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Laser mechatronic system used for accurate measurement of spatial shapes

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The paper presents a new method for measuring the tools active surfaces with high accuracy during the technological process. The principle is based on recording the period the object is covered up with the laser ray continuously. We have designed a control software for the electrical stepper motor in order to impose the sine law dependence for the angular speed versus time. The experimental setup of the mechatronic system approved the theoretical considerations. The DAQ board was used as well as optical sensors and electrical stepper motor.

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1. Introduction

By using laser measuring mechatronic systems we may find out very accurately the dimensional values of technological assembly components and of some other mechanical elements too. All of them could have miniature spatial shapes and this is the reason why some other classical methods are useless.

As state-of-art for technical improvements due to the laser using, it could be mentioned: experiments for verifying the mechanical constants, some new measuring methods for time and length, new way for measuring the speed by using the Doppler physical phenomenon as well as the technological processes such as cutting and weldment. The laser is one of the best solutions for health treatment, too. Meantime the laser technique enables the pollution detection over a wide area even at ten kilometers further.

The most important problem for using laser as measuring mean is to stabilize its frequency, so the He-Ne laser is the best from this point of view. The CO2 laser has a larger wave length with the opportunity of varying it, but it needs cooling [1].

The laser radiation could provide superiority, because of its main properties, such as being very intense and focused on the object as well as monochromatic and coherent. The laser ray advantages could be adduced as evidences for using interferometer principles for measuring speed level and length values out. When it is affordable for speed level recording, its amplitude that exceeds an imposed range could be neglected.

The laboratory apparatus based on interferometer principles, implies some optical subassemblies and electronic devices and the main advantage refers to the lack avoidance needed for maintaining the stability of ray intensity.

The laser ray has the main advantage of using the entire strength of light supplier. Consequently, the He-Ne laser, which has the wave length λ=633nm, may use the radiant power of an array A=0.57μm^2, as it was computed according to optical law. [1]

Regarding the improvements of the He-Ne coherent laser radiation, there are three properties that could be applied for attending the positional alignment and distance measurement:

- A great accuracy for spatial position due to the geometry of source ray;
- The higher contrast of laser ray in opposition to the classical light suppliers;
- The spatial spread of laser ray over the distance is about $10^{-3} – 10^{-5}$[rad].

The utmost importance is the wave length of laser radiation, which has to become a guide mark. So, we have to record the total number of half wave length needed for the total distance value. In order to do this, the wave length has to fulfill the following conditions: it has to be stable; it may be repeated identically; it should be known with great accuracy.

The reasons above may lead us to the conclusion of maintaining the ray frequency stability by using constant values for wave length and power. There are two ways of keeping the stability: the active one, which implies some characteristics of designing the laser cavity; the passive way, which is accomplished by avoiding vibration and mechanical perturbation due to the external factors.

The purpose of paper [6] was to design a mechatronic system, which could be used for accurate measuring of very low diameter values of the object. The principle is based on recording the period the object is covered up with a laser ray continuously. The target could be a mobile one, or could be stationary. As we may notice from Fig. 1 the system implies a hexagonal mirror having the role of deflecting the ray toward an optical system for detecting and concentrating the same ray. Later on, the ray intersects the target, which is meaning the solid body we aim to find out its dimensions. The sweeper, which in fact refers to the laser ray, is covering the plan where the object is placed, so that its speed is:

$$v = 2 \cdot \omega \cdot f \tag{1}$$

where: ω – the angular speed of the mirror.

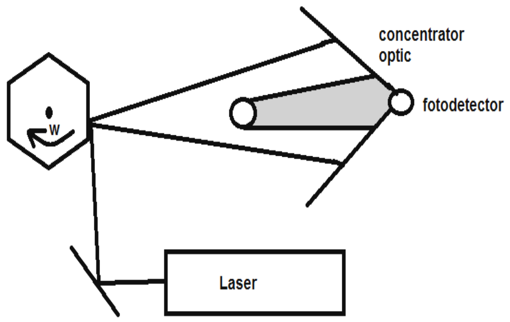

Fig. 1. Schematic of the system principle.

We may observe that the reflected ray is moving with double of angular speed ω value, so that the entire displacement is:

$$\Delta y = v \cdot \Delta t = 2 \cdot \omega \cdot f \cdot \Delta t \tag{2}$$

The accuracy is depending on laser ray diameter value, which has to be less than the target diameter as well as on system dynamic stability.

The aim of this paper is to study the measurement accuracy of the proposed mechatronic device, in order to improve the mirror and laser frequency stability without any perturbation, by controlling the actuation system.

2. Description of the device

In order to accomplish accurate measurement of the tools active surfaces during the technological process, the mechatronic device presented in Fig. 2 was designed [7,8]. As we may infer, it implies a mirror whose hexagonal surfaces have to reflect the laser ray. The mirror 1 with suitable mechanical system of bearings 2 for the rotational movement is actuated by electrical stepper motor 4 with controlled speed variation. The optical sensor 3 placed on the mirror shaft sends signals to the DAQ board. Meantime, the electrical stepper motor provides the speed according to the imposed theoretical law as well as the sensor information.

Regarding the focused direction of the ray, a special requirement was imposed to the mechanical subassembly of laser system. Movement guidance with rolling screw was used for setting the positional point of starting the measurement process (Fig. 3).

The sensor system was used in order to measure the rotational speed of the mirror, whose signal was sent to the DAQ NI USB - 6009 board.

Finally, the assembly haqs to be positioned following a suitable plane geometry with an imposed tolerance between the object position and the mechatronic device.

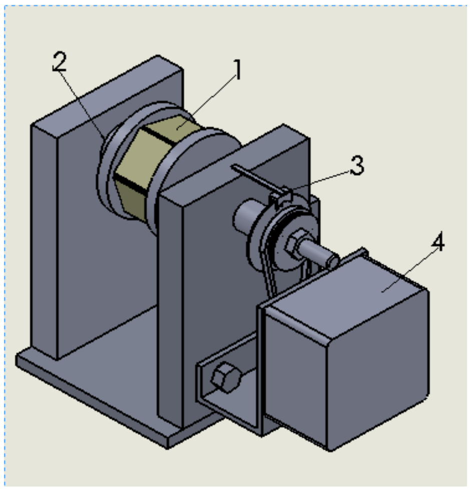

Fig. 2. The mirror and the electrical stepper motor subassembly.

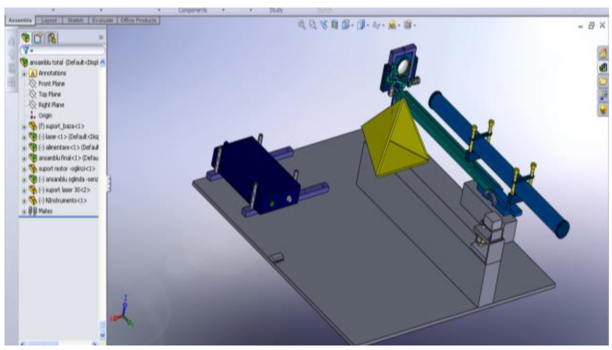

Fig. 3. The laser beam subassembly.

3. Theoretical considerations

The measurement mechatronic device with high accuracy positioning feature requires actuation system which should follow a very well known law for movement. Any external perturbation should be analyzed and overcompensated for its strength influence, so that the feed-back parameters may improve the technical performances.

Meantime, the software actuation has to perform technical parameters according to critical information sent by the sensor unit during very short periods.

We aim to control the rotational speed as sinusoidal dependence on time for starting period nearby deceleration too. In order to do that, we should establish the maximum speed value imposed by practice assessment. Because of the loosing step avoidance, we have to compute the one step movement time from the mathematical model.

The mathematical model given below (eq. 1) takes into account the system with electrical tension equation for the supplied phase and the mechanical movement equation. The last one should make the equilibrium between the motor electrical torque and the resistant one, which has the inertia as main component. Due to the higher acceleration values, the inertial torque is the main perturbation factor.

The differential equation system is:

$$\begin{cases} \dfrac{dI}{dt} = \dfrac{1}{L} \cdot [U - R \cdot I + I \cdot L_p \cdot \sin(2 \cdot p_z \cdot \theta_m)] \\ \dfrac{d\omega_m}{dt} = \dfrac{1}{J_{rr}} \cdot (M_m - M_r - D \cdot \omega_m) \\ \dfrac{d\theta_m}{dt} = \omega_m \end{cases} \quad (3)$$

The electrical inductance of the supplied phase L is dependent on θ_m – the angular displacement of the motor shaft as following:

$$L = L_0 + L_p \cdot \cos(2 \cdot p_z \cdot \theta_m)$$

where: I - electrical current for supplied phase; L - electrical inductance; L_0 - electrical inductance of the motor phase; L_p – the amplitude of co-sinusoidal variation law for L; p_z – the number of rotor step for one rotational movement; U - electrical voltage of the motor; R - electrical resistance; ω_m – the angular speed of the motor; J_{rr} – the inertial mass constant; M_m – the motor torque; M_r – the resistant torque; D – the viscous friction coefficient.

The numerical setup was made with the following parameters for the electrical stepper motor HY 200-4288 [9]: I=8.9 [A]; R=0.3 [Ω]; L_0=2.2 [mH]; M_m=15 [Nm]; J_r=8300 [gcm^2] . We have computed the following values: M_r = 4.52 [Nm]; J_{rr} = 156e-07 [Kgm^2];

By solving the mathematical model of (1) using numerical method Runge-Kutta, we have found out the dependence on time for the three unknown parameters: electrical current I(t), angular displacement θ_m(t) and angular speed ω_m(t). The variations are presented in Fig. 4, Fig. 5 and Fig. 6.

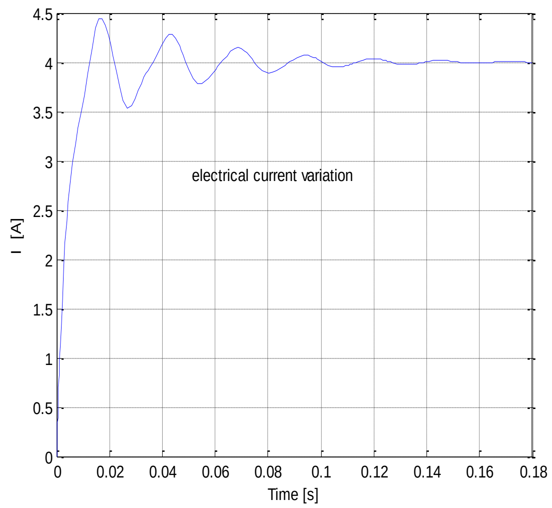

Fig. 4. The electrical current dependence on time.

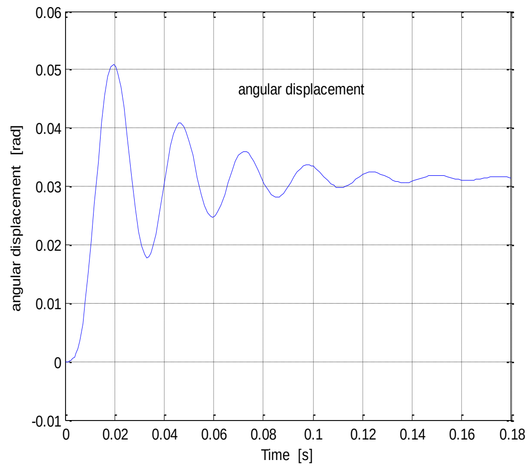

Fig. 5. Angular displacement dependence on time.

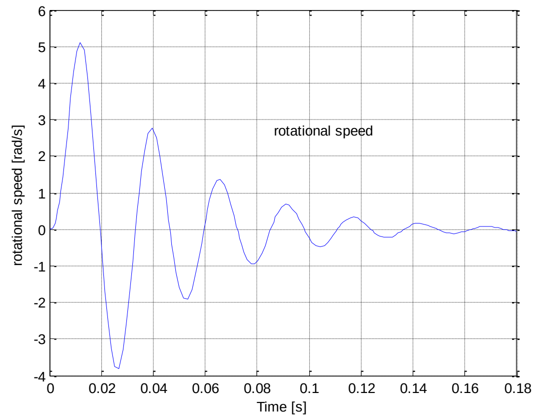

Fig. 6. Rotational speed dependence on time.

The main conclusion is that we may compute the time needed for one step movement with mechanical and electrical parameters imposition on the system dynamics.

4. The control software

After theoretical considerations mentioned above, we have to impose the sine law for controlling the speed dependence on time for the electrical stepper motor. We have used the LabView 8.6 release software [10, 11] and the DAQ board NI 6009 [12].

At first, we have chosen a constant time increment for the acceleration period assuming the theoretical value computed by using the mathematical model for the maximum speed value.

As we may infer from Fig. 7, which presents the block diagram of the control software, we have accepted a well known number of steps for acceleration period. We have admitted only the positive values of sinusoidal variations due to the physical conditions of developing the software.

The next research step is conducted to find out the frequencies values and their corresponding time for one step, so the motor will achieve the value of torque that allows the acceleration. The computation for these values has been done using Matlab Release 6.5 software for the mathematical model nearby the conditions for sine law variation of torque for each supplied phase of the motor. Additionally, we have admitted the intersection point between two curves with a suitable tolerance of ±0.01. Finally, all the computational results were written in a data file.

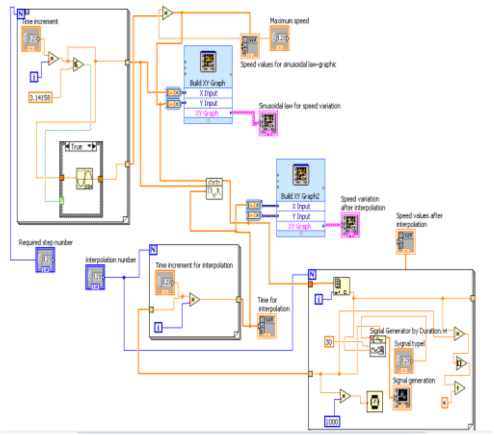

Fig. 7. The block diagram of the LabView file.

By reading this file and knowing the increment of time, we may apply the spline interpolation for Labview control software in order to attend each frequency during the acceleration period by steps.

Regarding the signal generation for the step of motor phase supplied each time, we aim to use three types: sine, triangle and square. The signal generation function was applied for a period required by one step movement as we make allowance for theoretical approach.

The results taken from the Front Panel of control software are presented in Fig. 8.

After spline interpolation the values of required frequencies for time increment were computed and their dependence on time reveals the sine law shape. Meantime, the signal generation was pointed out.

The virtual instrument for the electrical stepper control includes a sub-vi for sending the signal for each phase too (Fig. 9).

5. The experimental setup

The experimental setup was done for accurate measuring of active surfaces of a drill, which has the diameter value Φ=10[mm]. Theoretically, its dimension values are varying of about 0.1[mm] during the technological process.

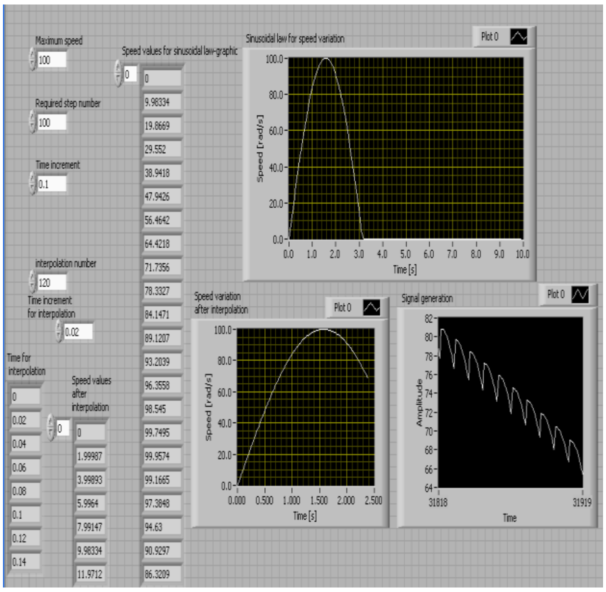

Fig. 8. The Front Panel of the control software.

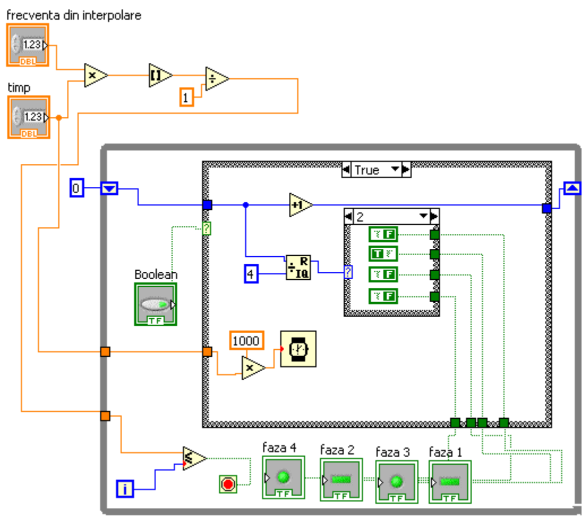

Fig. 9. The Block Diagram of the control software for the four phases of the electrical stepper motor.

We have chosen the He-Ne laser system designed by the 'Coherent' company [13] with λ=632.

For the sensor system we have used 3-Axis Digital Compass IC HMC 5883 and ITG-3200 for 3 axis MEMS gyroscope with individual 16-bit ADCs and signal conditioning [14].

The Fig. 10 presents the experimental setup as we have described above and the active surfaces for milling used for the accurate measurement of the spatial shape, for instance.

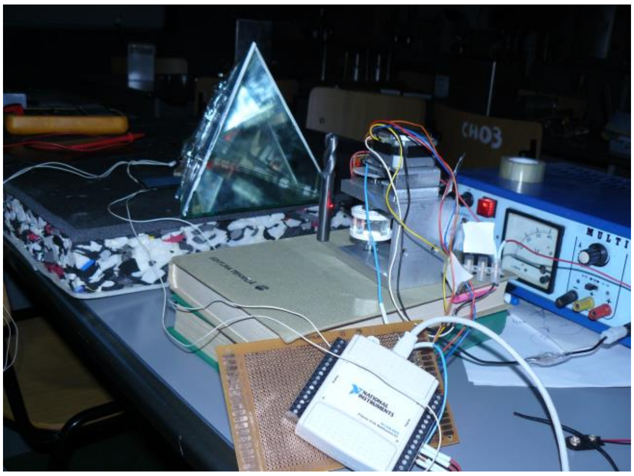

Fig. 10. The experimental setup for accurate measurement with laser system.

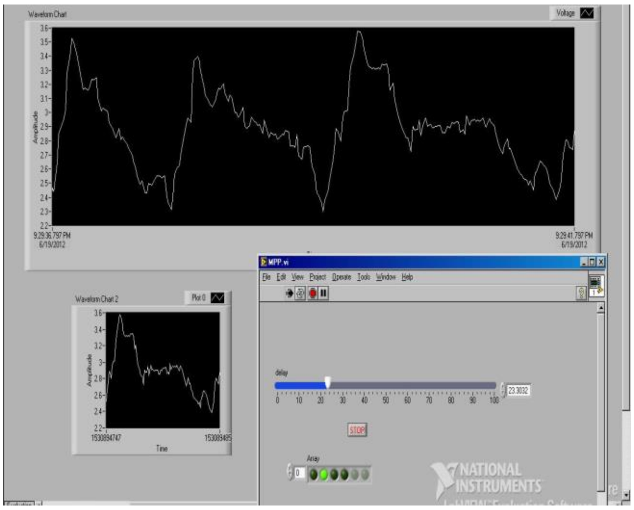

Fig. 11. The results of surface measuring by using the electrical stepper motor control.

As we may infer from Fig. 11, there are some equidistant periods along X axis representing the values of time in seconds. Along Y axis we have recorded the length values in [mm] during a full rotational movement of the drill. The errors appeared after the first period and there are amplified during the entire process.

Three types of movement laws have been accomplished, so that the best one from the accuracy point of view was chosen. The sine law have satisfied the impositions of dynamic conditions.

6. Conclusions

We have designed a mechatronic system actuated by electrical stepper motor with an imposition of motion law considering the rotational speed as main criteria. An optic sensor was used for detecting the speed values. The He-Ne laser system has the main advantages of spatial positioning and spatial spread of ray over the distance. Both of them could improve the accuracy of measurement.

The experimental setup approved the theoretical considerations applied for the mechatronic system.

As future work we aim to use the speed variations taking into account the perturbation factors, which are meaning in fact the inertial forces and torques. Meantime, the electronic device of data acquisition could be used for recording the angular displacement and rotational acceleration.

Acknowledgements

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