The Effect of Lubricant Traction On Wormgear Efficiency

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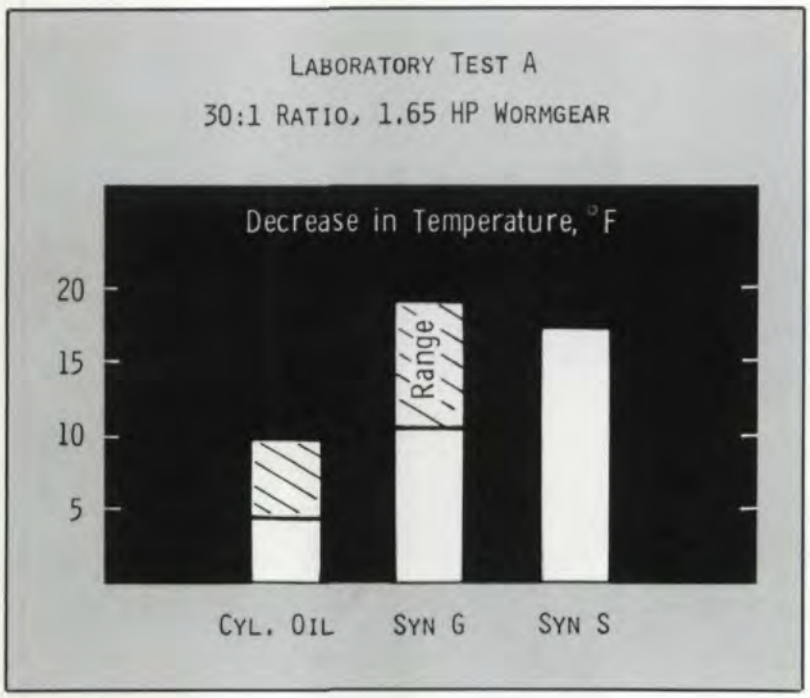

Fig. 1 – Improvement Over Conventional S/P Mineral Based Oil

Abstract

The effect of various lubricant factors on wormgear efficiency has been evaluated using a variety of gear types and conditions. In particular, the significant efficiency improvements afforded by certain types of synthetic lubricants have been investigated to determine the cause of these improvements. This paper describes broad wormgear testing, both in the laboratory and in service, and describes the extent to which efficiency can be affected by changes in the lubricant; the effects of viscosity, viscosity index improvers and, finally, synthetic lubricants are discussed. The work concludes that lubricant tractional properties can play a significant role in determining gear efficiency characteristics.

Introduction

Over the past ten years, the trends to hotter-running industrial gears has provided the authors' company with the opportunity to evaluate synthetic industrial oils developed with the superior thermal/oxidative performance. In several instances, it was noted that not only was oil life improved by using synthetic products, but that the equipment ran cooler than with the mineral-based products originally used. This behavior has been reported.[1] The simplest explanation for cooler-running is a reduction in horsepower loss; i.e. an improvement in power transmission efficiency.

These findings, in part, resulted in a significant effort to evaluate industrial gear efficiency characteristics of different lubricants, including the synthetic products.

Laboratory Evaluations of Wormgear Efficiency

Results of wormgear tests available in the authors' laboratories in Europe and the U.S. appear in Figs. 1 through 4.

Equilibrium operating temperature data obtained with Wormgear A operated at 1500 rpm and 100% nominal load are shown in Fig. 1. Both synthetics show significant temperature decreases. A conventional steam cylinder oil (AGMA 7 Comp.) is also shown for comparison against the reference, which is a conventional AGMA 7 EP mineral-based oil. The viscosity grades (see Table 1) for Syn S and Syn G were chosen from their respective product families to be similar to that of the reference oil at the approximate 100°C operating temperature of the tests.

Data in Fig. 2 compares both efficiency and temperature rise differentials using a second manufacturer's gearbox, Wormgear B. Similar temperature decreases were found for the synthetic products, but the steam cylinder oil ran slightly hotter than the reference conventional S/P mineral oil. These results are reflected in the efficiency data for these oils which show 2-3% benefit for the synthetics and a directional worsening for the cylinder oil. Efficiency measurements in this test were made by means of strain gauges on the input and output of the gearbox which was run at 1760 rpm input and reached about 100°C at equilibrium. Loading was achieved hydraulically as part of a four-square test arrangement.

Fig. 3 data shows benefits in efficiency for both synthetic products and the steam cylinder oil versus the reference mineral EP oil using Wormgear C (30:1 reduction ratio). This test is run at 1500 rpm and at 96 and 117% thermal load capacity. Fig. 4 shows similar data for Wormgear D, a 50:1 ratio wormgear operated at 1680 rpm input at 100 and 200% Class 1 mechanical rating. This latter test is run with the oil sump thermostatted at 95°C. Both tests C and D measure efficiency via input and output shaft torque strain gauges with dynamometer loading.

The data of Figs. 1 through 4 clearly show the correlation of improved efficiency and temperature control for lubricants Syn S and Syn G compared with the mineral sulfur/phosphorus oil reference. Steam cylinder oil, also, shows a general benefit for both measurements, but with significantly smaller degree of improvement.

These data are summarized in Table 2. Also shown are results of gear manufacturer tests with Syn S compared with reference mineral oils of either the compounded steam cylinder type or the AGMA EP type. The degree of efficiency benefit recorded in these latter tests depended on the operating conditions of the tests, and Table 2 lists the average benefits recorded. The gear manufacturer tests also indicated benefits in temperature control for Syn S.

The gear efficiency benefits for Syn S in tests B through G show a wide range of numerical results. These data are rationalized in Fig. 5 which shows a good correlation of efficiency benefit as a function of increasing gear reduction ratio. Based on the measured and catalog efficiencies for these gears (using conventional oil) the rule-of-thumb effect of Syn S is to reduce the gearbox *inefficiency* by 20-25%.

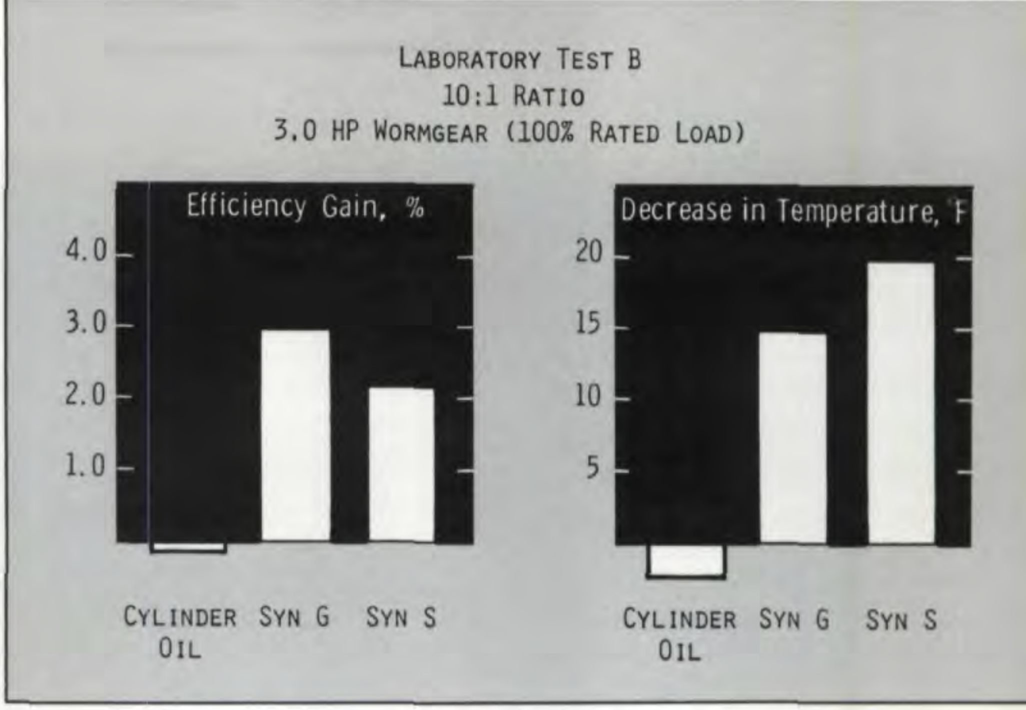

Fig. 2 – Improvement Over Conventional S/P Mineral Based Oil

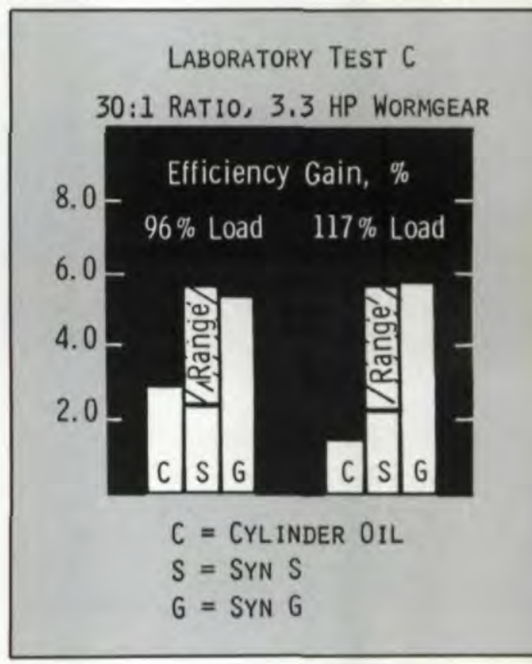

Fig. 3 – Improvement Over Conventional S/P Mineral Based Oil

Practical Applications for Improved Wormgear Efficiency

Benefits other than the cooler running characteristics initially found for these synthetic products are apparent:

One gear manufacturer, Hub City Division of Safeguard Power Transmission Co., has applied the benefits of Syn S to increase wormgear horsepower ratings. Catalog thermal input horsepower ratings have been increased 10 to 15% when the recommended synthetic oil (a Syn S rebrand) is used. This represents a new design application for this product which already is used in sealed-for-life wormgear units based on its extreme operating temperature capability.

A second application for increased transmission efficiency is to reduce equipment power requirements, thereby, reducing utility costs. Field measurements of power draw of various industrial equipment in customer plants has now been demonstrated for Syn S and is currently being evaluated for product Syn G.

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Syn S field results in Table 2 show measured average electrical power requirements for both worm and steel gear industrial transmissions. Efficiency measurements in field applications can be more difficult than in the laboratory because operating conditions are not as precisely controlled. A statistical approach is often necessary. This was the case in the second steel mill test in which the combined power requirements of the motor drives of a series of five wormgears were measured by means of a recording wattmeter. Two basic operations were evaluated in this corrugated steel pipe drive: a regular drive cycle and a cut cycle. Data for the two cycles are shown as normal distributions in Figs. 6 and 7.

The Syn S results show lower mean (50%) power draw for both cycles: the non-overlap of the 90% confidence limits for each distribution comparison indicates a greater than 99% confidence that the benefits measured were real and not the result of chance. The average benefits measured for the two cycles were 5.8 and 5.9%.

A different approach was taken in the power consumption test at the food processing company shown in Table 2. In this case, two food aerator units were operating in parallel. In this test the mineral oil in the gear drive of only one of the units was replaced with synthetic product and the other was maintained as a control. Fig. 8 demonstrates the relatively constant current draw for blower 2 (oil unchanged) compared with the second unit which had a measurable (6%) reduction when the mineral oil was replaced by Syn S.

The efficiency/power benefits for Syn S in laboratory, gear builder and customer evaluations are summarized in Fig. 9

Correlation of Wormgear Efficiency with Lubricant Traction

The mechanism by which synthetic lubricant products, Syn S and Syn G, improve wormgear efficiency has been investigated in the authors' laboratories. The wide acceptance of steam cylinder lubricants which employ relatively large percentages of fatty additives has been attributed to their ability to produce low friction films on the surface of the gear teeth. The present work generally supports the low friction/improved efficiency characteristics of the steam cylinder oils, and it was the surface friction mechanism which was first investigated as a possible explanation for the greater benefits shown by the synthetic lubricants.

In one comparison using Wormgear D, Syn S additives blended in the reference oil mineral base versus the mineral reference oil additives in the synthesized hydrocarbon base oil, clearly demonstrated the efficiency benefits to be retained not by the Syn S additives, but with the synthetic basestock. This indicated the efficiency benefits to be associated with the nature of the synthetic basestock, and not to result from a change in the frictional properties at the gear surfaces.

Operating viscosity was also considered as a possible explanation even

TABLE 1

TEST LUBRICANT INSPECTION PROPERTIES

	TEST LUBRICANT		
	S/P Mineral Reference	Syn S	Syn G
Base Oil Type	Mineral	Synthesized Hydrocarbon	Polyglycol
Viscosity			
AGMA Visc Grade	7	"6.5"	5
cSt @ 40°C	437	383	225
cSt @ 95°C	35	46	35
cSt @ 100°	30.2	39.0	29.7
Viscosity Index	95	145	164
Pour Point, °F	+20	−40	−15
Flash Point, °F	450	500	440

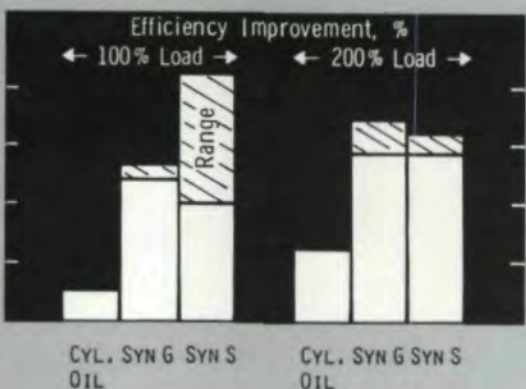

Fig. 4 – Improvement Over Conventional S/P Mineral Based Oil

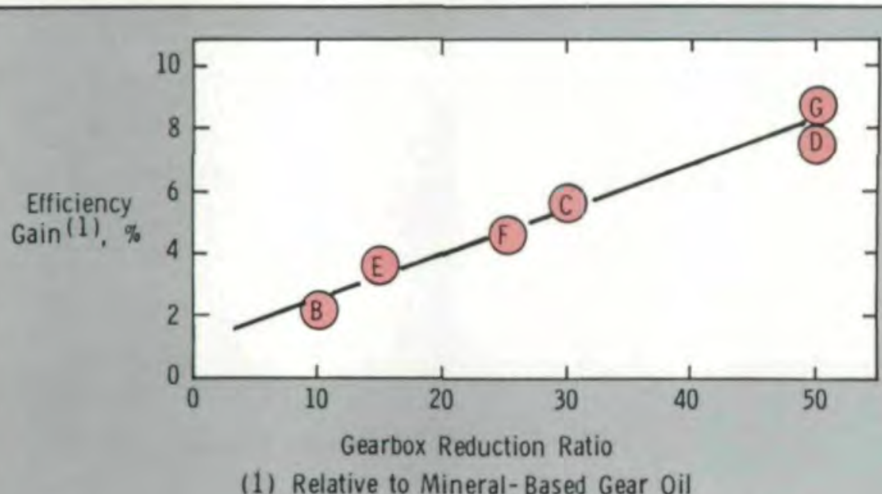

Fig. 5 – Energy Efficient Gear Lubricants Benefits For Syn S

though, as discussed earlier, the tests were designed to exclude this possibility. Nevertheless, ancillary experiments with Wormgear D evaluating the effect of changing the viscosity of the reference oil were undertaken and appear in Table 3. Compared with AGMA 7 EP reference oil, no significant difference is seen in either increasing or decreasing viscosity. This insensitivity to viscosity has also been verified in work with Syn S viscosity variations.

Table 3 also shows the results obtained with viscosity index-improved products. In this work, oil formulations were prepared with the normal reference oil functional additives, using AGMA 5 viscosity base oil, but with VI-improvers, X and Y, added to bring the final viscosity to the AGMA 7 level. In this way a quasi multigrade industrial oil was produced, but in neither case was a significant efficiency benefit obtained, with VI improper Y giving a negative effect. An explanation for this may be the poor shear stability found for Y in viscosity measurements under high shear conditions; X was found to be highly shear stable.

Finally, fluid tractional properties were considered as a possible explanation of efficiency effects. Traction here is defined as unit fluid friction in the high-pressure mesh of the gear, and is distinct from both viscous churning losses and gear surface metal/metal frictional effects.

The tractional properties of test fluids were measured using a roller disc machine. This equipment employs a pair of 3.265" diameter cylindrical test rings mounted on hydrostatic bearings which can be loaded against each other by means of a hydraulic piston. Each ring can be driven independently in either direction by induction drive units with electronic feedback control. The traction force between the discs is measured by strain gauges mounted in each disc drive mechanism. The absence of disc surface frictional effects is ensured by polishing disc surfaces to better than 2 microinch finish. Elastohydrodynamic calculations verified high specific film thickness and absence of metal contact during the tests.

Operating conditions for the roller disc machine traction measurements are shown in Table 4. Materials and surface loading were chosen to simulate the conditions of Wormgear Test D operating at 100% Class I load.

TABLE 2

EFFICIENCY BENEFITS MEASURED FOR SYNTHETIC INDUSTRIAL GEAR OILS COMPARED WITH CONVENTIONAL MINERAL-BASED PRODUCTS

	Gear Manufacturer	Reduction Ratio	Operating Horsepower	Average Efficiency Benefit, %	
				Syn S	Syn G
Authors' Laboratory Tests					
A – Mobil Oil Francaise	Lechner	30:1	1.65	*	*
B – Mobil R&D Corp.	Boston	10:1	3.0	2.2	3.0
C – Mobil Oil Francaise	Durand	30:1	3.2/3.9	5.6	4.0
D – Mobil R&D Corp.	Cone Drive	50:1	3.0/6.0	7.7	7.1
Gear Manufacturers' Evaluations					
E – Hub City Division Safeguard Power Transmission Co.	Hub City	15:1	1.55/2.0	3.8	–
F – Ex-Cell-O Corp., Power Transmission Division	Cone Drive	25:1	6.5/8.1	4.4	–
G – Winsmith Division of UMC Industries, Inc.	Winsmith	50:1	0.5-1.0	8.8	–
Equipment Users' Evaluations					
Steel Mill	B&K	15:1	122-142	6	–
Steel Mill	IMW Industries	39:1	75	5.8	–
Food Processing Company	Philadelphia Gear	3:1(a)	–	6	–
Textile Company	–	–(b)	~50	2	–

*Temperature Rise Measurements only; differential compared with reference mineral oils: Syn S, −17°F; Syn G, −15°F.

(a) Helical gear.
(b) Spur gear/chain drive combination.

TABLE 3

VISCOSITY EFFECTS ON WORMGEAR EFFICIENCY (TEST D)

AGMA Viscosity Grade	Percent Efficiency Change* Relative to Reference
8 EP	+0.1
7 EP	Ref
6 EP	−0.5
5 EP	−0.4
5/7 EP (V.I. Improver X)	+0.7
5/7 EP (V.I. Improver Y)	−3.3

*Test repeatability ~1.0%

TABLE 4

ROLLER DISC MACHINE OPERATING CONDITIONS

Disc Material:	A – AISI 4150 Resulfurized Steel, ~54 Rc (3/4" face width)
	B – SAE 65 Bronze, 80 Brinell Hardness (1" face width)
Disc Speeds, U:	A – 400-1600 rpm
	B – ± 120-1400 rpm
Bulk Oil Temperature:	150°F
Disc Load	400 lb
Hertzian Surface Stress:	48,600 psi

TABLE 5

ROLLER DISC MACHINE TRACTION COEFFICIENT RESULTS

Lubricant	Traction Coefficient(1) @ 720 fpm	Estimated Gear(2) Friction, f
Syn S	0.012	0.015
Syn G	0.013	0.015
EP Mineral Oil	0.018	0.021
Syn T	–	0.030

(1) Slide/Roll Ratio $= \frac{U_A - U_B}{1/2\,(U_A + U_B)} = 2$ ("Pure" sliding)

(2) Wormgear Test D results using equation:

$$\text{Efficiency} = \frac{1 - f \tan\lambda}{1 + f \cot\lambda}$$

where f = friction coeff.
λ = lead angle (Reference 2)

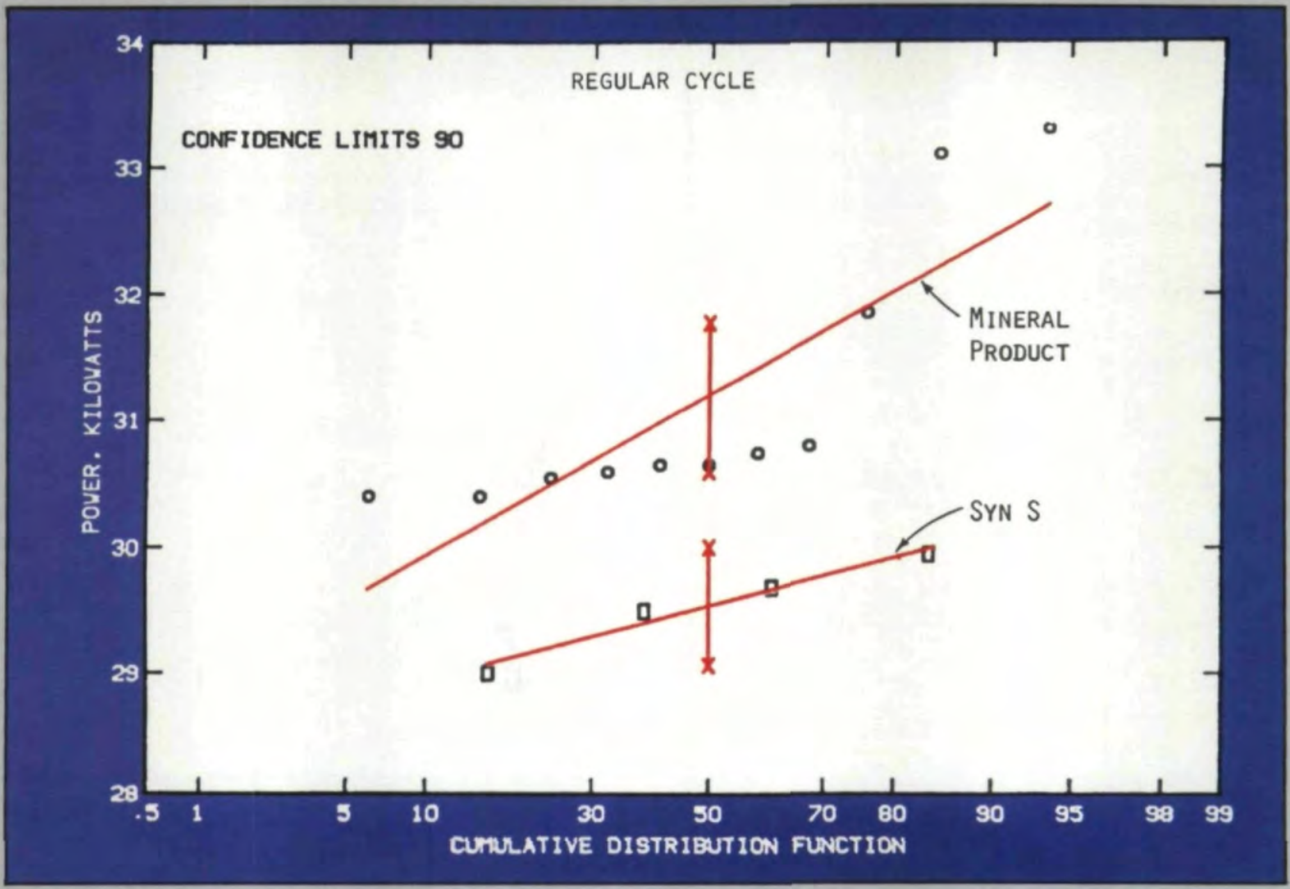

Fig. 6 – Corrugated Steel Tube Drive Test

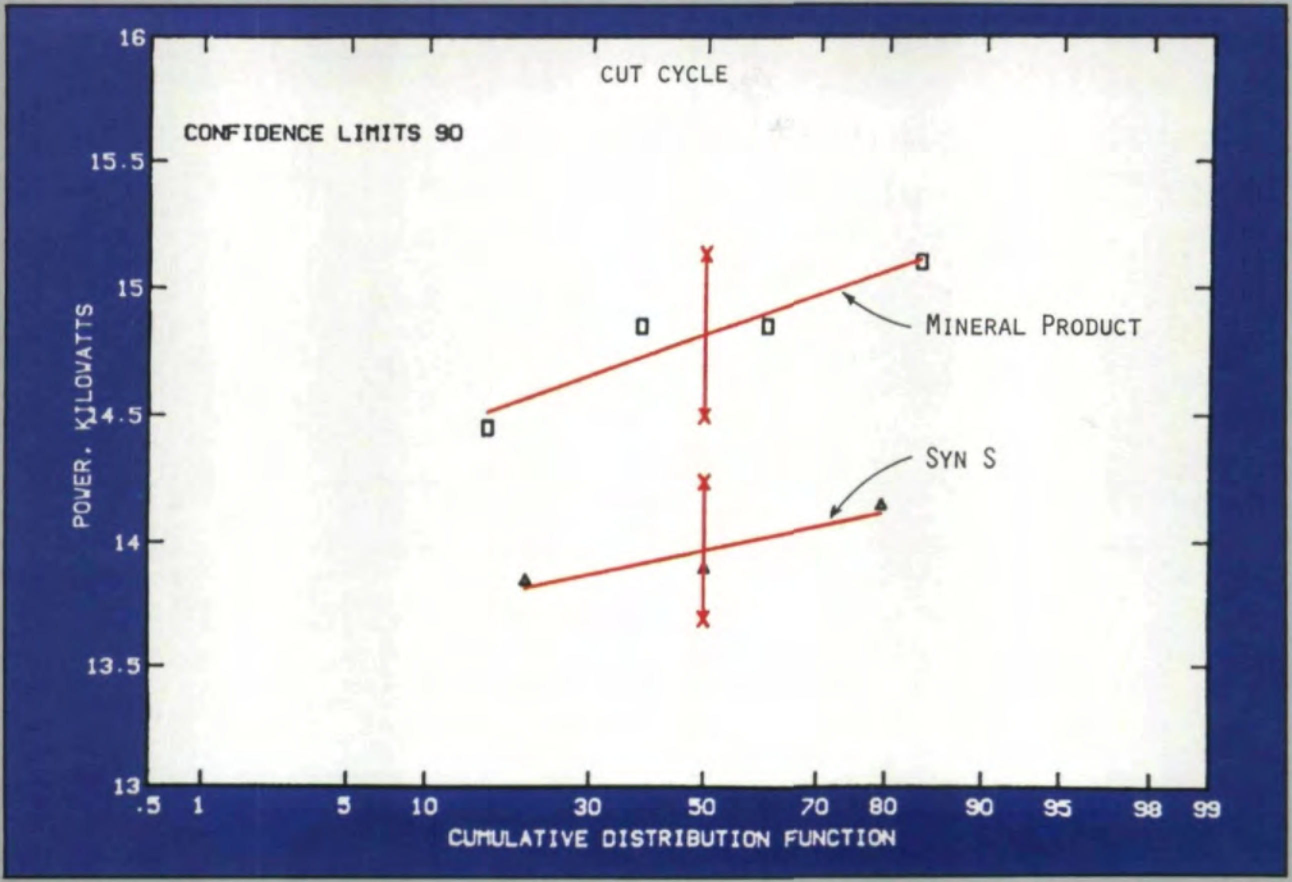

Fig. 7 – Corrugated Steel Tube Drive Test

Based on the disc speeds chosen, results are calculated in terms of traction coefficient as a function of slide-to-roll ratio and relative sliding speed. Data for the condition of pure sliding at a speed of 720 fpm are shown in Table 5, indicating a significant reduction in traction coefficient for the synthetic oils. For comparison, an estimate of gear friction based on a theoretical relationship[2] for wormgear efficiency is also shown in Table 5. Despite the simplicity of the relationship, good correlation is obtained between the traction and friction data as a function of lubricant type. Note also that the traction co-efficients for the synthetic products are reduced about 30% compared with mineral oil – a reasonable agreement with the gear inefficiency reduction discussed previously. The calculated gear friction results are somewhat higher, which may be explained in terms of the other loss mechanisms outside the gear mesh; e.g., churning, bearing and seal losses.

This strong correlation was recently verified by evaluating a commercial synthetic traction fluid in Wormgear Test D. The manufacturer's information indicated the traction coefficient of this fluid, designated Syn T, to be about 50% greater than that of a mineral oil. Based on this, a significant detriment to efficiency in the wormgear was predicted. Due to the low viscosity of Syn T, the reference mineral oil viscosity was reduced to an AGMA 2 EP oil, and the tests were run at 125°F where both oils have viscosities equal to that of the usual reference oil at 195°F, the normal temperature of the test.

This work showed Syn T approximately 10% less efficient than the reference mineral oil at 100% loading. At 200% loading, the efficiency with Syn T was so poor that the cooling water to the gearbox was unable to maintain the operating temperature at 125°F and the test was terminated to avoid damage to the gears. These results strongly support the influence of fluid traction in determining wormgear efficiency.

Work is now underway to measure the traction coefficient of Syn T in the roller disc machine for inclusion with Table 5 results. Substitution of the gear efficiency result for Syn T in the gear friction equation yields a value approximately 50% greater than that for mineral oil – in good agreement with the manufacturer's reported finding for traction coefficient.

An important aspect of the work with Syn T is that not all synthetic lubricants possess low tractional characteristics. It is most likely that lubricant molecular structure is the key to tractional properties and that structures can be synthesized to give either high or low traction depending on the needs of the application.

Conclusions and Further Work

1. The cooler running characteristics of two synthetic industrial lubricants in gear applications have been correlated with wormgear efficiency.
2. Gear efficiency improvements have been shown to result in lower power requirements in industrial applications.
3. The improved efficiency afforded worm gears by these synthetic oils has been used to increase wormgear thermal horsepower ratings.

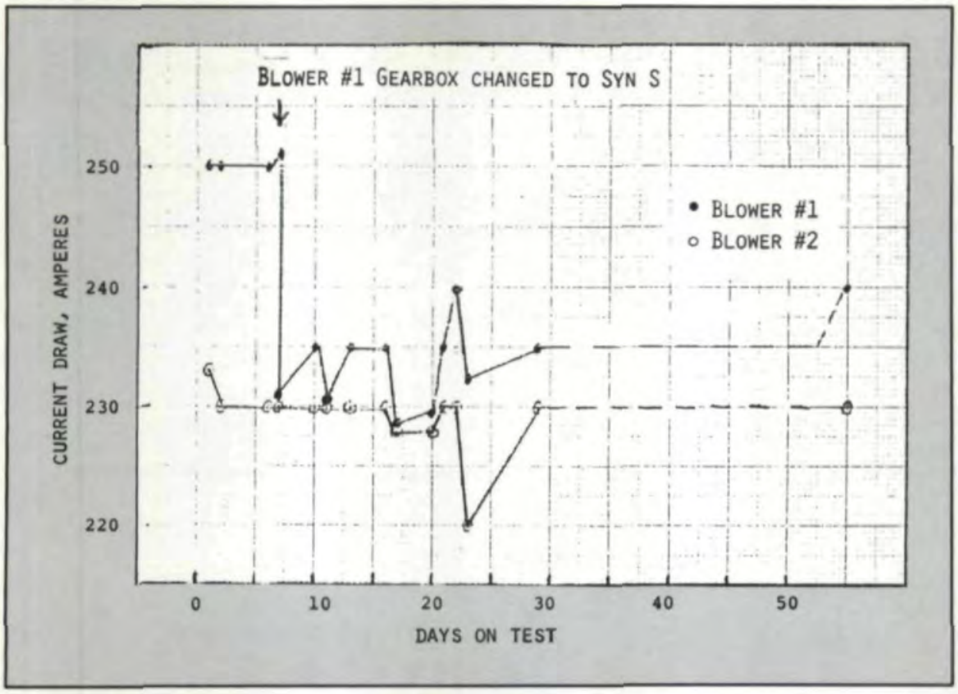

Fig. 8 – Food Processor Power Consumption Test

4. Lubricant tractional properties have been shown to be a significant factor in determining wormgear efficiency.
5. Future work will focus on the efficiency characteristics, particularly with respect to synthetic lubricants, of non-worm industrial gearing and will evaluate lubricant tractional properties at the higher pressures operating in steel gearing.

The authors gratefully acknowledge the permission granted by the gear manufacturers to publish their results.

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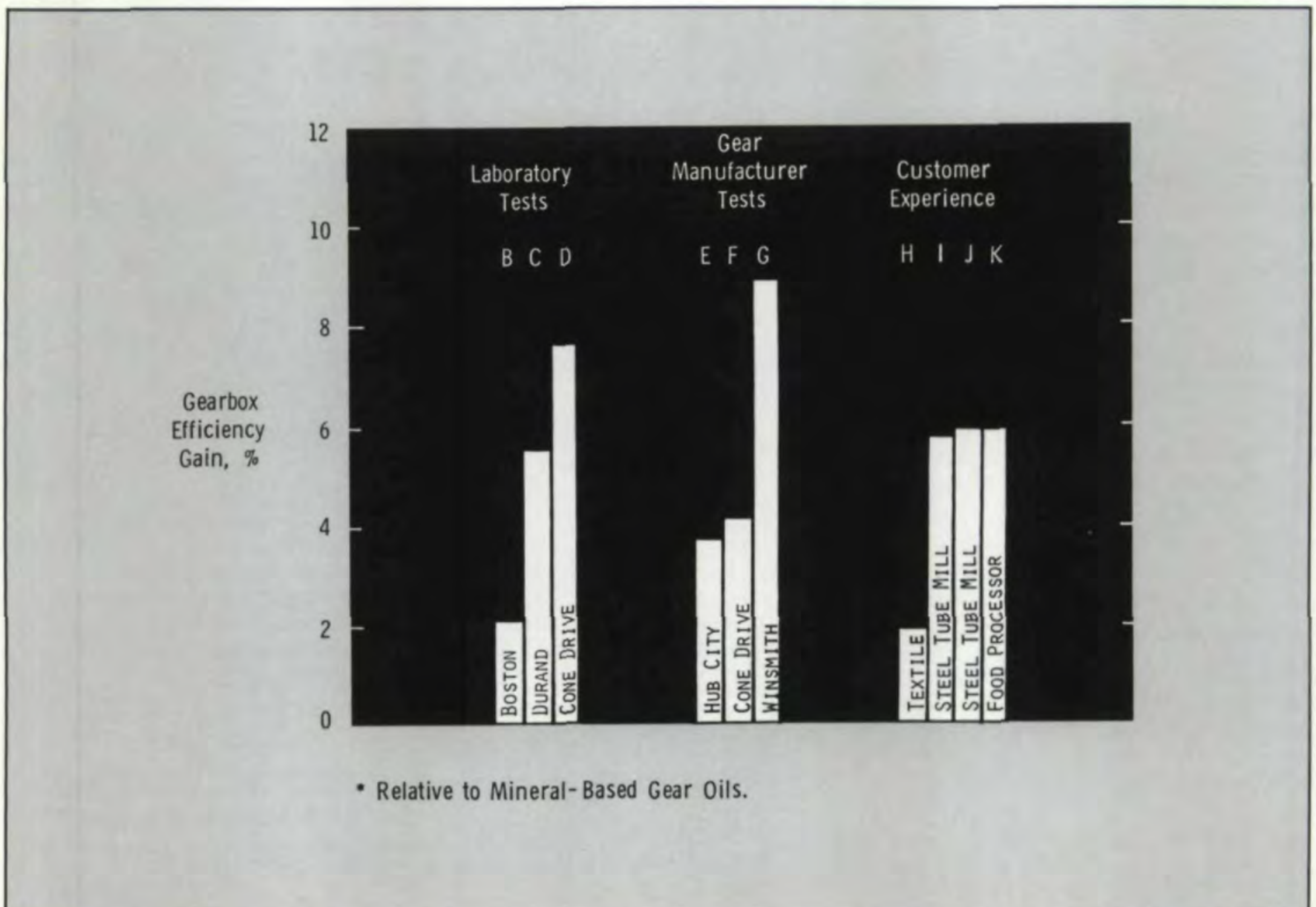
Fig. 9 – Average Efficiency Benefits* Demonstrated for Syn S



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