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INFLUENCE OF VIBRATION LOAD ON ELASTOHYDRODYNAMIC LUBRICATION OF TEXTURE SURFACE

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ВПЛИВ ВІБРАЦІЙНОГО НАВАНТАЖЕННЯ НА ЕЛАСТИЧНУ ГІДРОДИНАМІЧНУ ЗМАЗКУ ТЕКСТУРНОЇ ПОВЕРХНІ

Purpose. The study of the influence of vibration load on elastohydrodynamic lubrication of textured surface by numerical calculation.

Methodology. Based on the elastohydrodynamic lubrication model of the textured surface subjected to vibration and impact load and its solution, a series of phenomena were discussed.

Findings. The research showed that the instantaneous oil film of the textured surface has a similarity of the thickness time variance and similarity of pressure time variance in a vibration load excitation cycle. The texture in the low-pressure region has little effect on the thickness and pressure distribution of the oil film, but the one in the high-pressure region has an obvious influence on the thickness and pressure distribution of the oil film and its dynamic pressure effect is significant.

Originality. In the whole calculation region, the number of the pressure peaks is related to the one of the texture in the high pressure region. The study showed that the maximum pressure and the average friction coefficient of the oil film increases and the minimum film thickness decreases with the increase of the load amplitude. The maximum pressure, minimum thickness and the average friction coefficient of the oil film decrease with the increase of the vibration frequency.

Practical value. Research results are of importance for the design of the texture of the surface bearing vibration load.

Keywords: *vibration load, texture surface, elastohydrodynamic lubrication, maximum pressure, minimum film thickness, average friction coefficient*

Introduction. Elastohydrodynamic Lubrication (EHL) displays lubrication problems under dynamic load, and mechanical vibration would inevitably lead to lubricating oil film dynamic response when the machine rotates at a high speed [1–3]. Because sine function is the most basic cycle function, the study is focused on the response of the elastohydrodynamic oil film under dynamic load changing in sine law. In the last decades, artificial texture has been proved to be an effective method to improve the lubrication performance, reduce friction and wear, and improve the bearing capacity of the friction pair [4–5].

It is significative that the research about the elastohydrodynamic oil film of the surface with pitches under dynamic load, especially for cyclic load, should be carried out for engineering practice. Based on the elastohydrodynamic lubrication model of the textured surface under vibration and impact load, the pressure and thickness distribution characteristics of the elastohydrodynamic lubrication oil film were analysed. The effect of the load amplitude and resonant frequency on the oil film pressure, minimum thickness and average friction coefficient were discussed.

Texture surface lubrication model under vibration load and its solution. ***Fundamental equation.*** Due to the load and film under shock and vibration are function of time, the Reynolds equation considering time-dependent effects was adopted [6]

$$\frac{\partial}{\partial x}\left(\frac{\rho h^3}{\eta}\cdot\frac{\partial p}{\partial x}\right)=12u\frac{\partial(\rho h)}{\partial x}+12\frac{\partial(\rho h)}{\partial t}, \qquad (1)$$

where x is the coordinate in direction of motion, p is oil film pressure, h is oil film thickness, u is entrainment velocity, η and ρ are lubricating oil viscosity density, respectively.

The boundary conditions for equation (1) are: $p(x_{\text{in}}, t) = 0$, $p(x_{\text{out}}, t) = 0$, $p(x, t) \geq 0$ $(x_{\text{in}} < x < x_{\text{out}})$, here x_{in} is the starting point of oil film pressure domain and x_{out} is the end point of oil film pressure domain.

Film thickness equation is presented as follows

$$h(x,t)=\begin{cases} h_0(x,t) & x\notin\Omega \\ h_0(x,t)+h_p(x,t) & x\in\Omega \end{cases},$$

where Ω is region of all pits of the texture surface, $h_p(x, t)$ is pit depth of x, and $h_0(x, t)$ is oil film thickness of non-texture surface, calculated as follows [6]

$$h_0(x,t)=h_{00}+\frac{x^2}{2R}-\frac{2}{\pi E'}\int_{x_{\text{in}}}^{x_{\text{out}}} p(x',t)\ln(x-x')^2\,dx',$$

where h_{00} is average central oil film thickness, R is equivalent curvature radius and E' is equivalent elastic modulus.

Pressure-viscosity relationship of lubricating oil is [7]

$$\eta(x,t)=\eta_0\exp\{(\ln\eta_0+9.67)[(1+5.1\times10^{-9}p(x,t))^{Z_0}]\},$$

where η_0 is lubricating oil viscosity at ambient pressure and Z_0 is viscosity-pressure coefficient [7].

Density–pressure relationship is expressed as follows [8]

$$\rho(x,t)=\rho_0\left[1+\left(0.6\times10^{-9}p(x,t)\right)/\left(1+1.7\times10^{-9}p(x,t)\right)\right],$$

where ρ_0 is lubricating oil density at ambient pressure.

Load equation for linear contact periodic load problems is [9]

$$\int_{x_{\text{in}}}^{x_{\text{out}}} p(x,t)\,dx = C_w(t)\,w_0,$$

where $C_w(t)$ is load change function, for sinusoidal periodic load problems, $C_w(t) = 1 + C_{w0}\sin(2\pi ft)$, f is load frequency and C_{w0} is load magnitude, $C_{w0} < 1$.

Periodic equation of parameter is

$$V(x, t) = V(x, t + T),$$

where T is load cycle, $T = 1/f$.

Numerical computation method. After equation has been non-dimensionalized, full multigrid method [10] is adopted to solve it for multiple working conditions by Matlab program. Each cycle was divided into 24 instantaneous points, which would be solved through the 6 level grid based on W cycle mode by Gauss-Seidel iteration regarding Hertz pressure as its initial pressure.

Results and discussion. ***Basic parameters.*** Working parameters: Dimension univoltine calculation domain $x_{\text{in}} = -4.6$, $x_{\text{out}} = 1.4$. Average velocity, $US = 1\ \text{m} \cdot \text{s}^{-1}$. Slide-roll ratio: $CU = 0.25$. Integrated elastic-modulus, $E' = 2.21 \times 1011\text{Pa}$. Equivalent contact radius, $R = 0.02$ m. Dimensionless material parameters, $G = 5000$. Ambient viscosity, $\eta_0 = 0.08\text{Pa} \cdot \text{s}$. the Roelands viscosity-pressure coefficient: $Z = 0.68$.

Sine vibration load-time curve is displayed as in Fig. 1.

The lubrication performance of oil film of the texture surface exerted the vibration load. Oil film characteristics of instantaneous point applied by the vibration load. Fig. 2 shows the distribution of oil film pressure P and thickness H along the width X of bearing area for $W = 1.0 \times 10^5$ N, $C_{w0} = 0.1$, $f = 1500$ Hz, pit diameter $D =$ $= 100$ um and depth $H = 5$ um.

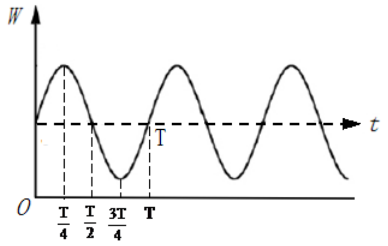


Fig. 1. Sinusoidal vibration load-time curve

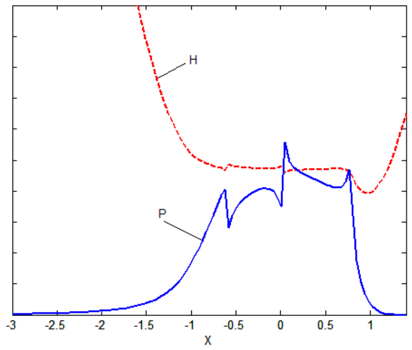


Fig. 2. Oil film thickness H and pressure P distribution along the width X of bearing zone

According to the analysis and solution of texture surface lubrication model under vibration load, it is shown that, at t = T/4, T/2, 3T/4, T, the oil film thickness distribution curves shape is similar and pressure distribution curves shape is similar, too. Fig. 2 shows that the texture in the low-pressure interval (–2.6392, –1.98046) has little effect on the film thickness and pressure distribution of the oil film. There are three pressure peaks in the whole calculation region and the texture of the interval (–0.61954, 0.0392) is between the first pressure peak and the second pressure peak. Obviously, the texture of the interval (–0.61954, 0.0392) in the high pressure has a significant impact on the film thickness and pressure distribution. The effect of the dynamic pressure is obvious. The oil film dynamic pressure that is produced due to its suction causes the first pressure peak. Because the oil flow is suddenly retarded, the second pressure peak is generated. The third pressure peak located in exports area still retains the typical characteristics of elastohydrodynamic lubrication and it is relative to the shrink oil film in Fig. 2. The number of times the texture correlation peak pressure and high-pressure area. There is a correlation between the number of pressure peaks and the texture of the high-pressure region.

Table presents the comparison of the maximum pressure, minimum film thickness and mean friction coefficient of the oil film as $t = T/4\ T, T/2, 3I/4, T$.

Table

Oil film parameters of the sinusoidal periodic impact load

Parameters / Time	Maximum Pressure	Minimum Film Thickness	Mean Friction Coefficient
$T/4$	5.589523e8	3.917707e–7	6.1496e–1
$T/2$	5.559116e8	3.922974e–7	5.8878e–1
$3T/4$	5.525312e8	3.930253e–7	5.5842e–1
T	5.559116e8	3.922974e–7	5.8878e–1

As can be seen from Table, when $t = T/2$ and t = T, the vibration load, which the film subject to, is the same and the maximum pressure, minimum thickness and average coefficient of friction is respectively equal. When $t = T/4$, the vibration load affecting the film is maximal and the maximum pressure, the average coefficient of friction is greater than the one as $t = T/2$, while the minimum thickness is maximal. When $t = 3T/4$, vibration loads the oil film subject to is the smallest, the maximum pressure, the average friction coefficient is the minimum and the minimum film thickness is the greatest. As a result, the external vibration has great influence on the lubrication performances of texture surface.

Influence of load amplitude C_{w0} on oil film characteristic. Keeping other parameters constant and only changing the load amplitude C_{w0}, we have studied the characteristics of oil film of $t = T/4$.

From Fig. 3, it can be seen that the maximum pressure P_{max} and average friction coefficient M_u of the oil film on texture surface increase along with the load amplitude, and the minimum thickness $H_{\min}$ is decreased.

Influence of vibration frequency of load on the oil film characteristic. As $W = 1.0 \times 10^5$ N, $C_{w0} = 0.6$, pit diameter

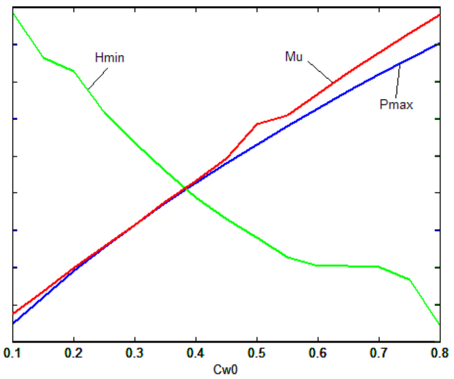


Fig. 3. Maximum pressure P_{max}, average friction coefficient Mu and minimum film thickness H_{min} distribution along load amplitude C_{w0}

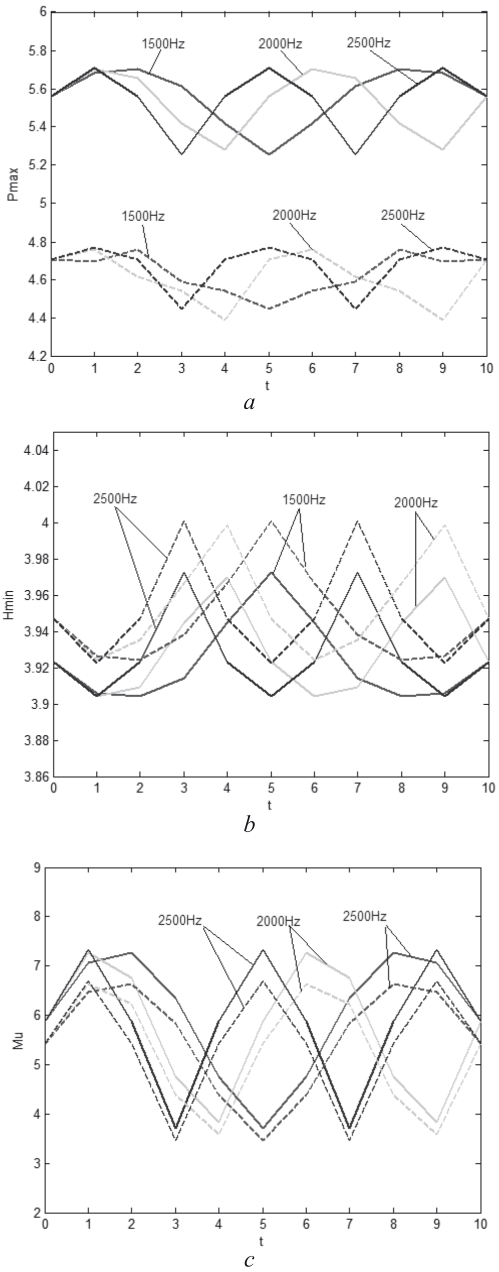
D = 100 um and depth H = 5 um, the variation characteristics of the maximum pressure P_{max}, minimum film thickness H_{min} and average friction coefficient M_u of oil film have been studied for f = 1500 Hz, 2000 Hz, 2500 Hz.

In Fig. 4, the solid line is time-history of the maximum pressure P_{max}, minimum thickness H_{min} and average friction coefficient M_u of the oil film of texture surface subjected to the different frequency vibration load. By contrast, the dotted line is time-history of the ones of the smooth surface exerted by the different frequency vibration load.

Fig. 4, *a* shows that the maximum pressure of the texture surface oil film is greater than that of the smooth surface oil film excited by different frequencies of vibration load, but these two time-history curves appear similar, and when subject to the same frequency vibration, the cycle of this two time-history curves is identical. With the increase of vibration frequency, the cycle of the time-history curve of the oil film is decreased.

Fig. 4, *b* shows that the minimum thickness of the oil film of the textured surface is less than the one of the oil film of the smooth surface subjected to vibration loads with different frequencies and these two time-history curves are similar too. When subjected to the same frequency vibration, the cycle of these two time-history curves is identical too. With the increase of the vibration frequency, the cycle of the time-history curve of the oil film is decreased.

Fig. 4, *c* shows that the average friction coefficient of the textured surface is less than the one of the oil film of the smooth surface subject to vibration load with different frequency and these two time-history curves are similar too. When subject to the same frequency vibration, the cycle of these two time-history curves is identical too. With the increase of the vibration frequency, the cycle of the time-history curve of the oil film is decreased.



a

b

c

Fig. 4. Influence of vibration frequency of load on the oil film characteristic: a – Change of maximum pressure P_{max} with time $t(\times 10^{+8})$; b – Change of Minimum film thickness H_{min} with time $t(\times 10^{-7})$; c – Change of mean friction coefficient M_u with time $t(\times 10^{-1})$

Discussion and conclusion. The instantaneous oil film of the textured surface has similarity of the thickness time-varying and similarity of pressure time-varying in a vibration load excitation cycle. The texture in the low-pressure interval has little effect on the thickness and pressure distribution of the oil film. However, the texture in the high pressure has more significant impact on the film thickness and pressure distribution. The effect of the dynamic pressure is obvious. In the whole pressure region, there exist pressure peaks and their number is related to the one of the texture in the high-pressure region.

In a vibration load cycle, the maximum pressure of the oil film of the textured surface varies at different moments. For minimum film thickness and the average friction coefficient, it is the same case. It is shown that vibration load parameters have a great influence on the EHL of the oil film of the textured surface.

The minimum thickness of the oil film of the textured surface is less than the one of the oil film of the smooth surface subjected to vibration loads with different frequencies and these two time-history curves are similar too. When subjected to the same frequency vibration, the cycle of these two time-history curves is identical too. With the increase of the vibration frequency, the cycle of the time-history curve of the maximum pressure, minimum thickness and average friction coefficient of the oil film are decreased.

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Мета. Вивчити вплив вібраційного навантаження на пружногідродинамічну змазку текстурованої поверхні за допомогою чисельного розрахунку.

Методика. На основі моделі пружногідродинамічної змазки текстурованої поверхні, схильної до впливу вібрації й ударних навантажень, та її рішення, розглянуто ряд явищ.

Результати. Дослідження показують, що зміни товщини й тиску в масляній плівці текстурованої поверхні в кожен момент часу зазнають схожі зміни в кожному циклі вібраційного навантаження. В області низького тиску текстура здійснює незначний вплив на розподіл товщини масляної плівки та тиску в ній, проте в області високого тиску вона здійснює очевидний вплив на розподіл товщини й тиску в масляній плівці та суттєво впливає на динамічний тиск.

Наукова новизна. У всієї розрахункової області, кількість піків тиску пов'язана з їх кількістю в області високого тиску текстури. Дослідження також показало, що, зі збільшенням амплітуди навантаження, максимальний тиск і середній коефіцієнт тертя масляної плівки зростають, а мінімальна товщина плівки зменшується. Максимальний тиск, мінімальна товщина та середній коефіцієнт тертя масляної плівки зменшуються зі збільшенням частоти коливань.

Практична значимість. Результати дослідження мають велике значення для розробки текстури поверхні, що піддається вібраційному навантаженню.

Ключові слова: *вібраційне навантаження, текстура поверхні, пружногідродинамічна змазка, максимальний тиск, мінімальна товщина плівки, середній коефіцієнт тертя*

Цель. Изучить влияние вибрационной нагрузки на упругогидродинамическую смазку текстурированной поверхности с помощью численного расчета.

Методика. На основе модели упругогидродинамической смазки текстурированной поверхности, подверженной воздействию вибрации и ударных нагрузок, и ее решения, рассмотрен ряд явлений.

Результаты. Исследования показывают, что изменения толщины и давления в масляной пленке текстурированной поверхности в каждый момент времени претерпевают схожие изменения в каждом цикле вибрационной нагрузки. В области низкого давления текстура оказывает незначительное влияние на распределение толщины масляной пленки и давления в ней, однако в области высокого давления она оказывает очевидное влияние на распределение толщины и давления в масляной пленке и существенно влияет на динамическое давление.

Научная новизна. Во всей расчетной области, количество пиков давления связано с их количеством в области высокого давления текстуры. Исследование также показало, что, с увеличением амплитуды нагрузки, максимальное давление и средний коэффициент трения масляной пленки возрастают, а минимальная толщина пленки уменьшается. Максимальное давление, минимальная толщина и средний коэффициент трения масляной пленки уменьшаются с увеличением частоты колебаний.

Практическая значимость. Результаты исследования имеют большое значение для разработки текстуры поверхности, подвергаемой вибрационной нагрузке.

Ключевые слова: *вибрационная нагрузка, текстура поверхности, упругогидродинамическая смазка, максимальное давление, минимальная толщина пленки, средний коэффициент трения*

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