a = pressure viscosity coefficient in (kg sq cm)$^{-1}$ defined from the standard exponential equation

$\eta_p = \eta_0 \exp(ap)$....see hereafter

This equation is a generalization from 3 computed values and it is only valid for P_{max} above 10,000 kg/sq cm. We have found it convenient to compute in a transposed form:

$$h_{min} = \left[\frac{\eta_0 URa}{169}\left\{\frac{\eta_0 UP_{max}}{R}\right\}^{1/4}\right]^{1/2}$$

Petrusevich states he has taken into account the compressibility of the oil as well as the temperature of the oil under sliding and its thermal conductivity. No details of its derivation or computation are available.

The Grubin and Vinogradova equation [8] is:

$$h_{min} = 1.13\,\frac{(\eta_0 Ua)^{0.727}R^{0.364}}{[P(\theta_1 + \theta_2)]^{0.091}}$$

in addition to the previously defined symbols:

P = load/unit length

$$\theta = \frac{1 - \sigma^2}{\pi E}$$

with

σ = Poisson's ratio

E = Young's modulus

This formula is dimensionally consistent so any homogeneous system of units can be used.

The correlation we use for the pressure viscosity coefficient is due to Wooster [15] and is

$$a = (0.6 + \log_{10}\eta_0) \times 10^{-3}$$

with a in (kg/sq cm)$^{-1}$

η_0 in centipoises.

DISCUSSION

E. K. Gatcombe[3]

The main point of discussion raised here is whether or not the oil film changes thickness at the pitch point phase of mating.

From information gained through research I have concluded that these hydrodynamic films can change thickness very suddenly, both in the way of a sudden decrease in thickness as well as a possible sudden increase in thickness if proper conditions exist.

We can imagine that the film is of a certain thickness at the first phase of contact, where the velocity of sliding is relatively high and the loads relatively light. Then, as contact progresses towards the pitch point phase, the velocity of sliding decreased to zero and the loads are relatively high.

Now the high velocity of sliding might cause the bulk viscosity of the oil to be decreased and thus the magnitude of the oil film thickness might be reduced. But we must remember that a high relative velocity, in general, is proper for the build-up of relatively thick hydrodynamic films, except for cases where certain factors, as mentioned above, the resultant associated decrease in viscosity, may cause the films to be reduced in thickness.

Then, on the assumption that hydrodynamic films exist, I would expect that there could be a decrease in the film thickness *right* at the pitch point phase, as is indicated by your oscillograph traces.

[3] Professor, Mechanical Engineering Department, U. S. Naval Postgraduate School, Monterey, Calif. Mem. ASME.

But if we assume that plastic films result from these extremely high contact pressures, then they probably change in thickness only very slightly over the entire tooth engagement cycle.

Authors' Closure

Dr. Gatcombe has raised some question about the relative magnitude of the oil film thickness at the pitch line, suggesting that there might be a drop in its thickness at the pitch line during single pair action under conditions of pure rolling. We find, however, that for heavily loaded contacts pure rolling can be expected to be a more favorable situation for oil film formation. In spite of the fact that two pairs of teeth are sharing the load at roots and tips, it is the high impact coupled with a high sliding action which tends to reduce the oil film at this point. For all 20-deg involute tooth forms the combined deflection of a pair of teeth is found to be roughly 0.001 of an inch per 2000 lb/in. load.[4] The results suggest that, as soon as the combined deflection of the outgoing teeth in mesh exceeds the tip relief provided then serious interference results at root and tip of the incoming pair. Referring to Fig. 3, the oil film at root and tip rapidly deteriorates from approximately a 1000 lb/in. load and upward. When tip and root relief (Fig. 2) are considered together, the over-all relief on the teeth amounts to approximately 0.0005 in., which just about approximates the combined deflection of the teeth for this load. Dr. Gatcombe's suggestions of some sort of "squeeze action" during conditions of pure rolling needs study and it is the author's opinion that more attention will have to be given in the future to the theory to differentiate between conditions of pure rolling and pure sliding even when the temperature effects are taken into consideration in the latter case.

In regard to Dr. Felan's remark during the discussion about extreme pressure additives, so far we have only tested straight mineral oils. The authors suspect, however, that the use of an additive oil will not appreciably change the traces shown. In other words, the E.P. additives are operable in the region of so-called zero oil film. Thus the technique used only measures the thickness of a hydrodynamic film and does not offer a satisfactory calibration for surface films formed under the action of heat and pressure.

It is true that, with the measuring technique used, it is not possible to determine the relative disposition of the oil film thickness during two pair action. The oscillograph traces do show the minimum of the two oil films present. In regard to his suggestion of using a contact ratio of 1, this has not been tried. The difficulty, of course, with such a small contact ratio is that it results in rough action of the gears causing higher impact loads which might nullify any results which might be obtained. We have considered the use of a single tooth which is insulated from the rest of the gear but the reader can appreciate that this would be difficult to do and still simulate the elastic characteristics of the remainder of the teeth on the gear.

Dr. Poritsky has asked for some clarification of the reasons for scatter in the oscillograph traces shown. Some idea of the relative influences of the various factors which govern the nature of the picture may be obtained from the list of sizes given here:

Oxide layer.....................0.1 microinches, ref. [29]
Surface roughnesses..............16 to 25 microinches
Dirt particles...................50 to 100 microinches
Oil film thickness...............50 to 250 microinches
(Net, minus thickness of dirt particles)

[4] H. Walker, "Gear Tooth Deflection and Profile Modifications," *The Engineer*, vol. 166, p. 409.