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DISCUSSION

John R. Barton[2]

From the metallurgical sectioning results of this paper and the more comprehensive results of Barton and Lankford [12] covering the same investigation, it is apparent that magnetic perturbation inspection can be used effectively to precisely predict the size and location of near surface inclusions in bearing races. Kusenberger, et al. [28] have shown that signal amplitude can be related to inclusion size, Fig. 15. With simple cyclic stressing conditions (uniaxial tension), such near surface inclusions have been shown to be dominant sources of fatigue crack initiation [28], and the

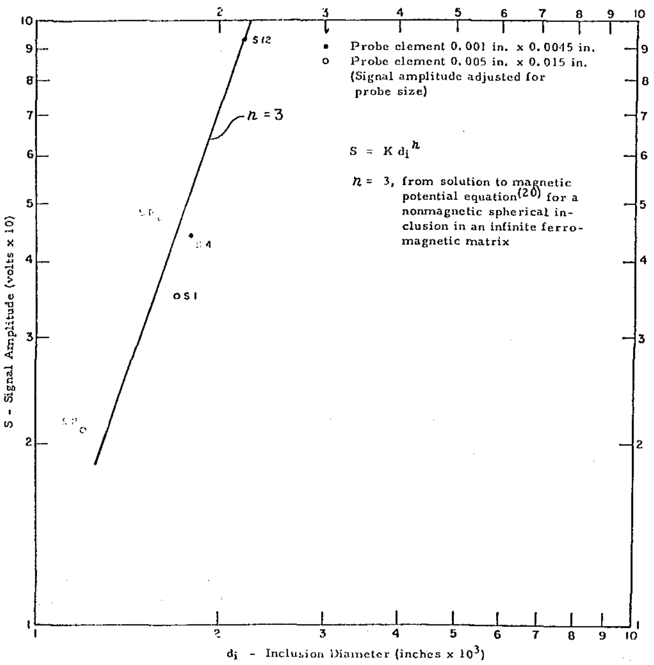

Fig. 15 Functional dependence of magnetic signal amplitude on inclusion size

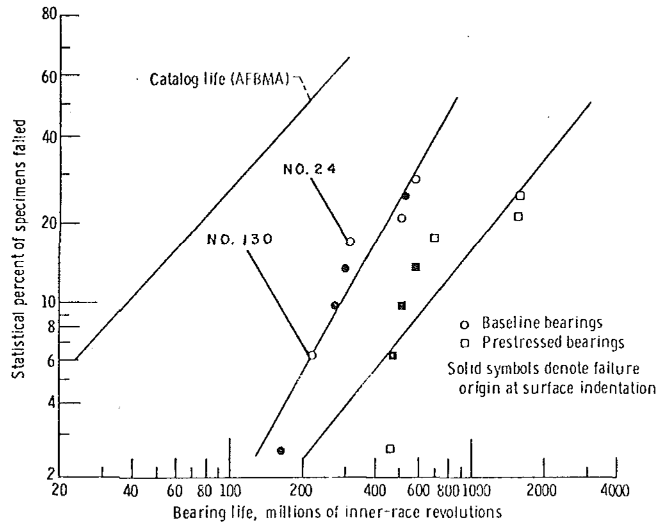

Fig. 17 Results of fatigue tests with 207-size ball bearings tested at a radial load of 5860 newton (1320 lb) and a shaft speed of 2750 rpm with a super-refined naphthenic mineral oil

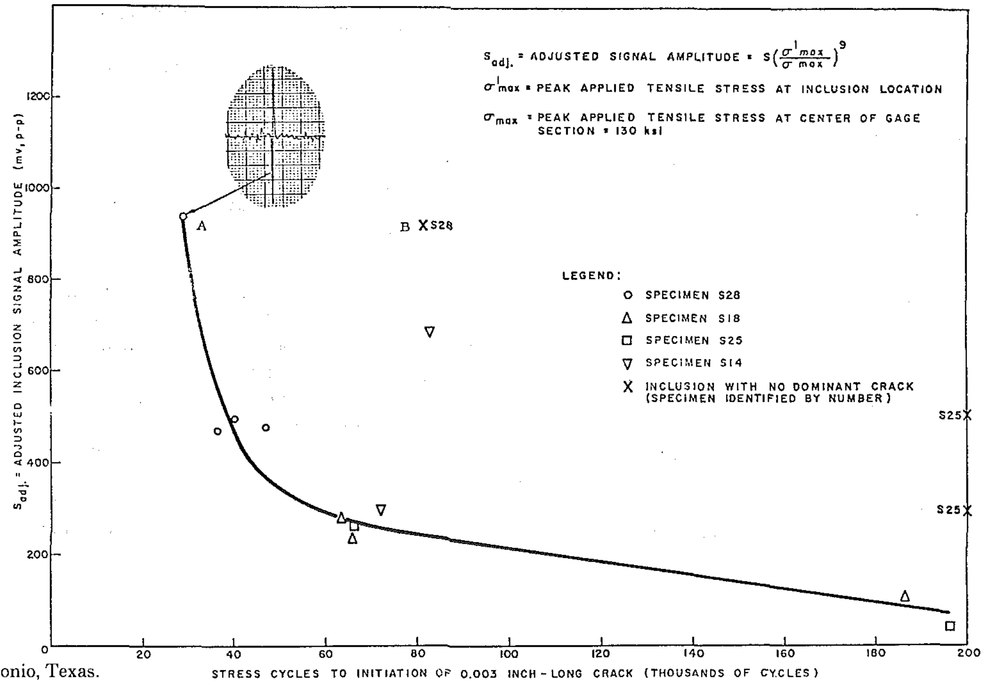

Fig. 16 Precycle inclusion signal amplitude versus stress cycles to initiation of 0.003-in. crack

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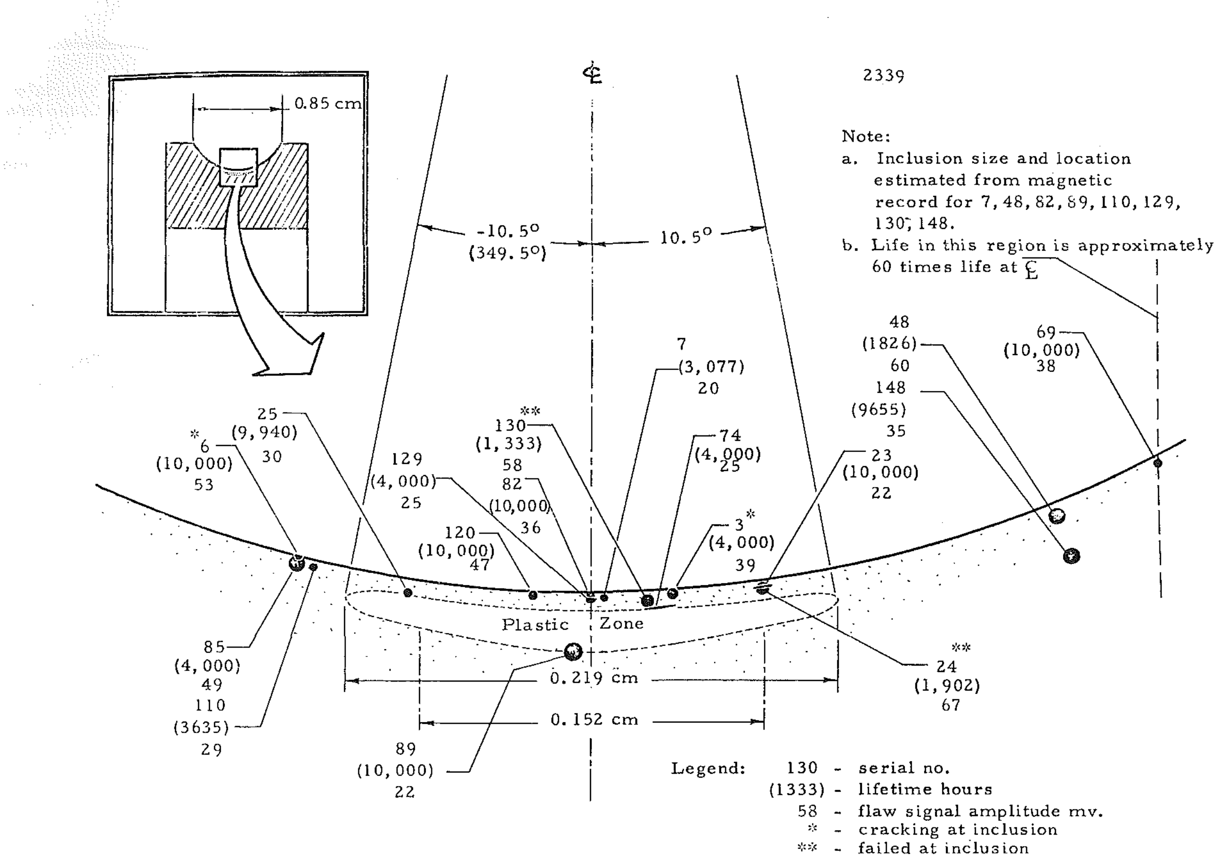

Note:
a. Inclusion size and location estimated from magnetic record for 7, 48, 82, 89, 110, 129, 130, 148.
b. Life in this region is approximately 60 times life at ℄

Legend:
130 - serial no.
(1333) - lifetime hours
58 - flaw signal amplitude mv.
* - cracking at inclusion
** - failed at inclusion

Fig. 18 Schematic showing inclusion locations and subsurface plastic zone

time to develop a 0.003-in. long fatigue crack is functionally related to signal amplitude, Fig. 16. Whether such inclusions will be dominant or even statistically important sources of fatigue spalls in ball-bearing races (where stresses are complex) cannot be determined directly with high confidence from the results presented in this paper.

The Weibull plots of Fig. 17 (from [14]) and the diagram showing inclusion location and size in Fig. 18 help clarify the situation. In Fig. 17 for the baseline bearings it is significant that specimens No. 130 and No. 24 failed at the precise location of the magnetic perturbation signal and respectively at 6 percent and 16 percent statistical life.

These two "early failures" could have been eliminated by rejecting only those specimens with magnetic perturbation signatures greater than approximately 60 mv. Of the 100 specimens inspected, only three specimens, numbers 130, 24, and 48, are in this category. Specimen numbers 130 and 24 failed; not only were these inclusions large, but they were located in the region of high stress, i.e., near the center of the ball track as shown in Fig. 18. Also, these inclusions were 0.0020 in. and 0.0014 in. deep, respectively (the edge of the plastic zone is 0.003 in.), which is in the region of minimum residual compressive stress measured on these bearings and shown in Fig. 1 of [14]. Specimen number 48 was in a region where the stresses were relatively low.

It is pointed out that sectioning disclosed cracking at the inclusion in specimen number 3 after 4000 hr endurance running. To eliminate this specimen, which would probably have failed with additional running, requires setting the rejection limit at approximately 40 mv. Only nine bearings (3, 6, 24, 48, 69, 85, 120, 130, and 148) from the total group of 100 are in this category. Two failed (24 and 130); two have cracking at the inclusion (3 and 6); four are outside the region of high stress (48, 69, 85, and 148); and one was prestressed (120).

Accordingly, it is suggested that these limited results are very encouraging, and further evaluation will be required to refine the prediction capability and to provide a more adequate statistical base.

Additional Reference

28 Kusenberger, F. N., et al., "Nondestructive Evaluation of Metal Fatigue," Scientific Report AFOSR-TR-73-1070, AD 762 608, 1973.

Author's Closure

The author agrees with Dr. Barton that the results of these tests are encouraging and show the ability of this nondestructive technique to detect inclusions in bearing races. To show statistical significance in fatigue life results would apparently require a fatigue test program of much greater scope that the present program, specifically a greater amount of subsurface fatigue failure data. With the cleaner vacuum-processed (consumable-electrode vacuum-melted or double vacuum-melted) steels currently used where high reliability is required, the effect of inclusion-initiated fatigue has been minimized. As a result, such data will be extremely difficult, if not impossible, to obtain.