INCREASE OF WEAR AND FRETTING RESISTANCE OF MINING MACHINERY PARTS WITH REGULAR ROUGHNESS PATTERNS

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Abstract

The paper discusses the advantages of surfaces with regular roughness patterns, machined using the method of vibration burnishing, over those machined with the use of conventional techniques, with regard to improvement in the related parts' performance. The results of the investigation disclosed show a change in the part performance specifications as a function of microgroove profile variations, both with and without lubrication. The diagrams are included, showing surface roughness parameters versus machining conditions. The curves can be used for optimization of the machining parameters, in order to achieve the preselected roughness pattern, thus providing the needed part performance specifications. Vibration burnishing is a simple and cost-efficient machining method, which may be recommended as a substitute for a variety of conventional, environmentally harmful techniques. Examples of items, including mining machines, are given, which can be recommended for the proposed method of processing.

Keywords: vibration burnishing; regular roughness; wear resistance; friction pair.

1. Introduction

Any of the part performance specifications, primarily its reliability and life time, are greatly dependent on the part's surface roughness. For every combination of part operation conditions an optimum roughness can be specified to provide the designed life time [1; 3; 6; 7; 12; 16].

This problem is relevant for a number of friction pairs of mining machinery parts working at high loads and vibrations. Currently, various types of mining, transport and enrichment equipment is used in mines and careers, and in recent years the equipment used has been very powerful, sometimes even heavy-duty. The pressure their use causes is oftentimes the reason behind the considerable wear of crucial parts, which in many cases leads to extreme cases of wear, such as scuffing, galling, jamming and fretting corrosion damage [8].

In many cases, various covers for parts' work surfaces are used to prevent this type of damage. At the same time, positive results can often be obtained through implementing special surface finishing methods that are based on the plastic surface deformation of the surface layers of the part, such as surface vibration burnishing with the creation of a regular microgroove pattern.

Most of the conventional finishing methods (turning, grinding, lapping, honing) offer few possibilities for roughness optimization, since they will typically yield roughness patterns, which can be described as irregular, if not chaotic [8; 9].

The considerable improvement on conventional techniques would be the implementing of a finishing method that provides a regular surface microgroove pattern, in particular, the vibration burnishing process [1; 4]. Among the advantages, involved in a regular roughness pattern, are the following:

- 1) all the rolled microgrooves are identical in shape, size and relative position;
- 2) microgroove ridge and bottom radii can be increased by 2 to 3 orders;
- 3) the areas with such a roughness pattern gain higher strength and surface hardness;
- 4) the possibility appears to separately control the depth, pitch and relative location of grooves, which can be precalculated as functions of needed part performance specifications;
- 5) on the other hand, the said values can be derived from a combination of the vibration burnishing process parameters, thus enabling the latter to be calculated as a function of the part's desirable performance.

Upon using this method (alongside the effect caused by the plastic surface deformation finishing that guarantees the hardening of surface layers) the presence of grooves caused by vibration burnishing allows for the creation of "oil reservoirs" on the surface, thus facilitating the work of the friction pair in the case of boundary lubrication or its absence, avoiding the scuffing and galling of surfaces.

2. Experimental

Vibration burnishing involves, unlike the cutting process, the fine plastic deformation of the metal surface layers by means of a hard tool (hardened ball or rounded diamond tip), which is forced into the surface and moves relative to the latter as shown in Fig. 1. The surface roughness pattern can be fully or partially regular (non-contiguous grooves, contiguous grooves, intersecting grooves). The pattern can be varied and finely adjusted across a wide range of values, by changing the speed/frequency of the part rotation and/or the tool feed.

Fig.1. Vibration burnishing kinematics.

In addition to cylindrical ones, surfaces with a regular microgroove pattern can be achieved in edge, flat, spherical, profile, screw and involute surfaces [10].

The research carried out for many years has resulted in defining the optimum regular groove patterns for a number of typical groups of friction wearing parts, which can substantially contribute to the improvement in the part performance characteristics, namely:

- 1) life time and reliability;
- 2) wear resistance, run-in period, friction-related losses;
- 3) ability to stem fretting, scoring and scuffing;
- 4) contact rigidity and fatigue strength;
- 5) corrosion resistance etc. [10].

This paper presents some results of the research staged with a view to reveal a correlation between the regular groove pattern parameters and the wear resistance characteristics of the mining machined friction pairs.

3. Results and Discussion

One of the key factors influencing the friction and wear processes is the lubrication of the surfaces. The regular groove pattern contributes to retaining the lubricant and facilitating its spreading over the surface, especially during the run-in [10]. Fig. 2 shows the run-in duration and wear for various machining techniques turning, polishing, lapping, roller burnishing, vibration burnishing. The materials of the tested friction pair parts were bronze and

C50E, with pressure feed lubrication. Both the wear rate and run-in period substantially decrease as the groove peak and valley radii increase, or as the groove depth dispersion decreases. Improvement in the wear resistance during run-in can be, to a certain extent, accounted for the surface layer hardening, but the simultaneous reduction in the run-in duration can be only explained by the dominant influence of the improved microgeometry and the higher regularity of the groove shapes and sizes [13].

Fig.2. Wear and run-in period after machining with varying methods: 1 – turning; 2 – polishing; 3 – lapping; 4 – roller burnishing; 5 – vibration burnishing.

It should be noted that the curve, which represents the relationship between the scuffing resistance and the machining parameters that influence the resulting regular roughness pattern, has an apparent optimum point. This can be seen from Fig. 3, which shows a diagram of scuffing resistance vs. vibration burnishing speed, with (1) and without (2) lubrication.

Fig.3. Scuffing resistance vs vibration burnishing speed: 1 – with lubricant; 2 – with no lubricant.

Sharp groove edges, particularly those on non-regular microgeometry surfaces, act as stress concentrators. Huge instantaneous stress values are developed in them, accompanied with excessive heat release. This results in the emergence of scuffing nuclei, proliferating as an avalanche. On the other hand, contact of too smooth surfaces with low oil retaining capacity results in the adhesion becoming the key friction factor. Both effects are considerably moderated by vibration burnishing.

This can be illustrated by the comparative run-in test results for some automotive engine parts. In particular, vibration burnished cylinder liners have shown a run-in wear rate 1.3 to 1.6 times lower than the honed ones, the run-in period being 2 to 3 times shorter.

During run-in, parts are most vulnerable to such abnormal forms of friction wear as galling and scuffing. As a result of the next series of tests, friction surface temperature vs. load curves have been plotted (Fig. 4) to characterize the scuffing resistance after: 1 – polishing, 2 – vibration burnishing. Curve 1 indicates the scuffing point for a polished surface at a load of as little as 4.9 MPa.

Fig. 4. Surface temperature vs. load curves for parts: 1 – polished; 2 – vibration burnished.

All the test conditions being equal (pressure, speed, lubrication), the vibration burnished samples have a surface temperature 52°C lower than the polished ones, and develop no scuffing.

Most of the known experiments have only revealed the relationship between the friction coefficient and the microgroove height of the contacting surfaces. But it should be noted that the friction coefficient is proportional to the effective contact area F_k , which, in its turn, depends on the ridge rounding radius divided by the (biggest) groove height.

The friction coefficients without lubrication were defined for pairs of samples, each consisting of a grey cast iron bushing and a disc of normalized Steel 45. The discs were machined by turning, $R_a = 0.7\text{--}1.25\text{ }\mu\text{m}$. The three bushing samples were lathe bored, reamed and vibration burnished correspondingly. The friction coefficient of the latter was found to be 25–30% lower, than in case of the pairs machined by standard cutting methods.

Fretting wear was investigated on vibration burnished and polished samples. A sample bushing was put in rotational reciprocation movement, while pressed against the immobile counterpart at variable vibration amplitude and load. Pairs of parts from Steel 20 were tested at a load of 20 MPa, a vibration amplitude of 100 μm and an oscillation frequency of 900 Hz. Pairs of grey cast iron/C22E were tested at a load of 87 MPa, a vibration amplitude of 50 μm and an oscillation frequency of 500 Hz. The results (mass and volume wear) after 500000 cycles are shown in Fig. 5 (1, 2 - steel/steel pair, 3, 4 – cast iron/steel pair; 1, 3 – polished surfaces, 2, 4 – vibration burnished surfaces). The vibration burnished samples showed wear rates 3 to 4 times lower than the polished ones.

Fig. 5. Fretting wear for pairs: 1, 2 – steel part vs. steel counterpart; 3, 4 – cast iron part vs. steel counterpart.

The difference between the two types remained also after electroplating the surfaces or the application of polymer coatings. Coated vibration burnished surfaces demonstrated wear rates 30–35% lower, than the polished ones, the difference under lubrication being 25–30%.

Friction surfaces of polished samples are populated with cavities filled with oxidized debris, typical of fretting wear. There are also spots, covered with particles of several micrometers in diameter without vestiges of oxidation, where typical brittle fracture cracks are clearly visible (Fig. 6, a). Friction tracks on vibration burnished samples are split into separate areas (domains), commensurate in size with the fretting dither magnitude (Fig. 6, b). Such a structure of the friction track may possibly be accounted for the process of splitting the stress and strain waves on surfaces with regular microgeometry, which may substantially contribute to the improvement of fretting resistance.

Fig. 6. Friction track on fretted steel surface [2]: a – polished; b – vibration burnished.

Increase of the resistance to fretting as a result of implementing regular surface roughness patterns is also noted in [11; 12; 13; 14].

The conducted experiments [2, 5] allow to make the conclusion that the wear of steel and cast iron samples after vibration burnishing with the formation of a regular microgroove pattern in fretting conditions is comparable with the wear of samples with galvanic and sprayed surfaces, friction-mechanical brass plating, laser strengthening, and in a number of cases it looks more preferable. Fig. 7 shows the results of the experiments made on a steel sample (Fig. 7,a) and cast iron counterpart (Fig. 7,b): polished without a surface cover (1), as well as with various surface covers: galvanic copper (2, 3) and bronze (4) of different thicknesses, friction-mechanical brass plating (5), molybdenum spraying (6), with laser treatment in hard phase (8), in comparison to vibration burnished samples without covering (7).

Fig. 7. The results of the experiments for fretting wear: a – sample wear, mg; b – counterpart wear, mg.

Samples: 1 – no surface cover; 2 – galvanic copper 5–8 μm ; 3 – galvanic copper 30 μm ; 4 – electrolytic bronze 15 μm ; 5 – friction mechanical brass plating 3–5 μm ; 6 – molybdenum spraying 0.2 mm; 7 – vibration burnished with the creation of regular microgrooves; 8 – with laser treatment in hard phase.

The experiment conditions were as follows: normal pressure 25 MPa, amplitude 100 μm , frequency 900 cycles per minute, imitating real conditions that arise during the use of the loaded junctions in mining machines. The number of experiment cycles was 5×10^5 . The wear of vibration-burnished steel samples during the experiments proved to be smaller than of samples employing surface covers, and was insignificantly higher compared to the wear of the samples that had been laser-treated and sprayed with molybdenum, whereas the wear of cast iron counterparts was insignificantly lower only in the case of laser treatment.

It can be concluded based on the results that in a number of cases the use of vibration burnishing with the formation of a regular microgroove pattern may successfully compete with the more expensive possibilities of special wear-proof surface covers.

The combination of vibration burnishing and thin surface covers seems especially promising, as this method preserves the loads that had been planned during the construction of the junction.

4. Conclusion

1. Vibration burnishing as a method of providing regular surface roughness patterns offers vast possibilities to improve a number of part performance specifications, primarily – the wear and fretting resistance. The vibration burnished surface is highly hardened. Its roughness pattern is formed as a set of regular microgrooves, uniform in shape, depth and location, acting as lubricant accumulators. The method is simple and reliable.

2. Use of a controlled roughness pattern improves the supporting capacity of the contact surface. Regularly arranged grooves contribute to the improvement of lubricant circular leakage conditions, the removal of wear products from the contact zone, the splitting of stress and strain waves, thus effectively preventing fret development.

3. In the conditions of fretting corrosion, the vibration burnishing method that creates a regular microgroove pattern is able to compete with the traditional methods of surface covering (galvanic, sprayed and other). A rather promising solution seems to be the combination of vibration burnishing and fine surface covers capable of reducing fretting wear without disrupting the loads that were planned during construction.

4. The paper shows the positive effect of regular microgeometry obtained on vibration burnished surfaces on the wear and fretting resistance of friction pairs. The vibration burnishing method can be offered as an advantageous substitute for such labour-consuming and environmentally harmful technologies as abrasive polishing, scraping and other cutting-related processes.

5. References

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