RESEARCH

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Coefficient of Dynamic Behavior as the Diagnostic Parameter of the TiN Coating Condition

In this paper are considered problems of destruction of the TiN coating obtained by the PVD procedure. The investigations were performed of the tribometers with the "pin on disc" contact geometry (with dry or lubricated contact surfaces). For the quantification of dynamic processes in the contact zone, the coefficient of dynamic behavior K_d, that represents the ratio of the dynamic and static components of the friction force, are used. Obtained results show that the dynamic behavior coefficient can be used as the diagnostic parameter of the tribomechanical systems, from the aspect of the friction process stability, namely the process of the destruction of the TiN coating.

Keywords: tribodiagnostics, coefficient of dynamic behavior, TiN coating

1. INTRODUCTION

To decrease material and energy dissipation in the processes of friction and wear, several different procedures of the tribomechanic elements contact surfaces modifications are applied.

In this paper are considered problems of destruction of the TiN coating obtained by the PVD procedure. The investigations were performed of the tribometers with the "pin on disc" contact geometry (with dry or lubricated contact surfaces).

As the critical tribomechanical systems elements, whose contact surfaces are being modified, start to lose their function, with the beginning of the TiN coating destruction, the basic objective of the performed investigation was, based on the contact zone dynamic processes analysis, to diagnose the condition of elements in contact, as well as the starting moment of the coating layer destruction.

For the quantification of dynamic processes in the contact zone we used the coefficient of dynamic behavior K_d, that represents the ratio of the dynamic and static components of the friction force.

During investigations the modern measurements setup was applied, which included the PC with the AD converter, data acquisition and analysis of the friction process dynamics via the spectral analysis during different phases of the coating layer destruction process.

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Obtained results show that the dynamic behavior coefficient can be used as the diagnostic parameter of the tribomechanical systems, from the aspect of the friction process stability, namely the process of the destruction of the TiN coating.

DIAGNOSTICS OF TECHNICAL SYSTEMS as well as their constructive components - tribomechanic systems (TMS) is related to definition of the systems status in conditions of limited number of information. The essence of everything is to discover and prevent the potential failure, and by that also to increase reliability and available resources of the technical system.

One of the fundamental requirements in technical diagnostics or technical systems monitoring, namely their TMS (tribomechanic systems), is to "on site" identify processes that are happening in them. We started from the assumption that the friction process stability, to the greatest extent, depends on the third part characteristics (contact elements with or without the PVD coating, friction process with or without the lubricant in the contact zone).

The friction force has dynamic nature with all the characteristics of the random process. For identification and quantification of dynamic processes in the contact zone the spectral analysis was used (the power spectrum), of the friction force as one of the most reliable indicators of random processes.

For quantification of dynamic processes, or the destruction process, in the contact zone applied was the coefficient of dynamic behavior K_d that represents the ratio of the dynamic and static components of the friction force.

In the initial phase (0) of contact realization, the friction process is defined by materials of the contact elements $(TiN / STEEL)_0$, contact surfaces topography (Amplitude distribution, Bearing ratio, Roughness, etc.), lubrication conditions, normal load, and the sliding speed.

After the initial phase of the friction process the "tribological balance" (TB) is being established, i.e., $(TiN / STEEL)_{TB}$. This is primarily manifested through change of topography of this contact surface, and change of the friction force nature.

In the later phase, the destruction process (D) begins of the TiN coating, thus the contact is partially realized between the TiN and steel, e.g., TiN / STEEL, and partially between steel and steel - STEEL / STEEL.

The mentioned process can be represented in the following way:

$$(TiN / STEEL)_0 \Rightarrow (TiN / STEEL)_{TB} \Rightarrow (TiN \text{ and } STEEL/ STEEL)_D$$

The mentioned changes lead to the change of the friction force nature, and that can be quantified by the coefficient of dynamic behavior.

All the investigations were done in the Laboratory for Tribology at Faculty of Mechanical Engineering in Kragujevac - Yugoslavia.

2. CRITERIA FOR EVALUATION OF DYNAMIC PROCESESS IN THE CONTACT ZONE

For quantification of dynamic processes in the contact zone we introduced the coefficient of dynamic behavior K_d that represents the ratio of effective value of the friction force dynamic component ΔF_{feff} to the average value of the friction force $\overline{F}_f$ (Figure 1):

$$K_d = \frac{\Delta F_{feff}}{\overline{F}_f}$$

Figure 1 represents the idealized form of the friction force recording for the contact realization geometry shown in Figure 2, where the dynamic component of the friction force comes from the fact that the plane of the moving disk is not perpendicular to the rotation axis. Real recording of the friction force contains in it also some other influences, where some of them have characteristics of the stochastic process (vibrations that arise from the driving motor, friction variator, measurements setup noise, ...).

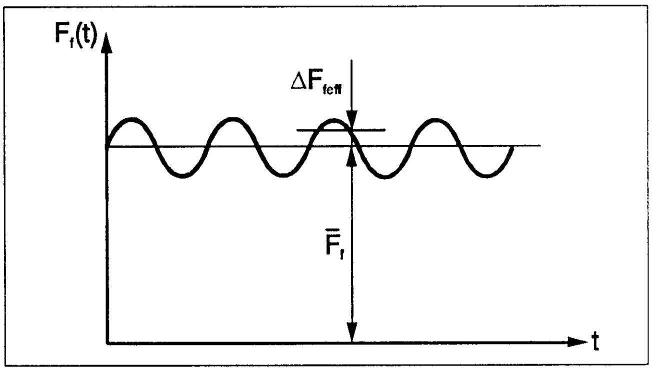

Figure 1: Idealized form of the friction force.

Apart from the dynamic behavior coefficient K_d, which represents the ratio of the dynamic and static components of the friction force, it was necessary to determine the structure of the friction force dynamic component. Due to that it was necessary to transform the friction force dynamic component from the time domain into the frequency domain. This was done by the Fourier integral that reads:

$$F(j\omega) = \int_{-\infty}^{+\infty} f(t) \cdot e^{-j\omega t} \cdot dt,$$

and which resolves the time function into the continuous spectrum in the frequency domain. The function $F(j\omega)$ is called the amplitude spectral density.

In the paper, for the analysis of the friction force dynamic component content, we used the energy spectral density (power spectrum) which is defined as a product of the complex conjugate values $F(j\omega)$ and $F^*(j\omega)$:

$$S(\omega) = F(j\omega) \cdot F^*(j\omega) = |F(j\omega)|^2.$$

3. EXPERIMENTAL SETUP AND TESTING PROGRAM

Geometry of contact realization ("pin on disk"), as well as the components of the experimenatl setup are given in Figure 2. The friction force signal which is obtained from the strain gauges is being led to the HBM signal amplifier, and then intothe AD converter which is built into the PC. In the PC, with help of the adequate software, the processing and storage is being done of the recorded signals that carry information about the friction force.

By the testing program it was predicted to measure the friction forces (continuously over the certain time interval), i.e., their dynamic components as a function of materials of the contact elements, sliding speed, normal load, and present quantity of lubricant in the contact zone.

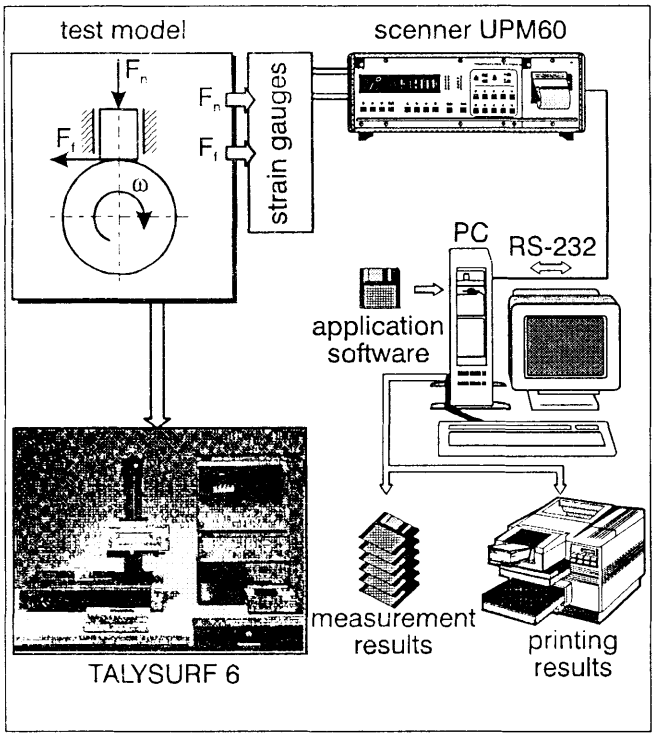

Figure 2: Schematic of the experimental setup.

4. TESTING CONDITIONS

Contact pair consists of pin and disc (contact "pin on disc") what is shown in Figure 2. Contact between them was along a line of the 9 mm length (theoretical idealization).

- The moving disc was made of carbon steel (0.35 % C) for hardening with subsequent tempering, of 180 HB. The contact surface was roughly ground, and then polished. The disc diameter was 35 mm, and width 10 mm.
- The pin was made of carbon steel (0.35 % C) for harden-ing with subsequent tempering, then coated with the very thin TiN coating (1 μm) applied by the arc procedure. The contact surface was ground prior to coating deposition.
- The lubrication multigrade oil was SAE - 15 W / 40 (MIL - L - 46 152 B).
- The sliding speed was V_{sl} = 1 m/s.
- The normal load was F_n = 5 daN.

5. TESTING RESULTS

In the first phase of the friction process (with lubricant in the contact zone) the decrease of the friction coefficient occurs (Figure 3), decrease of contact time of approximately 10 minutes. Then the friction coefficient starts to slowly increase (t ≈ 30 min). This lasts until the beginning of the TiN coating destruction (t ≈ 50 min).

The transient phase from initial destruction of the TiN coating until the irregular friction process (total destruction of coating) lasts very short (≈ 5 min), Figures 12 and 13.

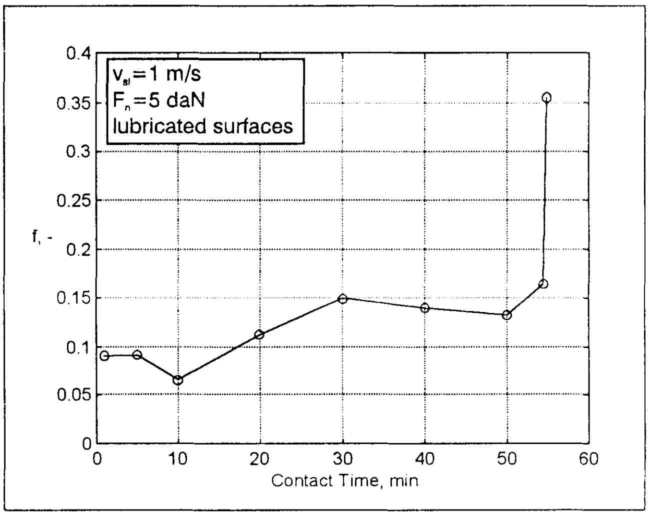

Figure 3: Dependence of the friction coefficient on contact duration time.

The growth of the friction coefficient after 10 minutes is accompanied by small instability of the friction process, i.e., the increase of the dynamic friction coefficient, Figure 4.

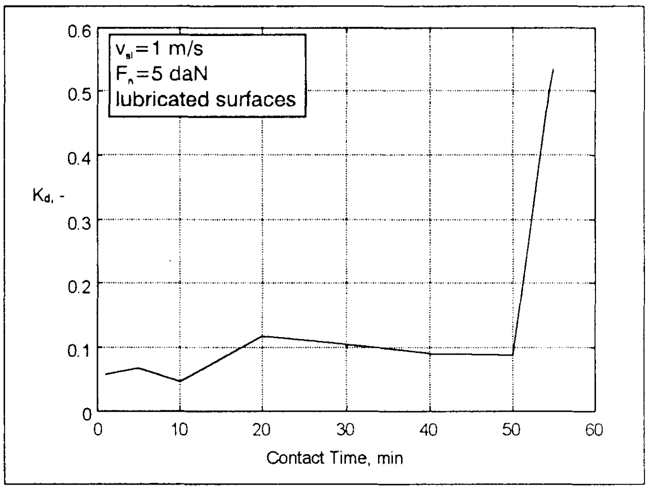

Figure 4: Dependence of the dynamic behavior coefficient on contact duration time.

Prominent instability of the friction process starts with initial destruction of the TiN coating (t ≈ 50 min). Under these conditions, the dynamic load intensifies in the contact zone, and that in turn leads to more intensive coating destruction.

Change of dynamic processes in the contact zone, in the phases of stable and unstable friction process (the TiN coating destruction process) is the best illustrated by the power spectrum of the friction coefficient, Figures 5, 6 and 7. From initial to total destruction of the TiN coating the process unfolds with high speed. During that, the nature of the friction process also changes.

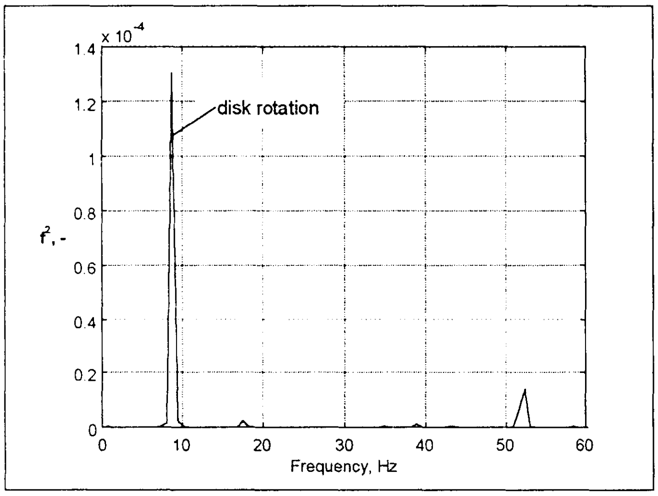

Figure 5: Power spectrum of the friction coefficient after the contact duration time of 20 minutes.

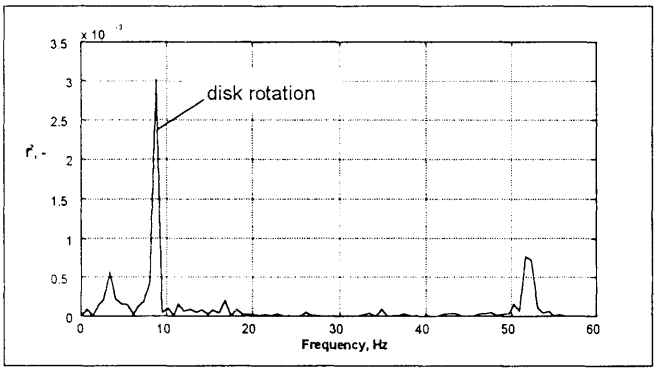

Figure 6: Power spectrum of the friction coefficient after the contact duration time of 54 minutes and 20 seconds.

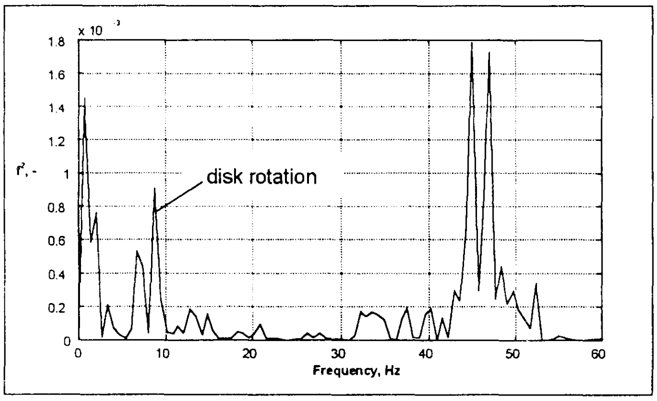

Figure 7: Power spectrum of the friction coefficient after the contact duration time of 54 minutes and 40 seconds.

The TiN coating hardness on the pin is significantly higher than that on the disc. Due to that before destruction of the TiN coating, the lowering of the disc contact surface roughness occurs, Figure 8 (Figure 9 to 13).

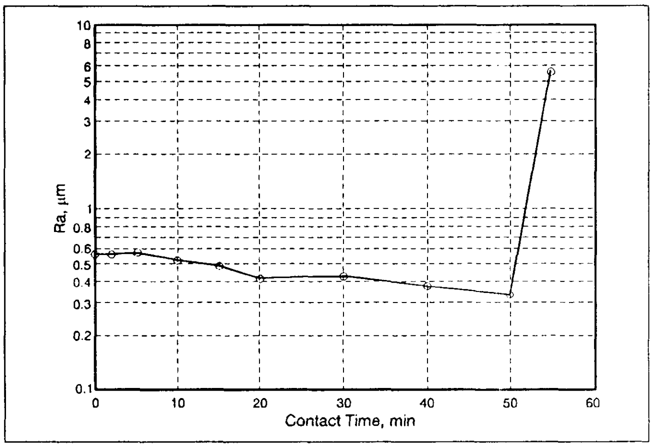

Figure 8: Variation of the disc average roughness with contact duration time.

In order to reliably identify phases of the TiN coating destruction, the recording was done of the contact surfaces profiles, for both pin and disc. This was done with the help of the system Talysurf 6 - Taylor Hobson, and obtained results are shown in Figures 9 to 13.

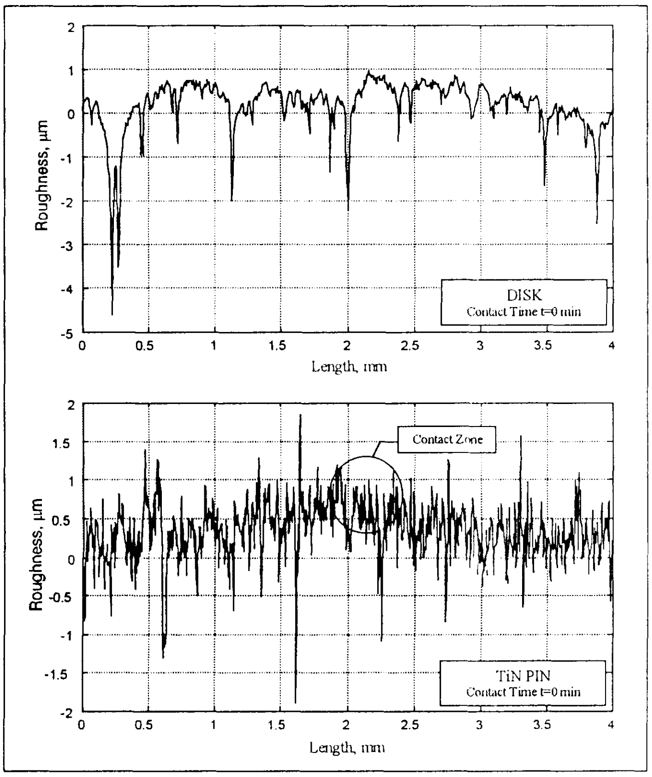

Figure 9: Surface profiles at the beginning (t = 0).

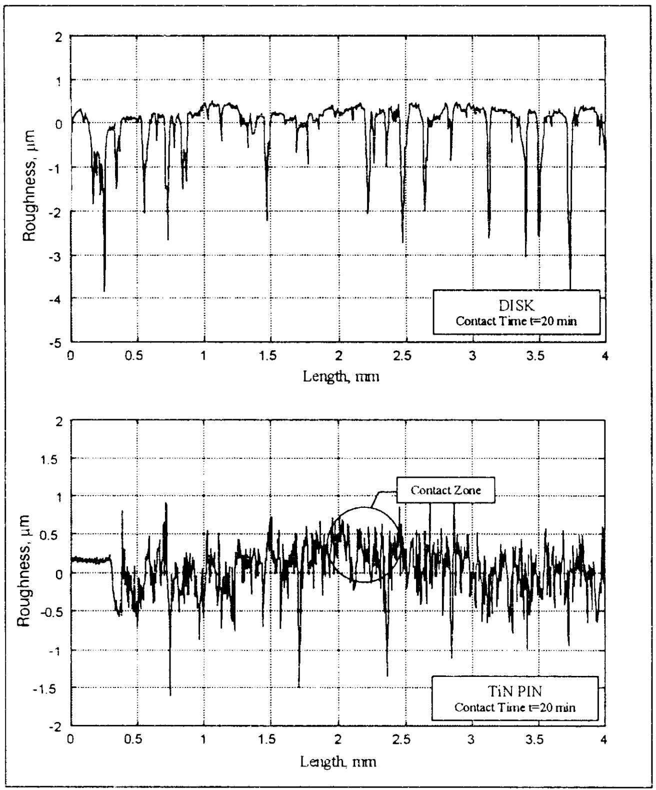

Figure 10: Surface profiles after contact time t = 20 minutes.

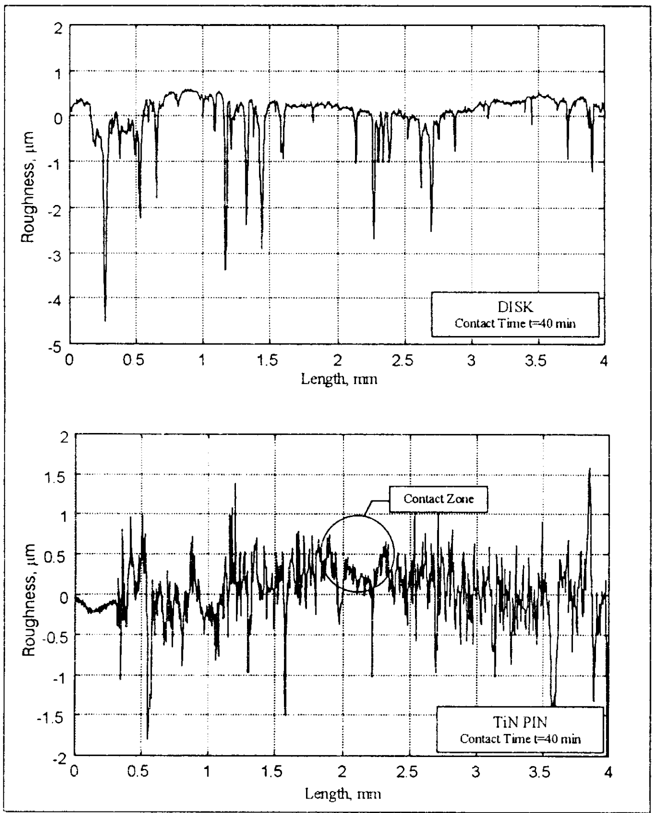

Figure 11: Surface profiles after contact time t = 40 minutes.

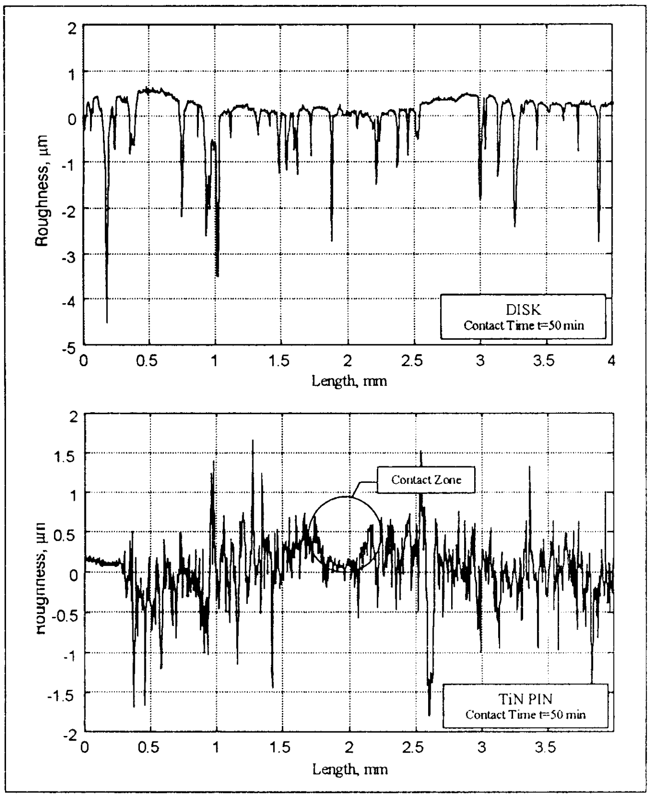

Figure 12: Surface profiles after contact time t = 50 minutes.

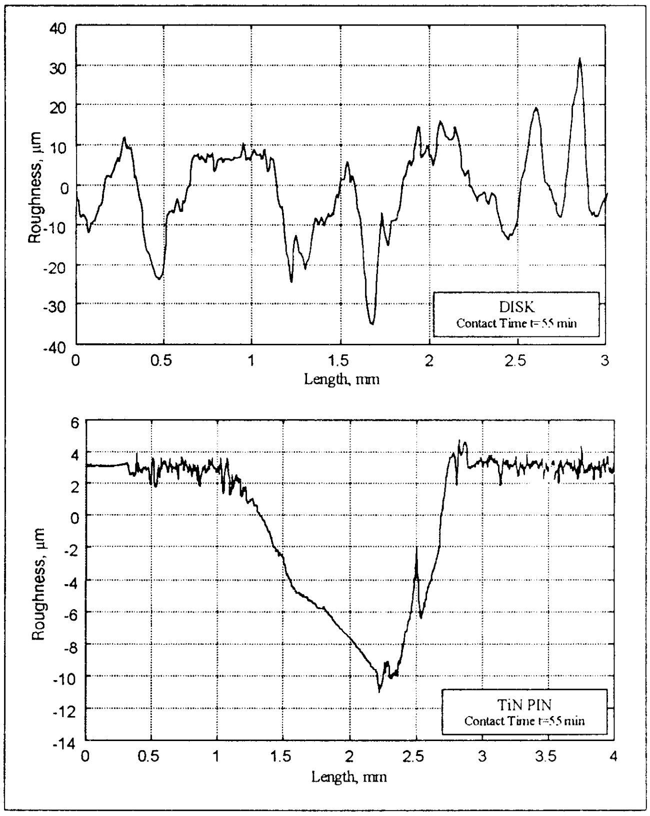

Figure 13: Surface profiles after contact time t = 55 minutes.

By comparison of the pin contact surfaces (Figures 12 and 13) one can reliably speak about total destruction of the TiN coating in the period between 50 and 55 minutes, as well as about drastic worsening of the disc roughness.

When the matter is the friction process of the dry surfaces, the TiN coating destruction occurs very quickly. This process starts after 20 seconds. It is manifested by the increase of the friction coefficient (Figure 14), and the coefficient of dynamic behavior.

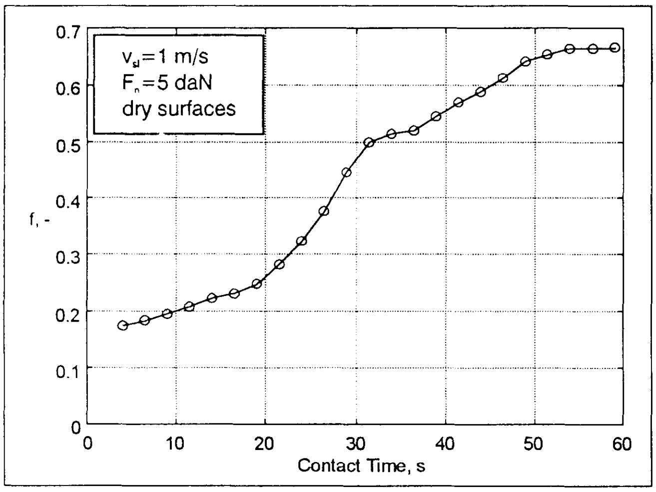

Figure 14: Friction coefficient as a function of contact duration time.

At total destruction of the TiN coating, the friction coefficient increased for approximately 4 times, with respect to the beginning. At the same time, the coefficient of dynamic behavior increased approximately 9 times.

In different phases of the TiN destruction process the nature of dynamic processes in the contact zone also changes significantly, Figures 15 to 17.

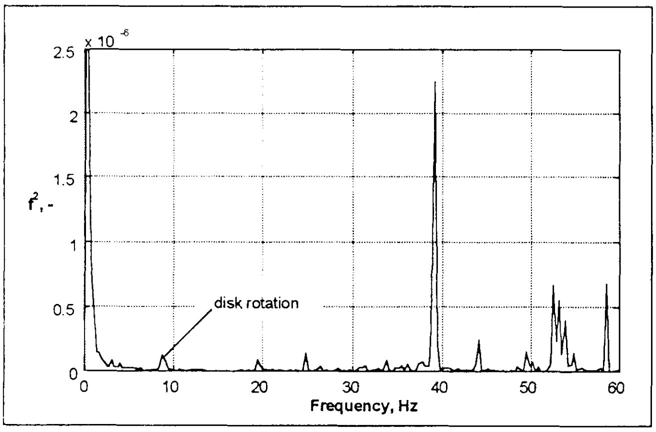

Figure 15: Power spectrum of the friction coefficient in the period 2 - 5 seconds.

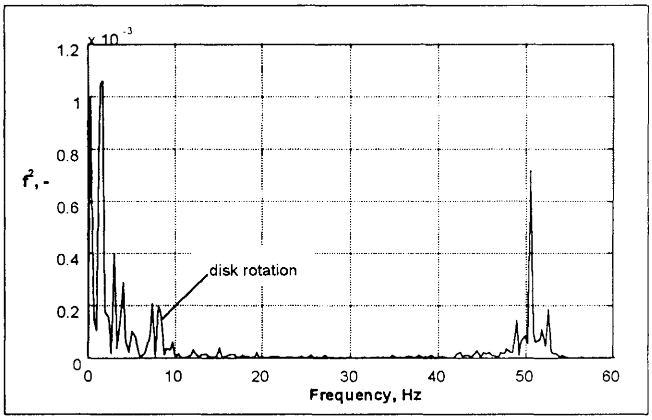

Figure 16: Power spectrum of the friction coefficient in the period 21 - 24 seconds.

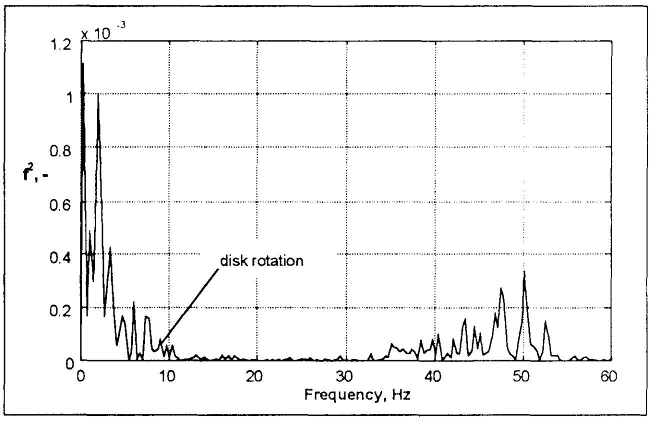

Figure 17: Power spectrum of the friction coefficient in the period 45 - 48 seconds.

6. CONCLUSION

From the aspect of tribodiagnostics, the nature of the TiN coating destruction is almost the same, regardless of that whether the friction process is with or without the lubricant in the contact zone.

Stability of the friction process, as well as the phenomenon of initial destruction, can be identify by the coefficient of dynamic behavior as the diagnostic parameter. From initial destruction of the TiN coating up to its total destruction, the nature of the friction process changes, with prominent presence of dynamic forces in the contact zone.

Time from the initial destruction of the TiN coating until its total destruction is short and it significantly depends on the lubrication conditions of the contact surfaces.

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