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Design of Mechatronic Systems for Inspection of Shafts Coating

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Abstract: *The paper provides a concept for the design of a mechatronic system for inspection of the coating of renovated shafts. The mechatronic system for inspection of coatings is a part of renovating shafts manufacture. The shafts are used to extrude sheet material (PVC, Plexiglas, other plastics) by laying and polishing. The shafts working area is covered with new types of highly wear-resistant coatings based on ultra disperse nickel coatings with nano-particles. We suggest a mechatronic system technology for input and output shaft control. The frame of the shafts and the system for inspection of coatings is analyzed by finite element method. In order to achieve efficient control of the mechatronic system a kinematical model is derived.*

Keywords*: Mechatronic system, kinematic model, shafts coating.*

Introduction

Extruding (pressing by pushing) of sheet material from non-metal materials (Plexiglas, PVC, other plastics) is widely used in households. Gifts, flowers, sugar and chocolate packing is made from thin aluminum sheets. Thin Plexiglas sheets are used to make pack-boxes, and thick nylon sheets are used to make bags, raincoats, etc. With the time and at high production rate, the shafts age, their surface wears out, and sometimes scratches appear in incidents. All this makes the shaft surface not precisely circular and even. Because of a new shaft’s very high price, renovation of the defected shaft is applied in such cases by applying a new coating and polishing it to mirror shine.

A technological line for chrome based smooth shaft renovation should include at least the following technological cells and operations: 1) grinding of the old chrome layer at a given roughness; 2) coating of a new chrome layer in a galvanic (cyanide) bath; 3) rough grinding of the coating down to a predetermined diameter and roughness; 4) fine grinding of the shaft down to a predetermined roughness; 5) polishing of the chrome to a predetermined smoothness (Ra ~ 0.02-0.03). The grinding of the old chrome layer is a routine and easy operation if one has lathes with long guides, accurate screws and good bearings. Usually 120 µm to 150 µm of the old chrome are taken off, where greater roughness is required to enable the new chrome layer to stick better.

The laying of the new layer of chrome can be done in a galvanic bath where a part of the shaft is dipped and it is slowly rotated. Thus relatively big thickness (120-150 µm) and unevenness of the coating is achieved. The evenness is improved through the next operation. The idea of polishing the steel base of the shaft to the necessary smoothness emerged on the basis of these studies and it also included laying a thin (15-25 µm) nickel coating with nano-particles in it, or a thicker one (25-40 µm) including other micro- and nano-dispersoids for increasing the hardness and wearing out resistance [1].

The shafts for renovating (Fig. 1) have following properties:

– the biggest diameter is 3.5 m,

– the max length – 4.5 m,

– the mass – 16 t,

– the type of coatings is Ni+P and additional dispersion materials; the thickness of the coating is between 0.03-0.08 mm,

– 250 pieces per year.

The requirements related to accuracy of the geometrical form, dimensions and roughness are very high. These requirements aid to achieve a high degree of automation of measurements and electronic reporting of the measurement results [2, 3]. With regard to the largest dimensions of shafts and to avoid subjective mistakes of measuring, a robotized system for shafts inspection has to be developed in a technological line. For example, the inspection of the work surface for any scratches and other defects must be performed by a camera that moves along the shaft while the latter rotates.

These requirements differ depending on the application and dimensions of the shafts, but in any case, they are quite high. For example, the requirements for smoothness of the working areas prior to placing the coating include grinding and polishing. Fig. 1 gives an example of a drawing of a calender roll which is used in the manufacture of plastic sheets. The extremely demanding requirements with regard to axes parallelism of axle bearings (0.015 mm if the shaft is longer than 3 m) and precision of dimensions of the operating part (Φ 412 ± 0.02 mm for length of 2300 mm) can be seen.

Nowadays the robotization of various operations in the domain of biology, micro-electronics, nano technologies and in manufacture is rapidly developing. Robots with appropriate kinematic systems, gripping devices, actuated by piezo-actuators are under development [4-7, 9, 10].

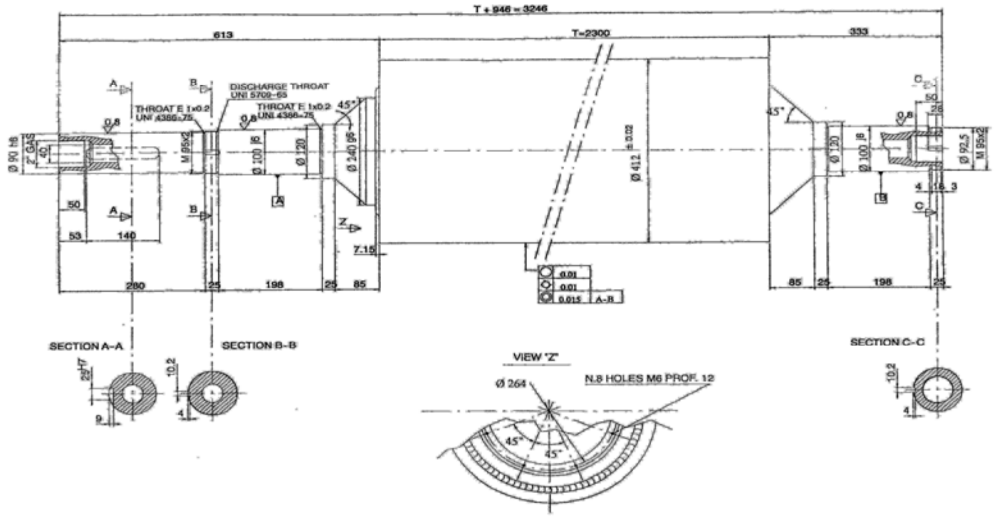


Fig. 1. Shaft for extruding sheet material

The objective of this study is to design a mechatronic system for coating inspection of renovating shafts with nano-dispersoids and/or nano particles. The parameters of the shafts (Fig. 1) and the properties of the coatings are mentioned above in the text. Also technology for robotized inspection of shafts coating is provided. In accordance with the objective the study consists of the following sections: *Robotic station for incoming control in the manufacture*, *Design of the frame of the mechatronic system for coating inspection and Kinematic model.*

Robotic station for incoming control in the manufacture

From the warehouse the shaft is transported by a crane and placed on a stand for input control. The purpose of the stand is to determine and qualify the condition of the individual elements of the shaft construction, namely: operating part – thickness and smoothness of the metal coating, presence of rough scratches or other faults on the operating surface, deviation from the round shape of the cross-sections; to monitor the surface condition of the axle bearings and fulfill the requirements for parallel axes; to check the condition of the key and splines on the shafts. Based on the established findings, which are also recorded in a computer, a route technology is developed for each individual shaft.

Due to the big size of the shafts and in order to avoid subjective errors, all measurements must be made automatically by the respective measuring devices and systems. For example, the inspection of the operating surface for the presence of scratches and other faults must be performed by a camera that moves along the shaft's length, the shaft turning simultaneously around its axis. The images taken by the camera are developed by a software product for identification of images and then compared to the image of an ideal surface having no faults. Any differences found are recorded as a separate file and then printed on paper. The described measurements are done in the following order (Fig. 2).

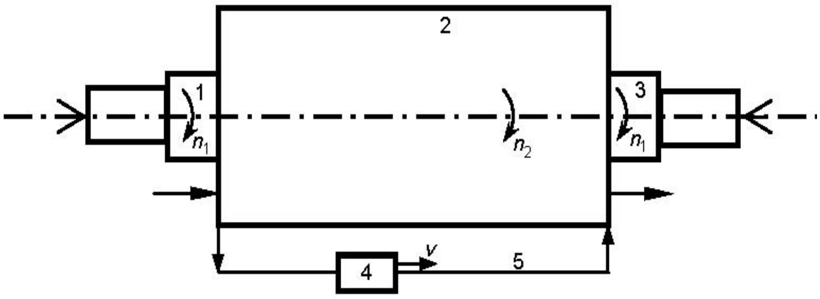


Fig. 2. Scheme for consistency of the movement of the measuring devices platform:
1 – left bearing, 2 – work surface, 3 – right bearing; 4 – measuring devices platform; 5 – path of movement of the platform

The movement of the platform with the camera and sensors starts from the beginning of the left bearing. The rotation of the shaft turns to lower speed, then forward displacement of the platform starts until the end of the working surface of the shaft at the right bearing. The movement of the platform and the rotation of the shaft stops, then the platform moves forward to the right bearing. Platform 4 is held and moved by a specially designed robot with high accuracy of linear displacements. The signals for turning the shaft and the rotation speed are sent to the motor that rotates the shaft by the processor of the robot, after taking into account the moving position of the platform. The found defects/faults/ are recorded in a separate file on a computer and on paper [1-3]. It is appropriate to use camera CCD – C8484-15 produced by Hamamatsu. The camera has high resolution.

Non-contact sensors fix to the micromanipulator are attached to the moving platform with the camera which measure the thickness of the coating and determine the deviation from the round shape of the cross-sections. The data from the sensors are processed by a specialized software product and saved in a separate file. The previours authors’ study was to design a manipulator-holder for micro-nano-positioning and orientation of the touchless sensors and gauges for measuring roughness, thickness of coat, deviation from cylindricity or the micro-hardness of the shaft coating [1]. The manipulator (Fig. 3) should be positioned on the mobile platform of a specialized robot for measuring shaft coatings (Fig. 2). This requires that the output link of the manipulator (sensor or gauge) should be orientated or shifted along normal to the measured surface. The co-operation of the macro and micro robots is necessary when the manipulated object has to be handled into a macro-space and in order to carry out a precise finishing operation in a micro-zone [8]. In mechanisms with incorporated macro – micro structures DoF, as well as the accessible area increase, the structures are compact and have fewer backlashes. Finally it will be investigated how the length variation of the piezo-ceramic links will influence the motion of the working tool. Hysteresis is a disadvantage of the piezo actuators. However, there are some methods for compensation of the hysteresis effect in piezoelectrical actuators [8, 9].

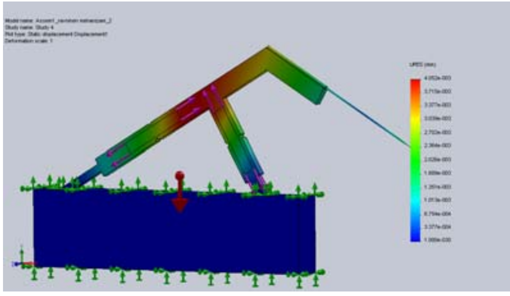


Fig. 3. Displacement of the manipulator made of Poly Carbonate material under the influence of actuator's force of 50 N

Design of the frame of the mechatronic system for coating inspection

The shafts intended for coating are placed on the frame. The frame must bear a load of 16 tons. Also, the mechatronic system for coating inspection adds to the frame. In designing of the frame the Finite Element Method (FEM) is used. After some simulations are performed, we choose the profile Bosch Rexort – L200×100 mm (Fig. 4) for making the frame.

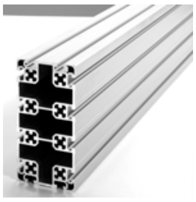
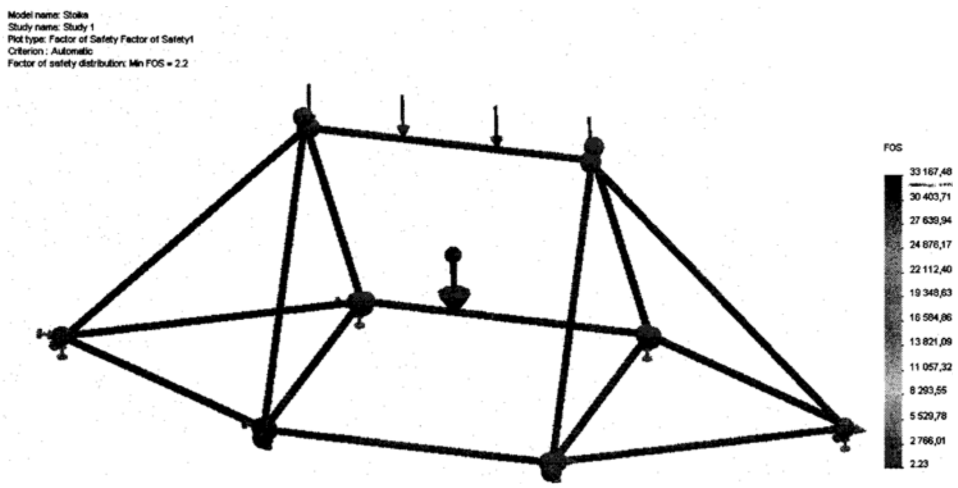


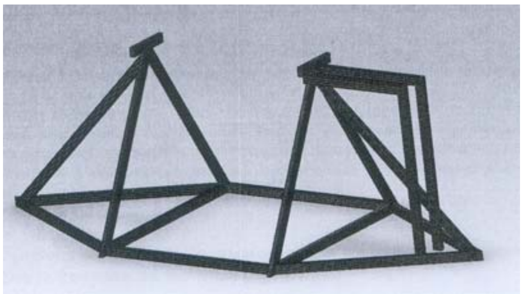
Fig. 4. Bosch Rexort profile

The maximum stress inside the frame calculated by FEM was less than the allowable stress for the aluminum alloy – 100 MPa. The results of stress analysis – 33167.48 MPa demonstrated the sufficiency of the frame structure. The safety coefficient of the frame is about 3.01. Also, after stress analysis we choose the appropriate geometry of the frame (Fig. 5).

The driving unit for the mechatronic system should be mounted on the body frame. After some calculations we chose a motor with a planetary gearbox produced by Frienteded Transmission machinery Ltd. company. The motor must drive the shafts. The motor has the following properties: P=75 kW, M=20÷30 kN.m, n = 9÷87 min^{-1}.



(a)


(b)

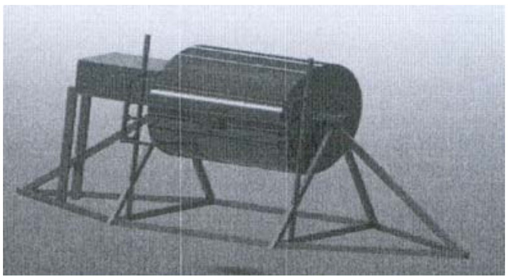

(c)

Fig. 5. The frame of the mechatronic systems for coating inspection: FEM analysis of the frame (a); CAD models of the frame (b) and (c)

Kinematical model

The operating of the mechatronic system for coating inspection of renovating shafts runs in the following order:

The shaft rotation is switched over to lower revolutions, upon which the platform starts moving longitudinally along the axis of the shaft until the end of the shaft operating part is reached. The platform moves forward to the right axel bearing while the shaft rotates slowly. The platform 4 (see Fig. 2) performs a complex compound motion in relation to the shaft (2). In relation to the axis of the shaft we introduce a fixed coordinate system. The frame along which platform 4 moves performs a transfer motion towards the fixed coordinate system. The platform 4 with the camera and sensors performs uniform relative motion. In order to measure the shaft coating, the camera and sensors monitor a given point of the shaft. The purpose of the measurement is to determine the absolute velocity and acceleration of the point on the shaft for a given time interval.

The platform 4 performs a reciprocal back and forth motion according to a periodic or linear law.

If the shaft turns around its axis by any laws, such as $\varphi = at^2 - bt^3$, the linear velocity of the shaft will be

(1) $$\dot{\varphi} = (2at - 3bt^2).R \ \text{min}^{-1}.$$

The transfer velocity of platform (4) is

(2) $$\dot{\varphi} = (2at - 3bt^2).R_\text{p} \ \text{min}^{-1}.$$

where R is the radius of shaft, R_p – the radius of the frame with platform 4, t – the time period.

Let the platform 4 moves along its axis by any law, such as $x' = c\sin\theta t$ or $x' = t^2$. We assume (Fig. 2) that $x = OM$ is the path of movement of the platform and x' is the length of the working surface, m.

The absolute velocity of the given point of the shaft is $\vec{v}_\text{a}$

(3) $$\vec{v}_\text{a} = \vec{v}_\text{r} + \vec{v}_\text{e}$$

where $\vec{v}_\text{r}$ is the relative velocity of the platform, and $\vec{v}_\text{e}$ – the transfer relative velocity of the platform, $\vec{v}_\text{e}$ is directed normally to the radius:

(4) $$v_\text{e} = \omega R_\text{p} = \dot{\varphi} R_\text{p} = (2at - 3bt^2).R_\text{p} \ \text{m/s},$$

(5) $$v_\text{r} = \dot{x}' \ \text{m/s},$$

(6) $$v_a = \sqrt{v_\text{e}^2 - v_\text{r}^2} \ \text{m/s}.$$

Acceleration of the point

(7) $$\vec{a}_\text{a} = \vec{a}_\text{r} + \vec{a}_\text{e} + \vec{a}_\text{c}$$

where $\vec{a}_\text{r}$ is relative acceleration of the platform, and $\vec{a}_\text{e}$ – the transfer relative acceleration of the platform, and $\vec{a}_\text{c}$ – Coriolis acceleration.

(8) $$\vec{a}_\text{r} = \ddot{x}' \ \text{m/s}^2,$$

(9) $$a_\text{e} = a_\text{e}^\text{rot} + a_\text{e}^\text{cen} \ \text{m/s}^2,$$

where

(10) $$a_\text{e}^\text{rot} = \varepsilon R_\text{p} = \ddot{\omega} R_\text{p} \ \text{m/s}^2,$$

(11) $$a_\text{e}^\text{cen} = \omega^2 R_\text{p} \ \text{m/s}^2,$$

(12) $$a_c = 2\omega v_r \sin 90^\circ \quad \text{m/s}^2.$$

In solving the problem, the directions of the velocities and accelerations must be observed. Also, the trajectory of the given point on the shaft can be found against the two coordinate systems – the fixed and the mobile ones.

Conclusions

The paper provides a design of a mechatronic system and technology for input and output coating inspection of renovating shafts. The considered mechatronic system is a part of a technological line for shafts renovating. The shafts working area is covered by new types of highly wear-resistant coatings based on ultra disperse nickel coatings with nano-particles. The frame of the shafts and the system for inspection of the coatings is designed and analyzed using the finite element method. After some calculations, an appropriate driving unit for the shaft was chosen. Also, a camera and a manipulator were selected for shaft coating inspection. The manipulator is positioned on the mobile platform of a specialized robot for measuring thr shaft coatings and it has micro-positioning and orientation of the noncontact sensors and gauges for measuring the roughness, thickness of coat, deviation from cylindricity or micro-hardness of the shaft coating.

In order to achieve the efficient control of the mechatronic system, a kinematic model is derived.

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References

1. K o t e v, V., D. K a r a s t o y a n o v, K. K o s t a d i n o v. Micromanipulator for Inspection of Shafts Coating with Nano Components. – In: Int. Conf. on Manipulation, Manufacturing and Measurement on the Nanoscale (3M-Nano 2011), 29 August- 2 September 2011, Changchun, China.
2. G a v r i l o v, G. Nano – Powders by Nickeling. – Journal Electrochem. Soc., Vol. **152**, 2005, 132-137.
3. G a v r i l o v, G., D. K a r a s t o y a n o v. Method for Renovating of Coating over Steel Surfaces. BG Patent No 110745 (02.09.2010).
4. K a r a s t o y a n o v, D. Control of Robots and Another Mechatronical Systems. Prof. Marin Drinov Academic Publishing House, 2010. ISBN 987-954-322-415-9 (in Bulgarian).
5. M i l u s h e v, M. Hardware and Software Design for the Robot Leg Control. Wissenschaftliche Konferenz FDIBA "Technik und Wirtschaft in der Globalen Krise", Sofia, November, 2009.
6. C h a k a r o v, D., M. A b d e l-W a h a b, R. K a s p e r, K. K o s t a d i n o v. Synthesis of Tense Piezo Structures for Local Micro- and Nano-Manipulations. – In: 8th Magdeburg Days of Mechanical Engineering and 7th Mahreg Innovation Forume, 10-11 October 2007. Magdeburg, 2007, 173-180.
7. K o s t a d i n o v, K., V. K o t e v, P. G e n o v a. Some Ideas for Cooperating of Macro and Micro Robots. – Mechanics of Machines, Vol. **79**, 2009, 75-78.
8. M a r i n o v, M. Methods for Compensation of Hysteresis Effect in Piezoelectrical Actuators. – Journal Mechanic of the Machines, Vol. **79**, 2008, 33-37.
9. B i s h o p, R. Mechatronic Systems, Sensors and Actuators. The Mechatronics Handbook. CRC Press, 2008.

Разработка мехатронной системы для инспекции покрытий валов

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(Р е з ю м е)

Настоящая работа предлагает концепцию разработки мехатронной системы для инспекции обновления валов. Система является часть процесса обновления валов. Валы используются для экструдирования продуктов из PVC, Plexiglas, других пластмасс. Рабочая поверхность валов покрывается новым типом устойчивых покрытий на основе дисперсии никеля нано размера. Предложена мехатронная система для управления ввода и вывода валов. Система инспекции покрытий анализируется методом крайных элементов. Чтобы получить эффективное управление мехатронной системы, создана кинематическая модель.