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学位論文題目	EFFECT OF TEMPERATURE ON DYNAMIC CHARACTERISTICS OF A PAD SLIDING ON A DISC （ディスク上を滑るパッドの動特性に与える温度の影響）
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論文の内容の要旨

Friction-induced oscillation is a common phenomenon observed in mechanical systems. In most of the cases, this oscillation has an adverse effect on the performance and is undesired. Therefore, prognostication of the occurrence and the characteristics of friction-induced oscillations is necessary when designing friction systems. One of the main factors affecting frictional processes, including friction-induced oscillation, is temperature at the sliding interface. This factor is especially noticeable for polymer materials which are widely used in brakes, clutches and bearings.

Many experimental and theoretical studies have been done to investigate the influence of temperature on the oscillatory sliding and the relation between the mechanical oscillation and the temperature oscillation. Some of them deal with polymer materials. However, the analysis of the literature shows that, despite the various results obtained, the effect of temperature is studied insufficiently. In particular, it has not been clarified under which conditions the temperature factor can result in the occurrence of oscillation.

In the present study, oscillation of a pad on a rotating disc is investigated, considering the dynamic characteristics and the temperature of the pad. For this purpose, a tribometer with a resin pad on a steel disc is developed. The pad is attached to a pliable beam and can move in the tangential direction in relation to the disc friction surface. The normal force and the disc velocity are controllable. The displacement of the pad is measured by a laser sensor. The surface temperature is measured by tape thermocouples. A tape thermocouple consists of two thermoelectrodes in the form of parallel metallic tapes with an insulation between them. It is embedded in the pad so that the tapes are exposed at the sliding surface. Under friction, the tapes are deformed and metal from one of them is transferred to the other, forming a measuring junction.

It is shown that for low-conductivity materials, such as polymers, tape thermocouple responses faster by orders of magnitude than a conventional thermocouple with the same characteristic size. The original chromel–alumel tape thermocouples are developed and tested. They have a response time of 1–4 milliseconds and allow measuring

temperature oscillating at a frequency of hundreds of Hertz. A validation of the temperature measurement is done by comparing the measured temperature with the true surface temperature for the regime of stationary friction. According to the experimental data, the true temperature corresponds to the lower bound of the measured temperature.

The dynamic characteristics of the pad are studied, depending on the temperature and the disc velocity. It is established that a rise of the pad temperature by several tens of degrees Celsius results in the occurrence of friction-induced oscillation. The oscillation frequency coincides with the first natural frequency of the pliable beam and has an order of 100 Hz. The oscillation amplitude is of the order 0.1–1 mm. It is found to increase with the temperature and with the disc velocity in the range of low velocities.

A relation between the mechanical oscillation and the temperature oscillation is investigated. By analyzing the numerous trajectories in the plane temperature–displacement, four qualitatively different patterns of the temperature oscillation are distinguished: harmonic pattern, peak-like pattern, asymmetric pattern and figure-of-eight pattern. The harmonic pattern and the peak-like pattern are frequently observed. The quantitative analysis shows that the amplitude of the temperature oscillation is proportional to the mechanical oscillation amplitude. The proportionality coefficient depends slightly on the disc velocity.

An analytical study on the oscillation of a body on a moving counterbody is done. We assume that the thermal contact between the body and the counterbody is imperfect and the friction decreases with the surface temperature of the body. It is revealed that a stick–slip oscillation can occur due to the decrease of the friction coefficient in the phase when the body moves in the opposite direction to the counterbody. A sufficient condition of the oscillation occurrence is obtained. It is represented in the form of a limit curve which separates the area «oscillation» and the area «stable sliding». The analysis of this condition shows that the normal force has a significant effect on the occurrence of oscillation, while the counterbody velocity is of minor importance.

Thus, it is experimentally confirmed that for a polymer-on-metal sliding contact the temperature has a significant influence on the occurrence and the amplitude of friction-induced oscillation. The revealed relations between the mechanical oscillation and the temperature oscillation are useful for simulating the interrelated thermomechanical processes at the sliding contacts. The obtained sufficient condition of the oscillation occurrence allows prognosticating the oscillations for the systems with temperature-dependent friction.

論文の審査結果の要旨

This research is concerned on the development of a system for measuring temperature of a pad sliding on a disc. It clarifies the effect of temperature on dynamic characteristics of the pad. The summary is as follows.

Study objective.

The objective of the present study is to investigate the temperature at the friction surface of a pad oscillating on a spinning disc by the use of the tape thermocouples and the relation between this temperature and the dynamic characteristics of the pad.

Chapter 1. Background.

Friction-induced oscillation is a common phenomenon observed in mechanical systems. In most of the cases, this oscillation has an adverse effect on the performance and is undesired. Therefore, the prognostication of the occurrence and the characteristics of friction-induced oscillations are necessary when designing friction systems. One of the main factors affecting the frictional processes, including friction-induced oscillations, is temperature at the sliding interface. This factor is especially noticeable for polymer materials which are widely used in brakes, clutches and bearings. Many experimental and theoretical studies have been done to investigate the influence of temperature on the oscillatory sliding and the relation between the mechanical oscillation and the temperature oscillation. Some of them deal with the polymer materials. However, the analysis of the literature shows that, despite the various results obtained, the effect of temperature is studied insufficiently. In particular, it has not been clarified under which conditions the temperature factor can result in the occurrence of oscillation.

Chapter 2. Experimental techniques.

We investigate the oscillation of a pad on a spinning disc, considering the dynamic characteristics and the temperature of the pad. For this purpose, a tribometer with a resin pad on a steel disc is developed. The pad is attached to a pliable beam and can move in the tangential direction in relation to the disc friction surface. The normal force and the disc velocity are controllable. The displacement of the pad is measured by a laser sensor. The surface temperature is measured by the tape thermocouples. A tape thermocouple consists of two thermoelectrodes in the form of parallel metallic tapes with insulation between them. It is embedded in the pad so that the tapes are exposed at the sliding surface. Under friction, the tapes are deformed and the metal from one of them is transferred to the other, forming a measuring junction.

Chapter 3. Tape thermocouple analysis.

It is shown that for the low-conductivity materials, such as polymers, the tape thermocouple responses faster by orders of magnitude than a conventional thermocouple with the same characteristic size. The original chromel–alumel tape thermocouples are developed and tested. They have a response time of 1–4 milliseconds and allow measuring temperature oscillating at a frequency of hundreds of Hertz. A validation of the temperature measurement is done by comparing the measured temperature with the true surface temperature for the regime of stationary friction. According to the experimental data, the true temperature corresponds to the lower bound of the measured temperature.

Chapter 4. Friction materials properties estimation.

The thermophysical properties of the resin pad, such as specific heat capacity, thermal diffusivity coefficient and thermal conductivity coefficient, are estimated. The friction coefficient is thoroughly studied. The experiments show that it decreases with the sliding velocity and increases with the temperature.

Chapter 5. Mechanical oscillation analysis.

The dynamic characteristics of the pad are studied, depending on the temperature and the disc velocity. It is established that a rise of the pad temperature by several tens of degrees Celsius can result in the occurrence of friction-induced oscillation. The oscillation frequency coincides with the first natural frequency of the pliable beam and has an order of 100 Hz. The oscillation amplitude is of the order 0.1–1 mm. It is found to increase with the temperature and with the disc velocity in the range of low velocities.

Chapter 6. Study of temperature oscillation.

The relation between the mechanical oscillation and the temperature oscillation is investigated. By analyzing the numerous trajectories in the plane temperature–displacement, four qualitatively different patterns of the temperature oscillation are distinguished: harmonic pattern, peak-like pattern, asymmetric pattern and figure-of-eight pattern. The harmonic pattern and the peak-like pattern are frequently observed. The quantitative analysis shows that the amplitude of the temperature oscillation is proportional to the mechanical oscillation amplitude. The proportionality coefficient depends slightly on the disc velocity.

Chapter 7. Analytical study of thermofrictional oscillation.

An analytical study on the oscillation of a body on a moving counterbody is done. We assume that the thermal contact between the body and the counterbody is imperfect and the friction decreases with the surface temperature of the body. It is revealed that a stick–slip oscillation can occur due to the decrease of the friction coefficient in the phase when the body moves in the opposite direction to the counterbody. A sufficient condition of the oscillation occurrence is obtained. It is represented in the form of a limit curve which separates the area «oscillation» and the area «stable sliding». The analysis of this condition shows that the normal force has a significant effect on the occurrence of oscillation, while the counterbody velocity is of minor importance.

Conclusion.

It is experimentally confirmed that for a polymer-on-metal sliding contact the temperature has a significant influence on the occurrence and the amplitude of friction-induced oscillation. The revealed relations between the mechanical oscillation and the temperature oscillation are useful for simulating the interrelated thermomechanical processes at the sliding contacts. The obtained sufficient condition of the oscillation occurrence allows prognosticating friction-induced oscillations for the systems with temperature-dependent friction.

On the whole, the dissertation work is performed at a high qualification level. The obtained results contribute to the understanding of the phenomenon of friction-induced oscillations. Some of the results are applicable in practice. The work satisfies the requirements specified for the Ph.D. dissertations.