New types of coordinate measuring machines and symbols used for their parameters Part II: Examples of portal machines

Nowe rodzaje współrzędnościowych maszyn pomiarowych i oznaczenia ich parametrów Część II: Przykłady maszyn o konstrukcji portalowej

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Gantry type coordinate machines belong to a group of machines operating to the highest accuracy standards and they are most commonly used for geometric measurements of machine elements, especially in automotive industry. Description of characteristics and functions of the machines offered by different manufacturers is presented.
KEYWORDS: coordinate measuring machines, portal type machines

On the domestic market, there are coordinate portal machines of such companies as Carl Zeiss [3], Leitz Messtechnik and DEA (Hexagon Metrology) [4], Japanese Mitutoyo [5, 6] and Nikon Metrology [7], German Wen- zel [8] and Zett Mess [9], Polish Institute of Advanced Manufacturing Technology [10], Spanish Trimek [11], English Aberlink [12] and German Mora [13]. Some of these machines - especially the most accurate ones - will be featured in this paper.

Carl Zeiss machines

Carl Zeiss offers a range of portal machines that differ in measuring ranges and precision, functional parameters and type of measuring heads. These include: PRISMO, ACCURA, CONTURA, MICURA and the latest of them - XENOS. ACCURA, CONTURA, MICURA and XENOS will be briefly described.

The Zeiss measuring machine ACCURA (fig. 1) is available in 12 sizes with measuring ranges from 900×1200×800 mm (model 9/12/8) to 2000×4200×1500 mm (model 20/42/15). These machines can be equipped with VAST gold, VAST XT gold, VAST XTR gold, VAST XXT scan heads and the VIScan optical head or the triangular Laser Scanning LineScan with RDS-D rotary-tilt head.

The main parameters characterizing the accuracy of two dimensional groups with respect to VAST XT gold, VAST gold and VAST XTR gold scan heads are shown in Table I.

Fig. 1. Zeiss measuring machine ACCURA

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TABLE I. Major parameters of Zeiss ACCURA machines*

Parameter	Parameter designation	9/12/8 to 9/16/8	20/24/15 to 20/42/15
Permissible threshold error for length measurement according to ISO 10360-2:2010 for 20÷22 °C, µm (L – measured length, mm)	$E_{L0}/E_{L150,MPE}$	1,2+L/350	3,9+L/300
	opcja HTG 15÷30°C	1,9+L/150	–
Maximum permissible threshold for repeatability difference, µm	$R_{0,MPL}$	1,2	2,4
Scanning error according to ISO 10260-4:2000, µm	*THP*	2 40	6,1 40
Permissible threshold error for the shape of a single spindle according to ISO 10360-5:2010, µm	$P_{FTU,MPE}$	1,2	3,9
Permissible threshold error for the shape of a multi-spindle assembly according to ISO 10360-5:2010, µm	$P_{FTM,MPE}$	2,6 3,2 **	4,2
Permissible threshold error for the dimension of a multi-spindle assembly according to ISO 10360-5:2003, µm	$P_{STM,MPE}$	1,4	1,9
Maximum permissible threshold of a multi-spindle assembly arrangement according to ISO 10360-5:2010, µm	$P_{LTM,MPL}$	1,9 2,0 **	2,9

* The data refer to the spindle with a length of 60 mm and the diameter of the measuring tip 8 mm;
** The data refer to the head VAST XTR gold

ACCURA machines are made in the so-called CARAT (Coating Aging Resistant Aluminum Technology), which maintains a good mass to volume ratio, allows for increased speed and acceleration and guarantees good rigidity and temperature stability. The machine portal has innovative, highly effective thermal protection in the form of foam insulation technology. With minimum thickness, the guards provide maximum insulation. This allows machines to operate even at ambient temperatures between 20÷26 °C - this applies to models from 9/12/8 to 12/24/10. For the HTG model from 9/12/8 to 12/24/10 the temperature range is even higher - from 15 to 30 °C.

The temperature gradient for models from 9/12/8 to 12/24/10 is 1.0 K/h, 2.0 K/d and 1.0 K/m. Similar values are set for models from 12/30/10 to 20/42/15. However, for HTG models from 9/12/8 to 12/24/10, the gradient values are 2.0 K/h, 5.0 K/day, and 1.0 K/month.

Axial measurement velocities are in the range of 0÷70 mm/s, and in the case of measurements in CNC mode, they reach a maximum of 460 mm/s, while the measurement velocities reach 800 mm/s. Vector acceleration does not exceed 2.3 m/s^2. The software used is Zeiss CALYPSO, Zeiss GEAR Pro and Zeiss HOLOS.

The Zeiss CONTURA measuring machine (fig. 2) is made in four dimensional groups with the symbols: 7/7/6÷7/10/6, 9/12/8÷9/16/8, 10/12/6÷10/16/6 and 12/18/10÷12/24/10; Measuring ranges in the *X* axis are in the range 700÷1200 mm, in the axis *Y* 700÷2400 mm, and in the axis *Z* 600÷1000 mm.

The main parameters characterizing the precision of the CONTURA machines are given in Table II. Machines with the smallest (model 7/7/6) and the largest (model 12/24/10) measuring range are equipped with VAST XT gold and VAST XTR gold head.

The Zeiss CONTURA measuring machines can be equipped with VAST XT gold and VAST XTR gold active scanning heads, VAST XXT passive scanning head, XDT pulse spot measuring head, and VIScan and Line Scan contactless optics - optionally with RDS swivel head.

Fig. 2. The Zeiss CONTURA portal coordinate measuring machine

TABLE II. Important parameters of the Zeiss CONTURA machines*

Parameter	Parameter designation	7/7/6 to 7/10/6	20/18/10 to 12/24/10
Permissible threshold error for length measurement according to ISO 10360-2:2010 for 20÷22 °C, µm (L – measured length, mm)	$E_{L0,MPE}$	1,5+L/350	2,1+L/350
Maximum permissible threshold for repeatability difference, µm	$R_{0,MPL}$	1,2	1,5
Scanning error according to ISO 10360-4:2003, µm	*THP*	2,0 40	3,5 40
Permissible threshold error for the shape of a single spindle according to ISO 10360-5:2010, µm	$P_{FTU,MPE}$	1,5	1,8
Permissible threshold error for the shape of a multi-spindle assembly according to ISO 10360-5:2010, µm	$P_{FTM,MPE}$	2,5	3,9
Permissible threshold error for the dimension of a multi-spindle assembly according to ISO 10360-5:2010, µm	$P_{STM,MPE}$	1,2	2,5
Maximum permissible threshold of a multi-spindle assembly arrangement according to ISO 10360-5:2010, µm	$P_{LTM,MPL}$	1,7	2,8

CONTURA has optoelectronic reflective measuring systems with a resolution of 0.2 µm, a Zeiss C99 controller, and a multi-sensor rack (MSR).

The ambient temperature can range between 18 and 22 °C (HTG machines are available with a temperature of 18÷26 °C) if the error values given in Table II are to be met. Temperature gradients are 1.0 K/h, 1.5 K/d and 1.0 K/m.

The Zeiss MICURA measuring machine (fig. 3) is one of the Carl Zeiss range of 500×500×500 mm portal machines. Its measurement accuracy - achieved using the VAST XT gold and VAST XTR gold measurement heads – are listed in Table III. The length of the VAST XT gold spindle can be up to 500 mm and the minimum spindle tip diameter is 0.3 mm. With the VAST XTR gold head, the stem length can be 350 mm and the minimum tip size is 0.5 mm.

The machines use optoelectronic, reflective measuring systems with a resolution of 0.2 µm, a Zeiss C99 controller and a frame magazine for the MSR measurement heads.

The ambient temperature may range between 20 and 22 °C. Temperature gradients should be: 1.0 K/h, 0.5 K/d and 0.51 K/m, so that the accuracy of the length measurement errors mentioned in Table III.

TABLE III. Important parameters of the Zeiss MICURA machines*

Parameter	Parameter designation	VAST XT gold **	VAST XTR gold ***
Permissible threshold error for length measurement according to ISO 10360-2:2010 for 20÷22 °C, µm	$E_{L0,MPE}$	0,7+L/400	0,8+L/400
	$E_{L150,MPE}$	0,9+L/400	1,0+L/400
Maximum permissible threshold for repeatability difference, µm	$R_{0,MPL}$	0,7	0,8
Scanning error according to ISO 10260-4:2000, µm	*THP*	1,2 40	1,3 40
Permissible threshold error for the shape of a single spindle according to ISO 10360-5:2010, µm	$P_{FTU,MPE}$	0,8	0,9
Permissible threshold error for the shape of a multi-spindle assembly according to ISO 10360-5:2010, µm	$P_{FTM,MPE}$	2,3	2,7
Permissible threshold error for the dimension of a multi-spindle assembly according to ISO 10360-5:2003, µm	$P_{STM,MPE}$	0,6	0,7
Maximum permissible threshold of a multi-spindle assembly arrangement according to ISO 10360-5:2010, µm	$P_{LTM,MPL}$	1,6	1,7

Fig. 3. The Zeiss MICURA portal coordinate measuring machine

The pressure of purified air supplying the aerostatic bearings should be between 6÷8 bar, with a maximum consumption of 110 Nl/min. The required power supply is a maximum of 1000 W with a typical consumption of 280W.

Axial velocity measurements are in the range 0÷70 mm/s, and in the case of measurements in CNC mode they reach a maximum of 125 mm/s, while vector speeds - up to 492 mm/s. Vector acceleration is up to 1969 m/s^2.

The XENOS coordinate measuring machine (fig. 4) is one of Carl Zeiss's newest and most accurate machines. It was constructed of special materials and has a specific construction, so that accuracy was achieved with acceptable $E_{L0,MPE}$ = ±(0.3+L/1000) µm. Its measuring ranges are 900×1500×700 mm.

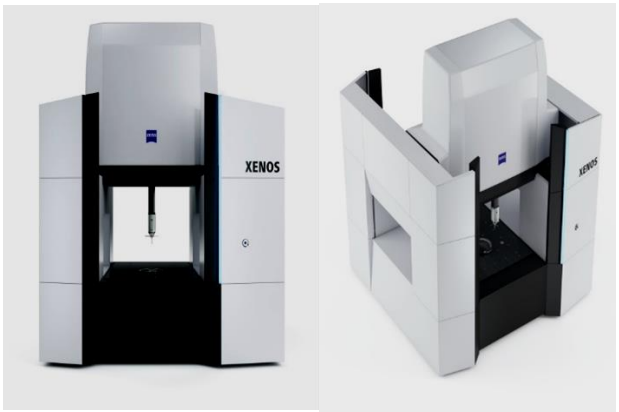

Fig. 4. Coordinate measuring machine XENOS

Zeiss XENOS uses the new Zeiss CenterMax design concept. Unlike the standard portal construction, the *Y* direction guides are located at the top of the side walls, which separate the moving axles from the attachment zone - thus the model can be classified as gantry. Since only the transverse beam moves in the *Y* direction, the moving masses are smaller. This state is maintained all the time - it's a great advantage compared to the movable table design. Weight reduction and constantly moving masses allow optimum coordination of the drive in terms of acceleration and maximum speed.

The Zeiss XENOS construction parts, which are responsible for accuracy, are manufactured using innovative carborundum ceramics technology. So far, this material has rarely been used in the manufacture of parts of such size or similar accuracy. Compared to standard alumina-based ceramics, carborundum ceramics are about 50% less thermal, up to 30% stiffer and 20% less weight. It also has double the stiffness at half weight compared to steel.

The XENOS is standard equipped with a VAST gold reference head for shafts up to 800 mm in length and up to 500 g in weight, including asymmetrical spindle configurations. New airbags with even stiffer joints increase stability so you can get better accuracy.

New acceptance methods based on the computer-aided accuracy (CAA) and additional CAA corrections play an increasingly important role in achieving the maximum accuracy of XENOS machines.

Coordinate portal measurement machines by Leitz Messtechnik (Hexagon Metrology)

Models PMM-C, PMM-Xi, Infinity, Reference (Xp/Xi/XE) and Ultra are the most accurate. It should be clarified that in 2001 the Hexagon Metrology Group, which is part of the global Hexagon Group, has joined several measurement companies: German Leitz Messtechnik, Italian DEA, American Brown & Sharp and Swiss Tesa, and in 2004 - Sheffield and Romer. In Poland, Haxagon Metrology is represented by Hexagon Metrology with its headquarters in Cracow and Warsaw.

Fig. 5 shows the Leitz PMM-Xi machine and fig. 6 - Leitz Infinity. Most portal machines have a fixed measuring table and a mobile portal. On the other hand, the PMM and Infinity series have a sliding table and a fixed portal.

Fig. 5. Coordinate measuring machine Leitz PMM-Xi

There are nine models in the PMM-Xi series, which differ mainly in measuring ranges and accuracy. Their parameters are presented in the Table IV. These machines are equipped with LSP-X5 measuring heads

with 0.1 µm inductive sensors for scanning and Heidenhain's high resolution steel code lines, with automatic temperature compensation.

Fig. 6. Coordinate measuring machine Leitz Infinity

Leitz PMM-Xi makes it possible to measure gears up to 1550 mm in diameter. With this machine, gear tools, such as broaches and cutters, can be checked.

TABLE IV. Main parameters of Leitz PMM-Xi machines*

	Model	Model	Model	Model
Parameters	8.10.6 12.10.6 12.10.7	16.12.7 24.12.7	24.16.7 16.1210	24.12.10 24.16.10
Permissible threshold error of the length measurement $E_{L0,MPE}$, µm (L – measured length, mm)	0,6+L/550	1,0+L/550	1,1+L/550	1,7+L/500
Maximum permissible threshold for repeatability difference $R_{0,MPL}$, µm	0,4	0,6	0,6	0,8
Permissible threshold error for the measurement head MPE_P for point measure-ment, µm	0,6	0,8	0,9	1,4
Permissible threshold error MPE_{THP} of the measurement head for scanning measurements, µm, during 45 s	1,2	1,3	1,3	2,1
Permissible temperature values	20 ±1°C	20 ±2°C	20 ±2°C	20 ±2°C

*Values of $E_{L0,MPETHP}$ were determined using measurement spindle of L = 80 mm length and measurement tip diameter of 5 mm, and to determine the MF, MS and ML values, a head was equipped with a set of five measurement spindles arranged in a star.

Infinity series machines are available in two 1200×100×600, 1200×1000×700 mm measuring ranges and similar accuracy. Their permissible limit error is $E_{L0,MPE}$ = (0.3+L/1000) µm, repeatability measurement error length R_0 = 0.2 µm, MPE_P measurement error tolerance for point measurements is 0, 4 µm, and for scanning measurements MPE_{THP} = 1.1 µm over 60 s (LSP-S4 measuring head). On the other hand, Leitz Ultra models are characterized by $E_{L0,MPE}$ = 0.4+L/850 µm, $R_{0,MPL}$ = 0.25 µm, MPE_P = 0.5 µm and MPE_{THP} = 1.2 µm The listed accuracy is maintained at an ambient temperature of 19÷21 °C.

Reference series mobile portal machines (fig. 7) - the smallest of them, e.g. HP 5.4.3, have a measuring range of 500×400×300 mm, and the largest models XP 45.12.9 and Xi 45.12.10 offer ranges measurements of 4500×1200×900 mm and 4500×1200×100 mm, respectively.

Fig. 7. Leitz Reference portal measuring machines

The HP Reference portal machines are made in eight measuring ranges and the Xi series in nine. The parameters characterizing the accuracy of these machines for the smallest and largest measuring ranges in both series are shown in Table V.

The Leitz Reference series models incorporate AURODUR steel fins with automatic temperature compensation and the FRICISION portal beam. These machines can be equipped with LSP-X measuring heads with a measuring spindle length of up to 500 mm, LSP-X3c with a spindle length of 300 mm and a rotary-tilt head for connection to the LSP-X1h/LSP-X1s TESASTAR probe. It is possible to use a contactless head in the form of a CMS laser scanner, which generates 1000 points per scan line.

TABLE V. Main parameters of Leitz Reference machines

Parameters	Model HP 5.4.3	Model HP 45.12.9	Model Xi 5.4.3	Model Xi 45.12.10
Permissible threshold error of the length measurement $E_{L0,MPE}$, µm (L – measured length, mm)	0,7+L/400	1,7+L/350	1,1+L/350	1,8+L/300
Maximum permissible threshold for repeatability difference R_0, µm	0,45	0,7	0,6	0,9
Permissible threshold error for the measurement head MPE_P for point measurement, µm	0,8	1,2	1,1	1,6
Permissible threshold error MPE_{THP} of the measurement head for scanning measurements, µm	1,6 35s	2,1 45s	2,0 45s	2,5 45s
Permissible temperature values	20 ±1°C	20 ±2°C	18÷24 °C	18÷24°C

Portal coordinate measuring machines by DEA (Hexagon Metrology)

There are four types of machines in this group: DEA Global (Silver Classic, Silver Performance, Advantage and Silver SF), DEA Pioneer, DEA Micro-Hite DCC and DEA MICRA.

Fig. 8 shows the DEA Global Silver Performance machine, which is offered with an X axis in four ranges: 500, 700, 900 and 1200 mm, with the option of X axis = 500 mm with Y axis in two dimensions: 500 or 700 mm and Z axis of 500 mm range. Largest ranges: X - 1200 mm, Z - 1000 mm, Y - 1500, 2200 or 3000 mm. Limit error allowed length measurement MPE_E = (1.5+L/333) µm.

Patented triangular sectional portal made of TRICISION technology is noteworthy. The machine is equipped with temperature compensation to allow measurements even within the range of 16÷26 °C. Adaptive Scanning PC-DMIS software automatically calculates the optimum scan parameters for the best possible scanning performance - after entering the geometry parameters into the PC-DMIS form, the software processes them and sets the scan parameters.

Measurements can be made using Leitz contact heads, for example LSP-X5 for scanning measurements or LSP-Xi heads with TESASTAR rotary-tilting head. The contactless head can be used as a laser scanner CMS 106. TESASTAR is a so-called. Motorized head with angular displacement of 5°, which allows to obtain in the measuring space 2952 the positions of the measuring probe. It is also possible to use five-way pulse heads for spot measurements: TESASTAR-p and TESASTAR-mp.

Fig. 8. DEA Global Silver Performance measuring machine

The CMS 106 is a fully automated linear laser scanner with three horizontal magnifications, with laser lines of 24, 60 or 124 mm. It is suitable for measurements of almost any material, including machined, pressed, forged, cast parts, both metal and plastic, and even rubber, wood and ceramics. Laser power regulation is automatic.

Mitutoyo portal machines

Mitutoyo offers a palette of portal coordinate measuring machines: four types of CRYSTA machines, two types of STRATO machines and the most accurate of them - the LEGEX machine. CRYSTA machines are available in the CRYSTA Plus M, Apex C1200 and CRYSTA Apex S versions, and the STRATO 355 series in two STRATO Apex variants.

CRYSTA and STRATO series machines differ not only in design but above all in measuring ranges and accuracy. For example: CRYSTA Plus M Series 196 machines are offered in eight measuring ranges from 400×4000×300 mm to 700×1000×600 mm. Their permissible error lies in the range from $E_{L,MPE}$ = (3+0.4L/100) µm to $E_{L,MPE}$ = (3.5+0.45L) µm, where: L - measured length in mm. These machines are equipped with Renishaw's TP20 measuring heads, which allow for single stem measurements with accuracy $P_{FTU,MPE}$ = 1.7 µm, and MPE_{THP} = 2.3 µm for scanning measurements. Temperature gradients are 2.0 K/h, 5.0 K/d and 1 K/m. More accurate results can be obtained with the 191 CRYSTA Apex S Series machines. They are available in 10 measuring ranges: from 500×400×400 to 900×2000×800 mm. The permissible threshold error, depending on the measuring range and temperature, is in the range of $E_{0,MPE}$ = (1.7+0.3L/100) µm at 18÷22 °C to $E_{0,MPE}$ = (1.7+0 4L/100) µm at 16÷26 °C. The SP25M measuring head, equipped with a 50 mm long spindle and Ø4 mm diameter, allows accuracy at $P_{FTU,MPE}$ = 1.7 µm, and MPE_{THP} = 2.3 µm. Temperature gradients are

for the temperature range 18÷22 °C: 1.0 K/h, 2.0 K/d and 1.0 K/m. For the ambient temperature range, one of the indicators is magnified, namely 5.0 K/d.

The STRATO Apex 355 series measuring machines are worth noting. They come in five measuring ranges: from 500×700×400 mm to 900×1600×600 mm. Permissible threshold error of machines with the lowest measurement range $E_{0,MPE}$ = (0.7+0.25*L*/100) µm, and for machines with the highest measurement range $E_{0,MPE}$ = (0.9+0.25*L*/100) µm. As in the previous series of machines, the SP25M measuring head is also used in these machines, equipped with a 50 mm spindle and a Ø4 mm diameter. It allows to perform point and scan measurements. It is also possible to use a laser head for contactless measurement. Temperature gradients are 1.0 K/h, 2.0 K/d and 1.0 K/m. The machine is equipped with temperature compensation systems, so it can work even in the production hall.

The 356 Series LEGEX machines are available in four measuring ranges: from 500×700×450 mm (model 574) to 900×1000×600 mm (model 9106). These are the most accurate Mitutoyo products on offer. Their limit error is allowed to measure length $E_{0,MPE}$ = (0.28+0.1*L*/100) µm, with spot error in $P_{FTU,MPE}$ = 0.4 µm and MPE_{THP} = 1.8 µm. These machines employ 0.01 µm lengths of crystalline glass with a low expansion coefficient of 0.01 × 10^{-6} /K. These machines have a travel speed of 200 mm/s and 3D acceleration of 981 mm/s^2 and can operate in the temperature range of 18÷22 °C. Temperature gradients are 0.5 K/h, 1.0 K/d and 1.0 K/m. These machines can work with impulse and scan measuring heads, both contact and non-contact type laser scanner.

Mitutoyo coordinate machines can use self-production or Renishaw measuring heads. The MPP-310Q scanning head with a resolution of 0.01 µm, measuring range ±1 mm and measuring pressure 0.03 N, is noteworthy. It is aerostically mounted. The length of the spindle reaches up to 200 mm. SP80, SP25M and SP600M scanning heads can be used, as well as a variety of pulse heads, such as the TP7M, TP200, TP200 with rotary-pulse heads from Renishaw PH20, powered by MCOSMOS software. In addition, optical heads such as the SurfaceMeasure line laser scanner for 12 µm uncertainty with 75,000 dots per second and the QVP video viewer capable of reproducing a 0.375 to 3.75x magnification image can be used.

Mitutoyo machines are equipped with their own MCOSMOS software, MCOSMOS-1 is the basic package, MCOSMOS Manual is used for manual machines, MCSOSMOS-2 is a CAD package, and MCOSMOS-3 is a full-package. These packages include Part Manager options (system configuration, data management, report templates creation, etc.) and GEOPAK (online and offline work, spatial metrics, parametric programs). Options CAT1000P and CAT1000S include, among others. CAD programming, free surface inspection and graphical report. The SCANPAK option is: contour measurements, analysis and editing, data exchange with CADF and SN systems. In addition, there are additional software packages, such as gear wheels - GEARPAK package or ROUNDPAK-CMM shape deviation measurement.

Machines from other manufacturers

As pointed out earlier, ALTERA measuring machines from Nikon Metrology are also on the market, and Smart Solutions in the country [7]. They are: ESSENTIAL, OPTIMUM and ULTIMATE and IK series.

The German company Wenzel [8] manufactures a number of portal machines, both manual and CNC. Manual machines include two XCite models measuring ranges from 500×600×500 to 700×800/1000/1200×500 mm, three series of LH54, LH1212, LH1512 and XOrbit machines. The LH54 series have a measuring range of 500×600/1000×400 mm. The LH1210 and LH1512 series have the largest measuring ranges (e.g. LH1512 - 1500×2000/2500/3000/4000×1200 mm) and are available in Standard, Premium and Premium-Select.

The Aberlink 3D coordinate measuring machine series, represented in Poland by Oberon 3D [12], includes portal models such as Axiom, Axiom too Manual, Axiom too CNC and Axiom too, and Zenith too and Azimuth.

Axiom coordinate measuring machines are also available in manual, CNC and HS. Manual machines have three measuring ranges: 640×600×500 mm, 640×900×500 mm and 640×1200×500 mm. Their MPE_E limit error = (2.9+*L*/250) µm. Axiom too CNC machines and Axiom too HS have four measuring ranges: 640×600/900/1200/1500×500 mm. Limits for Axiom too CNC machine errors for all measuring ranges are the same: MPE_E = (2.9+*L*/250) µm. The accuracy of Axiom too HS machines is higher: MPE_E = (2.1+*L*/250) µm. In these machines, the control unit and the main computer unit were placed in the base.

Zenith measuring machines are also made in ten measuring ranges, with the *X* axis having a measuring range of 1000 mm, *Z* - 600 or 800 mm, while the *Y* axis has a measuring range of 1000, 1500, 2000, 2500 or 3000 mm. Error limit allowed for all machines Zenith too MPE_E = (3.8+*L*/250) µm. These machines use Renishaw linear measuring systems with a signal resolution of 0.5 µm.

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