Tribology International 120 (2018) 179–186

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Influence of silver surface treatment and frictional materials on the operating properties of piezo-electric actuators

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ARTICLE INFO

Keywords:
Piezo-electric actuator
Silver surface processing
Rotation speed
Loading torque

ABSTRACT

The tribological effect of differently processed silver coatings and frictional materials on the operating efficiency of piezo-electric actuators (PEA) when using different frictional contact materials were investigated. Best results for PEA speed stability and load-bearing capacity range are obtained when silver coating operates with diatomite compound with minium. Grinding of the silver coating surface improves the PEA characteristics by increasing the effective contact area, i.e. continuous operation of PEA was at relatively wide loading range and the rotation speed was higher. The decrease of rotational speed due to higher loading can be compensated by clamping force. At low loading output torque the frictional material with corundum ensures maximum speed; so this material could be used for low loaded high-speed actuators.

1. Introduction

Piezo-electric actuators (PEA) or ultrasonic motors are tribological actuators that use contact friction between a stator (or vibrator) and a rotor (or slider) converting the stator ultrasonic vibrations into linear motion or rotation of the rotor. The physical and chemical interactions between the contacting surfaces and the environment determine the friction characteristics. The mechanical characteristics and longevity of PEA depend on the material of the rotor surface coating or its modification using surface processing methods. The frequency of longitudinal vibration, properties of the contact surface (contact area, roughness), tangential friction force, elastic modulus and hardness of the tribomaterials indicate good output torque and running stability [1,2].

The tribomaterials used for PEA for achieving the roughness and hardness parameters can be classified as: polymer matrix (PTFE, PPS, PBT, PEEK, PPS, Ekonol); ceramic coatings (Al_2O_3, ZrO_2, $BaTiO_3$, $Pb(Ti,Zr)O_3$, polycrystalline materials); metal alloys, carbides and oxides (AlMgZnCu1.5, TiAl6V4, AlFeXYTM23, $LiNbO_3$, LiTaO, $Ti_2Cr_2O_7$; Ti_4O_7/Ti_5O_9 etc.); metallic powders; metal coatings [1,3–8]. The peculiarity of piezoelectric ceramic materials is their extreme hardness, and piezo-ceramic contact can cause wearing of the softer counter bodies which are usually from such materials as steel, bronze, copper, or aluminium. Interaction of friction pairs requires tribological processes characterization at the contact zone and looking for solutions by using coatings that could stabilize the friction surfaces [5,6,9]. However, PEA longevity requires high wear resistance during efficient operation at high friction torque. Therefore investigation of the surface characteristics and interaction conditions of the rotor and counter body is very important. Those characteristics are influenced not only by the material of friction pair, but also by its processing, i.e. surface roughness. The PEA vibration amplitude is of a magnitude similar to that of the surface asperities. Therefore the contact characteristics are directly influenced by the roughness of the surface. Increased wear and decreased PEA longevity could be indicated by the change in roughness compared to the non-equilibrium state of the contact interface [1,2,10].

Different investigations were carried out on hard materials for the PEA rotor (ceramic and carbide coatings, Si-diamond-like carbon) showing significant improvement of PEA operation characteristics. However these hard rough coatings can increase the surface wear of the counter body, speed and torque instability, and, as a consequence, the

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https://doi.org/10.1016/j.triboint.2017.12.039
Received 25 July 2017; Received in revised form 21 December 2017; Accepted 25 December 2017
Available online 30 December 2017
0301-679X/

decreasing trend of the rotation speed [3,11,12]. One of the disadvantages of hard coatings is that low roughness of hard surfaces is hardly ensured, i.e. it is difficult to provide a large real contact area. Treatment of the steel rotor working surface with the polymeric material fluorine oligomer increases the surface hardness and consequently stabilizes the speed and makes the piezoelectric actuator operation smooth. However, the efficiency of fluorine oligomers has been tested only with steel surfaces and its longevity was not thoroughly investigated [9]. Despite the fact that research on PEA silver friction surfaces has not yet been carried out, the tribological performance of silver coatings at electric connectors was investigated under operating conditions similar to PEA. This investigation showed that the tribological efficiency of such friction pairs depends significantly on the silver coating thickness (the lifetime of the friction surface increases significantly when the silver thickness is greater than 10 μm) and the dominating type of friction in such pairs is adhesive friction [13]. Silver coatings can be efficiently produced by electro-spark alloying (ESA) controlling the mass transfer and coating thickness by the ESA pulse energy and power, but the surface roughness of such coatings is not regular and requires surface processing. Silver coatings has been selected for investigation, because of plasticity of silver, which creates a relatively homogeneous layer by ESA. Due to the plasma-induced electro-impulse discharges during ESA the fine-grained wear resistant coating structure is formed [14–17].

Most investigations of materials for PEA friction pairs include testing different materials with an accordingly processed surface, but there is a clear lack of research on the influence of surface processing on the running-in of a PEA friction pair and its further operation.

The aim of this research is the evaluation of influence of differently processed silver coats and its interaction with different frictional materials on the operating efficiency of piezo-electric actuators when using different frictional contact materials.

2. Experimental

2.1. Preparation of testing samples

Samples of hardened stainless steel 30X13 treated by electro-spark alloying using an EFI-10M industrial unit with electric energy discharges of 0.3 J were investigated. The principal scheme of the ESA unit is presented in Fig. 1 [16].

2 mm diameter rods made of pure silver were used as the electrodes for ESA alloying of the surface of the PEA rotors.

The thickness of heterogeneous structure silver coating after ESA was 30–40 μm. This coating structure is caused by manufacturing process peculiarities. During the passing of electrical pulses between the processing electrode (i.e. the anode) and surface (cathode), material is transferred from the anode to the cathode in both vapour and liquid phase. This transferred material intensively interacts with the environment materials (oxygen and nitrogen) and the surface, forming on it a coating with specific properties and structure differing from the materials of the anode and cathode.

After coating the surface was flattened with a diamond tool (diamond smoothing) and the part of the samples were grinded. The purpose of the grinding was to have the whole surface polished, i.e. to avoid the untreated areas. During the grinding, 40–60% of the coating thickness was removed.

The hardness and roughness of all the specimen surfaces were measured to evaluate the possible impact of those parameters on the operating conditions of the PEA friction surfaces. Microhardness after surface processing of the specimens was measured with a CSM Micro-Combi Tester according to the instructions for the procedure. Maximal indentation load was 100 mN (selected according alloyed layer thickness, counting that depth of indentation must not exceed 10% of coating thickness). The indenter type was a Vickers pyramid. Roughness of the specimens was measured with a MahrSurf GD25 roughness meter.

Fig. 2 displays the view of the tribo-couple [12].

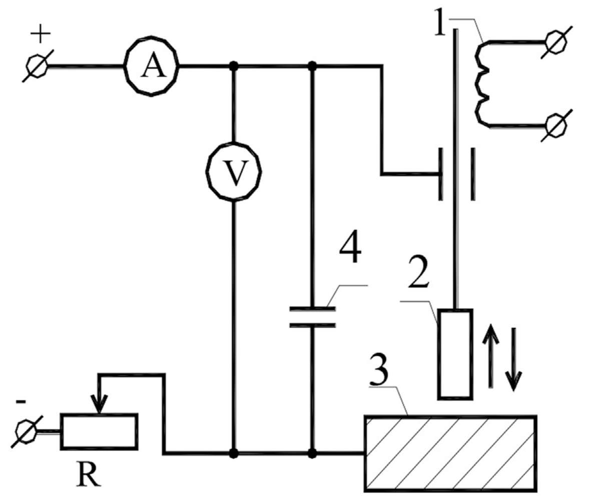

Fig. 1. Schematic diagram of Electro-spark alloying: 1 – electromagnetic vibrator; 2 – electrode; 3 – coating surface; 4 – condenser [16].

A prism-shape counter body (2, Fig. 2) was used for the tribological PEA tests. It was made from 4 kinds of frictional materials (presented in Table 1) with the following dimensions: length of – 2,5 mm, width – 1,5 mm, height – 1 mm.

2.2. Tribological testing and surface analysis

The investigation was carried out using an original design friction bench for the tribological investigation of standing wave rotary piezoelectric actuators [12]. The principal scheme of the test rig is presented in Fig. 3.

The supply of sinusoidal current at the required amplitude and frequency is produced by the frequency generator (9) through the amplifier (10) to the piezoelectric element (2) where it excites an effect of the standing wave. This creates rotation torque in the PEA friction pair between the frictional material (5) and the cylindrical surface of the rotor (6). The normal contact load (clamping force) on the PEA friction pair is automatically adjusted and sensed continuously or in selected steps (with increasing or decreasing trend) during the whole testing period. The rotating torque is measured by automatically switching on (off) the electrical rotor brake. Stopping torque up to a full stop is created either by steps or continuously, or in accordance with the adjusted minimal rotation speed. The normal load in the friction couple and stopping

Fig. 2. Picture of tribo-couple: 1 – rotor with the coating, 2 – block of counter body, 3 – piezoelectric element, 4 – air-bearing, 5 – holder of piezoelement [12].