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NEW MEMS & NEMS SOLUTIONS FOR INTELLIGENT MECHATRONICS MICROSYSTEMS USED FOR ULTRAPRECISE MEASUREMENTS

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Abstract: *The scientific paper will research and consider new solutions MEMS & NEMS for intelligent mechatronics microsystems used for ultraprecise measurement, linear and angular, describing the structural architecture, including hardware and their software. There are realized experimental research laboratory where they are studied metrology and functional parameters, highlighting the quality and intelligent control of the whole industrial process.*

Keywords: MEMS, NEMS, mechatronics, integronics, displacements

1. INTRODUCTION

The intelligent mechatronics microsystems with incremental disks photoelectric transducer for dimensional and angular displacements measurement in industrial environment is intended for positioning / micro-positioning, direct measurements, angular displacements / micro-displacements and equipping as NC and/or CNC system, technical and technological installations and equipments. The intelligent system, converts an analogical quantity (angular displacement) in a digital quantity (number of impulses).

The intelligent mechatronic microsystem, by photoelectric transducer subsystem supplies at exit four rectangular signals in quadrature and zero signals.

An adequate processing of those signals in electronic subsystem for measurement and digital display, allows electronic sub-partitions with 2, 4, 8 (in case of analogical exits can be made sub-partitions with 2, 4, 5, 10, 20) and detection of angular displacement orientation.

2. THE INTELLIGENT MECHATRONIC MICRO SYSTEM

The intelligent mechatronic micro system includes structural and functional the following main subsystems (figure no. 1):

- mecatronic subsystem dimensional rotation incremental photoelectric transducer;
- electronic subsystem digital unit for measurement and display;
- electronic subsystem serial interface for data transfer;
- specific informatics subsystem for processing, registering and transfer, at central informatics subsystem of flexible technological processing line or inspection system integrated to industrial fabrication.

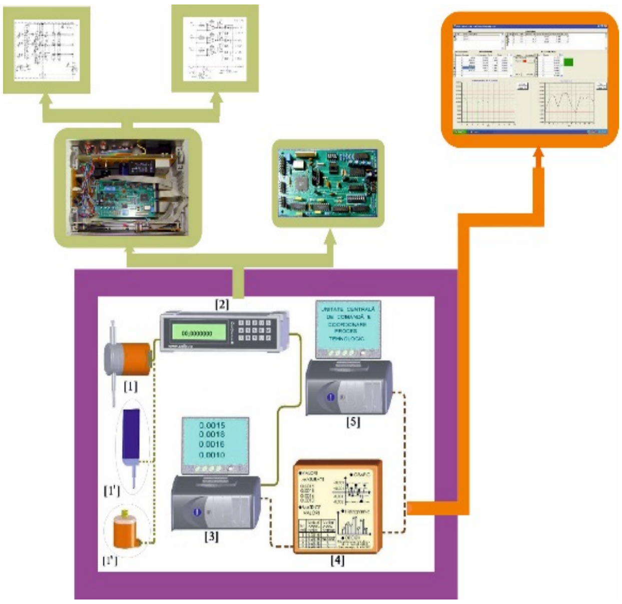

Fig.1 The intelligent mechatronic microsystem structure

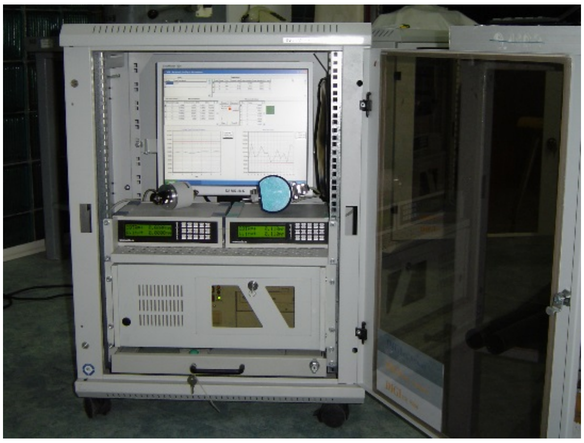

Fig. 2 The intelligent mechatronic microsystem structure – real view

2.1. Technical characteristics of the intelligent mechatronic microsystem:

a.Rotation mode

- Measurement interval: 10mm; (and 30; 50; 80;100mm for product development)
- resolution (R) : 0,001mm ;(and 0,0005mm; 0,0001mm for product development)
- accuracy(at 20^0C):

  $A_{20C}{}^0$= $(1+L/50)10^{-3}$mm; L in mm;
- counting error: ±1 bit;
- Accuracy error : $\leq R/8$;
- Null impulse (reference) : one at 360^0 ;
- Display capacity: 8 decade +1 decade for sign;
- Null impulse width: max R;
- Hysteresis error: R/4
- Shift of impulses

  A and B: b/p = 0,25 ±0,05;
- signals output : TTL and with free collector
- Attaching diameter : Φ8mm;
- Electrical impulses frequency: 0÷100Hz;
- Impulses filling factor: a/p=0,5±0,1;
- R (550h): 0,9;
- R (950h): 0,76;
- Z (550h): 2,8 $\bullet 10^4 h^{-1}$;
- Z (950h): 4,4 $\bullet 10^4 h^{-1}$;

b. Linear mode

- Measurement domain:: infinite; rotation angle is infinite; measurement interval $0^0 \div n \cdot 360^0$;
- resolution : $R = \frac{360^0}{N}$, [0,', "] ; where :

  N = number of impulses / rotation;
- accuracy (correctness error) :

  max. ± R/4;
- Hysteresis value: max. ± R/7;
- Accuracy error: max. ± R/8;
- Null impulse width : max. R;
- Electrical impulses frequency: 0÷100 Hz;
- Null impulse (reference): one at 360^0;
- Impulses filling factor:

  a/p = 0,5 ± 0,1;
- Shift of impulses A and B : b/p = 0,25 ± 0,05;
- signals output : TTL and with free collector
- Photoelectric transducer subsystem weight: max. 0,5 kg
- Overall size (photoelectric transducer subsystem: max. Ø 58 x 95 mm;
- MTBF : 1500 hours;
- R (550 h): 0,9 ; R (950 h): 0,76 ;
- Z (550 h): 2,8 · $10^4 h^{-1}$;

2.2. Mechanical characteristics

(a) max admitted rotation at the intelligent system axle: $n = \frac{60 \cdot 10^5}{N}$ rot. / min., where N = number of impulses / rotation, but not more than 9000 impulses / rotation;

(b) the inertial moment of the intelligent system: max. 16 gcm^2;

(c) friction moment of the intelligent system axle: max. 40 cNcm;

(d) max. force admitted by the axle :

- axial : 10 N;
- radial : 20 N;

2.3. Conditions for proper performance:

a) ambient temperature for work: $+5^0C \div +40^0C$

b) relative humidity for work : max. 80 % la 20^0C

max. 50 % la 40^0C

c) depositing and transport temperature : $-10^0C \div +55^0C$

d) operating in adequate fields according to 1st mechanical protection IP 54 STAS 5325-79 and for using category I STAS 10951-77;

e) intelligent system – photoelectric transducer subsystem (of rotation) cannot be exposed to vibrations at assembling place with a frequency higher than 15 Hz and amplitude 0,1mm;

f) environment will be active chemical substances free and electromagnetic fields capable to affect the function of intelligent system– photoelectric transducer subsystem (of rotation);

g) intelligent subsystem – photoelectric transducer subsystem (of rotation) is designed for temperate climate area STAS 6535-83 and for exploration category 3 STAS 6692-83.

3. THEORETICAL AND PRACTICAL STUDY FOR MEASUREMENT WITH THE INTELLIGENT MECHATRONIC MICROSYSTEM

The process of measuring / positioning as matrix comprises:

- measuring the size and position of the piece ;
- simulation of calibration (after Taylor's law);
- mounting simulation;
- complex measurement (including form and profile);
- measurement and positioning

$$u_G = \sqrt{\sum_{\substack{i,j=1\\ i>j}}^{n} \left(\frac{\partial z}{\partial x_i}\right)^2 u_i + 2\sum_{\substack{i,j=1\\ i>j}}^{n} \frac{\partial z}{\partial x_i}\frac{\partial z}{\partial z_j}\rho_{ij} u_i u_j} + f(t) \qquad (1)$$

where:

$z = z(x_1 \ldots x_i, x_j \ldots . x_n)$ correlation function;

ρ_{ij} -correlation coefficient between x_i şi x_j;

f -repetitive error unnoticed.

The result of a measurement / positioning is always influenced by the action of several disturbing factors.

These influences are grouped as follows:

- Own errors of mechatronic system;
- Sensor errors;
- Errors due to the methodology for measuring / positioning;
- Probing errors (deviations of form and roughness of the piece);
- Errors due to the calcul algorithm and computer system.

The theoretical analysis ot errors assumes the following methodology for calculation (according to markings in figure 3):

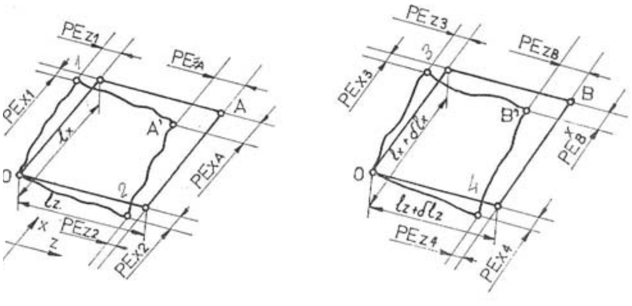

Fig. 3 Determine the planar error

a) to calculate the displacement error:

$$PE = \pm PE(s) \pm 3\sigma_0; \qquad (2)$$

$$PE = (PE_A - PE_B);$$

$$PE = (PE_{max} - PE_{min});$$

b) to calculate the planar error:

$$\Delta P_A = \sqrt{(PE_{XA})^2 + (PE_{ZA})^2} \qquad (3)$$

where :

$PE_{XA} = PE_{X1} + PE_{X2} = l_Z \sin\theta_{XZ} + (l_X - l_X \cos\theta_{XZ});$

$PE_{ZA} = PE_{Z1} + PE_{Z2} = l_X \sin\theta_{XZ} + (l_Z - l_Z \cos\theta_{XZ});$

$\theta_{XZ} = NOE_{XZ} + \gamma_X + \gamma_Z$

NOE_{XZ} is the deviation measured from the perpendicularity of the two axes

γ_X is derived axis X, and γ_Z is derived axis Z, both measured angular errors.

According to figure no. 4, the planar error between two points result:

$$\Delta P_{AB} = \sqrt{(PE_{XA} - PE_{XB})^2 + (PE_{ZA} - PE_{ZB})^2} \qquad (4)$$

For maximum possible planar error, we choose the greater of ΔP_{AB1} and ΔP_{AB2}. Thus there was obtained:

$$\Delta P_{AB1} = \sqrt{(PE_{XAmax} - PE_{XBmin})^2 + (PE_{ZA} - PE_{ZB})^2} \qquad (5)$$

and

$$\Delta P_{AB2} = \sqrt{(PE_{ZAmax} - PE_{ZBmin})^2 + (PE_{ZA} - PE_{ZB})^2} \qquad (6)$$

Deviations from straightness movement is calculated as shown in Figure 4.

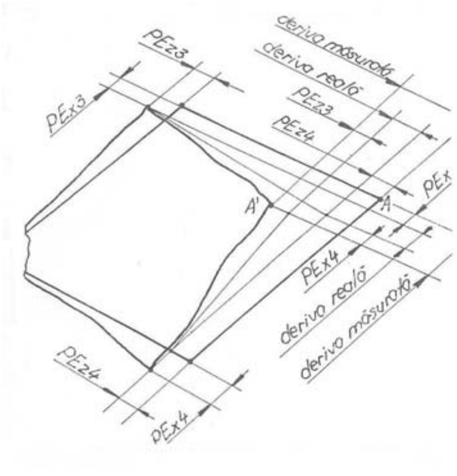

Fig. 4. Deviations from straightness movement

Deviations from straightness movement is measured from the real deviation from equal straightness plus errors due to angular position and position errors due Abbe effect. So that:

$$E_{Zreal} = E_{Zmeasured} - (P_{Z3} + P_{Z4}) \qquad (7)$$

and:

$$E_{Xreal} = E_{Xmeasured} - (P_{X3} + P_{X4}) \qquad (8)$$

c) for volumetric error calculation (when is taken account of the gripper mounted on the Z axis, considering for this arm Y). We consider a point, at lX, lZ şi lY distance from origin point O, as shown in figure 5.

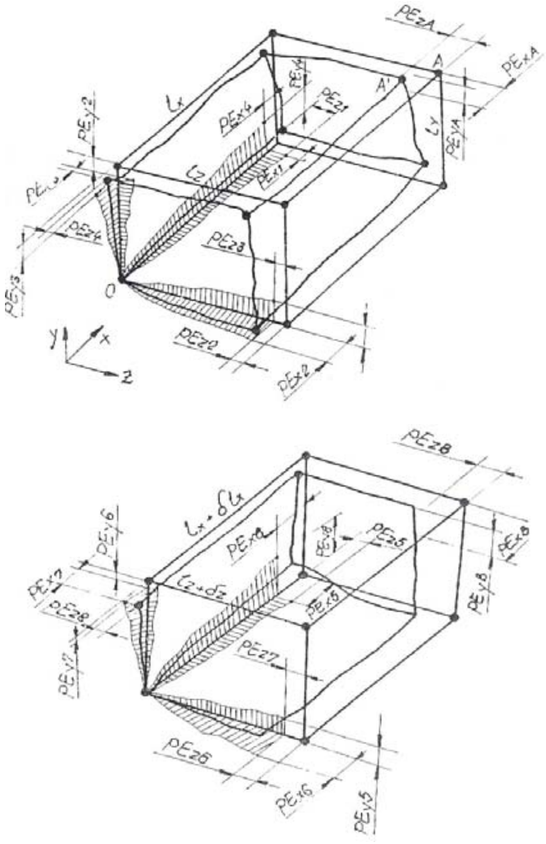

Fig. 5 Determine the volumetric error

According to the notation used in figure no.5, the volumetric error is calculated by the formula:

$$\Delta V_A = \sqrt{PE_{XA}^2 + PE_{ZA}^2 + PE_{YA}^2} \qquad (9)$$

where:

$$PE_{XA} = l_Z \sin\theta_{XZ} + (l_X - l_X \cos\theta_{XZ}) + l_Y \sin\theta_{XY} + l_X \cos\theta_{XY}) ; \qquad (10)$$

$$\theta_{XZ} = NOE_{XZ} + \alpha_Y + \gamma_X + \gamma_Z \qquad (11)$$

$$\theta_{XY} = NOE_{XY} + \alpha_Z + \beta_X + \beta_Y \qquad (12)$$

$$PE_{YA} = l_Z \sin\theta_{YZ} + (l_Y - l_Y \cos\theta_{YZ}) + (l_Y - l_Y \cos\theta_{XY}) + l_X \sin\theta_{XY}; \qquad (13)$$

$$\theta_{YZ} = NOE_{YZ} + \alpha_X + \gamma_Y + \beta_Z \qquad (14)$$

$$PE_{ZA} = (l_Z - l_Z \cos\theta_{XZ}) + l_X \sin\theta_{XZ} + (l_Z - l_Z \cos\theta_{YZ}) + l_Y \sin\theta_{YZ}; \qquad (15)$$

The notation α, β, Y were used for the errors of roll, pitch and drift on the X, Z and Y directions. If the sensor moves to another point B, introducing new mechatronic system errors.

Volumetric error unto to “O” of point B, as shown in Figure 9.4 is calculated by the relationship:

$$\Delta V_B = \sqrt{PE_{XB}^2 + PE_{ZB}^2 + PE_{YB}^2} \qquad (16)$$

And the volumetric error between any 2 points A and B is:

$$\Delta V_{AB} = \sqrt{(PE_{X4} - E_{X6})^2 + (PE_{ZA} - PE_{ZB})^2 + (PE_{YA} - PE_{YB})^2} \qquad (17)$$

By measuring geometric errors for each point in space network nodes, can determine the maximum possible volumetric error with relations:

$$\Delta V_{AB1} = \sqrt{(PE_{XAmax} - PE_{XBmin})^2 + (PE_{ZA} - PE_{ZB})^2 + (PE_{YA} - PE_{YB})^2}$$

$$\Delta V_{AB2} = \sqrt{(PE_{YAmax} - PE_{YBmin})^2 + (PE_{XA} - PE_{XB})^2 + (PE_{ZA} - PE_{ZB})^2} \qquad (18)$$

$$\Delta V_{AB3} = \sqrt{(PE_{Zmax} - PE_{Zmin})^2 + (PE_{XA} - PE_{XB})^2 + (PE_{YA} - PE_{YB})^2}$$

Forward is determined the deviations from the straightness motion using the law: the measured deviation from the straightness motion (in one direction) is equal to the real deviation from straightness, adding the angular errors in the other two directions (PE_{Y7}) and position errors duet o non-compliance with the Abbe principle (PE_{Y8}).

The method recommends adding to the errors determined the rightness and repeatability errors, directly.

In accordance with the Digital Electronic AUTOMOTION - Italy, volumetric error in a point P (X_P, Z_P, Y_P) is calculated as follows:

$$V_E = \sqrt{V_X^2 + V_Y^2 + V_Z^2} \qquad (19)$$

where:

$$V_X = E_X + L_{ZX} + Q_{YZ} Y_P + Q_{ZX} Z_P;$$

$$V_Y = E_Y + L_{XY} + L_{ZY} + Q_{ZY} Z_P; \qquad (20)$$

$$V_Z = E_Z + L_{XZ} + L_{YZ};$$

where: E represents errors accuracy; L represents deviations from straightness motion / movements; Q represents deviations from perpendicular axes.

We take mesurement calibrators: 1±0,0004; 5±0,0005; 10±0,0006; 15±0,0006; 20±0,0007 şi 24±0,0007;[mm].

Table 1 shows, centralized, the ten values obtained from standard measurements taken for each calibrator piece.

Table 1 Values obtained after measurements taken for each calibrator piece [mm]

X_{ei} Val. abs.	X_{e1}	X_{e2}	X_{e3}	X_{e4}	X_{e5}	X_{e6}	X_{e7}	X_{e8}	X_{e9}	X_{e10}
(1)	1,0004	1,0005	1,0004	1,0005	1,0005	1,0004	1,0005	1,0004	1,0004	1,0004
(2)	5,0005	5,0006	5,0005	5,0006	5,0005	5,0006	5,0006	5,0006	5,0005	5,0005
(3)	10,0006	10,0005	10,0006	10,0006	10,0005	10,0006	10,0006	10,0005	10,0005	10,0006
(4)	15,0005	15,0006	15,0006	15,0005	15,0006	15,0006	15,0006	15,0005	15,0005	15,0006
(5)	20,0006	20,0006	20,0006	20,0006	20,0005	20,0005	20,0005	20,0006	20,0006	20,0005
(6)	24,0005	24,0006	24,0005	24,0005	24,0006	24,0006	24,0006	24,0005	24,0005	24,0006

- **Average (calculated)**

Average is calculated with:

$$\overline{Xe} = \frac{\sum X_{ei}}{m_{(1\div10)}} \text{ [mm];} \qquad (21)$$

So, using relation (21), we have:

$\overline{X}_{e(1)}$ = 1,00044mm

$\overline{X}_{e(2)}$ =5,00055mm

$\overline{X}_{e(3)}$ =10,00056mm

$\overline{X}_{e(4)}$ =19,00056mm

$\overline{X}_{e(5)}$ =20,00056mm

$\overline{X}_{e(6)}$ =24,00055mm.

- **Variation of repeatability (calculated)**

Varioation of repetability is calculated with relation:

$$V_r = \frac{1}{10}\sum_1 \left(X_{ei} - \overline{X}_e\right)^2 ; \qquad (22)$$

So, using relation (22), is calculated:

$V_{r(1)}$ = 0,0000;

$V_{r(2)}$ = 0,0000;

$V_{r(3)}$ = 0,00000;

$V_{r(4)}$ = 0,00000;

$V_{r(5)}$ = 0,00000;

$V_{r(6)}$ = 0,00000.

- **Incertitude of measurement (calculated)**

Incertitude of measurement is calculated with relation:

$$I_e = 2\sqrt{V_n} \text{ [mm]} \qquad (23)$$

So, using relation (3), we have:

I_{e1} = 0,000110 mm;

I_{e2} = 0,000120 mm;

I_{e3} = 0,000121 mm

I_{e4} = 0,000123 mm;

I_{e5} = 0,000127 mm;

I_{e6} = 0,000129 mm.

- **Incertitude of repetability (Ir) (calculated)**

Incertitude of repetability is calculated with:

$$I_r = 2 \text{ x } s_r \qquad (24)$$

where:

$$s_r = \sqrt{\frac{\sum_{j=1}^{m}(X_{1j} - \overline{X}_{1j})^2}{m-1}} \qquad (25)$$

The meaning of the terms is as follows:

s_r = standard deviation;

m = number of measurements;

j = measurement index;

$\overline{X}$ = average value;

where:

$$I_r = 2\sqrt{\frac{\sum_{j=1}^{m}(X_{1j} - \overline{X}_{1j})^2}{m-1}} ; \qquad (26)$$

So, we have:

$$I_{r(4.2.1)} = 2\times\sqrt{0,0000000305} = 2x0,00001816$$

$$I_{r(4.2.1)} = = 0,00003632 \text{ mm}$$

$$I_{r(4.2.2)} = 0,00009282\text{mm}$$

$$I_{r(4.2.3)} = 0,00009934\text{mm}$$

$$I_{r(4.2.4)} = 00015732\text{mm}$$

$$I_{r(4.2.5)} = 00019568\text{m}$$

$$I_{r(4.2.6)} = 0,00024241\text{mm}$$

4. CONCLUSION

In conclusion, the intelligent mechatronic microsystem has the metrological capacity and capability in accordance with standards.

For the future work we intend to use other types of sensors and transducers in order to determine the best solutions.

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