New types of coordinate measuring machines and new indications of their parameters Part I: Parameters characterizing accuracy

Nowe rodzaje współrzędnościowych maszyn pomiarowych i nowe oznaczenia ich parametrów Część I: Parametry charakteryzujące dokładność

EUGENIUSZ RATAJCZYK*

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The main parameters characterizing the accuracy of coordinate measuring machines were defined. These parameters were illustrated by reference to an exemplary measuring machine Prismo by Carl Zeiss.

KEYWORDS: coordinate measuring machines, parameters characterizing accuracy

In the first part of the article, new types of parameters characterizing the accuracy, referred as an example to the Carl Zeiss Prismo measuring machine, will be presented. Part II will be devoted to portal-type machines, while part III will be for machines with cantilever structure.

The third edition of ISO 10360-2 of 2010 [1] introduced new parameter symbols characterizing the accuracy of the machine, taking into account the axial displacement of the measuring tip by the dimension *L* (understood as the axle distance of the measuring point from pinola axis, measured perpendicular to pinola axis). The following symbols apply:

- E_L - length measurement error,
- R_0 - distance repeatability of the length measurement error,
- $E_{L,MPE}$ - limit error allowed length measurement,
- $R_{0,MPL}$ - maximum limit of repeatability.

The E_L means an indication error when measuring the calibrated length using CMM with the spindle tip offset against the pinion axis *L* (fig. 1), using one sampling point (or equivalent) at each end of the measured test length.

The R_0 is the distance (the largest value minus the smallest) of the three repetitive CMM length measurements with the spindle tip offset relative to the pinola axis of zero. $E_{L,MPE}$ is the highest value of E_L length measurement error permitted by the specification, and $R_{0,MPL}$ is the extreme repeatability value of the R_0 length measurement error permitted by the specification. E_L, $E_{L,MPE}$, R_0 and $R_{0,MPL}$ are reported in micrometers and L in millimeters.

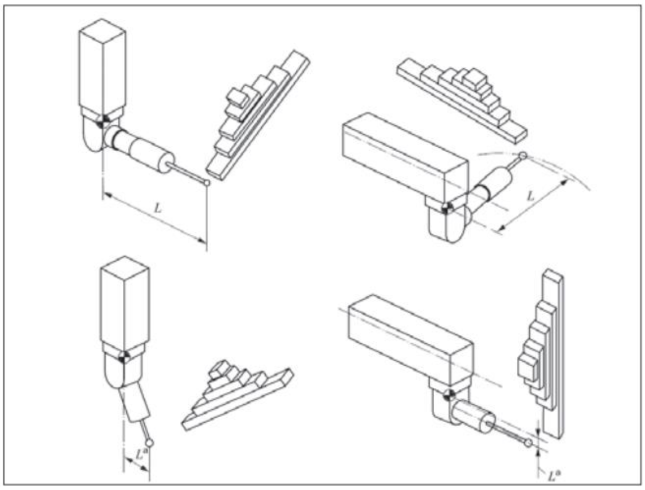

Fig. 1. Examples illustrating the offset of the spindle tip on the length L with respect to the pinola axis for the pivoting head assembly

In the case of measuring heads, PN-EN ISO 10360-5: 2010 standards apply, which distinguishes the following parameters:

- P_{FTj} - error (measurement) of the shape of a polyhedron assembly,
- P_{STj} - dimension error of polyvalent complex,
- P_{LTj} - the value of the location of the polyhedron assembly,
- P_{FTU} - single spindle shape error,
- P_{STU} - dimension error of a single spindle,
- $P_{FTj,MPE}$ - boundary error of the permissible shape of the polyhedral complex,
- $P_{STj,MPE}$ - boundary error of the permissible dimension of the polyhedral complex,
- $P_{LTj,MPL}$ - maximum allowable limit value of the position of the multi-
- $P_{FTU,MPE}$ - limit error allowed for the shape of a single spindle.

Error (measurement) of the shape of a polyvalent massif PFTj is the error of the indication in which the radial distance of the Gaussian criterion can be determined by the least squares fitting to the points measured on the test sphere (using five different spindles on one test ball located anywhere CMM

* Prof. dr inż. Eugeniusz Ratajczyk (erat33@interia.pl) – Wydział Inżynierii i Zarządzania Wyższej Szkoły Ekologii i Zarządzania w Warszawie

measurement area, point sampling mode). The letter P means that the error is related to the operation of the measuring head assembly, and the bottom index F - that is a shape error. The bottom index T indicates that the measuring head assembly is compatible with the contact character and allows unambiguous identification of the alternative sampling system.

There are four types of error in the shape of a multi-tier system, depending on the different measuring head systems and methods of operation: j = E (swivel-tilt test assembly using test qualification), j = I (swivel-head measuring unit using interpolated test) j = M (stationary set of measurement head, i.e. fixed multispeed unit), j = N (fixed, fixed, multi-head assembly).

P_{STj} - multi-pin assembly error - this is an error in the indication, in which the diameter of the test ball can be determined by the least squares fitting to the points determined by measurements made with five different measuring spindles on one test ball positioned at any point in the spot sampling mode of the CMM. The lower index S means that this is a dimension error.

P_{LTj} - the value of the location of the multi-pin assembly - this is the maximum value of the X, Y and Z coordinate ranges in which the position of the test sphere can be determined by the least squares adjustment to the points determined by measurements made with five different measuring spindles on one test sphere set anywhere in the CMM measuring area in point sampling mode . The lower index L means that it is the value of the location (location). All values are absolute.

P_{FTU} - single spindle shape error – this is an error in the indication, in which the radius of the beam can be determined by the least squares fitting to the points measured on the test sphere, determined from measurements made with a single spindle on a test sphere located anywhere in the spot metering area CMM. The letter P indicates that the error is mainly related to the operation of the measuring head assembly. The U index indicates the use of a single spindle. The P_{FTU} parameter corresponds to parameter P in ISO 10360-2: 2001.

P_{STU} - single spindle dimension error - this is an error of the difference between the smallest squared diameter to the test point on the test sphere and the standard diameter from CMM measurements with a single spindle in point sampling mode; Points are collected on a test ball located anywhere in the measuring area of the machine. The letter P indicates that the error is mainly related to the operation of the measuring head assembly. The bottom index U indicates the use of a single stem. The lower S index indicates that this is a dimension error.

$P_{FTj,MPE}$ - permissible error of the shape of a polyvalent complex - this is the extreme value of the error of the shape of a P_{FTj} multifunctional assembly, acceptable to the CMM by specifications, specifications, etc. The value of the permissible error of the $P_{FTj,MPE}$ can be expressed in one of the following forms:

- $P_{FTj,MPE}$ = minimum $(A+L_p/K)$ i B,
- $P_{FTj,MPE} = (A+L_p/K)$,
- $P_{FTi,MPE} = B$,

where: A - positive constant, expressed in micrometers and given by the manufacturer; K - dimensionless positive constant given by the manufacturer; L_P - distance in 3D between the center of the reference ball and the test ball, in millimeters; B - permissible error $P_{FTj,MPE}$, expressed in micrometers and fixed by the manufacturer.

$P_{STj,MPE}$ - limit error of the permissible dimension of a multi-pin assembly - this is the extreme value of the P_{STj} polyvalent dimension error by specifications, specifications, etc. The limit value of the permissible dimension of the P_{STj} multifunctional assembly MPE can be expressed in one of the following three forms:

- $P_{STj,MPE}$ = minimum $(A+L_p/K)$ i B,
- $P_{STj,MPE} = (A+L_p/K)$,
- $P_{STi,MPE} = B$,

where: B is the permissible error $P_{STj,MPE}$, expressed in micrometers, as determined by the manufacturer.

$P_{STj,MPE}$ can be specified at the tip length of the measuring head tip or at the description of the three spindle system.

$P_{LTj,MPL}$ - maximal limit value of the position of the multi-pot assembly - this is the extreme value of the location of the P_{LTj} multipass assembly, which is acceptable for CMM by specifications, specifications, etc. The value of the limit error of the permissible dimension of the P_{LTj} multiplexer assembly can be expressed in one of the following forms:

- $P_{LTj,MPL}$ = minimum $(A+L_p/K)$ i B,
- $P_{LTj,MPL} = (A+L_p/K)$,
- $P_{LTi,MPL} = B$.

The MPL maximum permissible limit specification - unlike the MPE limit error - is used when the test measurements do not identify errors, so the MPL specification does not require the use of artifacts.

$P_{FTU,MPE}$ - limit error allowed for the shape of a single spindle - this is the extreme value of a single P_{FTU} spindle shape error acceptable to CMM by specifications, specifications, etc. $P_{FTU,MPE}$ can be specified at the offset length of the measuring head tip or by the description of the spindle system. $P_{FTU,MPE}$ is identical to MPE_P according to ISO 10360-2:2003.

An example of the application of these parameters and their values is illustrated in the table with reference to the Carl Zeiss Prismo measuring machine [2, 3].

The Prismo coordinate measuring machine is designed to measure the dimensions and geometric deviations of precisely machined parts. Available in four dimension options: Zeiss Prismo 5 + 7 X = 700 mm and Zeiss Prismo 5 + 7 X = 900 mm, Zeiss Prismo 10 X = 1200 mm and Zeiss Prismo 10 X = 1600 mm. Zeiss Prismo Ultra and Zeiss Prismo Navigator are also available (fig. 2). The table gives the values of the major parameters characterizing the precision of the Prismo Ultra Sensor with respect to the Vast Gold head with a 60 mm spindle length and a 8 mm diameter tip, although it is possible to use a Vast Gold head with a maximum spindle length of 800 mm and with a minimum tip diameter of 0.3 mm.

Fig. 2. Coordinate measuring machine Zeiss Prismo Navigator: 1 - portal, 2 - pinola, 3 - side portal drive, 4 - standard ball, 5 - spindle, 6 - Vast measuring head [3]

TABLE. Important parameters of the Zeiss Prismo Ultra Sensor *

Parametr	Parameter designation	Machine Prismo 5 + 7 X = 700 mm, X = 900 mm	Machine Prismo 10 X = 1200 mm	Machine Prismo 10 X = 1600 mm
Permissible error limit of length measurement according to ISO 10360-2: 2010 (for 20 ÷ 22 °C)	$E_{L0,MPE}$, µm	0,5 + L/500	1,2 + L/500	1,9 + L/400
	$E_{L150,MPE}$, µm	0,8 + L/500	1,6 + L/500	2,5 + L/400
Maximum permissible repeatability distance limit	$R_{0,MPL}$, µm	0,4	0,7	0,8
Scanning measurement error according to ISO 10360-4:2002	*THP*, µm τ, czas, s	0,9 40	1,1 40	1,6 40
Permissible limit error of the shape of a single spindle according to ISO 10360-5:2010	$P_{FTU,MPE}$, µm	0,5	0,8	1,1
Permissible limit error of the shape of the multi-pin assembly according to ISO 10360-5:2010	$P_{FTM,MPE}$, µm	1,9	2,2	2,3
Permissible limit error of the dimension of the multi-pin assembly according toISO 10360-5:2010	$P_{STM,MPE}$, µm	0,6	0,9	1,1
Maximum permissible limit value of the position of the multi-pin assembly according to ISO 10360-5:2010	$P_{LTM,MPL}$, µm	1,2	1,5	1,7
*Data refer to the 60 mm long spindle and the 8 mm measuring tip diameter				

The machine is equipped with a high dynamic acceleration servo drive. Each axle has electronic drive control, and the *X* and *Z* axes additionally limit travel forces. The machine is controlled in three axes by a vector microprocessor.

The measuring speed of the mentioned Prismo machines is in the range 0 ÷ 70 mm/s, while in CNC mode the axial velocity is maximum 300 mm/s, vector - maximum 520 mm/s, and with the Navigator option - maximum 350 mm/s. Axis acceleration for Prismo 5 + 7 and Prismo 10 machines is up to 1.2 m/s^2, Prismo 10 X = 1600 - maximum 0.8 m/s^2, and Prismo Ultra - 0.38 m/s^2. Vector acceleration values are as follows: 1.87; 1.87; 1.38; and for the Ultra version - 0.67 m/s^2.

The maximum error values shown in the table will be maintained at this level, provided that the thermal fluctuation is maintained, for example, for the Prismo Navigator 5 + 7 machine: 0.8 K/h, 1.8 K/day, and gradient The thermal gradient spacial reaches a value of 0.8 K / m. Prismo 10 X = 1200 mm and 1600 mm are the highest values and are 2 K/h, 5 K/day and 1 K/m [4-6].

The resolution of the measuring system signal is 0.2 µm for the Prismo Navigator and 0.02 µm for the Prismo Ultra. The power supply is 100/240 V (±10%); Total power consumption is up to 2500 V·A at typical current consumption of 380 W.

The pneumatic supply pressure is 6 bar, maximum 8 bar with consumption of approx. 50 N·l/min. An air purification of ISO 8573, Part 1: Class 4 is required. The ambient conditions are 40 to 70% relative humidity.

Portal moves on eight pneumatic (aerostatic) bearings - four in each axis. The special arrangement of pneumatic bearings around the guide bar prevents the machine portal from twisting. The drive for travel is carried out through a system of rubber belts that drive the engine with a rubber roller.

In the granite measuring table there are 30 holes spaced every 200 mm. These holes are fitted with threaded M12 sleeves to fix the holders to hold the objects to be measured.

The machine design provides vibration damping through the use of triple-layered systems including elastomeric, elastic and viscose damping. The protective casing protects the gauges and gauges from dust and damage, and reduces the effect of temperature on the ruler and slider systems.

The machine uses optoelectronic patterns of incremental type reflective light. The lines were constructed from Zeroduru with a linear expansion coefficient of 0 ± 0.05 µm/Km for 0 ÷ 50 °C. The constant fields of incremental lines are 10 µm and the resolution is 0.2 µm due to interpolation. On the *Y* axis, two measuring systems on the sides are used to eliminate the displacement error resulting from the side portal drive. Results of the readings from both *Y*-axis lines are averaged. Currently, one measuring system is mounted on the opposite side of the drive and the side-by-side errors are compensated by computer.

The Prismo machines can be equipped with a measuring head (fig. 3): for active Vast Gold and Vast XTR gold scanning, passive Vast XXT scan with RDS rotary head and two VIScan and LineScan optical heads with RDS swivel head.

Vast Gold head can be equipped with a variety of gauges depending on the shape of the part to be measured. The most commonly used is the so-called *starry configuration*, also known as star.

Prismo measuring machines are equipped with so-called. frame of the spindle and measuring head (e.g. model MT - fig. 4). This magazine has four slots and is used to store the spindles and measuring heads used in CNC mode. The magazine is not necessary, but it helps to shorten the CNC measurement time. It is possible to manually change the terminals. In fig. 4, an additional magazine for the measuring heads is shown on the right side.

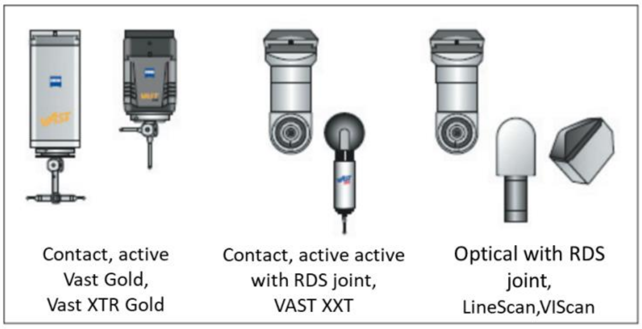

Fig. 3. Measuring heads for use in Prismo machines

The magazine is fixed rigidly at any point of the measuring table after having defined the position of the magazine sockets on the measuring table of the machine.

The Carl Zeiss offers several control panels. Prismo has a standard "blue" control panel (fig. 5).

The Hewlett-Packard PC - Workstation x2100 PC with accessories is included as a set of digital data processing units. Minimum requirements for this configuration resulting from the Carl Zeiss Calypso software provided by the manufacturer are: 200 MHz microprocessor, 64 MB RAM, 2.5 GB hard disk drive, 1.44 MB disk drive, CD ROM drive, NVIDIA Quadro graphics card, 19 inch monitor, inkjet printer.

Fig. 4. Frame of heads and measuring spindles (tips): 1 - one of the measuring heads, 2 - measuring spindle, 3 - fixing plate, 4 - socket, 5 - socket mounting frame

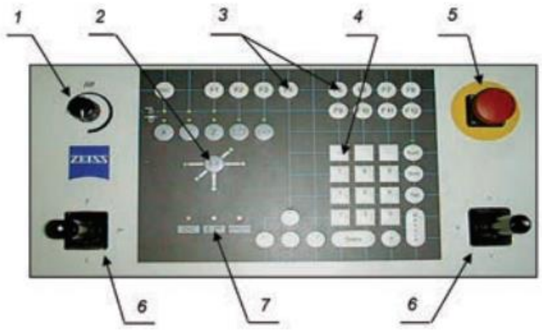

Fig. 5. Control panel: 1 - knob for adjusting the pinion travel speed; 2 - spindle selection button; 3 - Function buttons F1 to F12; 4 - numeric keypad for entering data; 5 - safety switch; 6 - two joysticks for manual control of the machine movement of the machine in three axes; 7 - indicators informing about the status of the machine (there are more lights at the top of the desktop)

In practice, Carl Zeiss company equips the machine with the following units:

- minimum Station: Minimum configuration: Intel Core i3-4150 CPU 3.3 GHz 3 MB, 8 GB RAM (2 × 4 GB0 DDR3 1600 MHz non EEC), NIVIDA NVS 310 Graphics, 2 × LAN 1O / 100, DVD Burner, Windows 7;
- 8-GB hard drive, 1 GB hard drive, 1 GB SATA 7.2 kb, 16 GB RAM (2 × 8 GB) DDR3 1600 MHz non EEC, NIVIDA Quadro K2000 graphics, 2 GB, 2 × 10/100 LAN, DVD burner.

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