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QRDUK/LAS4/R-QRDUK

DRAFT REPORT

MAIN BEARING SHELL ANALYSIS
#2B EMERGENCY DIESEL GENERATOR
DUKE POWER COMPANY - CATAWBA UNIT #2

Prepared for

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1.0 INTRODUCTION

At the request of Duke Power Company, Failure Analysis Associates (FaAA) examined damaged main bearing shells from two sequential failures of the No. 7 main bearing of the 2B Emergency Diesel Generator, Catawba Nuclear Station, Lake Wylie, South Carolina. This diesel engine was manufactured by the Engine and Compressor Division of Transamerica Delaval Incorporated (TDI). The engine builder also fabricated the babbitt-electroplated aluminum bearing shells from castings supplied to TDI by Alcoa.

The first failure occurred after more than 180 hours of operation of the engine for test purposes at Catawba Nuclear Station. The first pair of failed bearing shells was the set originally installed by TDI prior to shipment of the engine to Catawba.

Upon removal of the bearing shells after the first failure, a replacement pair of bearing shells was installed by Duke Power Company's maintenance personnel assigned to diesel engine maintenance at Catawba Nuclear Station. This set of replacement bearing shells failed after approximately two minutes of operation of the engine. Subsequently, they were replaced with a third set of bearing shells which reportedly have operated successfully for over 100 hours, as confirmed by repeated visual inspection.

2.0 EXAMINATION OF FIRST FAILURE BEARING SHELLS

A preliminary visual examination of the failed bearing shells was conducted at Duke Power Company's General Offices in Charlotte, North Carolina. Later, these shells were delivered to Failure Analysis Associates in Alexandria, Virginia, for detailed laboratory investigation, including photodocumentation, chemical and metallographic examination, and fractography by scanning electron microscope (SEM), supplemented by energy dispersive x-ray spectroscopy (EDS) for chemical identification of fractographic features. Dimensional checks of remaining bearing shell wall thickness were also performed.

The upper bearing shell was intact, but the majority of the electroplated babbitt on the I.D. had been wiped from the surface. The lower shell was completely devoid of babbitt, and the nickel diffusion barrier/bonding layer was flaking and peeling off at the aluminum alloy substrate. The identity of the flaking nickel layer was confirmed by EDS of a sample of the material. The lower bearing had been fractured into three pieces. The main fracture ran primarily through the circumferential I.D. oil groove, and then traversed one land of the bearing near one parting line. A small triangular piece also was broken off of the main fracture at a locating notch on the opposite parting line.

The relative ages of various portions of the fracture could be judged by the degree of darkening of the fracture surface caused by exposure to lubricating oil which contains fine, black combustion soot in suspension. The older fracture surface adjoins the small triangular section, while the fresher or newer fracture is the fracture that traverses the land at the opposite end of the bearing shell.

Fractography via SEM showed features consistent with a fatigue fracture of the older surface and dimpled overload failure of the newer surface. In addition, EDS of material on the older fracture surface showed that it was lead-based babbitt from the overlay.

Chemical analysis of the aluminum proved that it met the requirements of the specified alloy, B852. Metallographic examination of a polished cross-section revealed a microstructure typical of TDI aluminum bearings with a well-dispersed tin phase and minimal, fine porosity and, as such, was not deficient in any way.

Thickness checks of the remaining bearing showed it to be consistent with the specified bearing thickness, with allowance made for the missing babbitt layer.

Examination of the lower bearing shell O.D. disclosed non-uniform contact between the shell and the bearing saddle in the engine base. Figures 1A and 1B show the range of contact evidence, from almost no contact (Fig. 1A) to normal contact (Fig. 1B), the latter characterized by the normal embedding of ferrous oxide in the aluminum.

The primary feature of note is the evidence of severe scoring by foreign particles on the bearing shell I.D. Figures 2A, 2B, and 2C show the degree of scoring on the lower bearing shell in which hard particles significantly larger than the overlay thickness abraded the surface and embedded themselves in the aluminum. Figures 3A and 3B document scoring of the upper (unloaded) bearing shell by relatively large particles. In addition, Duke Power Company engineers reported that the No. 7 main journal had been scored by large (many thousandths of an inch) hard particles, and that other, unfailed main bearing shells, e.g., Nos. 4 and 6, had high levels of dirt scoring and embedded particles. This is consistent with the reported history of Engine 2B's suffering contamination from grit-blasting media during the construction activities at Catawba Nuclear Station.

3.0 EXAMINATION OF SECOND FAILURE BEARING SHELLS

A visual examination of the bearing shells experiencing the second, very short-term failure showed severe wiping on the generator end bearing land, with removal of babbitt down to the nickel barrier, and moderate wiping of the governor end bearing land. Witness marks showing interference between the bearing locating keys and the bearing shell relief cutouts were evident in the lower shell cutouts. No other examinations of this set of bearing shells were deemed necessary.

4.0 DISCUSSIONS AND CONCLUSIONS

The circumstances and the evidence for the second failure all indicate that misalignment due to misinstallation was the root cause of failure of the bearing shells. The very short life is characteristic of the "infant mortality" suffered by misinstalled bearings. The arrangement of the locating keys and cutouts in the TDI engine make it sensitive to misalignment in that axial misplacement of the bearing shell will result in pinching of the bearing shell onto the crankshaft at the parting lines, preventing development of a hydrodynamic oil film and leading to wiping failure. As a result of the failure, a crack was induced in the lower bearing shell, probably representing an overload fracture due to combined differential thermal expansion and high, localized operational stresses.

The circumstances and evidence of the <u>first</u> bearing shell failure are not as diagnostic of the root cause. Clearly, the order of events was fatigue cracking of the bearing shell, with propagation to an extent that bearing movement interrupted the hydrodynamic oil film, causing wiping and the final failure. The extrusion of lead-base babbitt into the fatigue crack demonstrates that the crack existed before the wiping, while babbitt was still present on the bearing shell I.D. The subsequent wiping event probably forced the babbitt into the crack.

The fatigue crack appears to have had two contributing causes: The non-uniform O.D. contact pattern on the lower bearing shows that it was not seated perfectly in the bearing saddle and, thus, was not installed in its design condition. This would cause normal operating loads to develop higher than normal cyclic stresses in the bearing shell due to concentrated reaction loads and induced bending. Secondly, the large amount of embedded debris in the bearing I.D. also caused local stresses to be higher than normal. Embedded dirt particles displace bearing material, some of which is forced inward toward the crankshaft. These areas then support more of the operating loads than the nearby unaffected areas, raising local cyclic stresses. Due to the destruction of the surface details during the wiping incident, and lack of any way to characterize quantitatively the effect of the non-uniform O.D. support, it is now impossible to assign degrees of contribution among the two fundamental causes of the failure, minor misalignment and major particulate embedding.

It is very likely that both circumstances were necessary for this first failure to have occurred. There is no reason to suspect that the No. 7 main bearing had significantly more particles embedded in it than were embedded in other main bearings which did not fail. Thus, particles alone probably did not cause the first failure. Also, the length of operating time, 180 hours, is beyond the time that misinstallation normally will cause a failure. The explanation that best fits all of the evidence is that the combined effects of initial minor misinstallation and early dirt contamination initiated a fatigue crack that grew slowly during many hours of engine operation, until the compliance of the bearing increased to the point where it could no longer support operational loads and failed catastrophically. Subsequent to these failures, Duke Power Company representatives have reported that thorough engine flushing and careful bearing installation procedures have prevented recurrence of any problems in the No. 7 bearing during more than 100 hours of additional engine operation.

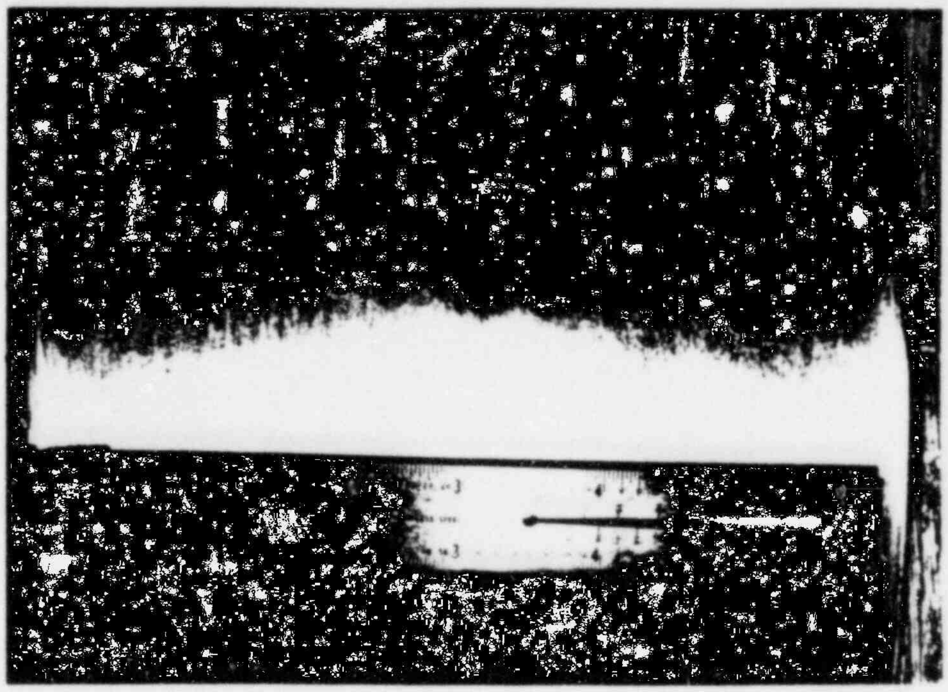

FIGURE 1A. Lower bearing shell O.D. showing minimal contact with engine base bearing saddle. (QRDUK, Roll 3, Exp. 7)

FIGURE 1B. Lower bearing shell O.D. exhibiting normal contact pattern. (QRDUK, Roll 3, Exp. 16)

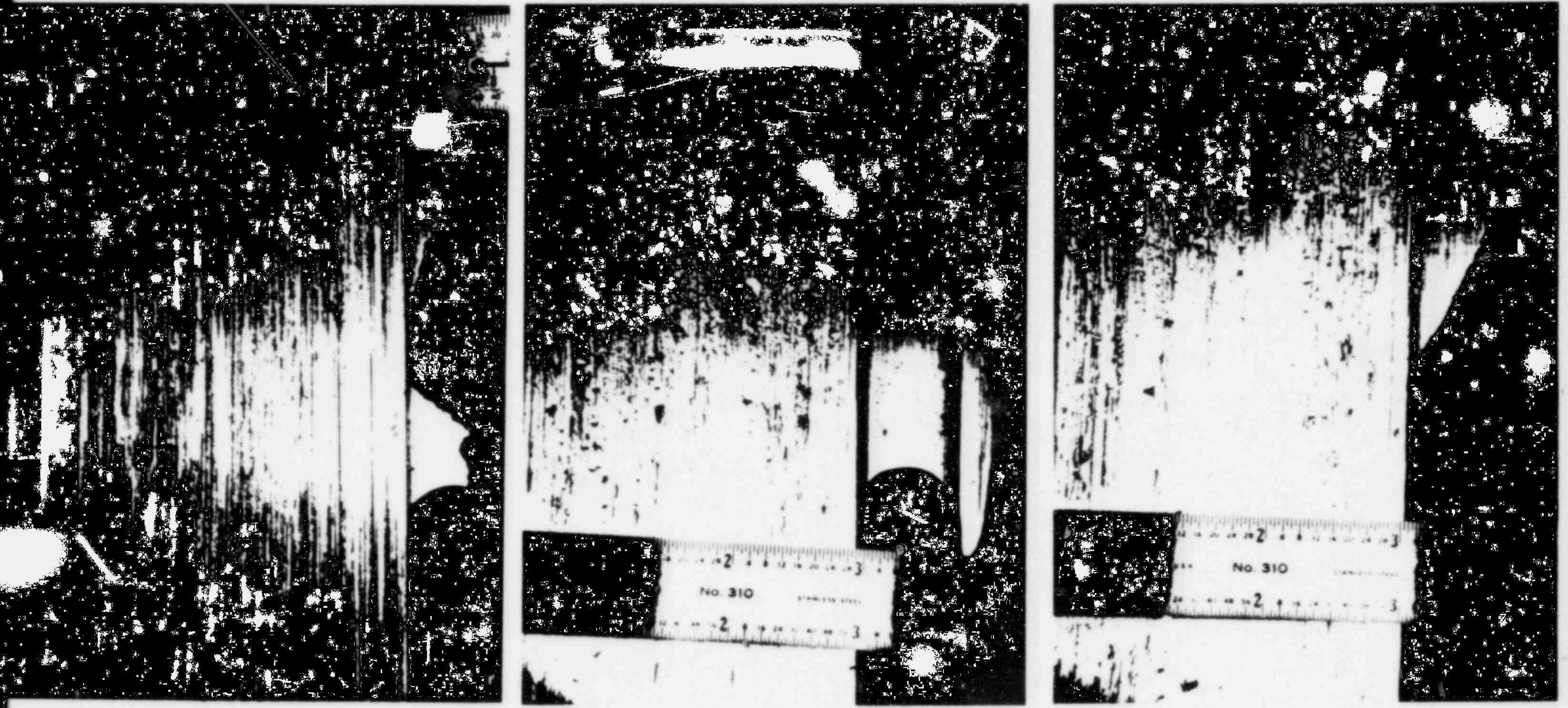

FIGURE 2A. (QRDUK, Roll 3, Exp. 32) FIGURE 2B. (QRDUK, Roll 1, Exp. 14) FIGURE 2C. (QRDUK, Roll 1, Exp. 9)

FIGURES 2A, 2B, 2C: Lower bearing shell I.D. with severely scored surface.

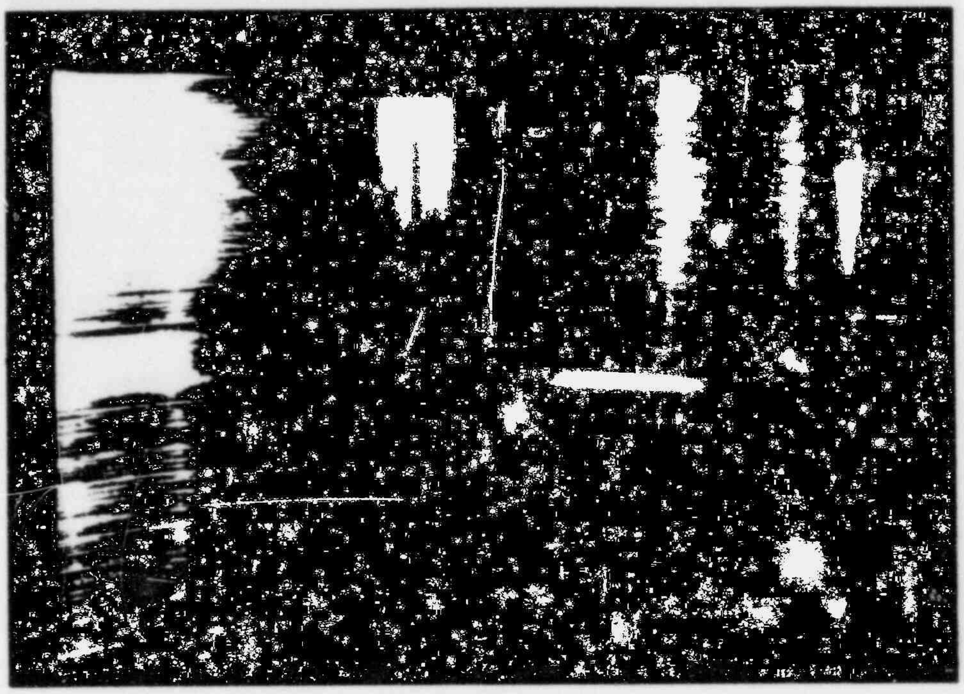

FIGURE 3A. Scoring of upper bearing shell I.D. (QRDUK, Roll 6, Exp. 5)

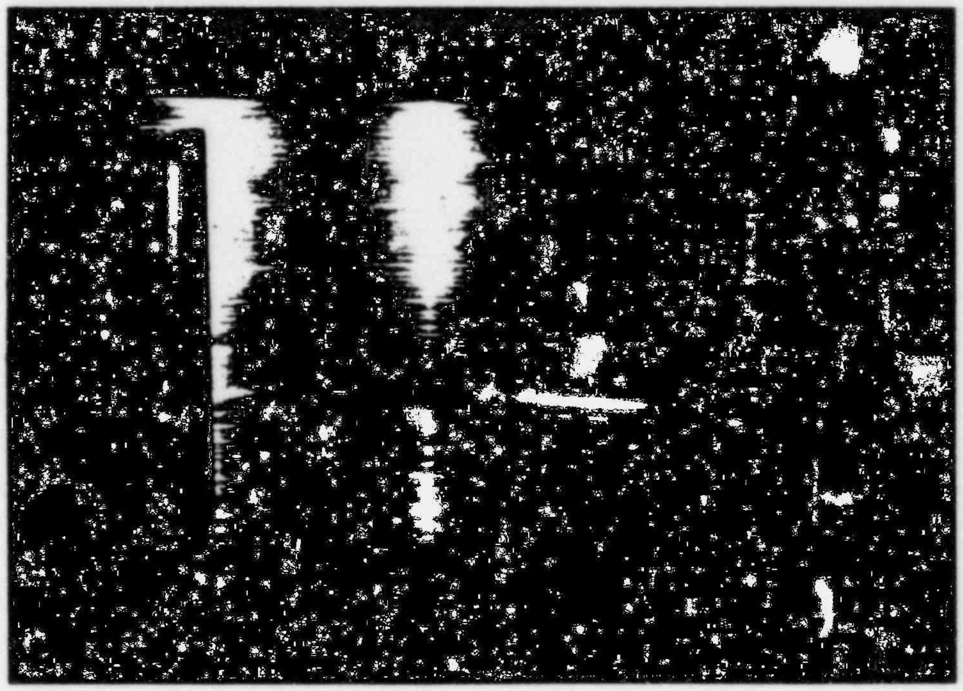

FIGURE 3B. Scoring of upper bearing shell I.D. (QRDUK, Roll 6, Exp. 6)

ATTACHMENT 2

Catawba Unit 2 Low Power License Condition No. 13
Attachment 1, Item 8 Confirmatory Information

a. Verify that each engine base has been fabricated from normal class 40 gray iron which is free of Widmanstaetten graphite microstructure.

The microstructure of both 2A and 2B engines bases have been characterized. The base on both engines shows flake type graphite with a Class A random orientation. The Widmanstaetten microstructure was not found in any samples taken.

b. Submit details concerning the nature and cause of the indication found on one rocker arm capscrew from Engine 2B. This information should address whether the indication is service induced or whether it occurred as a result of fabrication or installation.

An axial indication was found in the shank portion of the rocker arm capscrew (TDI part no. 03-390-05-AA) by Law Engineering using wet magnetic particle techniques. The capscrew was sectioned and examined metallographically. The magnetic particle indication was due to sulfide inclusions which formed during deoxidation and casting processes. These inclusions elongated during subsequent formation of the bolt stock. This shallow indication would not be detrimental to the strength of the capscrew. The capscrew would have been considered suitable for use in the engine had it not been sectioned for testing.

c. Submit an evaluation of the casual factors leading to the wear of the turbocharger thrust bearings in Engine 2B. Confirm that these casual factors have been found to be unique to the 2B turbochargers and justify how this conclusion was reached.

In late March 1985 the 2B diesel was first started. The engine tripped within a few seconds on low turbocharger oil pressure. Approximately five start attempts were made during the trouble shooting process. Turbocharger oil pressure was about 8 psi and main oil header pressure was about 35 psi at this time.

The low main oil pressure was found to be the result of a misinstalled check valve in the oil sump tank. After correcting this problem, turbocharger oil pressure rose to 18 psi and main oil header pressure increased to 55 psi.

While the main oil header pressure was in an acceptable range, approximately ten further attempts were made in an effort to increase the turbocharger oil pressure to the 23 to 28 psi range recommended by TDI. During this effort, some tubing configuration discrepancies were discovered and corrected.

Turbocharger oil pressure then reached 25 psi; safely within the normal range. It should be noted that the turbocharger prelubrication system was installed on both unit 2 engines in November 1984 and was used for all starts during the preoperational period.

During the DR/QR inspection, with the engine having about 180 hours of run time, the 2B left bank turbocharger thrust bearing and collar were found to be worn. The rotating assembly was replaced and the unit was returned to the left bank. The thrust bearing of the right bank unit was also replaced as a precautionary measure.

A review of records indicates that neither of the situations involved in the 2B thrust bearing damage were present on the 2A turbochargers. In addition the thrust clearances measured on the 2A turbochargers after about 200 hours of operation were well in specification. Previous experience with damaged thrust bearing has shown that thrust clearance readings to be an accurate indication of the bearing condition. On this basis a complete thrust bearing inspection on 2A was not deemed necessary.

d. Confirm that rotor float measurements have been conducted for both engine 2A turbochargers and that these measurements are acceptable per the TDI/Elliott specifications.

TDI/Elliott specifications call for rotor float clearances to be within a range of .008 to .018 inches. The 2A turbochargers (serial numbers A 809201-2 and A 909206-1) thrust clearances were measured and each found to be .0115 inches.

e. Verify implementation of TDI Service Information Memorandum (SIM) 300.

In an April 1, 1986 letter to the Elliott Division of Carrier Corporation, serial numbers were provided for all of Catawba's emergency diesel generators and a letter was requested verifying that SIM 300 had been performed. An April 3, 1986 letter from Richard Boyer of TDI states "Our records indicate that these turbochargers do not require the modifications covered by SIM 300 since they were manufactured with these changes incorporated."