Since the general shape of the phase difference-rate of shear curves for the synthetic grease changes little in shape with temperature, the structural changes responsible for the movement of this grease are not affected by temperature changes, a point not evidenced by the soap grease.

One tentative suggestion that can be made regarding the load-bearing capacity of these greases is that: The soap grease should provide greater load-bearing capacities because of the elastic response of the soap grease. A point not fully appreciated by many investigators is that this elasticity generates normal stresses which should assist the load-bearing performance of the bearing. Similar characteristics have been observed in polymer solutions, where normal stresses can be generated by either the elasticity of the polymer or by actual swelling of the polymer.

The reason for the poor dynamic stability of the synthetic grease (Vulcan XXX) was due to bleeding of the carrier fluid under gravity, a characteristic a grease must not possess if it is to be an efficient lubricant. One probable reason for this occurring could be attributed to the type of carbon-black particles; while being of an irregular spherical shape they possessed little porosity, unlike the other synthetic grease mentioned in the paper (Carbolac 1) which has a surface area five times that of the Vulcan XXX. The greater surface area provides for a greater degree of interaction between the particles, hence producing a more stable structure.

There is evidence that the soap structure yields, causing a fall in the stress amplitude, before increasing again with rate of shear. Criddle [10] has in fact shown that greases do possess yield points, but their nature depends largely upon the rate of deformation, work history, and type of deformation. Probably more significant than the yield value itself is how does the grease react beyond this point. As far as dynamic tests are concerned the stress increases with frequency, producing a response similar in nature to the work-hardening characteristics observed in certain solid systems. Whether a form of work hardening occurs beyond the yield point for this or similar greases only further tests can show.

The different suspensions are observed to produce differing harmonic stress amplitudes and phases. In reducing the particle size of the synthetic suspension by using another type of carbon black (Carbolac 1) the stability of the grease is improved considerably, but in so doing the nonlinear effects also increase. The soap gel would appear to be more sensitive to changes in rate of shear than the synthetic suspension, as evidenced by the differing negative slopes of the harmonic phase differences.

The principle of reduced variables applied not only to the fundamental components but also to the harmonics, demonstrating that the response to frequency or temperature changes can be related to a reference temperature (19 deg C) while covering a much larger range of frequencies. The temperature coefficients (shift factor) for the two greases were observed to differ considerably.

Conclusions

The instrumentation developed to carry out automatically a Fourier analysis of a nonlinear wave has been successfully applied to grease systems.

Experimental results show that greases are nonlinear viscoelastic materials when subjected to periodic disturbances at various strain amplitudes and test temperatures. In their present form and over the range of test conditions covered, the synthetic greases are less stable than the lithium soap grease. In terms of structural stability and test condition, the soap grease is superior to the synthetic grease, requiring increases in stress for the grease to flow, unlike the synthetic grease which flows at a constant stress level.

There is evidence that the soap grease possesses a yield point not evidenced in the synthetic grease.

The viscoelastic response of each grease differs considerably, the synthetic grease being of a viscous response over certain strain amplitudes, but when another carbon black suspension (Carbolac 1) is used strong elastic responses are detected under small strain amplitudes and low frequencies. The soap grease on the other hand suggests an elastic response, this being more noticeable at higher test temperatures. It is suggested that the elastic nature of the soap grease should provide better load-bearing capacities if it accepted that elasticity generates normal stresses.

The experimental results also illustrate that for the given test conditions the nonlinearity of each grease remained approximately constant. The harmonic phase differences associated with the synthetic grease are affected less by rate of shear and temperature than the soap grease.

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References


Discussion

A. B. Metzner

Suppose you assume that the grease was separated in two phases during the oscillatory deformation so that you had a highly viscous phase surrounded by low viscosity oil in contact with the surfaces. What kind of response would you expect to get in this case? Is this a reasonable question?

W. Philippoff

We did some work very similar to Dr. Bogie's work about ten years ago in our laboratory and we also analyzed the second and third harmonics and found essentially the same results that Dr. Bogie has found. However, the question is where does the third harmonic come from? Is it a nonlinearity in the stress-strain relationship or not? Especially, the change of phase angle with rate of shear is very mysterious. I couldn't find any rhyme to these experiments and therefore we did not publish them. I would like to know if Dr. Bogie has thought about this question? It would be easy to understand if the third harmonic occurred only as a function of amplitude. We went to much higher amplitudes about 800 percent shear and there it was also practically in...
R. I. Tanner

I would like to ask Dr. Bogie what the output stress wave shape looks like?

Author's Closure

In reply to Dr. Philippoff's question on why the 3rd harmonic phase difference changes with frequency: The magnitude and phase of the 3rd harmonic, I appreciate, hold the answers to one or two questions. I cannot give a solid reason as to why the 3rd harmonic phase difference should change with frequency. This observation is not restricted to the systems mentioned here but clay-water and certain polymer systems also show this effect.

As yet I have not found a way of separating the elastic component of the 3rd harmonic but the problem is being looked into.

In reply to Professor Metzner's question of separation of the suspension between the two geometries—the question of separation of the suspension within the geometry was certainly looked into, and the conclusions arrived at were: That the ring and plate type of geometry with both shearing surfaces roughened to a finish of 10-15 microns, could accommodate any carrier fluid which might bleed from the suspension. Separation of the geometries resulted in every instance of the suspension being drawn out finally breaking at the center, leaving very nearly equal quantities of material on each geometry, a point which would certainly not be fulfilled if any bleeding of the carrier fluid had occurred. Furthermore, an examination of the material while it was being sheared under high magnification showed no signs of slip at the boundaries.

Finally, in response to other questions, the inertial effect of the particles and secondary flow were eliminated by using a very small gap between the shearing geometries (0.001 and 0.002 in.) and restricting the movement of the upper platen or shearing geometry to a minimum. This latter requirement also fulfilled certain other requirements in that the natural frequency of the upper torsional system was greater than that of the highest harmonic frequency encountered.

Non-Newtonian and nonlinear viscoelastic effects of the carbon black greases were observed in concentrations as low as 2 percent, which demonstrates the fact that care should be taken when dealing with dilute systems as linear viscoelastic systems.

From tests just completed on the amplitude dependence of the synthetic grease Vulcon xxx, it has been found that the 3rd and 5th harmonic phase differences are independent of strain amplitude and entirely dependent upon frequency.

Furthermore it can be shown that the product of viscosity and shear rate at some current time \( t' \) in oscillatory motion gives the current viscous stress. The stress will contain a term in

\[
\cos (2\omega t - \alpha) \cos \omega t = \frac{1}{2} [\cos (3\omega t - \alpha) + \cos (\omega t - \alpha)]
\]

which states that the stress wave will contain a third harmonic of the fundamental, that the fundamental will lag the shear rate by an angle \( \alpha \), and this is the type of phase shift one observes in viscoelastic materials.