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Elliptical EHL Contacts under Dynamic Loading Conditions in HERB Drive

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Ball reducer (HERB Drive: High Efficient Wave Rolling Ball Drive) with waved grooves has many advantages over other types of reducers for high-reduction ratio, low noise and low energy loss, etc. The mechanism of force transmission is very similar to that of cam and follower in automobile valve train system especially in contact behaviors. In this study, we have investigated the traces of contact between ball and outer ring, and the dynamic contact behaviors of elastohydodynamic lubrication (EHL) with a certain reduction ratio. In order to verify the contact behaviors between ball and outer ring for the critical endurance life, the contact velocity and load are computed for a cycle. During some intervals of a cycle, the contact velocity reverses its direction very suddenly. It is expected that changing the contact direction causes undesirable endurance performance because EHL films frequently collapse at the moment of velocity reversal. From the computational investigation in this work, we hope to predict similar contact damages in other machinery due to this kind of contact behaviors, which is very typical in many contact phenomena.

Keywords : elastohydrodynamic lubrication, elliptical contact, reverse sliding

1. INTRODUCTION

Ball reducer with waved grooves is working by contacting balls with outer rings (Figure 1 (a)) that have waved grooves. It has many advantages over other type of reducer like gear type reducer for low noise and high reduction ratio, small volume and less additional mechanical fixtures. The main reason that the ball reducer can have these kinds of advantages is that the reduction is performed by rolling contact between ball and waved grooves that have cycloid curves in the outer ring. Another main advantage of ball reducer is that the driving shaft does not have to be aligned to the driven shaft, so that it can use the space very efficiently. However, the contact behavior that is the most important mechanism for transmitting torque is under the extreme condition of concentrated high stress. Most of the failure in the ball reducer happens on the waved groove for poor lubrication conditions. In order to prevent it, it is necessary to investigate the contact behavior such as variation and reversal of rolling velocities and fluctuation of applied loads during a cycle. Frequently the contact velocity between ball and waved groove changes its direction and then the collapse of lubrication film is crucial when the applied load is very high. In our study, we investigated the contact behavior between ball and waved groove for the applied load and the contact velocity. With these input values, the dynamic EHL film thicknesses are obtained during the cycle. It is surprisingly found that the EHL film thickness has unique shape that has edge patterns in both inlet and exit regions of lubricant entrainment without collapse when the contact velocity changes it direction. Although the EHL film thickness does not collapse at the moment of changing the direction of contact velocity, it has very thin film thickness at that moment. Therefore, it is recommended that profile of the groove should be designed to prevent changing direction of contact velocity for less chance of minimum film thickness.

2. COMPUTATION OF APPLIED LOAD AND CONTACT VELOCITY

The contact velocity and applied load between rolling ball and outer ring are computed by the following equations which show the traces of ball and outer ring. The centers of rolling ball and the contact points between ball and outer ring are traced by the kinematic relations as shown in Figure 1 (b).

The center of rolling ball is described as following equations:

$$x(\theta) = [e\cos(N_w\theta) + R + h]\sin\theta \tag{1}$$

$$y(\theta) = [e\cos(N_w\theta) + R + h]\cos\theta\,. \tag{2}$$

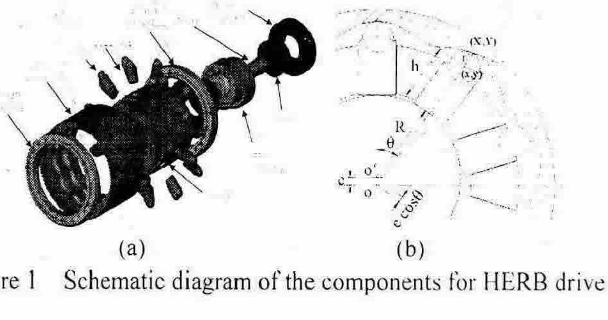
The kinematic relation for the contact point between rolling ball and outer ring is expressed as following equations.

$$\frac{(Y-y)}{(X-x)} = -\frac{dx}{dy} = -\frac{1}{k} \tag{3}$$

$$(X-x)^2 + (Y-y)^2 = r^2 \tag{4}$$

$$X = x - \frac{rk}{\sqrt{1+k^2}}, \quad Y = y + \frac{r}{\sqrt{1+k^2}} \tag{5}$$

$$k = -\frac{T_c\sin\theta + eN_w\sin(N_w\theta)\cos\theta}{T_c\cos\theta - eN_w\sin(N_w\theta)\sin\theta} \tag{6}$$

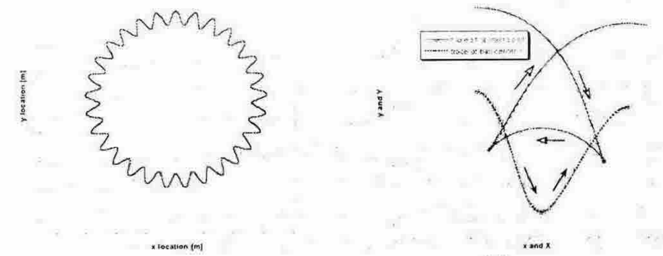


(a) (b)

Figure 1 Schematic diagram of the components for HERB drive

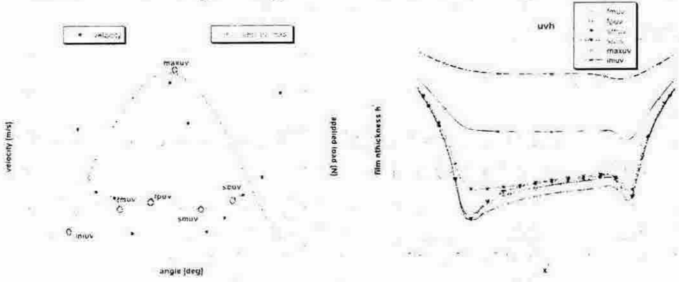
The applied load is obtained as following equation with the assumption that the rolling ball has never slip on waved profile in the outer ring similar to the contacts between cam and follower in automobile engine analysis.

$$P_i = \frac{F_i}{\cos\alpha - \mu\left(\dfrac{2a+b}{b}\right)\sin\alpha} \qquad (7)$$



(a) (b)

Figure 2 (a) Traces of rolling ball center during 30 revolutions of driving shaft (b) Traces of contact points between rolling ball and outer ring during one revolution of driving shaft

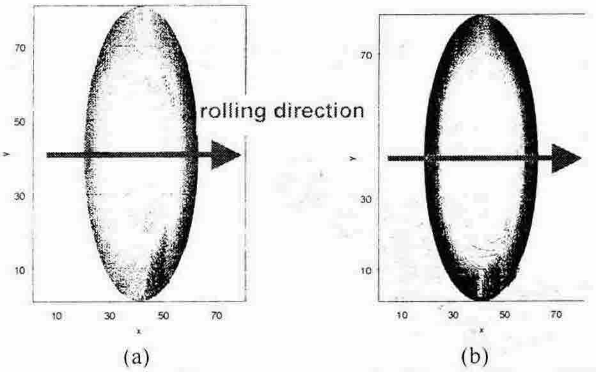


(a) (b)

Figure 3 (a) Applied forces and contact velocities during one revolution of driving shaft[2*ms*] (b) Film thickness at several instant during the cycle [$h^*=hR/b^2$]

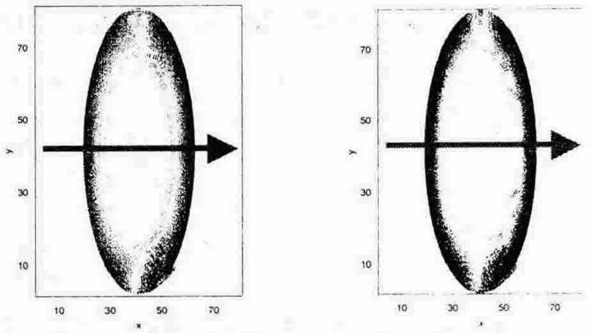
3. RESULTS

For the applied loads and contact velocities as shown in Figure 3 (a), we compute the film thickness of elliptical EHL. During a cycle, the contact velocity changes the rolling direction four times where the film thicknesses are shown in from Figure 4 to 6. At the moment of changing rolling velocities, the EHL film does not collapse and the film pattern has sharp edges in both entraining and exit regions of lubricant as shown in Figure 3(b).



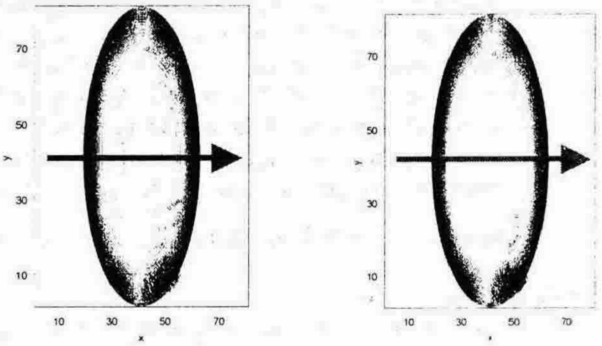
(a) (b)

Figure 4 (a) Fluid film pressure at point iniuv at Figure 3(b) (b) Fluid film pressure at point fmuv at Figure 3(b)



(a) (b)

Figure 5 (a) Fluid film pressure at point fpuv at Figure 3(b) (b) Fluid film pressure at point maxuv at Figure 3(b)



(a) (b)

Figure 6 (a)Fluid film pressure at point smuv at Figure 3(b) (b) Fluid film pressure at point spuv at Figure 3(b)

4. CONCLUSION

In this work, we investigated the elliptical EHL film thickness under dynamic loading condition with sudden change of contact velocity direction. It is found that the elliptical EHL film thickness does not collapse at the moment of changing velocity direction, which cannot be predicted with steady state analysis of elliptical EHL. However, in order to have better design for endurance performance-wise of HERB drive, it is necessary to design the grove profile that does not cause changing direction of contact velocity.

5. REFERENCES

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