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TRIBOLOGICAL CHARACTERISTICS OF NANO STRUCTURED NICKEL COATINGS FOR RENOVATING OF EXTRUDING SHAFTS

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Abstract: The methods for wear resistance testing is described and the experimental results for the dependence of the massive wear, wear speed, intensity of wear and wear resistance on the friction road and the time of a contact interaction are obtained. A testing micromanipulator with piezo actuators for measuring the roughness of the surface layer is developed. A methodology for thermographic testing and experimental results for wear and temperature changes in the contact by the wear process of the coatings under dry friction and abrasion is obtained

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 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 150µm 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 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 hardness and wearing out resistance. As dispersoids can be served micro-dusts of hard-fusible oxides, carbides, silicones, borides, nitrides, diamonds, ect. C – Diamond Synthesized - 4-25 nm; SiC - 50-60 nm;Al_2O_3 - alpha, 200 nm, [1]

The shafts for renovating have following properties: the biggest diameter - 3,5 m, max length-4,5m, mass-16t., the type of coatings is Nickel + Phosphorus and additional dispersion materials, 250 pieces per year. The requirements related to accuracy of geometrical form, dimensions and roughness are very high. These Requirements impose to achieve a high degree of automation of measurements and electronic reporting of measurement results [2].

The part of the present study is to design a manipulator - holder for micro-nano-positioning and orientation of the touch less sensors and gauges for measuring roughness, thickness of coat, deviation from cylindricity or micro-hardness of the shaft coating. The manipulator is positioned on the mobile platform of a specialized robot for measuring shaft coatings. The co-operation of the macro and micro robots is necessary when the manipulated object has to be handled into a macro-space and carry out a precise finishing operation in a micro-zone. 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

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 the load of 16 tones. 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 – L200x100mm (fig.1) for making the frame.

Fig.1**.** Bosch Rexort profile.

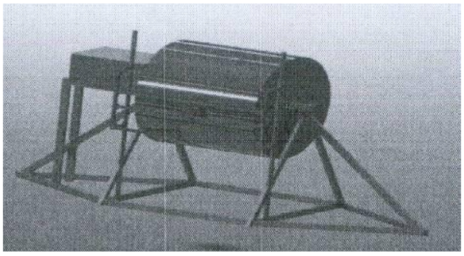

Fig.2. The frame of the mechatronic systems for coating inspection.

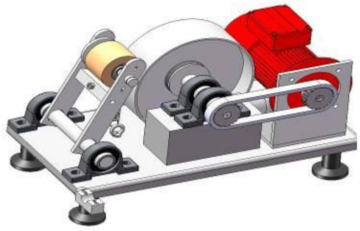

Fig. 3 Experimental stand for work conditions

The maximum stress inside the frame calculated by FEM was less than the allowable stress the aluminum alloy–100MPa. The results of stress analysis - 33 167,48 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.2).

The driving unit for mechatronic system should be mounted on the body frame. After some calculations we chose motor with a planetary gearbox produced by company Frienteded Transmission machinery Ltd. The motor has to drive the shafts. The motor has the following properties: $P=0{,}14\text{-}75\ kW, M=20\text{-}30\ kN.m, n=9\text{-}87 min^{-1}$.

Experimental results

The laboratory experiments were made for chemical nickelling with nickel – phosphorus matrix with micro/ nano scale dispersoids addition – silicon carbide, diamond synthesized. As optimal temperature is assumed 90-92^0 C, optimal pH – 4,7 to 4,9 and relation between cultivated area and volume of the solution (S /V) 1-2 dm^2/l.

In approximately observing of the parameters above, the mass percents of phosphorus are between 8 – 10 mass %. This value is corresponding to the matrix relative weight. From here we deduced a theoretical (average) speed for coating – 24-25 μm/h.

The coating for combination of experimental models was made – fig.3. The combinations for the different models were chosen to be close to the assumed value of the relation S/V.

In this series of experiments, where silicon carbide nano-filter 700 nm was used, the concentration of the working solution was chosen to be 0,4 g/l. In the experiments the dispersoid we added on the 15-th minute from the beginning of the process.

The weight measures of the polishing plates from 0,25 dm^2 proved calculated deposition speed – 23,8 to 25,2 μm/h. The coating follows the relief of the base and keeps the same smoothness.

Same experiments were made also with nano-filter 150 nm

Same experiments were made as well with dispersoid– nano – diamond dust. The following depositions were made:

- Pure nickel – phosphorus matrix
- \+ Diamond Synthesized - 4-25 nm

The relief and smoothness of the coating are remaining.

In some of the experiments the temperature was increased (for about 40 min up to 96^0 C). Harmful effects (decomposition of the solution) were not observed.

For a test in working conditions we designed a stand for high temperature testing (200^0C)– fig. 3

The stand is consists of hollow shaft, driven by electric AC motor, and heater, blowing the shaft with hot air. A heat-resistant Teflon roller is pressed to the shaft, which serves as extruded material.

PLC Allen Bradley is used for stand control and inverter SEW Eurodrive is used for driving mechanism. The personal computer is used to collect data regarding tests of wear resistance after continuous work, [2].

Wear: Methods of testing and experimental results

In the present work the investigation of the abrasive wear and the wear resistance of composite nickel coatings with nano sized SiC particles are performed in a laboratory.

Nano structured composite coatings are obtained by electro less nickel plating method EFTTOM-NICKEL developed at Technical University in Sofia. SiC nano particles average size of 35~40 nm are used as a strengthened phase. The density of the SiC nano particles in the coating is between 5~7%. Five different type of coatings are tested: electro less nickel coating (Ni), composite nickel coating with nano particles (Ni-SiC).The coatings are deposited on the different roughness surfaces $Ra = 0{,}3\mu m$ and $Ra = 2{,}1\mu m$. Some of the samples with the composite coatings are put to the thermal processing at 300^oC , 6 hours to improve the micro hardness and the adhesion of the coating to the padding. The coatings are deposited on the steel samples and their thickness is 50 μm.

The experimental tests are performed in the Tribology center at the Technical University in Sofia.

The Methods for abrasive wear test of nickel coatings is developed using a device working on a cinematic scheme back to back disc – fig. 4, [3]

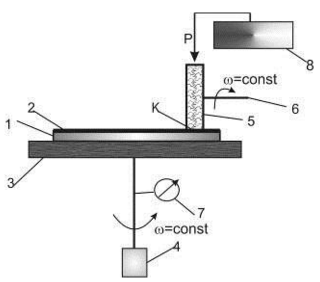

Fig. 4. Testing device

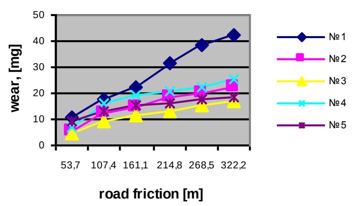

Fig. 5: Dependence of the massive wear on the rotation road

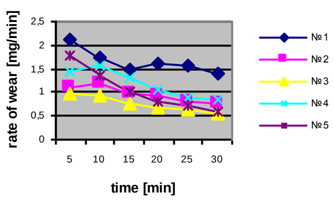

Fig.6: Dependence of the intensity of wear on the time

The disc sample 1 (solid) with coating 2 is fixed on a horizontal disc 3, which is moved by electric motor 4 with constant angular speed around a vertical axis. The antibody 5 is a disc from a special abrasive material CS10. The desire normal load P in the contact surface K is set through mounted in the antibody axle 6, which is operated by a special device 8. In this way the body 1 and antibody 5 are fixed on two cross axes. Upon the constant angular speed $\omega = const$ of the sample 1 and upon constant nominal contact pressure p_a=const the friction in the contact surface K keeps constant rotation speed of the antibody 5. Test basic parameters are: absolute massive wear m , speed of massive wear dm/dt; intensity of wear i - this is the lost coating thickness for an one friction cycle

$i = m / \rho A_a S$,where: ρ is the coating density; A_a is the nominal interaction contact surface; $S = 2\pi RN$ is the friction road, estimated by the number of cycles N; absolute wear resistance $I = 1/i$.
Experimental results for the massive wear and the speed of the massive wear of all type of coatings (fig.5, fig. 6). [5]

Thermal imaging of shaft's surface quality

When materials get hot, they radiate energy in the visible as well as in the infrared spectrum. This principle allows shafts quality inspection. A cost-effective infrared thermography (IRT) approach can be used to evaluate the quality of the shaft's surface. We can evaluate by passive or active thermography both renovation shaft surface and defected shaft surface by reason of wear. When the evaluation is accomplished during working conditions the active IRT can be used. It is important to ensure the object fills enough of the field of view (FOV) to get a reliable temperature measurement. FPA detector with 307 200 detector elements or cells, in a 640x480 matrix (infrared camera ThermaCAM SC640) is used. The discernible object size will depend on the lens used. In the experiments were used 45o lens, 24 o lens and close up 50µm lens. Errors in measurement and failure to resolve faults will occur if the object is too small or the distances too great. To ensure accurate resolution of small objects, the objects should be covered by at least three pixels of the array. For example, if the FOV of a 640x480 pixel array is 1m wide, the smallest accurately resolvable object will be 3x1000 mm/640 = 4.69 mm. A smaller object less than three pixels wide might not fill any of the pixels, and hence the temperature detected on all pixels would also be affected by the background temperature. The minimum discernible object size is affected by lens field angle, distance, and IR detector resolution, as defined by

$$S = \frac{6d}{n} tg\left(\frac{A}{2}\right) \quad (1)$$

where S is the minimum discernible object size in millimeters, d is the distance between lens and object in millimeters, n is the number of pixels in the camera field width or height, and A is the camera field angular width or height in degrees.

It can be seen that the discernible object size is in fact 2.828 x the pixel pitch, but it is safer to assume 3x. The minimum detectable object size clearly varies with number of pixels (used lenses) in the image and distance from the object.

The thermal radiation from an object depends on the temperature of the surfaces facing it. Reflected ambient temperature is a term used to mean the average effective temperature of those surfaces in the hemisphere facing the object. It is based on the amount of incoming thermal radiation, being the temperature of surfaces with emissivity of 1.0 that would produce the same incoming thermal radiation. [4] It can be estimated by one of two methods that are described in more detail in ISO 18434.

Emissivity and the environmental temperature are particularly important in mechanical thermography, because the equipment is often in plant rooms with other equipment at elevated or reduced temperature. The emissivity of the surface on machines varies greatly with new metal surfaces having values of 0.1 or below and dirty, corroded, or painted surfaces 0.9 or above. To compensate the error of unknown emissivity at a definite temperature an emissivity map is built by using ThermaCAM Researcher software and some preliminary measurements are competed.

IRT techniques are usually used under the assumption that the part being inspected has a planar surface. However, when complex surface objects, for example shafts, are examined, the surface geometry produces a signal distortion that may lead to faulty defect detection. Several techniques are known to manage the complex surface problem: point source heating, video thermal stereovision, direct calibration, and shape-from-heating. The last one was used in our investigation. Advantage of this reconstruction process is that it only requires a single early recorded thermogram.

On the other hand only relative heights are computed as in shape from shading technique, hence ΔR becomes available, but not R (R is the distance between point heating source and sample surface). Finally, calibration is not mandatory.

An additional image processing in MatLAB is applied to evaluate detected shaft's surface defects.

On the Fig.7 are shown some thermograms of a new shaft and an outworn shaft.

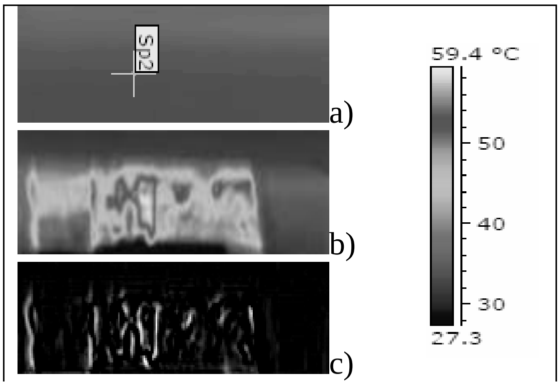

Fig.7. Thermograms of shafts: a) thermal image of a new shaft by active flash thermography; b) thermal image of a outworn shaft by passive thermography; c) thermal image of the same outworn shaft after image processing by edge detection

Conclusion

After the experiments in laboratory and work conditions, two types of mechanisms for shafts coating inspection manipulators are suggested. The manipulator is positioned on the mobile platform of a specialized robot for measuring shaft coatings.

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