MKW POWER SYSTEMS, Inc.

REPORT NO.: 10CFR21-0059
November 8, 1991

10CFR21 REPORTING OF DEFECTS
AND NON-COMPLIANCE

COMPONENT: Stud - EMD #80346[illegible]
Camshaft Locating Stud

SYSTEM: All Diesel Generators with EMD 645 Series Engines

CONCLUSION: Defect is Applicable Only to the Diesel Generators at Southern California Edison, San Onofre Nuclear Generating Station

PREPARED BY: Donald D. Galeazzi DATE 11/8/91
Donald D. Galeazzi, Engineering Manager

APPROVED BY: M. Van Mitchell DATE 11/8/91
M. Vann Mitchell, Quality Manager

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SUMMARY

This is a follow-up report to MKW Power Systems' notification to Mr. Thomas Murley of the NRC dated 10/11/91 (see Attachment 1).

MKW Power Systems received notification on 10/10/91 that, upon inspection of San Onofre Unit #3B diesel engine, one (1) camshaft locating stud (EMD #8034672) was found broken. Three (3) other studs were found cracked. The camshaft flange which contains the broken/cracked studs is located at the drivegear end of the left bank camshaft (see Attachment 2).

COMPONENT

Stud, EMD #8034672

CUSTOMERS AFFECTED

Southern California Edison, San Onofre Nuclear Generating Station only.

DEFECT

One (1) broken stud and three (3) cracked studs at the drivegear end of the left bank camshaft flange have been found.

ANALYSIS

According to Southern California Edison's failure analysis report contained in Attachment 1, examination of the broken dowel bolt under a Scanning Electron Microscope has revealed that it contained a high density of large and long sulphide inclusions. The analysis suggests that the broken dowel bolt was a unique failure due to sulphide inclusions.

Attachment 3 contains the engine manufacturer's (EMD's) evaluation of this issue. Based on the past success of the camshaft dowel bolt design and the expected nature of resulphurized steel, it is EMD's opinion that the reported material defect would not have caused the dowel bolt failure under normal engine service. A higher than normal force, which exists in Unit #3B due to the 5th order harmonic induced nonlinear gear train vibration, is necessary to cause the failure of a bolt which contains the previously discussed sulphide inclusions. Note that the dowel bolt failures were not found on the right bank camshaft; they were all found on the left bank camshaft which is where the 5th order vibration problem existed. Therefore, the reported bolt condition and a higher than normal gear force must co-exist to cause the subject dowel bolt failure.

The above demonstrates that the dowel bolt failure is not a generic problem and is limited to the San Onofre diesel generators because of the 5th harmonic induced gear train vibration.

CORRECTIVE ACTION

Inspect all left bank camshaft dowel bolts on the San Onofre diesel engines which had the 5th order harmonic vibration problem. All broken or cracked dowel bolts should be replaced.

ATTACHMENT 1
(5 PAGES)

NOTIFICATION TO NRC DATED 10/11/91

MKW POWER SYSTEMS, Inc.

October 11, 1991

Mr. Thomas Murley
Director - Office of Nuclear Reactor Regulation
11555 Rockville Pike
Rockville, MD 20852

Subject: Potential Reportable Defect for EMD 64, Series Camshaft Locating Studs (EMD #8034672)

Dear Sir:

On 10/10/91, MKW Power Systems received notification, upon inspection of San Onofre Unit #3 diesel engine, that one (1) of the eight (8) camshaft locating studs (EMD #8034672) was found broken. Three (3) other studs were found cracked. The camshaft flange which contains the studs is located at the drivegear end of the left bank camshaft.

Inspection by Southern California Edison reveals that the cracks were caused by fatigue loading. It was also found that the bolt material contained a concentration of sulfur stringers which may have reduced the bolt's mechanical properties. Inspection of the right bank camshaft studs revealed no evidence of cracking.

Preliminary evaluation of the SCE report (attached) by EMD has yielded the belief that the cracks were the result of the 5th harmonic torsional vibration (previously reported by MK/PSD on 5/10/88) translated to the left bank camshaft. This is contrary to the conclusion of the SCE report.

These studs have been manufactured using the same mechanical process since 1939 without any known fatigue cracking failures. As a result, we believe that this failure is specific to the SCE - San Onofre diesel generator units and is a result of the 5th harmonic problem which is currently being corrected on site.

Upon receipt of final results from EMD, a follow-up report will be issued.

Yours very truly,

MKW POWER SYSTEMS, INC.

/FOR

M. Vann Mitchell
Quality Manager

MVM:jb

Attachment: SCE Report (4 pages)

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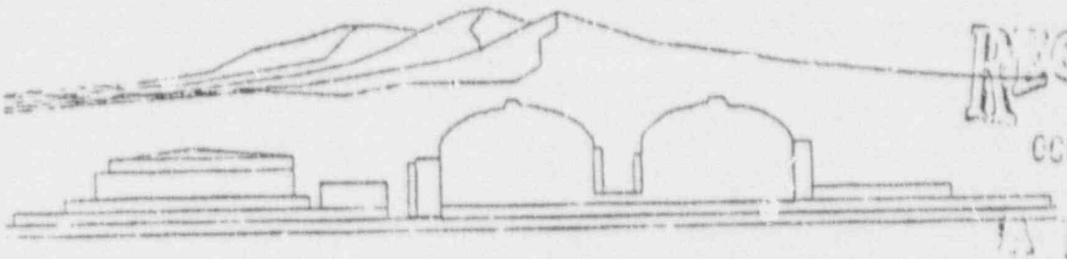
A020



SOUTHERN CALIFORNIA EDISON

SAN ONOFRE NUCLEAR GENERATING STATION

STATION TECHNICAL

FAX NO: (714) 368-6249

VERIFICATION: (714 368-9318

Number of pages (including cover sheet) 4

Date: 10/4/91

To: Scott Tharrington

From: Bill Poirier

Message:

36003 ROOT CAUSE ANALYSIS

[111] From: BILL STROM at ROOF3 10/3/91 6:07PM (7787 bytes: 147 ln)
To: SHERRY KUNZ at AWS2
cc: CHONG CHIU, BRIAN KATZ, ROBERT PLAPPERT at AWS, MIKE SHORT at AWS,
JAMES REILLY at NEGL4, MOSTAFA MOSTAFA, BILL STROM, HOWARD SCHUTTER at AWS
JOHN HIRSCH at AWS5
Subject: 3G003 JCO - final version for NCR disposition
---------- Message Contents ----------

NCR 9110 0002

JUSTIFICATION FOR CONTINUED OPERATION FOR 3G003

IDENTIFIED DEFICIENCIES

During an inspection of 3G003 cam shaft, one of the four cam shaft flange dowel bolts were found broken and the other three bolts were found cracked. The cam shaft flange that contains degraded dowel bolts is located at the drive gear end of the left camshaft.

FACTS AND EVIDENCE

As a result of the identified deficiencies, the following facts and evidence were collected:

(1) The total run time for the degraded dowel bolts is about 164.5 hours since their original installation. The total number of starts the degraded dowel bolts have experienced is Approximately 95.

(2) The material of all the degraded dowel bolts is AISI 1144 ETD (high temperature drawn) steel which is manganese carbon steel.

(3) There are no other deficiencies identified in 3G003. All the bearing cap bolts are tight (preload greater than 28 ft-lbf with a original 32 ft-lbf preload). All the anchor bolts on the "pork chop" bracket (provides support between the camshaft and drive gear) are tight. No cracks were found on the dowel bolts in a flange next to the flange containing degraded bolts

(4) Based on past operating experience, both 2G003 and 3G003 (not 2G002 and 3G002) have experienced several "pork chop" bracket failures. The cause of the failures was diagnosed by the Diesel Generator vendor to be 5th order torsional harmonics which only exist in the 20 cylinder engine. The brackets in all four diesel generators were improved in 1988 and 1989. The improved brackets have not failed since the modification.

(5) The 5th harmonic torsional vibration problem will be corrected with appropriate design modifications for 3G003 in the upcoming refueling outage (February, 1992).

(6) The flange bolts in the flange near the gear on the right hand side cam shaft (note that the flange that contains broken and cracked bolts is on the left hand side cam shaft) were examined by dye penetrant. No cracks were detected.

FRACTOGRAPHIC EXAMINATION OF THE DEGRADED BOLTS

The fracture surfaces of the broken bolt and three cracked bolts were examined under Scanning Electron Microscope. The results of the examination revealed the following facts:

(1) The failure mode of the broken bolt is a fatigue crack followed by overload. There is a small zone (about 20% of the total cross-sectional area) containing striation marks that are characteristics of fatigue fracture. 50% of the fracture surface was covered by a fatigue related failure, consisting of fracture along sulfide stringers in the longitudenal direction coupled with fatigue in the transverse direction. This fact indicates that the bolt material was severely degraded with a high density of sulfur stringers, which in turn had reduced the transverse mechanical properties. The remaining 30% of the fracture surface was a ductile overload.

(2) The failure mode of the three cracked bolts was pure fatigue. When the bolts were removed, the break-away torque had been reduced from a nominal 32 ft-lbs to 12 ft-lbs on the two bolts which exhibited substantial fatigue cracks. The third bolt had a fatigue crack about 5-10% through the diameter, and had a break-away torque of 30 ft-lbs. The number of beach marks (which indicate how many interruptions of spectrum loading occurred) on the fracture surface were counted.

There are 20 to 25 beach marks, indicating that there have been 20 to 25 stops of spectrum loading after crack initiation.

(3) AISI 1144 dowel bolts have been used in the EMD diesel generators since 1939 with a very good track record. Moreover, in the past, there have been several bracket failures, and none of the dowel bolts fractured. This fact indicates this broken bolt is a unique failure.

MOST LIKELY FAILURE SCENARIO

Based on the facts collected above, the most likely failure scenario is stated below:

(1) One of the flange bolts installed in 1999 contained a high density of large, long sulfide inclusions. This is mainly a result of inadequate mixing of the molten steel during the fabrication process. This results in an anisotropic material condition which produces substantial decreases in transverse mechanical properties, such as ductility, fatique life, and fracture toughness. The cracked flange bolts also contained sulfide inclusions to a lesser extent.

(2) The problem bolt fatigue fractured as a result of vibration normally encountered by the cam shaft gear. EMD (DG vendor) believes that the level of vibration is very low because the "pork chop" bearing is very rigid and it reduces the gear vibration to a very low magnitude at the location of the problem flange. EMD also believes that the AISI 1144 dowel bolts are adequate for their application.

(3) Once the problem bolt fractured, the flange contact stress is no longer symmetric, resulting in a larger cyclic stress.

(4) The larger vibration stress results in fatigue crack of the remaining three bolts.

ROOT CAUSES OF THE FAILURE

The most likely root causes of the failure is inadequate material of the broken bolt. It contains many large sulfur stringers that tend to produce substantial decreases in fatigue life and fracture toughness.

CORRECTIVE ACTIONS

Install new bolts that contain small and low density of sulfur stringers. The specific actions taken are stated below:

(1) New AISI 1144 bolts were ordered.

(2) Two bolts were taken from the same shipment. Metallographic analysis confirmed that the material contains small uniformly distributed sulfur stringers and an absence of large, long sulphur inclusions.

(3) New bolts from the same shipment were installed.

(4) After installing the new bolts, DG 3G003 was run for one hour. Torque checks confirmed there was no loss of preload.

OPERABILITY ASSESSMENT

The above stated corrective actions will eliminate recurrence of the identified failure.

Moreover, the past operation experience has shown that in many past bracket fracture events, these AISI 1144 bolts sustained the high vibration (much higher than that with an intact new design bracket) without fatigue or overload fracture. This fact suggests that AISI 1144 material (if fabricated properly) is adequate as dowel bolt material.

ATTACHMENT 2
(1 PAGE)

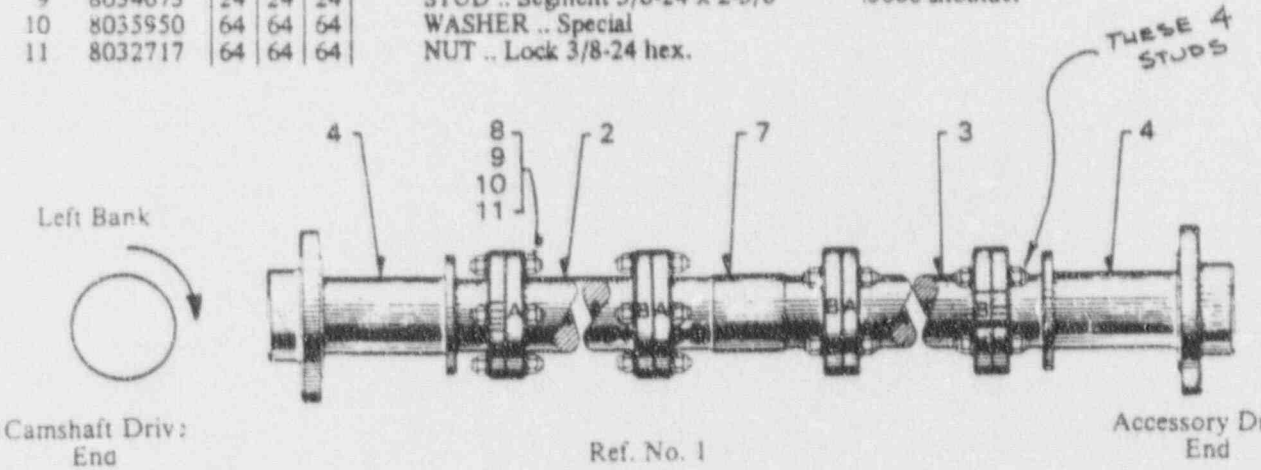
EMD PARTS LIST B28

CAMSHAFTS AND CAMSHAFT COUNTERWEIGHTS

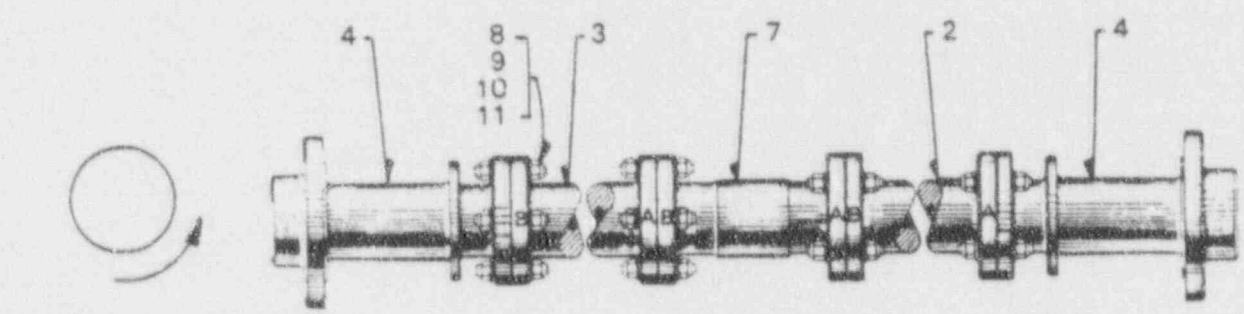
Camshaft Assembly
20-645 Engines

PLATE B28-4

Ref. No.	Part Number	Qty. Req.			Description
		A	-	-	20-645E4,E5,E7,E9 } Left Hand Rotation
		-	B	-	20-645E4B,E7B,E7C,E9B,E10B } Left Hand Rotation
		-	-	C	20-645E4,E4B,E5,E7,E7B,E7C - Right Hand Rotation
1	8361017	2	-	-	CAMSHAFT ASM. .. Right and left banks
1	8433603	-	2	-	CAMSHAFT ASM. .. Right and left banks
1	9319336	-	-	2	CAMSHAFT ASM. .. Right and left banks - Replaces 8374312
2	8361012	2	-	-	SEGMENT .. Camshaft } Accessory drive end - Right bank
2	8433618	-	2	2	SEGMENT .. Camshaft } Camshaft drive end - Left bank
3	8361013	2	-	-	SEGMENT .. Camshaft } Accessory drive end - Left bank
3	8433602	-	2	2	SEGMENT .. Camshaft } Camshaft drive end - Right bank
4	8028482	4	4	-	STUBSHAFT .. Both ends
5	8241972	-	-	2	STUBSHAFT .. Accessory drive end - Left bank Camshaft drive end - Right bank
6	8253382	-	-	2	STUBSHAFT .. Accessory drive end - Right bank Camshaft drive end - Left bank
7	8028637	2	2	-	SPACER .. Segment
7	8374313	-	-	2	SPACER .. Segment
8	8034672	8	8	8	STUD .. Locating 3/8-24 x 2-3/8 .4370 shoulder
9	8034673	24	24	24	STUD .. Segment 3/8-24 x 2-3/8 .5000 shoulder
10	8035950	64	64	64	WASHER .. Special
11	8032717	64	64	64	NUT .. Lock 3/8-24 hex.



Ref. No. 1



Ref. No. 1

All Left Hand Rotating 20 Cylinder Engines

ATTACHMENT 3
(1 PAGE)

EMD EVALUATION

ELECTRO-MOTIVE

Electro-Motive Division General Motors Corporation, La Grange, Illinois 60525 (708) 387-6000

During a recent inspection of Unit 3B, 20-645 engine, SONGS personnel discovered that the four camshaft dowel bolts which secure the left rear stubshaft to the left rear camshaft segment have failed. One of the four dowel bolts was found broken and the other three were found cracked. According to SONGS's failure analysis report, examination of the broken dowel bolt under a Scanning Electron Microscope has revealed that it contained a high density of large and long sulphide inclusions. The report further states that material defect was the most likely cause of the broken dowel bolt and that cracks initiated in the remaining three bolts subsequent to the failure.

Camshaft dowel bolts are made from AISI 1144 steel. These bolts have been used in commercial engines which have considerably more operating hours than nuclear engines without failure. When applied properly, this camshaft bolting system has proven to be highly reliable. Proper installation involves spacing the two nuts and washers approximately equal on both ends of the dowel bolt to insure that the nut and washer does not advance onto the dowel bolt shoulder, and positioning the 'D' shaped washer to avoid seating the washer in the fillet. Taking these precautions will insure adequate bolt stretch to maintain the proper bolt torque.

SONGS's failure analysis suggested that the broken dowel bolt was an unique failure due to sulphide inclusions. Based on the past success of the camshaft dowel bolt design and the expected nature of SAE 1144 resulphurized steel, it is the writer's opinion that the reported material defect would not have caused the dowel bolt failure under normal service. In the opinion of the writer, a higher than normal force, which exists in Diesel Train 3B due to 5th order harmonic induced nonlinear gear train vibration, is necessary to cause the failure of a weakened camshaft dowel bolt. Further more, service history of Unit 3B has proved that dowel bolts can withstand the nonlinear gear train vibration in Unit 3B. Consequently, the reported bolt condition and a higher than normal gear force must co-exist to cause the subject dowel bolt failure.

C. J. Farber

C. J. Farber
November 1, 1991
Power Products Servic