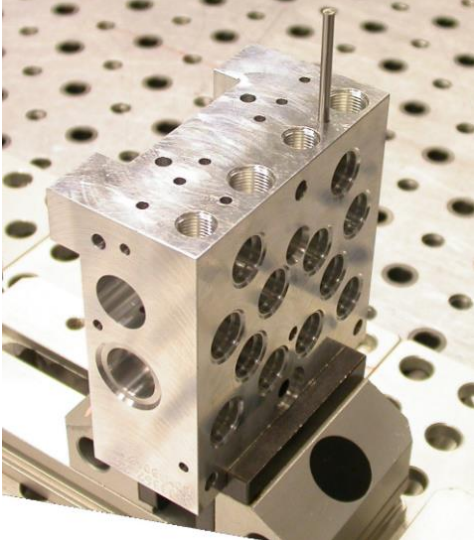


Figure A.3.8.14. Position 2 of the valve block.

12. After the valve block is correctly fitted, click on the green arrow in the lower left corner to continue to the measuring process. Once this is done, a new dialog appears showing the correct position of the pin gage for testing the position of the channels on the threaded connection side of the valve block. The same procedure as for the channels 10 to 15 is carried out. The position and size of the pin gage can be seen in Table A.3.2.

Table A.3.8.2. Pin gauges configuration for channels 16 to 17.

Position of the pin gauge	Channel number	Diameter of pin gauge (mm)
	<p>16</p>	<p>3,2</p>
	<p>17</p>	<p>3,2</p>

A.4. Measurement Report

<h1>Messprotokoll</h1>			
CONTINENTAL Division Chassis & Safety			
Bezeichnung	Ventilaufnahme	Auftragsnummer	
Grundzeichn. Nr.		Teil-Nummer	
Bemerkung	MK100 Kompl.-Prgr.	Sachnummer	10.0206-3064.1
Prüfer	Jorge Castro	Abteilung	QL FFM C
Fert.-Maschine / AG	Erstmuster	Prüfdatum	21-JUN-2016, 11:44:42
		Messmaschine	KMG PMM1

CNC-Name: VEN:VA_ERSTMUSTER_MK100_10_0206_3064_1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So11	Grafik
(Text)	(Selection)	(Actual value)	(Nominal value)	(Upper tolerance)	(Lower tolerance)	(Difference)	(Graphic)

A U S R I C H T E L E M E N T E (ATG N 110 11.11)

1. AUSRICHELEMENT P/Q

EBENE(1)		PLA					
	EBENHEIT	0.006	0.000	0.100	0.000	0.006	#+++++++

KR_Q_1		CIR					
	RUNDHEIT	0.008	0.000	0.023	0.000	0.008	.++#+++++
	DM	26.036	26.000	0.050	0.005	0.036	-===.#=#+

KR_Q_2		CIR					
	RUNDHEIT	0.008	0.000	0.023	0.000	0.008	.++#+++++
	DM	26.035	26.000	0.050	0.005	0.035	-===.#=#+

KR_Q_3		CIR					
	RUNDHEIT	0.007	0.000	0.023	0.000	0.007	.++#+++++
	DM	26.035	26.000	0.050	0.005	0.035	-===.#=#+

ACHSE		AXI					
	FORM	0.000					

RECHT_Q		AXI					
	SQRNES	0.002	0.000	0.040	0.000	0.002	#+++++++

ZYL(1)		CYL					
	FORM	0.008	0.000	0.023	0.000	0.008	.++#+++++
	DM	26.035	26.000	0.050	0.005	0.035	-===.#=#+

2. AUSRICHELEMENT P/Q

KREIS(1)		CIR					
RUNDHEIT		0.002	0.000	0.050	0.000	0.002	#+++++++
DM		15.400	15.400	0.050	-0.050	0.000	----#++++

KR(1)		CIR					
Y		0.000	0.000	0.100	-0.100	0.000	----#++++
Z		-25.489	25.500	0.100	-0.100	-0.011	----#++++

POS(1)		POI					
POSITN		0.021	0.000	0.200	0.000	0.021	#+++++++

KREIS_(1)		CIR					
RUNDHEIT		0.001					
DM		11.012					

POS_(1)		POI					
POSITN		0.022	0.000	0.300	0.000	0.022	#+++++++

KREIS(2)		CIR					
RUNDHEIT		0.004	0.000	0.100	0.000	0.004	#+++++++
DM		17.488	17.500	0.100	-0.100	-0.012	---#++++
Y		-0.002	0.000	0.250	-0.250	0.002	----#++++
Z		24.302	24.300	0.250	-0.250	0.002	----#++++

POS(2)		POI					
POSITN		0.005	0.000	0.500	0.000	0.005	#+++++++

2X DRUCKDAEMPFER GEM. ATG N 111 39.42

DAEMPF_1		CIR					
RUNDHEIT		0.005	0.000	0.025	0.000	0.005	.#+++++++
DM		10.541	10.500	0.050	0.000	0.041	----.++##
Y		23.967	24.000	0.125	-0.125	-0.033	---#++++
Z		12.788	12.800	0.125	-0.125	-0.012	----#++++

POS_DAEMP_1		POI					
POSITN		0.070	0.000	0.250	0.000	0.070	.#+++++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 3 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-So	Grafik

DAEMPF_2		CIR					
	RUNDHEIT	0.005	0.000	0.025	0.000	0.005	.#++++++
	DM	10.541	10.500	0.050	0.000	0.041	----.##+
	Y	-24.014	24.000	0.125	-0.125	0.014	----#++++
	Z	12.800	12.800	0.125	-0.125	0.000	----#++++

POS_DAEMP_2		POI					
	POSITN	0.027	0.000	0.250	0.000	0.027	#++++++

3X DURCHGANGSBOHRUNG 6,2MM GEM. ATG N 110 11.11

3X DURCHGANGSBOHRUNG 5,7MM MOTORSEITIG/BEZUG FUER KOAX

2X DURCHGANGSBOHRUNG 9,6MM GEM. ATG N 110 11.11

DURCHG_1		CIR					
	RUNDHEIT	0.002	0.000	0.050	0.000	0.002	#++++++
	DM	6.285	6.200	0.100	0.000	0.085	----.##+
	Y	38.959	39.000	0.100	-0.100	-0.041	--#-.++++
	Z	32.978	33.000	0.100	-0.100	-0.022	---#-.++++

POS_DURCH_1		POI					
	POSITN	0.093	0.000	0.200	0.000	0.093	.+++#+

DRG_1		CIR					
	RUNDHEIT	0.002	0.000	0.050	0.000	0.002	#++++++
	DM	5.758	5.700	0.100	0.000	0.058	----.##+
	Y	39.007					
	Z	33.012					

DURCH_1		CIR					
	FORM	0.010	0.000	0.050	0.000	0.010	.#++++++
	DM	9.675	9.600	0.100	0.000	0.075	----.##+
	Y	38.955	39.000	0.100	-0.100	-0.045	--#-.++++
	Z	32.977	33.000	0.100	-0.100	-0.023	---#-.++++

POS_DUR_1		POI					
	POSITN	0.102	0.000	0.200	0.000	0.102	.+++#+

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 4 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist- Soll	Grafik
DURCHG_2		CIR					
	RUNDHEIT	0.002	0.000	0.050	0.000	0.002	#+++++++
	DM	6.286	6.200	0.100	0.000	0.086	----.+#+
	Y	-39.009	39.000	0.100	-0.100	0.009	----#++++
	Z	32.998	33.000	0.100	-0.100	-0.002	----#++++

POS_DURCH_2		POI					
	POSITN	0.020	0.000	0.200	0.000	0.020	#+++++++

DRG_2		CIR					
	RUNDHEIT	0.001	0.000	0.050	0.000	0.001	#+++++++
	DM	5.758	5.700	0.100	0.000	0.058	----.#+++
	Y	-39.001					
	Z	33.015					

DURCH_2		CIR					
	FORM	0.004	0.000	0.050	0.000	0.004	#+++++++
	DM	9.675	9.600	0.100	0.000	0.075	----.+#+
	Y	-39.007	39.000	0.100	-0.100	0.007	----#++++
	Z	32.997	33.000	0.100	-0.100	-0.003	----#++++

POS_DUR_2		POI					
	POSITN	0.016	0.000	0.200	0.000	0.016	#+++++++

DURCHG_3		CIR					
	RUNDHEIT	0.003	0.000	0.050	0.000	0.003	#+++++++
	DM	6.287	6.200	0.100	0.000	0.087	----.+#+
	Y	-0.019	0.000	0.100	-0.100	0.019	----.#+++
	Z	-44.692	44.700	0.100	-0.100	-0.008	----#++++

POS_DURCH_3		POI					
	POSITN	0.041	0.000	0.200	0.000	0.041	.#+++++++

BEZUGSBOHRUNG N							
DRG_3		CIR					
	RUNDHEIT	0.002	0.000	0.050	0.000	0.002	#+++++++
	DM	5.756	5.700	0.100	0.000	0.056	----.#+++
	Y	-0.024					
	Z	-44.683					
=====							
2X GEWINDE M12X1 MOTORSEITIG							

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 5 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-So11	Grafik
M12X1_1		CIR					
	RUNDHEIT	0.003					
	Y	35.474	35.500	0.150	-0.150	-0.026	---#.++++
	Z	-41.897	41.900	0.150	-0.150	-0.003	----#++++

POS_M12_1_1		POI					
	POSITN	0.052	0.000	0.300	0.000	0.052	.#++++++

M12X1_2		CIR					
	RUNDHEIT	0.002					
	Y	-35.496	35.500	0.150	-0.150	-0.004	----#++++
	Z	-41.883	41.900	0.150	-0.150	-0.017	----#++++

POS_M12_1_2		POI					
	POSITN	0.034	0.000	0.300	0.000	0.034	.#++++++
=====							
SYMMETRIEN GEM. ATG N 110 11.11							
Abst_1		AXI					
	DZ	46.004	46.000	0.100	-0.100	0.004	----#++++

SYM_1		POI					
	Z	0.013	0.000	0.050	-0.050	0.013	----.#+++

SYMTRY_1		PLA					
	SYMTRY	0.026	0.000	0.100	0.000	0.026	.#++++++

Abst_2		AXI					
	DZ	46.003	46.000	0.100	-0.100	0.003	----#++++

SYM_2		POI					
	Z	-0.012	0.000	0.050	-0.050	0.012	----.#+++

SYMTRY_2		PLA					
	SYMTRY	0.025	0.000	0.100	0.000	0.025	.#++++++
=====							
SYMMETRIEN GEM. ATG N 110 11.11							
Abst_3		AXI					
	DY	51.002	51.000	0.100	-0.100	0.002	----#++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 6 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-So11	Grafik

SYM_3			POI				
	Y	-0.002	0.000	0.050	-0.050	0.002	----#++++

SYMTRY_3			PLA				
	SYMTRY	0.003	0.000	0.100	0.000	0.003	#+++++++

Abst_4			AXI				
	DY	65.387	65.400	0.100	-0.100	-0.013	---#.++++

SYM_4			POI				
	Y	-0.019					
=====							
1x SYMMETRY von Abstand 69,1mm - GEWINDESEITIG							
AXI_Y_S1			AXI				
	FORM	0.019					
AXI_Y_SS1			AXI				
	FORM	0.024					
SCHN_MOT_1			POI				
	Y	34.485	34.550			-0.065	

AXI_Y_S2			AXI				
	FORM	0.002					
AXI_Y_SS2			AXI				
	FORM	0.013					
SCHN_MOT_2			POI				
	Y	-34.583	34.550			0.033	

AB_VERST_1			AXI				
	DY	-69.068	69.100	0.150	-0.150	-0.032	---#.++++

SYM_VERST_1			POI				
	Y	-0.049	0.000	0.050	-0.050	0.049	----.+++ #

SYM_VER_1_1			PLA				
	SYMTRY	0.098	0.000	0.100	0.000	0.098	.+++++++ #
=====							

2X EBENE VON M12X1 GEWINDEN MOTORSEITIG

EB_MOT_M12_1		PLA					
	EBENHEIT	0.003	0.000	0.100	0.000	0.003	#+++++++
	X	9.988					

EB_MOT_M12_2		PLA					
	EBENHEIT	0.002	0.000	0.100	0.000	0.002	#+++++++
	X	9.993					

P U M P E N B O H R U N G E N GEM. ATG N 110 11.31

PUMPENBOHRUNG A

BEZUG A (REFERENZDURCHMESSER)

KR_A_1_1		CIR					
	RUNDHEIT	0.002					
	DM	15.877	15.880	0.020	-0.020	-0.003	---#.++++

KR_A_1_2		CIR					
	RUNDHEIT	0.003					
	DM	15.876	15.880	0.020	-0.020	-0.004	---#.++++
	X	-14.239	14.200	0.125	-0.125	0.039	----.###
	Z	-0.588	-0.600	0.125	-0.125	0.012	++++#----

KR_A_1_3		CIR					
	RUNDHEIT	0.003					
	DM	15.874	15.880	0.020	-0.020	-0.006	---#.++++

PFERCHZYLINDER

ZYL_A_PF		CYL					
	ZYL_FORM	0.005					
	DM	15.871	15.880	0.020	-0.020	-0.009	--#-.++++

HUELLZYLINDER

ZYL_A_HU		CYL					
	ZYL_FORM	0.005					
	DM	15.879	15.880	0.020	-0.020	-0.001	----#++++

ACHSE_A_1		AXI					
	FORM	0.000					

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 8 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-So11	Grafik
PARALL_A_1		PLA					
	PARALL	0.000	0.000	0.050	0.000	0.000	#+++++++

POS_A_1		AXI					
	POSITN	0.082	0.000	0.250	0.000	0.082	.#+++++

KR_A_2_1		CIR					
	RUNDHEIT	0.003	0.000	0.050	0.000	0.003	#+++++++
	DM	11.457	11.400	0.100	0.000	0.057	----.#+++

KOAX_A_2_1		POI					
	COAXTY	0.004	0.000	0.050	0.000	0.004	#+++++++

KR_A_2_2		CIR					
	RUNDHEIT	0.016	0.000	0.050	0.000	0.016	.#+++++
	DM	11.457	11.400	0.100	0.000	0.057	----.#+++

KOAX_A_2_2		POI					
	COAXTY	0.005	0.000	0.050	0.000	0.005	#+++++++

KR_A_3_1		CIR					
	RUNDHEIT	0.005	0.000	0.020	0.000	0.005	.#+++++
	DM	9.716	9.700	0.019	-0.002	0.016	----.##+

KOAX_A_3_1		POI					
	COAXTY	0.009	0.000	0.050	0.000	0.009	.#+++++

KR_A_3_2		CIR					
	RUNDHEIT	0.005	0.000	0.020	0.000	0.005	.#+++++
	DM	9.716	9.700	0.019	-0.002	0.016	----.##+

KOAX_A_3_2		POI					
	COAXTY	0.008	0.000	0.050	0.000	0.008	.#+++++

KR_A_3_3		CIR					
	RUNDHEIT	0.005	0.000	0.020	0.000	0.005	.#+++++
	DM	9.717	9.700	0.019	-0.002	0.017	----.##+

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 9 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So11	Grafik
KOAX_A_3_3		POI					
	COAXTY	0.008	0.000	0.050	0.000	0.008	.#++++++

PFERCHZYLINDER							
ZYL_PF_A		CYL					
	DM	9.712	9.700	0.019	-0.002	0.012	----.#+++

HUELLZYLINDER							
ZYL_HU_A		CYL					
	DM	9.720	9.700	0.019	-0.002	0.020	0.001 ◀

ZYLINDERFORM GEM. MZC							
ZYL_MZC_A		CYL					
	ZYL_FORM	0.005	0.000	0.020	0.000	0.005	.#++++++

KR_A_4_1		CIR					
	RUNDHEIT	0.007	0.000	0.050	0.000	0.007	.#++++++
	DM	6.214	6.200	0.050	-0.050	0.014	----.#+++

KOAX_A_4_1		POI					
	COAXTY	0.010	0.000	0.050	0.000	0.010	.#++++++
=====							
PUMPENBOHRUNG B							
BEZUG A (REFERENZDURCHMESSER)							
KR_B_1_1		CIR					
	RUNDHEIT	0.005					
	DM	15.877	15.880	0.020	-0.020	-0.003	---#.++++

KR_B_1_2		CIR					
	RUNDHEIT	0.006					
	DM	15.876	15.880	0.020	-0.020	-0.004	---#.++++
	X	-14.127	14.200	0.125	-0.125	-0.073	-#--.++++
	Z	0.579	0.600	0.125	-0.125	-0.021	---#.++++

KR_B_1_3		CIR					
	RUNDHEIT	0.006					
	DM	15.875	15.880	0.020	-0.020	-0.005	---#.++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 10 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-Soll	Grafik
PFERCHZYLINDER							
ZYL_B_PF							
	ZYL_FORM	0.008					
	DM	15.871	15.880	0.020	-0.020	-0.009	--#-.++++

HUELLZYLINDER							
ZYL_B_HU							
	ZYL_FORM	0.009					
	DM	15.881	15.880	0.020	-0.020	0.001	----#++++

ACHSE_B_1							
	FORM	0.000					

PARALL_B_1							
	PARALL	0.000	0.000	0.050	0.000	0.000	#+++++++

POS_B_1							
	POSITN	0.152	0.000	0.250	0.000	0.152	.++++#+++

KR_B_2_1							
	RUNDHEIT	0.003	0.000	0.050	0.000	0.003	#+++++++
	DM	11.457	11.400	0.100	0.000	0.057	----.#+++

KOAX_B_2_1							
	COAXTY	0.004	0.000	0.050	0.000	0.004	#+++++++

KR_B_2_2							
	RUNDHEIT	0.004	0.000	0.050	0.000	0.004	#+++++++
	DM	11.458	11.400	0.100	0.000	0.058	----.#+++

KOAX_B_2_2							
	COAXTY	0.003	0.000	0.050	0.000	0.003	#+++++++

KR_B_3_1							
	RUNDHEIT	0.005	0.000	0.020	0.000	0.005	.#+++++++
	DM	9.715	9.700	0.019	-0.002	0.015	----.#+++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 11 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So11	Grafik
KOAX_B_3_1		POI					
	COAXTY	0.009	0.000	0.050	0.000	0.009	.#++++++

KR_B_3_2		CIR					
	RUNDHEIT	0.004	0.000	0.020	0.000	0.004	.#++++++
	DM	9.715	9.700	0.019	-0.002	0.015	----.##+

KOAX_B_3_2		POI					
	COAXTY	0.009	0.000	0.050	0.000	0.009	.#++++++

KR_B_3_3		CIR					
	RUNDHEIT	0.005	0.000	0.020	0.000	0.005	.#++++++
	DM	9.716	9.700	0.019	-0.002	0.016	----.##+

KOAX_B_3_3		POI					
	COAXTY	0.007	0.000	0.050	0.000	0.007	.#++++++

PFERCHZYLINDER							
ZYL_PF_B		CYL					
	DM	9.712	9.700	0.019	-0.002	0.012	----.##+

HUELLZYLINDER							
ZYL_HU_B		CYL					
	DM	9.720	9.700	0.019	-0.002	0.020	0.001 ◀

ZYLINDERFORM GEM. MZC							
ZYL_MZC_B		CYL					
	ZYL_FORM	0.005	0.000	0.020	0.000	0.005	.#++++++

KR_B_4_1		CIR					
	RUNDHEIT	0.004	0.000	0.050	0.000	0.004	#++++++
	DM	6.213	6.200	0.050	-0.050	0.013	----.##+

KOAX_B_4_1		POI					
	COAXTY	0.011	0.000	0.050	0.000	0.011	.#++++++
=====							
Abstand Ventilblockseite zu Bezug PQ							

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 12 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-So11	Grafik
PKT_ABST_1_1							
	Y	-45.037	45.000	0.100	-0.100	0.037	----.+#++
PKT_ABST_1_2							
	Y	-45.103	45.000	0.100	-0.100	0.103	0.003 ◀
PKT_ABST_1_3							
	Y	-45.034	45.000	0.100	-0.100	0.034	----.+#++
PKT_ABST_1_4							
	Y	-45.040	45.000	0.100	-0.100	0.040	----.+#++
PKT_ABST_1_5							
	Y	-45.034	45.000	0.100	-0.100	0.034	----.+#++
=====							
2X DAEMPUNGSKAMMER JE EINE KOLBENBOHRUNGSEITE ATG N 110 11.21							
KREIS(3)							
	RUNDHEIT	0.003	0.000	0.025	0.000	0.003	.#+++++++
	DM	16.030	16.000	0.046	-0.005	0.030	----.+#++
	X	-12.923	13.000	0.125	-0.125	-0.077	-#-.++++
	Z	-24.713	24.700	0.125	-0.125	0.013	---#++++

POS(3)							
	POSITN	0.156	0.000	0.250	0.000	0.156	.++++#+++

KREIS(4)							
	RUNDHEIT	0.002	0.000	0.025	0.000	0.002	#+++++++
	DM	16.029	16.000	0.046	-0.005	0.029	----.+#++
	X	-13.040	13.000	0.125	-0.125	0.040	----.#+++
	Z	-24.680	24.700	0.125	-0.125	-0.020	---#.++++

POS(4)							
	POSITN	0.089	0.000	0.250	0.000	0.089	.++#+++++
=====							
Breite Ventilblock							
ABST_VB_1							
	DY	90.205	90.000	0.600	0.000	0.205	---#.++++
ABST_VB_2							
	DY	90.275	90.000	0.600	0.000	0.275	----#++++
ABST_VB_3							
	DY	90.207	90.000	0.600	0.000	0.207	---#.++++
ABST_VB_4							
	DY	90.208	90.000	0.600	0.000	0.208	---#.++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 13 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So	Grafik
ABST_VB_5							
	DY	90.197	90.000	0.600	0.000	0.197	--#-.++++

EBENE GEWINDEANSCHLUSS-SEITE

EB_ANSCHL			PLA				
	EBENHEIT	0.013					
	PA_PXMZ	89°59'20	90°00'00			-0°00'40	
	PA_PYMZ	90°00'00	90°00'00			0°00'00	

RECHTWINKLIGKEIT ZU P

RECHTW_P			PLA				
	SQRNES	0.013	0.000	0.200	0.000	0.013	#+++++++

RECHTWINKLIGKEIT ZU S

RECHTW_S			PLA				
	SQRNES	0.016	0.000	0.150	0.000	0.016	#+++++++

SEITE GEGENUEBERLIEGEND VON MOTORBOHRUNG

BILDUNG DES KOORDINATENSYSTEMS VZ in Tiefe 28 mm

1. AUSRICHELEMENT V/Z

KREIS_VZ			CIR				
	RUNDHEIT	0.005	0.000	0.028	0.000	0.005	.#+++++++
	DM	9.947	9.900	0.058	0.000	0.047	----.###+
	Y	-0.025	0.000	0.150	-0.150	0.025	----.#+++
	Z	-25.479	25.500	0.150	-0.150	-0.021	---#..++++

POS_BEZ_VZ			POI				
	POSITN	0.065	0.000	0.300	0.000	0.065	.#+++++++

2. AUSRICHELEMENT V/Z

KREIS(5)			CIR				
	RUNDHEIT	0.003	0.000	0.030	0.000	0.003	#+++++++
	DM	4.424	4.460	0.000	-0.060	-0.036	---#..++++

KR(5)			CIR				
	Y	0.000	0.000	0.100	-0.100	0.000	----#++++
	Z	31.980	32.000	0.100	-0.100	-0.020	---#..++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 14 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So11	Grafik
POS(5)		POI					
	POSITN	0.039	0.000	0.200	0.000	0.039	.#+++++++

SYMMETRY ACHSE Z ZU ACHSE P							
AXI_Z_P		PLA					
	SYMTRY	0.049	0.000	0.300	0.000	0.049	.#+++++++

PARALLAELLITAET ACHSE V ZU ACHSE Q							
PARALL_V_Q		PLA					
	PARALL	0.016	0.000	0.300	0.000	0.016	#+++++++
=====							
1X DRUCHSENSOR-BOHRUNG GEM. ATG N 110 11.13							
KR_DR_3		CIR					
	RUNDHEIT	0.002	0.000	0.025	0.000	0.002	#+++++++
	DM	6.027	6.000	0.050	0.000	0.027	----#++++
	Y	-21.001	21.000	0.100	-0.100	0.001	----#++++
	Z	55.465	55.500	0.100	-0.100	-0.035	--#-.++++

POS_DR_3		POI					
	POSITN	0.071	0.000	0.200	0.000	0.071	.##+++++++
=====							
V E N T I L M E S S U N G E N ZU BEZUG VZ							
2X VENTILE GEM. ATG N 110 11.20							
VENTIL 1							
K_V1_1		CIR					
	RUNDHEIT	0.004	0.000	0.100	0.000	0.004	#+++++++
	DM	11.426	11.400	0.100	-0.100	0.026	----.#+++

K_V1_2		CIR					
	RUNDHEIT	0.002	0.000	0.100	0.000	0.002	#+++++++
	DM	11.430	11.400	0.100	-0.100	0.030	----.#+++

K_V1_3		CIR					
	RUNDHEIT	0.004	0.000	0.025	0.000	0.004	.#+++++++
	DM	11.430	11.400	0.050	0.000	0.030	----.#+++
	Y	23.002	23.000	0.100	-0.100	0.002	----#++++
	Z	-10.166	10.200	0.100	-0.100	-0.034	--#-.++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 15 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-So11	Grafik
POS_114(1)		POI					
	POSITN	0.067	0.000	0.200	0.000	0.067	.##+++++

BEZUGSACHSE							
AXI_V1		AXI					
	FORM	0.001					

KR_83(1)		CIR					
	RUNDHEIT	0.005	0.000	0.020	0.000	0.005	.##+++++
	DM	8.326	8.300	0.040	0.000	0.026	----.##+++

R_LAUF_V1_83		AXI					
	RADRUN	0.012	0.000	0.025	0.000	0.012	.##+++++

KR_13(1)		CIR					
	RUNDHEIT	0.003	0.000	0.021	0.000	0.003	.##+++++
	DM	13.028	13.000	0.043	0.000	0.028	----.##+++

R_LAUF_V1_13		AXI					
	RADRUN	0.006	0.000	0.025	0.000	0.006	.##+++++
=====							
VENTIL 2							
KR_114(2)		CIR					
	RUNDHEIT	0.004	0.000	0.025	0.000	0.004	.##+++++
	DM	11.428	11.400	0.050	0.000	0.028	----.##+++
	Y	-22.983	23.000	0.100	-0.100	-0.017	---#.++++
	Z	-10.185	10.200	0.100	-0.100	-0.015	---#.++++

POS_114(2)		POI					
	POSITN	0.045	0.000	0.200	0.000	0.045	.##+++++
=====							
4X VENTILE GEM. ATG N 110 11.19							
VENTIL 3							
K_V3_1		CIR					
	RUNDHEIT	0.007	0.000	0.025	0.000	0.007	.##+++++
	DM	10.376	10.400	0.000	-0.050	-0.024	----.##+++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 16 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So	Grafik
K_V3_2		CIR					
	RUNDHEIT	0.005	0.000	0.025	0.000	0.005	.#+++++++
	DM	10.377	10.400	0.000	-0.050	-0.023	----#++++

K_V3_3		CIR					
	RUNDHEIT	0.004	0.000	0.025	0.000	0.004	.#+++++++
	DM	10.377	10.400	0.000	-0.050	-0.023	----#++++
	Y	31.790	31.800	0.100	-0.100	-0.010	----#++++
	Z	9.418	9.400	0.100	-0.100	0.018	----.#+++

POS_114(3)		POI					
	POSITN	0.041	0.000	0.200	0.000	0.041	.#+++++++

BEZUGSACHSE							
AXI_V3		AXI					
	FORM	0.003					

KR_83(3)		CIR					
	RUNDHEIT	0.010	0.000	0.020	0.000	0.010	.+++#+++++
	DM	9.957	9.975	0.000	-0.050	-0.018	----.#+++

R_LAUF_V3_83		AXI					
	RADRUN	0.012	0.000	0.025	0.000	0.012	.+++#+++++

KR_13(3)		CIR					
	RUNDHEIT	0.009	0.000	0.021	0.000	0.009	.+++#+++++
	DM	13.021	13.000	0.043	0.000	0.021	----#++++

R_LAUF_V3_13		AXI					
	RADRUN	0.017	0.000	0.025	0.000	0.017	.++++#+++
=====							
VENTIL 4							
KR_114(4)		CIR					
	RUNDHEIT	0.004	0.000	0.025	0.000	0.004	.#+++++++
	DM	10.378	10.400	0.000	-0.050	-0.022	----.#+++
	Y	10.799	10.800	0.100	-0.100	-0.001	----#++++
	Z	9.007	9.000	0.100	-0.100	0.007	----#++++

POS_114(4)		POI					
	POSITN	0.014	0.000	0.200	0.000	0.014	#+++++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 17 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So11	Grafik
=====							
VENTIL 5							
K_V5_1		CIR					
	RUNDHEIT	0.002	0.000	0.025	0.000	0.002	#+++++++
	DM	10.378	10.400	0.000	-0.050	-0.022	----.#+++

K_V5_2		CIR					
	RUNDHEIT	0.003	0.000	0.025	0.000	0.003	.#+++++++
	DM	10.378	10.400	0.000	-0.050	-0.022	----.#+++

K_V5_3		CIR					
	RUNDHEIT	0.003	0.000	0.025	0.000	0.003	.#+++++++
	DM	10.378	10.400	0.000	-0.050	-0.022	----#++++
	Y	-10.802	10.800	0.100	-0.100	0.002	----#++++
	Z	9.000	9.000	0.100	-0.100	0.000	----#++++

POS_114(5)		POI					
	POSITN	0.003	0.000	0.200	0.000	0.003	#+++++++

BEZUGSACHSE							
AXI_V5		AXI					
	FORM	0.001					

KR_83(5)		CIR					
	RUNDHEIT	0.006	0.000	0.020	0.000	0.006	.#+++++++
	DM	9.956	9.975	0.000	-0.050	-0.019	----.#+++

R_LAUF_V5_83		AXI					
	RADRUN	0.007	0.000	0.025	0.000	0.007	.#+++++++

KR_13(5)		CIR					
	RUNDHEIT	0.004	0.000	0.021	0.000	0.004	.#+++++++
	DM	13.022	13.000	0.043	0.000	0.022	----#++++

R_LAUF_V5_13		AXI					
	RADRUN	0.005	0.000	0.025	0.000	0.005	.#+++++++
=====							
VENTIL 6							

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 18 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So11	Grafik
KR_114(6)		CIR					
	RUNDHEIT	0.003	0.000	0.025	0.000	0.003	#+++++++
	DM	10.377	10.400	0.000	-0.050	-0.023	----#++++
	Y	-31.791	31.800	0.100	-0.100	-0.009	----#++++
	Z	9.390	9.400	0.100	-0.100	-0.010	----#++++

POS_114(6)		POI					
	POSITN	0.028	0.000	0.200	0.000	0.028	.#+++++++
=====							
2X VENTILE GEM. ATG N 111 32.11							
VENTIL 7							
K_V7_1		CIR					
	RUNDHEIT	0.003	0.000	0.100	0.000	0.003	#+++++++
	DM	11.432	11.400	0.100	-0.100	0.032	----.#+++

K_V7_2		CIR					
	RUNDHEIT	0.003	0.000	0.100	0.000	0.003	#+++++++
	DM	11.431	11.400	0.100	-0.100	0.031	----.#+++

K_V7_3		CIR					
	RUNDHEIT	0.004	0.000	0.025	0.000	0.004	.#+++++++
	DM	11.431	11.400	0.050	0.000	0.031	----.#+++
	Y	20.792	20.800	0.100	-0.100	-0.008	----#++++
	Z	24.905	24.900	0.100	-0.100	0.005	----#++++

POS_114(7)		POI					
	POSITN	0.019	0.000	0.200	0.000	0.019	#+++++++

BEZUGSACHSE							
AXI_V7		AXI					
	FORM	0.000					

KR_54(7)		CIR					
	RUNDHEIT	0.006	0.000	0.020	0.000	0.006	.#+++++++
	DM	5.428	5.400	0.040	0.000	0.028	----.#+++

R_LAUF_V7_54		AXI					
	RADRUN	0.006	0.000	0.025	0.000	0.006	.#+++++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 19 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-So11	Grafik
KR_13(7)		CIR					
	RUNDHEIT	0.004	0.000	0.021	0.000	0.004	.#+++++++
	DM	13.027	13.000	0.043	0.000	0.027	----.#+++

R_LAUF_V7_13		AXI					
	RADRUN	0.008	0.000	0.025	0.000	0.008	.#+++++++
=====							
VENTIL 8							
KR_114(8)		CIR					
	RUNDHEIT	0.002	0.000	0.025	0.000	0.002	#+++++++
	DM	11.432	11.400	0.050	0.000	0.032	----.#+++
	Y	-20.797	20.800	0.100	-0.100	-0.003	----#++++
	Z	24.886	24.900	0.100	-0.100	-0.014	---#.#++++

POS_114(8)		POI					
	POSITN	0.028	0.000	0.200	0.000	0.028	.#+++++++
=====							
4X VENTILE GEM. ATG N 111 32.10							
VENTIL 9							
K_V9_1		CIR					
	RUNDHEIT	0.005	0.000	0.100	0.000	0.005	#+++++++
	DM	11.427	11.400	0.100	-0.100	0.027	----.#+++

K_V9_2		CIR					
	RUNDHEIT	0.003	0.000	0.100	0.000	0.003	#+++++++
	DM	11.427	11.400	0.100	-0.100	0.027	----.#+++

K_V9_3		CIR					
	RUNDHEIT	0.003	0.000	0.025	0.000	0.003	.#+++++++
	DM	11.427	11.400	0.050	0.000	0.027	----#++++
	Y	31.785	31.800	0.100	-0.100	-0.015	---#.#++++
	Z	40.899	40.900	0.100	-0.100	-0.001	----#++++

POS_114(9)		POI					
	POSITN	0.029	0.000	0.200	0.000	0.029	.#+++++++

BEZUGSACHSE							
AXI_V9		AXI					
	FORM	0.000					

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 20 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So11	Grafik

KR_61(9)		CIR					
	RUNDHEIT	0.007	0.000	0.020	0.000	0.007	.++#+++++
	DM	6.124	6.100	0.040	0.000	0.024	----.#+++

R_LAUF_V9_61		AXI					
	RADRUN	0.009	0.000	0.025	0.000	0.009	.++#+++++

KR_13(9)		CIR					
	RUNDHEIT	0.006	0.000	0.021	0.000	0.006	.++#+++++
	DM	13.026	13.000	0.043	0.000	0.026	----.#+++

R_LAUF_V9_13		AXI					
	RADRUN	0.009	0.000	0.025	0.000	0.009	.++#+++++
=====							
VENTIL 10							
KR_114(10)		CIR					
	RUNDHEIT	0.002	0.000	0.025	0.000	0.002	#+++++++
	DM	11.427	11.400	0.050	0.000	0.027	----#++++
	Y	9.292	9.300	0.100	-0.100	-0.008	----#++++
	Z	39.194	39.200	0.100	-0.100	-0.006	----#++++

POS_114(10)		POI					
	POSITN	0.020	0.000	0.200	0.000	0.020	#+++++++
=====							
VENTIL 11							
K_V11_1		CIR					
	RUNDHEIT	0.004	0.000	0.100	0.000	0.004	#+++++++
	DM	11.427	11.400	0.100	-0.100	0.027	----.#+++

K_V11_2		CIR					
	RUNDHEIT	0.003	0.000	0.100	0.000	0.003	#+++++++
	DM	11.428	11.400	0.100	-0.100	0.028	----.#+++

K_V11_3		CIR					
	RUNDHEIT	0.002	0.000	0.025	0.000	0.002	#+++++++
	DM	11.427	11.400	0.050	0.000	0.027	----#++++
	Y	-9.302	9.300	0.100	-0.100	0.002	----#++++
	Z	39.188	39.200	0.100	-0.100	-0.012	---#.++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 21 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-So11	Grafik
POS_114(11)		POI					
	POSITN	0.025	0.000	0.200	0.000	0.025	.#+++++++

BEZUGSACHSE							
AXI_V11		AXI					
	FORM	0.000					

KR_61(11)		CIR					
	RUNDHEIT	0.005	0.000	0.020	0.000	0.005	.#+++++++
	DM	6.125	6.100	0.040	0.000	0.025	----.#+++

R_LAUF_V11_61		AXI					
	RADRUN	0.005	0.000	0.025	0.000	0.005	.#+++++++

KR_13(11)		CIR					
	RUNDHEIT	0.005	0.000	0.021	0.000	0.005	.#+++++++
	DM	13.027	13.000	0.043	0.000	0.027	----.#+++

R_LAUF_V11_13		AXI					
	RADRUN	0.008	0.000	0.025	0.000	0.008	.#+++++++
=====							
VENTIL 12							
KR_114(12)		CIR					
	RUNDHEIT	0.002	0.000	0.025	0.000	0.002	#+++++++
	DM	11.426	11.400	0.050	0.000	0.026	----#++++
	Y	-31.793	31.800	0.100	-0.100	-0.007	----#++++
	Z	40.875	40.900	0.100	-0.100	-0.025	---# .++++

POS_114(12)		POI					
	POSITN	0.052	0.000	0.200	0.000	0.052	.#+++++++
=====							
V E N T I L P O S I T I O N E N ZU BEZUG NZ							
2X VENTILE GEM. ATG N 110 11.20							
KK_V1_3		CIR					
	Y	22.992	23.000	0.100	-0.100	-0.008	----#++++
	Z	9.037	9.000	0.100	-0.100	0.037	----.#+++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 22 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.To1.	U.To1.	Ist-Soll	Grafik
POSS_114(1)		POI					
	POSITN	0.076	0.000	0.200	0.000	0.076	.++#+++++

KRR_114(2)		CIR					
	Y	-22.993	23.000	0.100	-0.100	-0.007	----#++++
	Z	9.018	9.000	0.100	-0.100	0.018	----.#+++

POSS_114(2)		POI					
	POSITN	0.039	0.000	0.200	0.000	0.039	.#++++++

V E N T I L P O S I T I O N E N ZU BEZUG NZ							
4X VENTILE GEM. ATG N 110 11.19							
KK_V3_3		CIR					
	Y	31.780	31.800	0.100	-0.100	-0.020	---#.++++
	Z	28.621	28.600	0.100	-0.100	0.021	----.#+++

POSS_114(3)		POI					
	POSITN	0.059	0.000	0.200	0.000	0.059	.++#+++++

KRR_114(4)		CIR					
	Y	10.789	10.800	0.100	-0.100	-0.011	---#.++++
	Z	28.210	28.200	0.100	-0.100	0.010	----#++++

POSS_114(4)		POI					
	POSITN	0.031	0.000	0.200	0.000	0.031	.#++++++

KK_V5_3		CIR					
	Y	-10.812	10.800	0.100	-0.100	0.012	----.#+++
	Z	28.204	28.200	0.100	-0.100	0.004	----#++++

POSS_114(5)		POI					
	POSITN	0.025	0.000	0.200	0.000	0.025	.#++++++

KRR_114(6)		CIR					
	Y	-31.801	31.800	0.100	-0.100	0.001	----#++++
	Z	28.594	28.600	0.100	-0.100	-0.006	----#++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 23 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-Soll	Grafik
POSS_114(6)		POI					
	POSITN	0.013	0.000	0.200	0.000	0.013	#+++++++

V E N T I L P O S I T I O N E N ZU BEZUG NZ							
2X VENTILE GEM. ATG N 111 32.11							
KK_V7_3		CIR					
	Y	20.782	20.800	0.100	-0.100	-0.018	---#.++++
	Z	44.108	44.100	0.100	-0.100	0.008	----#++++

POSS_114(7)		POI					
	POSITN	0.040	0.000	0.200	0.000	0.040	.#+++++++

KRR_114(8)		CIR					
	Y	-20.807	20.800	0.100	-0.100	0.007	----#++++
	Z	44.090	44.100	0.100	-0.100	-0.010	----#++++

POSS_114(8)		POI					
	POSITN	0.025	0.000	0.200	0.000	0.025	.#+++++++

V E N T I L P O S I T I O N E N ZU BEZUG NZ							
4X VENTILE GEM. ATG N 111 32.10							
KK_V9_3		CIR					
	Y	31.775	31.800	0.100	-0.100	-0.025	---#.++++
	Z	60.102	60.100	0.100	-0.100	0.002	----#++++

POSS_114(9)		POI					
	POSITN	0.050	0.000	0.200	0.000	0.050	.#+++++++

KRR_114(10)		CIR					
	Y	9.282	9.300	0.100	-0.100	-0.018	---#.++++
	Z	58.397	58.400	0.100	-0.100	-0.003	----#++++

POSS_114(10)		POI					
	POSITN	0.037	0.000	0.200	0.000	0.037	.#+++++++

KK_V11_3		CIR					
	Y	-9.312	9.300	0.100	-0.100	0.012	----.#++++
	Z	58.391	58.400	0.100	-0.100	-0.009	----#++++

POSS_114(11)			POI				
	POSITN	0.030	0.000	0.200	0.000	0.030	.#++++++

KRR_114(12)			CIR				
	Y	-31.803	31.800	0.100	-0.100	0.003	----#++++
	Z	60.078	60.100	0.100	-0.100	-0.022	---#.++++

POSS_114(12)			POI				
	POSITN	0.044	0.000	0.200	0.000	0.044	.#++++++

=====

3X DURCHGANGSBOHRUNG 5,7MM / 3X KOAX GEM. ATG N 110 11.11

DRG_1_1			CIR				
	RUNDHEIT	0.004	0.000	0.050	0.000	0.004	#++++++
	DM	5.759	5.700	0.100	0.000	0.059	----.#+++

DRG_1_2			CIR				
	RUNDHEIT	0.002	0.000	0.050	0.000	0.002	#++++++
	DM	5.759	5.700	0.100	0.000	0.059	----.#+++

AXI_DRG_1			AXI				
	FORM	0.003					

KOAXIALITAET VON DM 6,20MM ZU DM 5,7MM

COAX_DRG_1			POI				
	COAXTY	0.131	0.000	0.300	0.000	0.131	.+#++++

POSITION VON DM 5.7MM VENTILSEITE ZU VZ

DRG_1_3			CIR				
	Y	38.985	39.000	0.100	-0.100	-0.015	---#.++++
	Z	58.493	58.500	0.100	-0.100	-0.007	----#++++

POS_DRG_1			POI				
	POSITN	0.032	0.000	0.200	0.000	0.032	.#++++++

POSITION VON DM 5.7MM MOTORSEITE ZU VZ

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 25 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-Soll	Grafik
DRG_1_4		CIR					
	Y	39.002	39.000	0.100	-0.100	0.002	----#++++
	Z	58.511	58.500	0.100	-0.100	0.011	----.#+++

POS_DRG_1_1		POI					
	POSITN	0.023	0.000	0.200	0.000	0.023	.#++++++

DRG_2_1		CIR					
	RUNDHEIT	0.003	0.000	0.050	0.000	0.003	#++++++
	DM	5.759	5.700	0.100	0.000	0.059	----.#+++

DRG_2_2		CIR					
	RUNDHEIT	0.002	0.000	0.050	0.000	0.002	#++++++
	DM	5.761	5.700	0.100	0.000	0.061	----.#+++

AXI_DRG_2		AXI					
	FORM	0.006					

KOAXIALITAET VON DM 6,20MM ZU DM 5,7MM							
COAX_DRG_2		POI					
	COAXTY	0.041	0.000	0.300	0.000	0.041	.#++++++

POSITION VON DM 5.7MM VENTILSEITE							
DRG_2_3		CIR					
	Y	-38.998	39.000	0.100	-0.100	-0.002	----#++++
	Z	58.462	58.500	0.100	-0.100	-0.038	--#-.++++

POS_DRG_2		POI					
	POSITN	0.075	0.000	0.200	0.000	0.075	.++#++++

POSITION VON DM 5.7MM MOTORSEITE ZU VZ							
DRG_2_4		CIR					
	Y	-39.006	39.000	0.100	-0.100	0.006	----#++++
	Z	58.474	58.500	0.100	-0.100	-0.026	---#-.++++

POS_DRG_2_1		POI					
	POSITN	0.053	0.000	0.200	0.000	0.053	.#++++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 26 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-So	Grafik

DRG_3_1		CIR					
	FORM	0.002	0.000	0.050	0.000	0.002	#+++++++
	DM	5.755	5.700	0.100	0.000	0.055	----#++++

DRG_3_2		CIR					
	RUNDHEIT	0.003	0.000	0.050	0.000	0.003	#+++++++
	DM	5.755	5.700	0.100	0.000	0.055	----#++++

AXI_DRG_3		AXI					
	FORM	0.002					

KOAXIALITAET VON DM 6,20MM ZU DM 5,7MM

COAX_DRG_3		POI					
	COAXTY	0.021	0.000	0.300	0.000	0.021	#+++++++

POSITION VON DM 5.7MM VENTILSEITE

DRG_3_3		CIR					
	Y	0.014	0.000	0.100	-0.100	0.014	----.#+++
	Z	-19.196	19.200	0.100	-0.100	-0.004	----#++++

POS_DRG_3		POI					
	POSITN	0.029	0.000	0.200	0.000	0.029	.#+++++++

POSITION VON DM 5.7MM MOTORSEITE ZU VZ

DRG_3_4		CIR					
	Y	0.010	0.000	0.100	-0.100	0.010	----#++++
	Z	-19.204	19.200	0.100	-0.100	0.004	----#++++

POS_DRG_3_1		POI					
	POSITN	0.022	0.000	0.200	0.000	0.022	#+++++++

WEITERE RUNDLAEUFE VON VENTILBOHRUNGEN

2X VENTILE GEM. ATG N 110 11.19

VENTIL 3 FASENDURCHMESSR 14,3mm

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 27 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.To1.	u.To1.	Ist-Soll	Grafik
FASE_V3							
	FORM	0.002					

LF_FASE_V3							
	RADRUN	0.017	0.000	0.050	0.000	0.017	..#++++++

VENTIL 5 FASENDURCHMESSR 14,3mm							
FASE_V5							
	FORM	0.004					

LF_FASE_V5							
	RADRUN	0.013	0.000	0.050	0.000	0.013	..#++++++

VENTIL 7 GEM. ATG N 111 32.11							
FASENDURCHMESSR 14,3mm							
FASE_V7							
	FORM	0.002					

LF_FASE_V7							
	RADRUN	0.012	0.000	0.050	0.000	0.012	..#++++++

2X VENTILE GEM. ATG N 111 32.10							
VENTIL 9 FASENDURCHMESSR 14,3mm							
FASE_V9							
	FORM	0.002					

LF_FASE_V9							
	RADRUN	0.013	0.000	0.050	0.000	0.013	..#++++++

VENTIL 11 FASENDURCHMESSR 14,3mm							
FASE_V11							
	FORM	0.001					

LF_FASE_V11							
	RADRUN	0.015	0.000	0.050	0.000	0.015	..#++++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 28 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-So11	Grafik

VENTIL 1 GEM. ATG N 110 11.20

FASENDURCHMESSR 14,3mm

FASE_V1 CIR
FORM 0.003

LF_FASE_V1 AXI
RADRUN 0.009 0.000 0.050 0.000 0.009 .#+++++++

PLANLAEUFE KOLBENBOHRUNG A

EB_KOLB_A1 PLA
FORM 0.002 0.000 0.020 0.000 0.002 #+++++++

LF_KOLB_A_1 PLA
AXIRUN 0.003 0.000 0.020 0.000 0.003 .#+++++++

EB_KOLB_A2 PLA
FORM 0.002 0.000 0.050 0.000 0.002 #+++++++
Y 43.854 43.900 0.150 -0.150 -0.046 ---#.++++

LF_KOLB_A_2 PLA
AXIRUN 0.003 0.000 0.050 0.000 0.003 #+++++++

PLANLAEUFE KOLBENBOHRUNG B

EB_KOLB_B1 PLA
FORM 0.002 0.000 0.020 0.000 0.002 #+++++++

LF_KOLB_B_1 PLA
AXIRUN 0.004 0.000 0.020 0.000 0.004 .#+++++++

EB_KOLB_B2 PLA
FORM 0.002 0.000 0.050 0.000 0.002 #+++++++
Y -43.931 43.900 0.150 -0.150 0.031 ----.++++

LF_KOLB_B_2 PLA
AXIRUN 0.003 0.000 0.050 0.000 0.003 #+++++++

1X GEWINDE M6 IN SEITE B

KR_M6		CIR					
	FORM	0.015					
	X	-4.962	5.000	0.150	-0.150	-0.038	---#.++++
	Z	14.977	15.000	0.150	-0.150	-0.023	---#.++++

POS_M6		POI					
	POSITN	0.090	0.000	0.300	0.000	0.090	..#++++++

3X GERADER KANAL IN SCHNITT G-G UND SCHNITT O-O

SEITE B - POSITIONEN KREISAUSGEWERTET

SCHNITT G-G

KANAL_1		CIR					
	RUNDHEIT	0.002	0.000	0.030	0.000	0.002	#+++++++
	DM	3.224	3.260	0.000	-0.060	-0.036	---#.++++
	X	-4.626	4.700	0.250	-0.250	-0.074	---#.++++
	Z	-12.523	12.500	0.250	-0.250	0.023	----#++++

POS_KAN_1		POI					
	POSITN	0.156	0.000	0.500	0.000	0.156	..#++++++

SCHNITT G-G

KANAL_2		CIR					
	RUNDHEIT	0.004	0.000	0.030	0.000	0.004	..#++++++
	DM	3.224	3.260	0.000	-0.060	-0.036	---#.++++
	X	-15.136	15.200	0.250	-0.250	-0.064	---#.++++
	Z	-43.028	43.000	0.250	-0.250	0.028	----#++++

POS_KAN_2		POI					
	POSITN	0.140	0.000	0.500	0.000	0.140	..#++++++

SCHNITT O-O

KANAL_3		CIR					
	RUNDHEIT	0.003	0.000	0.030	0.000	0.003	#+++++++
	DM	4.410	4.460	0.000	-0.060	-0.050	-#-.++++
	X	-6.730	6.800	0.250	-0.250	-0.070	---#.++++
	Z	-41.422	41.400	0.250	-0.250	0.022	----#++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 30 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So11	Grafik
POS_KAN_3		POI					
	POSITN	0.146	0.000	0.500	0.000	0.146	..#++++++

3X GERADER KANAL IN SCHNITT G-G UND SCHNITT O-O							
SEITE A - POSITIONEN KREISAUSGEWERTET							
SCHNITT G-G							
KANAL_4		CIR					
	RUNDHEIT	0.002	0.000	0.030	0.000	0.002	#++++++
	DM	3.225	3.260	0.000	-0.060	-0.035	---#.++++
	X	-4.738	4.700	0.250	-0.250	0.038	----.#++++
	Z	-12.480	12.500	0.250	-0.250	-0.020	----#++++

POS_KAN_4		POI					
	POSITN	0.086	0.000	0.500	0.000	0.086	..#++++++

SCHNITT G-G							
KANAL_5		CIR					
	RUNDHEIT	0.001	0.000	0.030	0.000	0.001	#++++++
	DM	3.225	3.260	0.000	-0.060	-0.035	---#.++++
	X	-15.240	15.200	0.250	-0.250	0.040	----.#++++
	Z	-42.984	43.000	0.250	-0.250	-0.016	----#++++

POS_KAN_5		POI					
	POSITN	0.086	0.000	0.500	0.000	0.086	..#++++++

SCHNITT O-O							
KANAL_6		CIR					
	RUNDHEIT	0.004	0.000	0.030	0.000	0.004	..#++++++
	DM	4.413	4.460	0.000	-0.060	-0.047	-#--.++++
	X	-6.834	6.800	0.250	-0.250	0.034	----.#++++
	Z	-41.374	41.400	0.250	-0.250	-0.026	----#++++

POS_KAN_6		POI					
	POSITN	0.086	0.000	0.500	0.000	0.086	..#++++++
=====							
O B E R E VENTILAUFNahme - S E I T E							
SCHNITT D-D							

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 31 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So	Grafik
KANAL_8		CIR					
	RUNDHEIT	0.001	0.000	0.030	0.000	0.001	#+++++++
	DM	4.429	4.460	0.000	-0.060	-0.031	----#++++
	X	-19.797	19.800	0.250	-0.250	-0.003	----#++++
	Y	-0.009	0.000	0.250	-0.250	0.009	----#++++

POS_KAN_8		POI					
	POSITN	0.018	0.000	0.500	0.000	0.018	#+++++++
=====							
2X GEWINDE M6							
KR_M6_1		CIR					
	RUNDHEIT	0.014					
	X	-31.986	32.000	0.150	-0.150	-0.014	----#++++
	Y	31.984	32.000	0.150	-0.150	-0.016	----#++++

POS_M6_1		POI					
	POSITN	0.043	0.000	0.300	0.000	0.043	.#+++++++

KR_M6_2		CIR					
	RUNDHEIT	0.011					
	X	-31.995	32.000	0.150	-0.150	-0.005	----#++++
	Y	-32.012	32.000	0.150	-0.150	0.012	----#++++

POS_M6_2		POI					
	POSITN	0.026	0.000	0.300	0.000	0.026	#+++++++
=====							
2 NDS-BOHRUNG ATG N 110 11.58							
NDS 1 BOHRUNG: ELEMENTE FUER SPAETERE AUSWERTUNG							
KR_NDS_1_1		CIR					
	RUNDHEIT	0.016	0.000	0.025	0.000	0.016	.++++#+++
	DM	25.609	25.600	0.025	-0.025	0.009	----.#+

NDS 2 BOHRUNG: ELEMENTE FUER SPAETERE AUSWERTUNG							
KR_NDS_2_1		CIR					
	RUNDHEIT	0.010	0.000	0.025	0.000	0.010	.++#+++++
	DM	25.608	25.600	0.025	-0.025	0.008	----.#+

NDS 1 BOHRUNG							

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 32 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.To1.	u.To1.	Ist-So1l	Grafik
KR_NDS_1_2		CIR					
	RUNDHEIT	0.005	0.000	0.030	0.000	0.005	.#++++++
	DM	24.034	24.000	0.052	0.000	0.034	----.#+++

KR_NDS_1_3		CIR					
	RUNDHEIT	0.008	0.000	0.030	0.000	0.008	.#++++++
	DM	24.034	24.000	0.052	0.000	0.034	----.#+++
	X	-14.900	14.900	0.125	-0.125	0.000	----#++++
	Y	20.489	20.500	0.125	-0.125	-0.011	----#++++

POS_NDS_1		POI					
	POSITN	0.022	0.000	0.250	0.000	0.022	#++++++

KR_NDS_1_4		CIR					
	RUNDHEIT	0.012	0.000	0.030	0.000	0.012	.##++++++
	DM	24.034	24.000	0.052	0.000	0.034	----.#+++

NDS 1 PFERCHZYLINDER							
ZYL_NDS1_PF		CYL					
	DM	24.024	24.000	0.052	0.000	0.024	----#++++

NDS 1 HUELLZYLINDER							
ZYL_NDS1_HU		CYL					
	DM	24.042	24.000	0.052	0.000	0.042	----.##+

NDS 1 ZYLINDERFORM GEM. MZC							
ZYL_NDS1_MZC		CYL					
	ZYL_FORM	0.009	0.000	0.030	0.000	0.009	.##++++++

AXI_NDS_1		AXI					
	FORM	0.001					

LAUF_NDS_1		AXI					
	RADRUN	0.018	0.000	0.100	0.000	0.018	.#++++++

DRUCKRUECKHALTEVENTIL 1							
PT_DRV_1		POI					
	Z	21.103	21.100	0.100	-0.100	0.003	----#++++

KR_DRV_1		CIR					
	RUNDHEIT	0.002	0.000	0.025	0.000	0.002	#+++++++
	DM	7.535	7.525	0.025	-0.025	0.010	----.##++
	X	-17.108	17.100	0.125	-0.125	0.008	----#++++
	Y	21.438	21.400	0.125	-0.125	0.038	----.##++

POS_DRV_1		POI					
	POSITN	0.077	0.000	0.250	0.000	0.077	.##+++++

NDS 2 BOHRUNG

KR_NDS_2_2		CIR					
	RUNDHEIT	0.006	0.000	0.030	0.000	0.006	.#+++++++
	DM	24.034	24.000	0.052	0.000	0.034	----.##++

KR_NDS_2_3		CIR					
	RUNDHEIT	0.007	0.000	0.030	0.000	0.007	.##+++++
	DM	24.034	24.000	0.052	0.000	0.034	----.##++
	X	-14.906	14.900	0.125	-0.125	0.006	----#++++
	Y	-20.505	20.500	0.125	-0.125	0.005	----#++++

POS_NDS_2		POI					
	POSITN	0.016	0.000	0.250	0.000	0.016	#+++++++

KR_NDS_2_4		CIR					
	RUNDHEIT	0.008	0.000	0.030	0.000	0.008	.##+++++
	DM	24.034	24.000	0.052	0.000	0.034	----.##++

NDS 2 PFERCHZYLINDER

ZYL_NDS2_PF		CYL					
	DM	24.026	24.000	0.052	0.000	0.026	----#++++

NDS 2 HUELLZYLINDER

ZYL_NDS2_HU		CYL					
	DM	24.040	24.000	0.052	0.000	0.040	----.##++

NDS 2 ZYLINDERFORM GEM. MZC

ZYL_NDS2_MZC		CYL					
	ZYL_FORM	0.007	0.000	0.030	0.000	0.007	.##+++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 34 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-So	Grafik

AXI_NDS_2 AXI
FORM 0.001

LAUF_NDS_2 AXI
RADRUN 0.014 0.000 0.100 0.000 0.014 .#++++++

DRUCKRUECKHALTEVENTIL 2

PT_DRV_2 POI
Z 21.104 21.100 0.100 -0.100 0.004 ----#++++

KR_DRV_2 CIR
RUNDHEIT 0.002 0.000 0.025 0.000 0.002 #+++++++
DM 7.535 7.525 0.025 -0.025 0.010 ----.#+++
X -17.112 17.100 0.125 -0.125 0.012 ----#++++
Y -21.454 21.400 0.125 -0.125 0.054 ----.#+++

POS_DRV_2 POI
POSITN 0.111 0.000 0.250 0.000 0.111 .+++#+++++

K A N A L A E L E

KANAL_10 CYL
ZYL_FORM 0.013

KAN_10 CYL
PA_PXPZ 8°56'39 9°00'00 -0°03'21
PA_PYPX 89°58'12 90°00'00 -0°01'48

SCHN_KAN_10 POI
Y 31.097 31.100 0.250 -0.250 -0.003 ----#++++
Z 8.801 8.800 0.250 -0.250 0.001 ----#++++

POSITION KREISAUSGEWERTET

POS_KAN_10 POI
POSITN 0.006 0.000 0.500 0.000 0.006 #+++++++

POSITION ZYLINDERAUSGEWERTET

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 35 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-So11	Grafik
POS_KAN(10)		AXI					
	POSITN	0.069	0.000	0.500	0.000	0.069	.#++++++
=====							
KANAL_11		CYL					
	ZYL_FORM	0.013					

KAN_11		CYL					
	PA_PXPZ	8°53'12	9°00'00			-0°06'48	
	PA_PYPX	90°05'30	90°00'00			0°05'30	

SCHN_KAN_11		POI					
	Y	12.407	12.400	0.250	-0.250	0.007	----#++++
	Z	7.582	7.500	0.250	-0.250	0.082	----.#++++

POSITION KREISAUSGEWERTET							
POS_KAN_11		POI					
	POSITN	0.165	0.000	0.500	0.000	0.165	..#++++++

POSITION ZYLINDERAUSGEWERTET							
POS_KAN(11)		AXI					
	POSITN	0.163	0.000	0.500	0.000	0.163	..#++++++
=====							
KANAL_12		CYL					
	ZYL_FORM	0.011					

KAN_12		CYL					
	PA_PXPZ	9°00'26	9°00'00			0°00'26	
	PA_PYPX	90°09'21	90°00'00			0°09'21	

SCHN_KAN_12		POI					
	Y	-12.403	12.400	0.250	-0.250	0.003	----#++++
	Z	7.543	7.500	0.250	-0.250	0.043	----.#++++

POSITION KREISAUSGEWERTET							
POS_KAN_12		POI					
	POSITN	0.086	0.000	0.500	0.000	0.086	.#++++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 36 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-Soll	Grafik

POSITION ZYLINDERAUSGEWERTET

POS_KAN(12)			AXI				
	POSITN	0.208	0.000	0.500	0.000	0.208	.++#+++++

KANAL_13			CYL				
	ZYL_FORM	0.010					

KAN_13			CYL				
	PA_PXPZ	8°56'35	9°00'00			-0°03'25	
	PA_PYPX	90°08'41	90°00'00			0°08'41	

SCHN_KAN_13			POI				
	Y	-31.088	31.100	0.250	-0.250	-0.012	----#++++
	Z	8.773	8.800	0.250	-0.250	-0.027	----#++++

POSITION KREISAUSGEWERTET

POS_KAN_13			POI				
	POSITN	0.059	0.000	0.500	0.000	0.059	.#+++++++

POSITION ZYLINDERAUSGEWERTET

POS_KAN(13)			AXI				
	POSITN	0.185	0.000	0.500	0.000	0.185	.++#+++++

KANAL_14			CYL				
	ZYL_FORM	0.003					

KAN_14			CYL				
	PA_PXMZ	39°56'56	40°00'00			-0°03'04	
	PA_PYPX	90°02'08	90°00'00			0°02'08	

SCHN_KAN_14			POI				
	Y	18.778	18.800	0.250	-0.250	-0.022	----#++++
	Z	27.442	27.500	0.250	-0.250	-0.058	---#.++++

POSITION KREISAUSGEWERTET

POS_KAN_14			POI				
	POSITN	0.123	0.000	0.500	0.000	0.123	.#+++++++

POSITION ZYLINDERAUSGEWERTET

POS_KAN(14)			AXI				
	POSITN	0.099	0.000	0.500	0.000	0.099	.#+++++

KANAL_15			CYL				
	ZYL_FORM	0.005					

KAN_15			CYL				
	PA_PXMZ	40°01'29	40°00'00			0°01'29	
	PA_PYPX	90°06'09	90°00'00			0°06'09	

SCHN_KAN_15			POI				
	Y	-18.826	18.800	0.250	-0.250	0.026	----#++++
	Z	27.401	27.500	0.250	-0.250	-0.099	--#-.++++

POSITION KREISAUSGEWERTET

POS_KAN_15			POI				
	POSITN	0.205	0.000	0.500	0.000	0.205	.++#++++

POSITION ZYLINDERAUSGEWERTET

POS_KAN(15)			AXI				
	POSITN	0.248	0.000	0.500	0.000	0.248	.+++#+++++

6 KANAEL AUF DER GEWINDEANSCHLUSSEITE

AUSRICHELEMENTE FUER GEWINDEANSCHLUSSEITE

1. AUSRICHELEMENT P/Q

EB(1)			PLA				
	EBENHEIT	0.004					

KREIS_Q			CIR				
	RUNDHEIT	0.008					
	DM	26.035					

2. AUSRICHELEMENT P/Q

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 38 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-Soll	Grafik

KR_(1) CIR
 RUNDHEIT 0.001
 DM 11.012

KANAL_16 CYL
 ZYL_FORM 0.014

KAN_16 CYL
 PA_PZPX 1°03'27 1°00'00 0°03'27
 PA_PYPZ 89°55'41 90°00'00 -0°04'19

SCHN_KAN_16 POI
 X -29.147 29.100 0.250 -0.250 0.047 ----.#+++
 Y 23.026 23.000 0.250 -0.250 0.026 ----#++++

POSITION KREISAUSGEWERTET

POS_KAN_16 POI
 POSITN 0.108 0.000 0.500 0.000 0.108 .#++++++

POSITION ZYLINDER AUSGEWERTET

POS_KAN(16) AXI
 POSITN 0.283 0.000 0.500 0.000 0.283 .++++#+++

KANAL_17 CYL
 ZYL_FORM 0.052

KAN_17 CYL
 PA_PXPZ 89°56'03 90°00'00 -0°03'57
 PA_PYPZ 89°57'24 90°00'00 -0°02'36

SCHN_KAN_17 POI
 X -29.134 29.140 0.250 -0.250 -0.006 ----#++++
 Y -23.001 23.000 0.250 -0.250 0.001 ----#++++

POSITION KREISAUSGEWERTET

POS_KAN_17 POI
 POSITN 0.011 0.000 0.500 0.000 0.011 #++++++

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 39 von 40	
Text	Ausw.	Istmaß	Nennmaß	o.Tol.	u.Tol.	Ist-Soll	Grafik

POSITION ZYLINDERAUSGEWERTET

POS_KAN(17) AXI
 POSITN 0.121 0.000 0.500 0.000 0.121 .#+++++

KANAELE IN SCHNITT F-F

KANAL_18 CIR
 RUNDHEIT 0.001 0.000 0.030 0.000 0.001 #++++++
 DM 3.233 3.260 0.000 -0.060 -0.027 ----.#+++
 X -14.028 14.000 0.150 -0.150 0.028 ----.#+++
 Y 36.455 36.400 0.150 -0.150 0.055 ----.#+

POS_KAN_18 POI
 POSITN 0.123 0.000 0.300 0.000 0.123 .#+++++

KANAL_19 CIR
 ZYL_FORM 0.002

POS_KAN_19 POI
 POSITN 0.082 0.000 0.500 0.000 0.082 .#+++++

KANAL_20 CIR
 ZYL_FORM 0.001

POS_KAN_20 POI
 POSITN 0.066 0.000 0.500 0.000 0.066 .#+++++

KANAL_21 CIR
 ZYL_FORM 0.001

POS_KAN_21 POI
 POSITN 0.081 0.000 0.500 0.000 0.081 .#+++++

KANAL_22 CIR
 ZYL_FORM 0.004

Datum: 21-Jun-16, 11:46:20			MK100			Seite: 40 von 40	
Text	Ausw.	Istmaß	Nennmaß	O.Tol.	U.Tol.	Ist-Soll	Grafik
POS_KAN_22		POI					
	POSITN	0.111	0.000	0.500	0.000	0.111	.#+++++++

KANAL_23		CIR					
	RUNDHEIT	0.002	0.000	0.030	0.000	0.002	#+++++++
	DM	3.230	3.260	0.000	-0.060	-0.030	----#++++
	X	-14.014	14.000	0.150	-0.150	0.014	----#++++
	Y	-36.346	36.400	0.150	-0.150	-0.054	--#-.++++

POS_KAN_23		POI					
	POSITN	0.111	0.000	0.500	0.000	0.111	.#+++++++

KANAELE IN SCHNITT 0-0							
KANAL_24		CIR					
	RUNDHEIT	0.002	0.000	0.030	0.000	0.002	#+++++++
	DM	4.429	4.460	0.000	-0.060	-0.031	----#++++
	X	-6.837	6.800	0.250	-0.250	0.037	----.#++++
	Y	18.883	18.800	0.250	-0.250	0.083	----.#++++

POS_KAN_24		POI					
	POSITN	0.182	0.000	0.500	0.000	0.182	.+#+++++++

KANAL_25		CIR					
	RUNDHEIT	0.003	0.000	0.030	0.000	0.003	#+++++++
	DM	4.430	4.460	0.000	-0.060	-0.030	----#++++
	X	-6.827	6.800	0.250	-0.250	0.027	----#++++
	Y	-18.717	18.800	0.250	-0.250	-0.083	---#-.++++

POS_KAN_25		POI					
	POSITN	0.182	0.000	0.500	0.000	0.182	.+#+++++++
=====							

A.5. Company Information

A.5.1. Company Description

Continental AG is a leading German automotive manufacturing company specialized in tires, braking systems, automotive safety, powertrain and chassis components, tachographs, and other parts for the automotive and transportation industries. The Automotive Group of Continental AG develops intelligent technologies for transporting people and their goods. As a reliable partner, the international automotive supplier, tire manufacturer, and industrial partner provides sustainable, safe, comfortable, individual, and affordable solutions.

The project was done in the branch offices located in Frankfurt am Main in Germany, in the Chassis & Safety Division which has around 3,000 workers. The Chassis & Safety division develops and produces integrated active and passive driving safety technologies as well as products that support vehicle dynamics. The product portfolio ranges from electronic and hydraulic brake and chassis control systems to sensors, advanced driver assistance systems, airbag electronics and sensorics as well as electronic air suspension systems all the way to windscreen washer systems and headlight cleaning nozzles. The focus lies on a high level of system competence and the networking of individual components. Thus, products and system functions are developed along the SensePlanAct chain of effects, which form the foundation for automated driving. The division consists of four business units:

- Vehicle Dynamics
- Hydraulic Brake Systems
- Passive Safety & Sensorics
- Advanced Driver Assistance Systems (ADAS)

A.5.2. Department Description

The project was carried out in the Quality Control Department (in german Präzisionsprüfung) which is in charge of planning and carrying out tests to products to ensure the conformance of the product to its specifications. The role of the department is to set the procedures intended to guarantee that the manufactured products adheres to the specified quality criteria. The department also performs tests on the measuring instruments to verify they are

working properly and have the specified accuracy. Several units from all the different products of the Chassis & Safety division are tested and with statistical methods, generate decisions regarding the acceptance or rejection of the product.

B. Annexes

B.1. Datasheet Leitz PMM 866 (German)

Hexagon Metrology GmbH
Customer Support Leitz
Postfach 2060
35530 Wetzlar



Abnahmeprotokoll nach EN ISO 10360-2

Kunde:	Continental Teves AG & Co. oHG Guerickestraße 7 60488 Frankfurt	Gerät:	PMM 866 Seriennr. 213
Serviceauftrag:	vom 21.01.2016	Prüfnormal:	Koba Step
		Ident-Nummer:	200603 S289

Prüfnormale

Die zur Abnahme verwendeten Prüfnormale sind auf nationale Normale zur Darstellung der physikalischen Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI) rückführbar. Dies ist in einem Kalibrierschein der Physikalisch-Technischen Bundesanstalt bzw. des Deutschen Kalibrierdienstes dokumentiert.

Abnahmeverfahren

Die Feststellung der Meßunsicherheit erfolgte durch Ermittlung einer Distanz L (in mm) parallel zu einer Geräteachse bzw. diagonal im Meßvolumen durch zwei Antastungen an Parallel- oder Stufenendmaß mit einem beliebigen Kugeltaster des Standard-Tastersortimentes (ohne Verlängerungen) bei Einhalten der Aufstellbedingungen, ggf. mit Temperaturkompensation.

Abnahmeergebnisse

1. Messungen in den Achsen E_1

Achse	Toleranz	Spezifikation erfüllt
X	1,0+L/400 [µm]	Ja <input checked="" type="checkbox"/> Nein <input type="checkbox"/>
Y	1,0+L/400 [µm]	Ja <input checked="" type="checkbox"/> Nein <input type="checkbox"/>
Z	1,0+L/400 [µm]	Ja <input checked="" type="checkbox"/> Nein <input type="checkbox"/>

2. Messungen in den Raumdiagonalen E_3

Raumdiagonale	Toleranz	Spezifikation erfüllt
Diagonale 0	1,2+L/300 [µm]	Ja <input checked="" type="checkbox"/> Nein <input type="checkbox"/>
Diagonale 1	1,2+L/300 [µm]	Ja <input checked="" type="checkbox"/> Nein <input type="checkbox"/>
Diagonale 2	1,2+L/300 [µm]	Ja <input checked="" type="checkbox"/> Nein <input type="checkbox"/>
Diagonale 3	1,2+L/300 [µm]	Ja <input checked="" type="checkbox"/> Nein <input type="checkbox"/>

Wetzlar, den 21.01.2016



B.2. Datasheet Leitz PMM 866 (Relevant information)

The determination of the uncertainty of measurement carried out by determining a distance L (in mm) parallel to an axis of the instrument or diagonally in the measuring volume by two probings of parallel and step gauge block with any ball probe of standard probe assortment (without extensions) in compliance with the installation conditions, possibly with temperature compensation.

Table B.2.0.1. Measuring range in each axis

Axis	Range (mm)
X	800
Y	600
Z	600

Table B.2.0.2. Measurements in the axis E_1

Axis	Tolerance
X	$1,0+L/400$ [μm]
Y	$1,0+L/400$ [μm]
Z	$1,0+L/400$ [μm]

Table B.2.0.3. Measurements in diagonal space E_3

Axis	Tolerance
Diagonal 0	$1,2+L/300$ [μm]
Diagonal 1	$1,2+L/300$ [μm]
Diagonal 2	$1,2+L/300$ [μm]
Diagonal 3	$1,2+L/300$ [μm]