needs—Tests of Oil-Film Journal Bearings for Railroad Cars

Discussion

P. G. Exline. The writer is particularly interested in this paper because of some work of a similar nature carried out at the laboratories of the Gulf Research & Development Company during 1942. A standard A.A.R., 5 X 5 journal and bearing was used for a series of tests to compare the performance of a bearing having a normal diametral clearance of 1/16 in. with that of a bearing having 0.005 in. clearance. The load, 30,000 lb, was above normal, while the speed range was equivalent to 21/2 to 30 mph on a 36-in. wheel.

Measurements were not made of the coefficient of friction, but the bearing temperatures indicated a qualitative agreement with the data reported by the author.

It was noted that after a period of operation at 30 mph, the standard-clearance bearing would often show signs of distress when the speed was reduced to 21/2 to 5 mph. This did not occur with the 0.005-in-clearance bearings, indicating a higher factor of safety. The standard-clearance bearing also took a longer time to accommodate itself to a reversal of the direction of rotation even though it had been well run-in in the forward direction. In this respect, the low-clearance bearing behaved as one which had been well run-in for both directions of rotation.

The test journal was mounted substantially the same as the Pearce machine, in that it was supported by a spherical roller bearing at the wheel seat. This bearing was cooled by adjusting the temperature of the stream of oil pumped through it. It was found that changes in the temperature of this bearing could influence the temperature of the test bearing. It seems evident that the wheels of a railroad car can act as cooling fins and dissipate an important fraction of the heat developed in the oil film.

The author's results and those of the writer suggest that a properly designed railroad bearing with bath or oil-ring lubrication and having adequate protection against oil loss and tampering would provide trouble-free performance with less maintenance than the present bearings.

M. D. Hersey. This report not only shows how the problem of conservation of bronze and babbitt was solved, but offers in connection therewith a large amount of carefully checked information on the design and performance of railroad-car bearings. Of special interest is the use made of the theory of lubrication to calculate the "all-important" minimum oil-film thickness, and also the friction loss, with the aid of actual temperature measurements.

Might it not add to the permanent value of this record if the author would refer to the formulas or curves used for these calculations? The necessary procedure is not entirely obvious to the writer, and doubtless many other students of lubrication would appreciate an outline of the steps in a completely worked example.

J. R. Jackson. It was the writer's privilege to be associated with the author during the test program treated in this paper. The data made available through this research constitute a distinct contribution to the knowledge of railroad-car journal-bearing design and lubrication. Furthermore they indicate the direction for the betterment of the journal-box assembly of the future by utilizing more completely the advantages which an oil-lubricated solid-type bearing has over the present conventional waste-pack journal box.

It is perhaps difficult to understand why the present conventional design of railway-car journal-box assembly has been retained down through the years, and why advantage has not been taken of advances in the art of bearing lubrication to replace the waste-pack originally used and continued without essential change on the American railroads for a hundred years. The answer is simplicity and reliability together with long-established standards and practices of operating cars in interchange service, and the relatively large number of units in use.

It probably should be stated that the simple expedient of removing the waste pack and filling the bottom of the journal box with oil, as was done during the laboratory tests, would not work out in service because the oil could not be retained in the box. Bath or flood lubrication would necessitate a redesign of the conventional box to insure oil retention. This question of oil retention in the conventional journal box is also pertinent, in lesser degree, to some forms of pads or wick-type lubricators which have had limited service trials on railway equipment in this country. Completely redesigned journal-box assemblies, employing flood lubrication and other refinements, including provision for oil retention, have been developed and used in considerable numbers on some roads on equipment operated in on-line service. These have not found sufficient favor to be considered for adoption as standard in interchange freight service.

The increasing use of roller bearings for passenger equipment and their development for freight equipment will no doubt result in a reconsideration of the design, service, and economics of railway-car journal bearings in the immediate future. It is felt that this paper is a distinct contribution to the literature on this subject, and that a similar line of investigation of the roller bearing for railway equipment should be carried out.

L. B. Jones. In studying this report it should be borne in mind that the comparison between broached and fitted bearings was made with broached bearings which were just "starting out," so to speak. In other words, in actual service the broached bearing will continue to enlarge its contact area until it approaches the condition of the fitted bearing, with resultant improvement in oil-film condition.

While the tests were run mainly to determine oil-film conditions, it will be of interest to railroad men to note that the A.A.R. standard journal lining gave a good account of itself, and nothing developed in the test to indicate the necessity for a change in its composition.

The two principal indictments of the time-honored waste pack, pointed out by Mr. Pearce in his comments on this paper, are again highlighted in this report. The actual friction of the waste pack is equal to, or greater than, the bearing friction; and it also acts as a thermal insulator to discourage radiation of heat from the journal.

The drawbar resistance in pounds per ton due to the friction load on the journal, as indicated in Fig. 20 of the paper, shows that the journal friction is a relatively small part of the total resistance of loaded freight cars on level track, as determined by dynamometer tests. It therefore appears that improvements in journal-box performance will pay their largest dividends in hot-box insurance rather than in decreasing the rolling resistance of the train.

F. K. Mitchell. The author prefaces his remarks on the his...
tory of the improvements on railway-car bearings by the statement, "Despite the importance of the railway-car bearing and the great number replaced annually, little effort has been made to improve its performance." If he intended to say by that remark that the bearing itself had undergone very little improvement prior to the war period, his statement is unquestionably true, but the insinuation that little effort has been made to improve the performance of the bearing cannot be substantiated. Over the years, journal boxes, dust guards, wedges, and other related parts used in the assembly, of which the journal bearing is a part, have been subjected to a great deal of experimentation, and many important facts have been learned thereby, and certain very productive changes worked out and put into practice.

It is essentially true that the most extensive changes in the bearing itself have come about since the beginning of the war, and are children of necessity. These changes involved not only the bearing but also the lining and were promulgated through the necessity of minimizing the amount of critical materials required to produce a bearing of a certain size. As to the lining, the efforts in this respect have been confined generally to reducing its thickness and to producing a lining made of substitute material, both in order to save babbitt. It is generally conceded that the reduction in the thickness of the lining accomplished the required end. Substitute lining described by the author as a metal composed almost entirely of lead, alkali-earth-hardened, has not been entirely satisfactory, which fact cannot be discounted. On the other hand, the results so far obtained in the use of such a lining certainly do not warrant the complete discarding of the idea of its use. On the contrary, it is evident from the experience to date that further experimentation and development of such a lining offer worth-while possibilities.

The second series of major changes in the bearing itself, made to reduce the amount of critical material in the bearing back, has been enlightening, and also seems to be producing the desired results. There are still some features in connection with the various redesigned backs which have been offered for this purpose that need further study. These studies will no doubt be undertaken by the committee, of which the author is a member, in due time. Further comment in this regard will be made later.

It is unfortunate that the laboratory test equipment which was used to make the study under discussion does not duplicate in a practical manner the actual service conditions to which bearings are, in fact, subjected. It will be noted that the bearings were subjected to a constant uniform load of 16,375 lb. In actual service the load, of course, varies. Furthermore, in actual service the bearing is subjected to severe vertical and longitudinal shocks which the test equipment as used was unable to duplicate. This, it is felt, in itself materially affects the practicability of the information developed. It is pointed out by the author, under "Discussion of Results," "maintenance of sufficient oil-film thickness is the deciding factor in successful bearing operation." Therefore it would appear quite evident that the maintaining of such an oil film under the conditions imposed by the test apparatus is an entirely different problem from that which is found in actual service where, even under normal conditions, the bearing is constantly being disturbed by vertical shocks originating from uneven rail joints, etc., and longitudinal shocks arising from brake applications, slack action, etc.

While discussing the matter from the point of view of oil film, it should also be understood that with the laboratory test equipment used in these experiments, the journal being the driving instead of the driven element, the greater bearing clearance occurs on the rising side of the journal, whereas in actual practice the journal is driven by the bearing and the greater clearance is on the opposite side of the bearing. Hence under laboratory conditions the oil film produced by any method of lubrication, and under any bearing conditions, would be more favorable than under circumstances of actual usage where the clearance is the minimum on the rising side of the journal.

These facts in themselves make questionable the acceptability of some of the results obtained in this series of tests. They certainly do so to the point of discrediting the definite conclusion that "pad and waste pack are capable of supplying sufficient oil to maintain complete fluid-film lubrication at speeds at least as high as 300 mph, and that "the railway-car bearing is capable of carrying its maximum load without failure at temperatures at least as high as 375 F." Here it might also be noted that because many failures of bearings result from causes other than heat generated, the design of the back is an important factor, and unless it is shown that the back, however physically composed, is not only so designed as to distribute uniformly the load over the bearing area, but also is of such strength as to prevent breakage, then it cannot be concluded that the railway-car bearings tested were capable of carrying their maximum load without failure; this regardless of temperature. It is quite obvious that no failures from causes other than heating would be expected when the tests were conducted with the laboratory equipment which was used in these experiments, and the answer to this question was not obtained for any of the bearings under test.

It might also be said in passing that in the observation regarding heat transfer from the bearing to the related parts of the bearing-and-box assembly two confusing statements are incorporated in the report. The first is that the depressed-back (E. S. Pearce patent) bearing applies the load near the ends of the bearing instead of at random. Actually, this bearing applies the load over all but the one third of the area in the center. The application of the load near the extreme ends of the bearing has long since been proved to be mechanically incorrect. It is further stated that the back of the so-called "depressed-back bearing" is now machined. It will be found on check of the records that only a few railroads actually machine the back of the so-called "depressed-back bearing" for bearings used in passenger service, and that generally no roads are machining the depressed-back bearing used in freight service.

As to the transfer of heat, because of the greater contact area and therefore the improved heat transfer to the wedge, it will be interesting to note that bearings 93 and 95 have the large back area referred to, whereas bearing 94 has only four small bearing areas, nowhere comparable to that offered by bearings 93 and 95; yet the tests show that bearing 94 produced journal-temperature, bearing-temperature, and box-temperature rises at various speeds which generally lay between that of bearings 93 and 95. No explanation for this fact either in the ease of the fitted bearing or the broached bearing is offered.

Regarding the question of whether or not the broached and unfitted bearing is more satisfactory than the broached and fitted bearing: The author concludes, and the data developed indicate, that better results can be expected from a fitted bearing. While this is interesting, and no doubt true, it has no practical value for the reason that the expense and delay involved in fitting the bearing, particularly to freight cars, would in nowise be offset by the results obtained.

The data developed and conclusions reached in connection with the relative values of bath, pad, and waste lubricating systems would indicate that the committee has concluded from the results obtained that waste-packed lubrication is less satisfactory than pad lubrication and bath lubrication. This is no doubt true if it were not for the practical side of the problem. Certainly bath lubrication is a far cry from being practical at present. Pad lubrication is more or less in its infancy and offers considerable possibilities, yet, at the moment, the writer knows of no practical means of avoiding excessive loss of lubricant in the present freight-
car box assembly where either bath or pad lubrication is used. Here again a factor arises which the test equipment used by the committee does not bring out. The entire matter does emphasize the necessity for further experimentation and development along the desirable lines indicated by the tests.

As to the effect on drawbar resistance, neither the data having to do with the friction of the broached or unbroached bearing nor pad nor waste-packed boxes are of much practical value.

It is worthy of note that speeds for use in connection with these experiments (40, 80, and 100 mph) were selected. While 40 mph represents pretty closely the present freight-train movement, the immediate future no doubt will mean speeds for freight-train movement between the figures of 40 and 80, throughout which range the report is silent as to what might be expected. The author comments on this fact in his conclusions. It is regrettable that data were not also secured for speeds of 50, 50, and 70 mph.

While as previously indicated, the data submitted in this report are interesting, although in a great many respects somewhat impractical, it is respectfully suggested that either test equipment which will more closely simulate actual operational conditions should be designed and used for such a series of experiments, or final conclusions should be based on actual experience in the field.

E. S. Pearce. On certain phases of railroad journal operation this paper sets out most clearly two points of general and practical interest:

1. The very low power loss chargeable to the conventional journal-box assembly.

Power loss in journal friction as a factor in total train resistance is a particularly timely subject, as the railroads are contemplating operation at higher maximum and higher average speeds. The values given by the author cast considerable doubt on the advisability of substitution of roller bearings for solid bearings as a matter of sound economics.

2. The separation of the power loss between bearing and lubricating medium.

To those confronted with the everyday problems of journal operation, the significance of packing friction losses relative to those of the bearing alone will be of considerable practical interest.

Analyzing the author's paper in the light of the two major disclosures, obviously, much of constructive value to the railroads in the operation of a conventional journal-box assembly would result from a further exploration of this subject through a lower range of speeds and temperatures in combination with various methods of lubrication, lubricants, and bearing construction now available.

The accepted formula for calculating freight-car resistance on straight level track is

$$ R = 1.3 + \frac{29}{w} + 0.045V + \frac{0.0005A V^2}{w} $$

Fig. 21 of this discussion has been superimposed upon the author's Fig. 20 demonstrating what a small portion of total resistance can be charged to journal friction at the load and speeds used in the paper.

The values given by the author for power losses are roughly one tenth of that given by the first two terms of Equation [1] of this discussion.

Journal operating temperatures in this paper are at a level much higher than the generally accepted limit for safe performance in service. This is due in large part to operation in the still air of the laboratory. Pearce shows the magnitude of this difference at lower speeds than covered in this paper.

Another contributing factor to the high temperature obtained with the waste pack was the use of "oven-dried" waste as so designated by the author. In investigations of this kind, in the interest of accurate duplication of results, oven-drying of waste is done to offset the variation in moisture content and the effect on temperature which would otherwise exist between various samples of waste. In preparing the waste for test purposes it is dried at a temperature of 220°F. The effect of this drying upon operating temperatures is shown in Fig. 22 of this discussion.

The contribution of the lubricating medium to the total power loss of the bearing assembly has never been fully appreciated. The placing of a waste pack in a journal box is very similar to the installation of an opposed bearing, as there is an upward pressure of the waste pack against the lower half of the journal. Fig. 23 shows how this contributes to the elevation of the running temperature as the amount of packing at the same oil-waste ratio is varied in the same journal box.

To verify the power losses of the lubricating medium, as shown in Fig. 14 of the paper, a study was made of the reduction in power input to the driving motor by the momentary lowering of the lubricating medium from contact with the lower half of the

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journal. This was accomplished by the use of the bearing described by Pearce as bearing No. 18, this bearing being capable of operation for sustained periods on the stored oil. This time interval was quite adequate to take the necessary instrument readings. The box used was split on its horizontal center line and mounted on a jack so that it could be quickly lowered and again raised. Results are shown in Fig. 24 of this discussion, and comparison with the author's Fig. 14 indicates that the calculated loss of the lubricating medium is in good general agreement with the experimental findings.

R. J. Shoemaker. In connection with the results obtained with pad lubrication reported in this paper, we may state that one of the major trunk-line railroads of this country has been using pad lubrication (Magnus type) very successfully for a number of years past in connection with oil lubrication of driving-box brasses of main passenger and freight power, also on main-line passenger cars, locomotive tender, and locomotive truck and trailer brasses.

By the use of pad lubrication, considerable economy of operation has been accomplished as shown by reduction in the number of hotboxes, increased service life of the bearings, and correlated parts, reduction in friction, etc., as compared with results obtained with conventional lubrication formerly used.

With regard to the economy of materials accomplished in the tests of new types of bearings reported in the paper, the author states, "Since there appears to be no satisfactory substitute for babbitt, reduction in quantity is the only open course." The author further states that in redesigning the prewar type of journal bearing, the babbitt was reduced 50 per cent in weight, or in other words, reducing the lining metal from 1/4 to 1/8-in. thickness, as was done in the A.A.R. emergency-type bearing used in the early years of the war. However, in view of the unsatisfactory performance in service of this 1/8-in. lining, the babbitt metal was later restored to its original 1/4-in. thickness, as now used by the railroads in the present type of A.A.R. emergency journal bearing.

With regard to a satisfactory substitute for babbitt metal, we may mention that our company developed and put on the market a number of years ago an alkali-earth-hardened lining metal for bearings known as "Satco" metal, which is having widespread and successful use as a substitute for lead- and tin-base babbitts, block tin, etc., in various types of railway and other bearings.

This metal is a lead-base alloy containing from 95 to 98 per cent lead with the balance calcium, tin, and other hardeners. It contains no antimony or copper. During the late war great economies were effected by the use of Satco bearing metal in vital materials such as tin, copper, antimony, etc. Satco metal has a melting point approximately 150 F higher than that of babbitt metals with a correspondingly greater hardness at elevated temperatures. Tables 5 and 6 of this discussion show comparative physical properties of Satco metal, A.A.R. babbitt, tin-base babbitt, and antimonial lead at normal and elevated temperatures.

Because of its greater heat resistance Satco-lined bearings perform satisfactorily at temperatures which cause failure by melting in babbitt-lined bearings, consequently the alloy is more resistant to "waste grabs" which are a frequent cause of failure in railway bearings.

In addition to the various types of railway-car and locomotive bearings, Satco metal is also used as a lining in main and connecting-rod bearings and motor-support bearings of Diesel engines. The successful performance of the alloy in this service has been reported by L. M. Tichvinsky.

The author further reports that the lining metal in the "magnus special" bearing tested by the committee showed indications of corrosion during the 80-mph schedule. In this connection we wish to state from our experience with Satco-lined bearings, that corrosion is the exception rather than the rule. In the railway field particularly, corrosion of Satco linings is of rare occurrence.

Under certain conditions, however, particularly with lubricating oils which are compounded with free fatty acids, all types of lining metals regardless of their composition will corrode to some extent.


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**TABLE 5** DEGREES BRINELL HARDNESS OF VARIOUS BEARING METALS

<table>
<thead>
<tr>
<th>Metal</th>
<th>400</th>
<th>700</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satco</td>
<td>23.8</td>
<td>22.8</td>
<td>17.9</td>
<td>15.6</td>
<td>12.5</td>
</tr>
<tr>
<td>Tin-base babbitt</td>
<td>23.8</td>
<td>22.8</td>
<td>17.9</td>
<td>15.6</td>
<td>12.5</td>
</tr>
<tr>
<td>A.A.R. babbitt</td>
<td>17.9</td>
<td>15.6</td>
<td>12.5</td>
<td>10.0</td>
<td>7.7</td>
</tr>
<tr>
<td>Antimonial lead</td>
<td>12.5</td>
<td>10.0</td>
<td>7.7</td>
<td>5.5</td>
<td>3.3</td>
</tr>
</tbody>
</table>

* Indicates metal too soft to determine compressive strength due to excessive deformation.

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**TABLE 6** COMPRESSION STRENGTH OF VARIOUS BEARING METALS

<table>
<thead>
<tr>
<th>Metal</th>
<th>400</th>
<th>700</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satco</td>
<td>6000</td>
<td>4000</td>
<td>2700</td>
<td>2000</td>
<td>1200</td>
</tr>
<tr>
<td>Tin-base A.A.R.</td>
<td>6000</td>
<td>4000</td>
<td>2700</td>
<td>2000</td>
<td>1200</td>
</tr>
<tr>
<td>Antimonial lead</td>
<td>6000</td>
<td>4000</td>
<td>2700</td>
<td>2000</td>
<td>1200</td>
</tr>
</tbody>
</table>

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* Indicates metal too soft to determine compressive strength due to excessive deformation.

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12 Magnus Metal Corporation, Chicago, Ill.
NEEDS—TESTS OF OIL-FILM JOURNAL BEARINGS FOR RAILROAD CARS

Author's Closure

The discussion has brought to light some additional experimental work on the subject. It is hoped that Mr. Exline plans to publish the results of the railway-car journal bearing studies conducted in the laboratories of the Gulf Research and Development Company.

Data on lubricator power losses furnished by Mr. Pearce are most interesting inasmuch as they check the results given in the paper by an entirely independent method. With waste-pack lubrication, Fig. 24 shows the losses somewhat greater than the author's Fig. 14. Losses with the pad are in close agreement with the author's direct method of obtaining his data is probably somewhat more accurate than the author's indirect approach. The results, however, are in good agreement as has been pointed out, and may be said to verify some of the conclusions reached in the paper. Mr. Jones's comment that journal friction is a relatively small part of the total car resistance is well illustrated in Fig. 21.

Detailed procedure in the calculation of bearing oil-film thickness and friction, referred to by Mr. Hersey, was purposely omitted to reduce the length of the text. Basic data for these calculations will be found in previously published papers by Kingsbury and Needs.

The test results bring out the very interesting fact that despite the relatively large clearances of the railway journal bearing, clearances far beyond those permitted in other machinery, the bearing friction is slightly less than with the more normal clearances obtained by running the fitted bearings at operating temperatures. In other words, it appears that the friction of the bearing itself is about as low as can be expected and improvement can be hoped for only through method of lubrication. In this respect, statements by Mr. Jackson and Mr. Shoemaker that some of the railroads of this country have been using flood and paw lubrication for a number of years are significant.

A comparison of the test results given in the paper with similar data on roller bearings for railroad equipment as suggested by Mr. Jackson would be very interesting indeed and it is hoped that the Committee will be able to release such information in the not too distant future.

Mr. Shoemaker's data on variation of bearing-lining hardness with temperature are particularly interesting. From the fact that bearing 93-B carried a load of 1390 psi at 375°F with "A.A.R. babbitt" there appears to be ample babbitt hardness safety factor when operating at the usual loads and temperatures encountered in service.

That part of the discussion which is critical stresses the fact that a bearing under test in the laboratory is not meeting actual service conditions, and for this reason the test results are not of practical nature. When planning the tests the difference between laboratory and service conditions was realized. For example, it was not expected that the machine in which the tests were run would give any information on the ability of the bearing to withstand collar cracking forces. Such information is readily obtained by placing the bearing in service. The main objects of the laboratory tests were to investigate bearing friction and method of lubrication under steady comparable conditions and to compare these characteristics with those of the fitted bearing on the assumption that the fitted bearing was the best obtainable for the service. Since all successful bearings in actual service operate by virtue of their oil films, comparisons under comparable conditions of various methods of feeding these oil films are entirely valid, hence practical, regardless of whether the data are accumulated in the laboratory or on the railroad. In order to make the tests comparable they had to be run under steady conditions and since there are very few stretches of track where a train can run 80 or 100 mph for eight consecutive hours, the difficulty of obtaining our data from service is apparent. In some respects the conditions of the laboratory tests were more severe than the bearing would meet in service. Proof of this is the fact that every bearing surviving the laboratory test gave a good account of itself in service.

One or two other points raised by Mr. Mitchell can be answered more specifically. It is quite true that in a railroad car the two opposite bearings push the axle and wheels along. The horizontal component of the load which provides this force is essentially small as compared with the vertical component due to the weight of the car and its load. However small the horizontal load may be it causes the bearing center line to lead the journal center. This, however, has no effect whatever on formation of the oil film. Only the converging portion of the oil film can possibly generate positive load-carrying pressures. In the testing machine the load-carrying area is in the center of the bearing as shown in Figs. 11, 12, and 13. Because the bearing must carry the axle and wheels along in actual service the load-carrying bearing area will be shifted from the center a very slight distance opposite the direction of rotation. Under comparable operating conditions the films will be exactly the same otherwise.

Regarding heat transfer from bearing to wedge, the test results seem to indicate that the smaller contact area of bearing 94 is not a matter of concern. As Mr. Mitchell has pointed out, the operating temperatures of bearing 94 are much the same as the temperatures of the other two bearings under the same operating conditions. This would be expected inasmuch as friction is approximately the same with each of the three bearings. It will be noted from the tables, however, that the temperatures of bearings 93 and 95 are generally several degrees lower than the journal. With bearing 94 this difference is only a degree or so, the smaller difference being due to less contact area between bearing and wedge.