1975 MAYO D. HERSEY AWARD

The 1975 recipient of the ASME Mayo D. Hersey Award was Arthur F. Underwood, retired manager of the General Motors Research Laboratories. The citation for this award read, "For the pioneering concept of dynamically loaded bearing analysis and the innovative application of lubrication technology to internal combustion engines."

The Technical Editor has asked Mr. Underwood to reminisce about some of his experiences in those early days when "lubrication engineering" was in its development period in the automobile industry.

Arthur F. Underwood

THE "EDUCATION" OF A LUBRICATION ENGINEER

Even though I had just graduated from MIT with an MS in Mechanical Engineering, I found on joining General Motors Research Laboratories in 1928 that I knew nothing about lubrication! This was in spite of the fact that Mayo D. Hersey was only a few miles away at Brown University!

In those early years lubrication problems in the automotive industry were many and horrendous, and there was little engineering attention given to them. For example, piston pin noise was a common complaint. The only "cure" was to hand ream the bushing and fit a new oversize pin to a snug fit. It was some 15 years later that we fully understood the function of a "squeeze" oil film. But we did learn from our test work that a "proper" clearance and a means to get oil into the clearance cured the problem.

In the early 30's our Cleveland Diesel Division which made large submarine engines, had the (old) idea of making a "disc" crankshaft bearing to reduce engine length by some 4½ feet. This would require a 6 × 18½ inch bearing. Fortunately, someone wondered what the power loss would be. I was given the project but could find no engineering literature that would be of any help. So we designed and constructed a test machine for a full size bearing with a rotating load of 70,000 pounds up and 30,000 pounds down, the loading being obtained by using centrifugal weights and springs. We found that 33½ hp was required due to friction and since there would be nine bearings, this meant a loss of some 300 horsepower! The engine was never considered after that data became known.

It was during this period (and after) that Hersey's ZN/P factor came to my attention and we began to investigate the fundamentals of lubrication.

In those days rotating bearings, such as connecting rods and mains, were designed only on the basis of a *PV* factor. The maximum allowable value was some 15,000 which gave a maximum loading of about 600 psi at normal engine speeds. To determine the validity of using this *PV* figure in design, I counterbored the connecting rods of a Buick six cylinder engine to varying widths and found that when properly lubricated, the PV factor could be raised many times. It was indeed fortunate because today's automotive bearings, if designed by a PV factor, would be impossible to fit under the hood—they would be on the order of ten times larger than necessary.

To show how "scientific" engineering can go wrong, there were two MIT graduate students who convinced GM Research that Hersey's *ZN/P* concept should be investigated as applied to automotive engines. Their report showed the calculated values of *ZN/P* versus engine rpm of the rotating bearings for a number of current automobiles. On the basis of the report, none of the cars would run at low speed or above some 30–40 mph! When our Technical Director was handed the report by the two investigators, he took them to the 10th floor window of our Research Laboratories and they looked down upon one of Detroit's busiest streets. Pointing down to the hundreds of passing cars going contentedly at all speeds, he asked why they did not fail! The report was filed away.

The error in the experiment was that a 1 × 1 inch brass bushing was tested on a steel shaft with a unidirectional load applied by a weight. A *ZN/P* versus coefficient of friction curve was obtained. A minimum allowable *ZN/P* for the engine bearings was taken to be where the Hersey curve began to bottom out and curve upward. Again, the squeeze film concept of a dynamic load had not been recognized. Today we would not use a minimum *ZN/P* obtained from a statically loaded test bearing for a dynamically loaded bearing application.

Burned out, crystallized babbitt, pounded out (all these terms were used) were an expected part of frequent engine maintenance. The babbitt was up to ⅛ inch thick and frequently cast directly on the connecting rod. It was not unusual to have a spare connecting rod in the box under the front seat to install while "on the road". Over the years, we learned that it was the high oil film pressure which caused fatigue and progressively loosened "tiles" of metal. Making the babbitt thinner by casting it on a steel strip, forming the material into a semi-circle and then precision machining it increased the fatigue life manyfold. It is interesting to recall that this superior type of bearing was invented by an engineer in one of the automobile companies some 50 years ago but the company did not recognize the improvement and so he "sold" it to a supplier who was making oil-filled porous metal bearings. The ability to recognize a "good thing" is an important part of the education process.

An important facet of lubrication is bearing corrosion. It is difficult to believe, today, the troubles that we were plagued with in the '30's. One of the first problems was the corrosion of copper-lead bearings. Lead was disappearing from the surface. We had no understanding of the problem. Our first fact obtained in the education process was that the oil in a several thousand gallon oil tank which was used to final test production engines at GMC Truck, would also remove the lead from the bearings. So I would bring back drums of this used oil from Pontiac, Michigan to put in our bearing test machine. Rather rapidly we learned that the hot oil had become acidic by air oxidation in the recirculation system.

At the same time, Pontiac Motor Division had developed the cadmium-silver bearing which had fatigue qualities superior to tin-base babbitt. Simultaneously the oil industry had just announced a "great development" in processing which gave a better refined oil. When hundreds of engines were in the customers' hands, they were reported to be noisy from greatly increased rod bearing clearance. We learned that the improved oil was without its natural sulphur which normally acted as an inhibitor for oxidation. It is interesting to remember that before the answer was determined, a number of fancy theories were presented and run down. One specially amusing theory was that the oil—which was always shipped in drums (and hand pumped out into quart cans for engine refilling)—was being shipped in poorly cleaned lard-oil drums! We had learned that lard-oil (with its oleic acid content) was an excellent "starter" for the oxidation process; in fact, we began to use lard oil in accelerated corrosion tests instead of transporting recirculated oil from GMC Truck. An intensive program on oil additives was started and it required over 10 years for the industry to get satisfactory engine oils on the market. Incidentally, cadmium bearings received improved corrosion resistance by the addition of indium which was selling for $450 a pound but this was soon abandoned because of cost.

As I continued to learn more about dynamically loaded bearings, it became clear that there was some unrecognized mechanics which allowed greater loads to be carried dynamically than under static conditions. The culmination came one day when I was fatigue testing an Allison connecting rod. This was during WWII and the connecting rod was from a 1710 cubic inch piston engine that was used for aircraft. Our test machine would load the rod alternately to 15,000 pounds tension and 25,000 pounds compression. One day while the rod was on the push-pull test, I stuck my finger into the hole of the large wrist pin. There was zero resistance to turning it (or at least so slight that I could not feel it). My first reaction was that there was a squeezing action on the oil film which was formed between load applications.

John Stone and I then started a mathematical and engineering test program which developed a general equation based on Reynold's equation for a rotating bearing. Some of the conclusions were:

1 Assume that a unidirectionally loaded bearing with a rotating shaft is taken as unity load carrying capacity.

2 If the load is rotated in the *same* direction as the shaft and at the same speed, the load carrying capacity will be unity.

3 If the load is rotated in the *opposite* direction as the shaft and at the same speed, the load carrying capacity is tripled.

4 If the load is rotated in the same direction as the shaft but at half speed of the shaft, the load carrying capacity is ZERO—and failure occurs.

Squeeze films now seem to be well recognized as evidenced by the number of papers which have been squeezed out of the simple basic equation!

Fun and Games in Lubrication

For the 1932–33 Chicago World's Fair, a unique exhibit was prepared. It consisted of a four inch diameter shaft some six feet long which was rotated at slow speed and supported in two end ball bearings on six foot high pedestals. An 800 pound, 16 cylinder Cadillac engine was suspended from two half-bearings on the shaft. The engine moved along the shaft from end to end with no apparent mechanical connection. In fact there was none. In each end pedestal was a fan which blew air, alternately, against the sides of the engine. This demonstrated the near zero friction to lateral movement of hydrodynamic lubrication, with an air of mystery.

An exhibit using the energy of an oil film was constructed for a demonstration in 1948. A rather small bearing was run at moderate speed. When a person stood on a platform supported by the bearing, the maximum oil film pressure was roughly linear to the weight of the person. Then a pressure gauge, reading the maximum oil film pressure, was calibrated in pounds on the platform. The only mistake was that the gauge read an honest weight. In the first hour we had so many complaints from the ladies that we quickly made a lower reading scale!

Another feature was that the platform would "automatically" rise several inches whenever one stood on it to get weighed. The oil line from the top of the bearing also ran to a cylinder and piston. The oil which was bled from the bearing lifted the platform. As soon as one stepped off the platform, the oil leaked back out of the unloaded bearing. We had a sign next to the exhibit which said "LIFT YOURSELF BY YOUR OWN BOOTSTRAPS."

It Runs Longer Than Time

For an Auto Show, we constructed an air-pressured bearing according to Kingsbury's 1898 thesis done while he was at Cornell University. A flywheel on the bearing would be spun to a known speed in the morning and a clock would show the time of start. An identical flywheel with a ball bearing (so-called antifriction bearing) was similarly spun. The exhibit was the idea of J. B. Bidwell.

In the usual show tradition, the exhibit was not finished until it was time to ship it to New York. When it was run in New York, the ball bearing only ran a few hours. The air-pressurized bearing continued so long that we had to make a 24 hour clock to indicate the elapsed time!

Lubrication Is Worse

A GM division made an exhibit for the same auto show. It consisted of three separate drums about 12 inches in diameter, each running at the same speed. On the top of each vertically running drum was a fitted shoe with a weight on it, and a string to measure the pull of friction by a "fish scale." Two of the drums were lubricated by regular engine oil and castor oil, while the third drum was dry. Of course it was supposed to show that the dry bearing shoe had the highest friction, the regular oil had less and in those days there was a general belief that castor oil would show the lowest friction.

Again the exhibit was not run until it was set up in the Waldorf Hotel in New York. The next morning I received a phone call telling me that the demonstration was "reversed." The dry drum friction was lowest by far; the regular oil was "in the middle"; and the castor oil was very high! I leave it to you, the lubrication engineer—why was this occurring and what would you have told them to do?

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