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SUFFOLK COUNTY, 7/31/84

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	
LONG ISLAND LIGHTING COMPANY	)	Docket No. 50-322-OL
(Shoreham Nuclear Power Station, Unit 1)	)	

SUFFOLK COUNTY'S EXHIBITS TO JOINT DIRECT TESTIMONY

CYLINDER BLOCK EXHIBITS

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VOLUME 4
CYLINDER BLOCK EXHIBITS

7. Design Review of TDI R-4 and RV-4 Series Emergency Diesel Generator Cylinder Blocks and Liners, June 1984

24. Deposition of Maurice H. Lowery, pgs. 1, 14-16

32. Deposition of Clinton Mathews, pgs. 106-107

54. Letter from Reis to the Administrative Judges Concerning a Morning Report of 4/16/84

55. 3/20/84 Morning Report Concerning Con Rod Bearing Cracks and Eddy Current Examination of the Cylinder Blocks Cracks

56. TDI Owner's Group DRQR - Cylinder Block

57. Deposition of William J. Museler, pgs. 1, 7-8, 14-17, 43-46, 98-99

58. Deposition of Robert Taylor, pgs. 1, and Exhibit No. 1

59. Deposition of Robert Taylor, pgs. 1, 39-41, 67- 69-70

66. Deposition of Simon K. Chen, pgs. 1, 129

67. Handwritten Memo to Pratt from Lowery on Cylinder Block Casting - RV's

FaAA-84-5-4
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DESIGN REVIEW OF TDI R-4 AND RV-4 SERIES EMERGENCY DIESEL GENERATOR CYLINDER BLOCKS AND LINERS

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This report is final, pending confirmatory reviews
required by FaAA's QA operating procedures.

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Prepared by
Failure Analysis Associates
Palo Alto, California

Prepared for

TDI Diesel Generator Owners Group

June 1984

STATEMENT OF APPLICABILITY

This report summarizes a structural integrity investigation of the TDI R-4 and RV-4 series engines installed in emergency generator sets in nuclear power stations.

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EXECUTIVE SUMMARY

This report summarizes a generic investigation of the structural adequacy of the TDI R-4 and RV-4 series diesel engine blocks. The results are based on strain gage testing; analytical models, including several 2-D finite element analyses; and review of field experience.

Cracks in the block top region have been identified in the diesel generator engines at Shoreham Nuclear Power Station (SNPS) and in other engines in non-nuclear service. The majority of cracks can be classified either as radial cracks, extending in a vertical plane outward from the cylinder head stud counterbore, or as circumferential cracks, extending downward from a horizontal plane and outward from the corner of the cylinder liner landing. The radial cracks are the only type found in the SNPS engines, but both radial and circumferential cracks have been found elsewhere in non-nuclear service.

An additional type of cracking identified at SNPS is associated with the camshaft bearing supports. This cracking is unique to the inline engines and is attributed by FaAA to the casting process. At Comanche Peak, cracks unique to one engine block have been found. These have also been attributed by FaAA to the casting process.

There are three possible mechanisms of crack initiation (acting separately or in combination) in the block top. The first mechanism is low cycle fatigue (LCF) associated with the stress range from each startup to high load levels. The second is high frequency fatigue (HFF) due to the firing pressure stresses. For both LCF and HFF there is a high mean tensile stress resulting from thermal expansion and stud preloading. The sum of mean and alternating components may produce the third mechanism, overload rupture. This is most likely to occur above rated power level (>110%) in blocks with below average material properties.

All of the three mechanisms are potentially responsible for initiating cracks in the ligaments between the cylinder head stud holes and the liner counterbore, and such cracking is predicted to occur by Goodman diagram analysis. The only projected consequences of this ligament cracking are possible

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coolant leakage (but not into the cylinder) and greater chance of cracking between studs of adjacent cylinders. ~~Ligament cracks alone do not appear to affect the operation or availability of the engine, as shown by field experience.~~

Cracking between stud holes of adjacent cylinders has been observed infrequently, but is potentially more serious than ligament cracking. This cracking has been observed in SNPS engine DG103 to a depth of 5 1/2 inches. No adverse consequences to engine operation were experienced. Cracking between stud holes is conservatively predicted by Goodman diagram fatigue analysis, assuming a ligament to be cracked, either in LCF or HFF.

A linear cumulative damage model and the observed crack growth in SNPS engine DG103 were combined to predict conservatively the amount of crack propagation that might occur during one LOOP/LOCA event. This analysis indicates that blocks with ligament cracks (e.g., DG101 and DG102) are predicted to withstand a LOOP/LOCA event with sufficient margin provided that: (1) inspection shows no stud-to-stud cracks detectable between heads, and (2) the specific block material of DG103 is shown to be sufficiently less resistant to fatigue than typical gray cast iron, Class 40.

The block tops of all engines that have operated at or above rated load should be inspected for ligament cracks. Engines such as those at Catawba and Grand Gulf that are found to be without ligament cracks can be operated without additional inspection for combinations of load, time, and number of starts that produce less expected damage than the cumulative damage prior to the latest inspection. Engines that have been operated at or above rated load without subsequent inspection of the block top should conservatively be assumed to have cracked ligaments for the purpose of defining inspection intervals.

For blocks with known or assumed ligament cracks the basic approach to assuring reliability is inspection and material evaluation. The absence of detectable cracks between stud holes should be established by eddy current inspection between heads and at the ends of the block before returning the engine to emergency standby service after any period of operation other than

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1.0 INTRODUCTION

This report presents a generic analysis of structural integrity of cylinder blocks and liners for TDI R-4 and RV-4 series diesel engines. The integrity of any particular cylinder block depends upon several plant-specific variables such as firing pressure and temperature, assembly clearances, cylinder head stud configuration, and material properties.

1.1 Service Experience

Two types of cracks have been found to occur in cylinder block tops of this design: cracks in the radial/vertical plane at the stud holes, and circumferential cracks in the liner counterbore at the liner landing ledge [1-1]. Figure 1-1 depicts the potential location of block top radial and circumferential cracks. In addition, for the in-line engines, cracks have occurred in the cam gallery above the cam shaft bearing supports. The survey of industry experience with TDI R-4 and RV-4 engines summarized in this section has not been independently confirmed by FaAA, and therefore is not subject to FaAA's usual quality assurance procedures.

1.1.1 Shoreham Nuclear Power Station

Shoreham has three TDI DSR-48 diesel engines designated DG101, DG102, and DG103. As of April 30, 1984, the engines had operated between 1091 and 1270 hours. A significant percentage of those hours was at or above full load, as shown by Tables 1-1 through 1-3.

As part of the engine requalification program after the crankshaft replacement, each engine was operated for 100 hours at or above full load and was then disassembled and inspected. During these inspections, radial/vertical cracks were discovered in the blocks of all three engines. Crack maps for DG101, DG102, and DG103 are presented in Figures 1-2, 1-3, and 1-4, respectively.

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No circumferential cracks were found in any of the engines. However, each block had radial/vertical cracks between the cylinder bore and the stud hole. Sixty-seven percent of the ligament cracks were between 1 and 1 $^1/_2$ inches deep. A typical example of a cross-section of a radial/vertical crack through a ligament is shown in Figure 1-5. As depicted in the figure, none of the cracks extended below the corner formed by the counterbore and the counterbore landing. This demonstrates the apparent arrest of radial/vertical cracks that occur in the ligament region. In addition, when first inspected, the engine block from DG103 had a crack that extended between two adjacent studs on the exhaust side of Cylinder Nos. 4 and 5 as shown in Figure 1-6.

After inspection, DG102 was operated through 100 starts to loads greater than 50% and was then reinspected. Review of inspection reports before and after the 100 starts showed no crack extension discernable by eddy current examination of the stud holes and liner counter bores.

In order to allow calculation of the growth rate for the crack between stud holes in the DG103 block, a strain gage test of the block top was performed, as described in Section 3.0. After the strain gage test, LILCO continued with qualification testing of the DG103 engine. While operating the engine at full load, the plant experienced an abnormal load excursion. During this event, the power demand exceeded the diesel capacity and, over a period of 23 seconds, the diesel slowed to around 390 rpm, at which time the load was dropped. The diesel continued to run at low load for 10 minutes before it was manually shut off. Upon restarting the engine and continuing with qualification testing at 3900 kW, a crack at Cylinder No. 1 was noticed, and the testing was stopped. At the time the crack was noticed it was reported that the engine output parameters were satisfactory.

Inspection of the block top revealed cracks between stud holes with depth of 1 $^1/_2$ inches similar to those shown in Figure 1-6 at three locations. At four other locations, between-stud cracks developed along the top surface which did not extend to measureable depths down the sides of the stud hole. At one location a crack that previously extended 0.8 inch radially from one stud hole towards the adjacent stud hole grew to a maximum depth of 3.9 inches. In addition, the original crack between Cylinder Nos. 4 and 5 had ex-

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tended to a depth of at least 5 $^1/_2$ inches. As shown in Figure 1-7, the ligament cracks had also grown approximately 1 inch. Figure 1-8 is a crack map for DG103 as reinspected.

1.1.2 Inspection of Blocks at Other Nuclear Power Stations

Catawba Nuclear Power Station has operated its 1a emergency diesel generator approximately 810 hours. The 1a diesel has been inspected for block top cracks, and none have been found. The load history for the 1a engine is shown in Table 1-4.

River Bend has two TDI diesel engines of the DSR-48 design. Each engine has approximately 50 hours of factory operation only. Engine logs show that both engines were run at 100% load. To date one engine block has been inspected by the magnetic particle method. No cracks were found in the block top.

Comanche Peak Steam Electric Station has inspected both of its TDI DSRV-16-4 engines. The engines have been operated for approximately 90 hours at the site. Subsequent inspection of the block top region revealed several indications that are considerably different from radial/vertical cracks found at SNPS or elsewhere. The two largest indications, illustrated in Figure 1-1, have been metallurgically examined and were identified as interdendritic shrinkage or porosity resulting from the casting process.

Grand Gulf Nuclear Station has inspected the block top of the Division 1 engine after 1,397 hours of operation, including 338 hours between 80% and 100% load, and 14 hours at 110% load since November 1981 [1-2]. No indications were reported. The load history is shown in Table 1-4.

1.1.3 Non-Nuclear Service

The experience compiled for engines in non-nuclear service tends to support the observation of the apparent arrest of ligament cracks at the depth of the liner landing ledge ($1^1/_2$ inches) when cracks between stud holes are not present. The motor vessel Edwin H. Gott has been operating for at least

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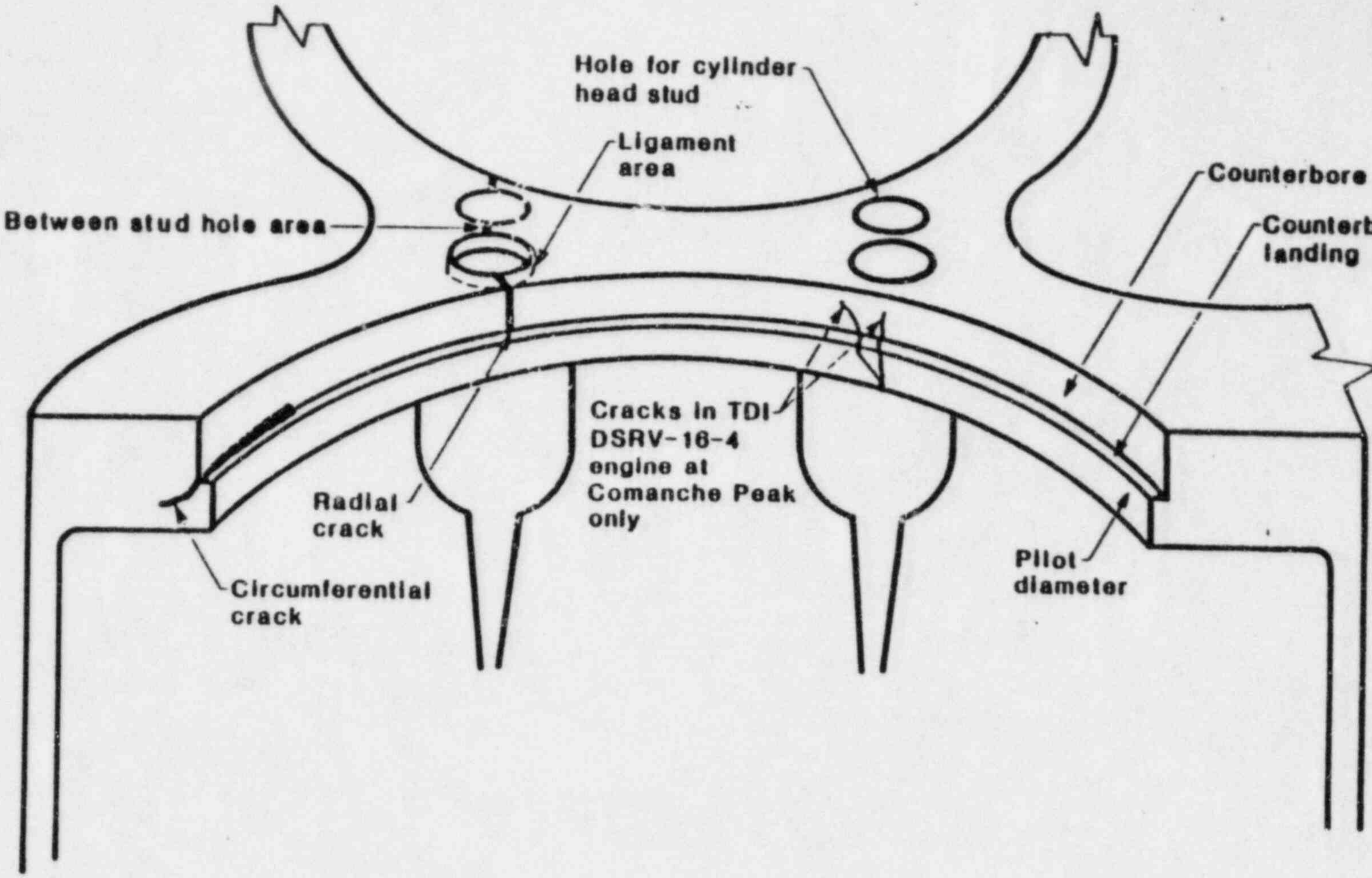

Figure 1-1. Location of cracks.

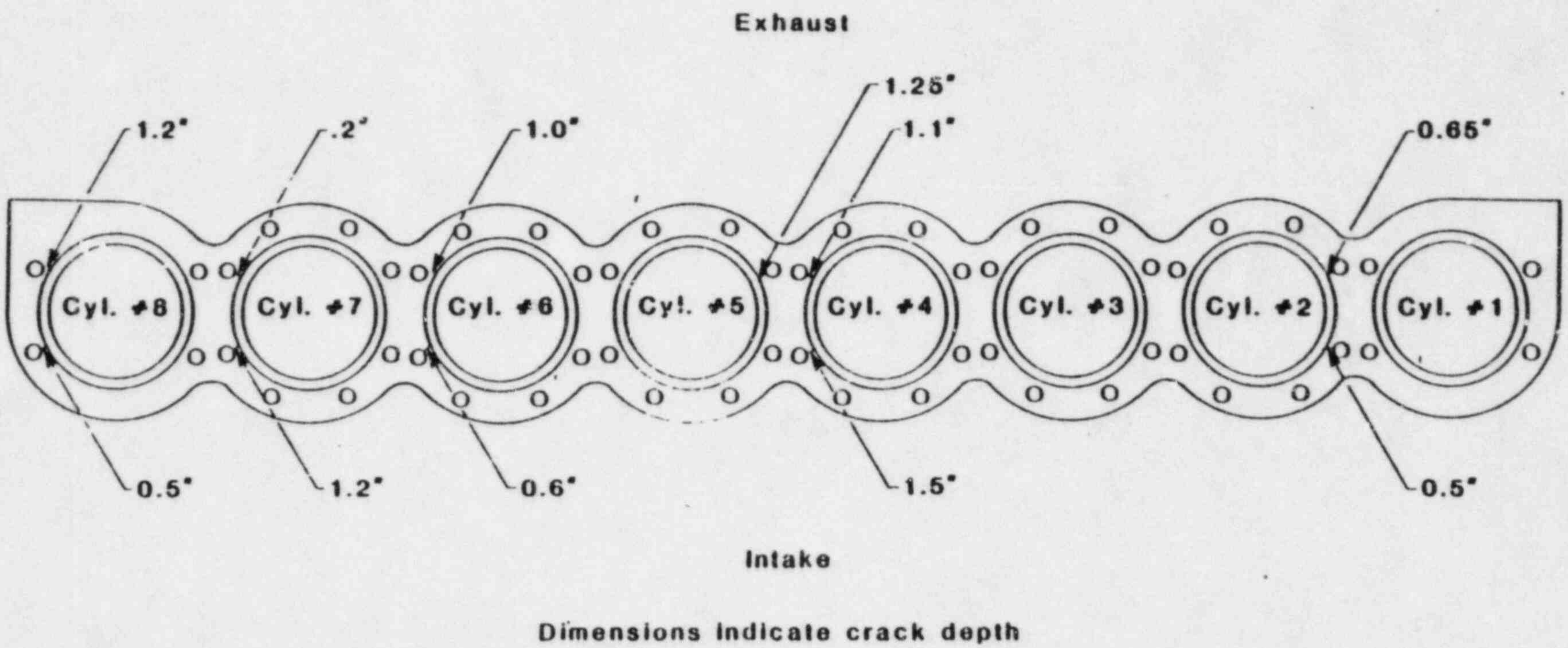

Figure 1-2. SNPS DG101 crack map.

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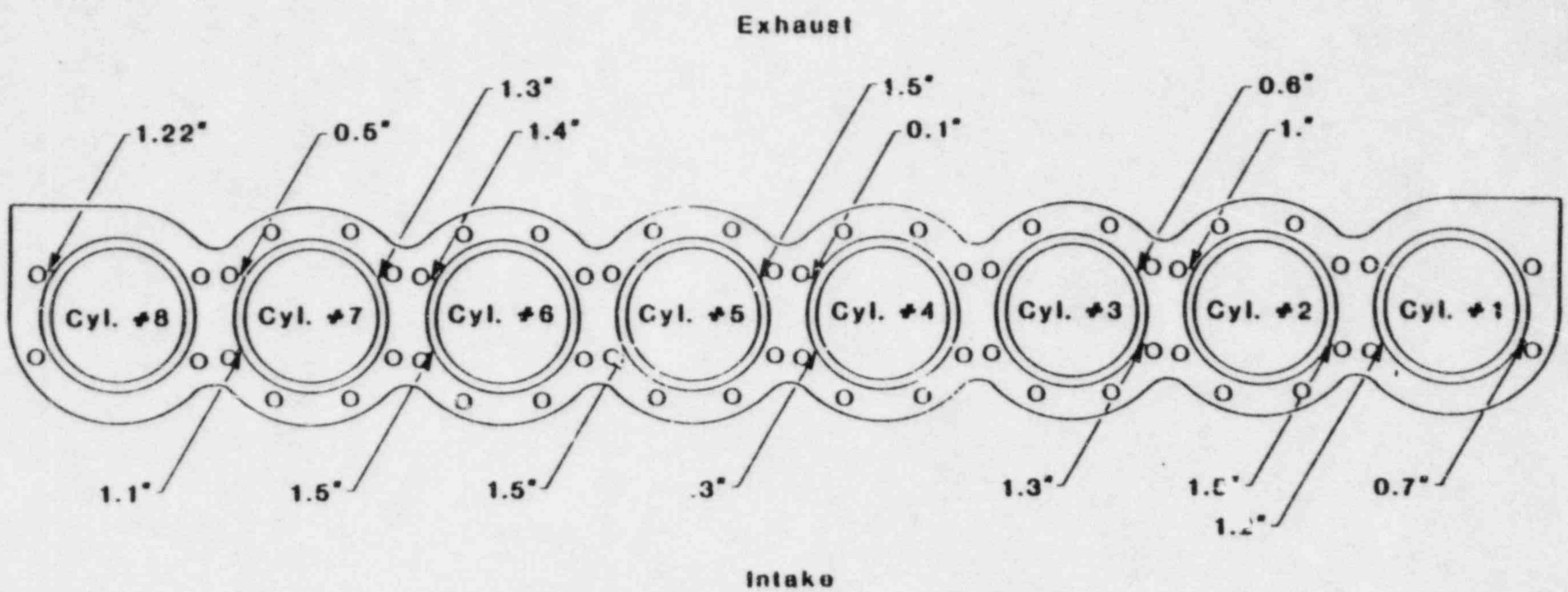
Ref: TER Q-308, TER Q-329, Q-95



Dimensions indicate crack depth

Figure 1-3. SNPS DG102 crack map.

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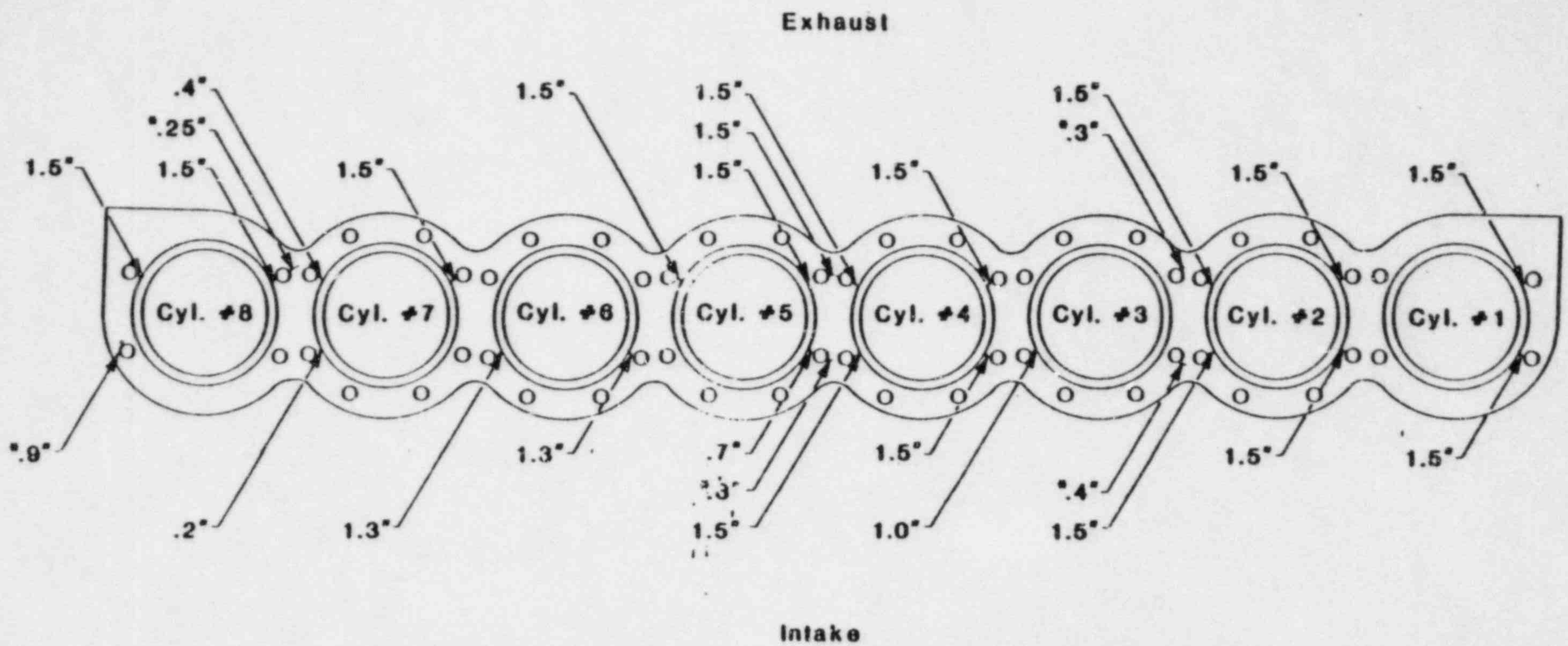

Dimensions indicate crack depth

*Top surface indication. Depth not measured

Figure 1-4. SNPS DG103 crack map as of 3/11/84.

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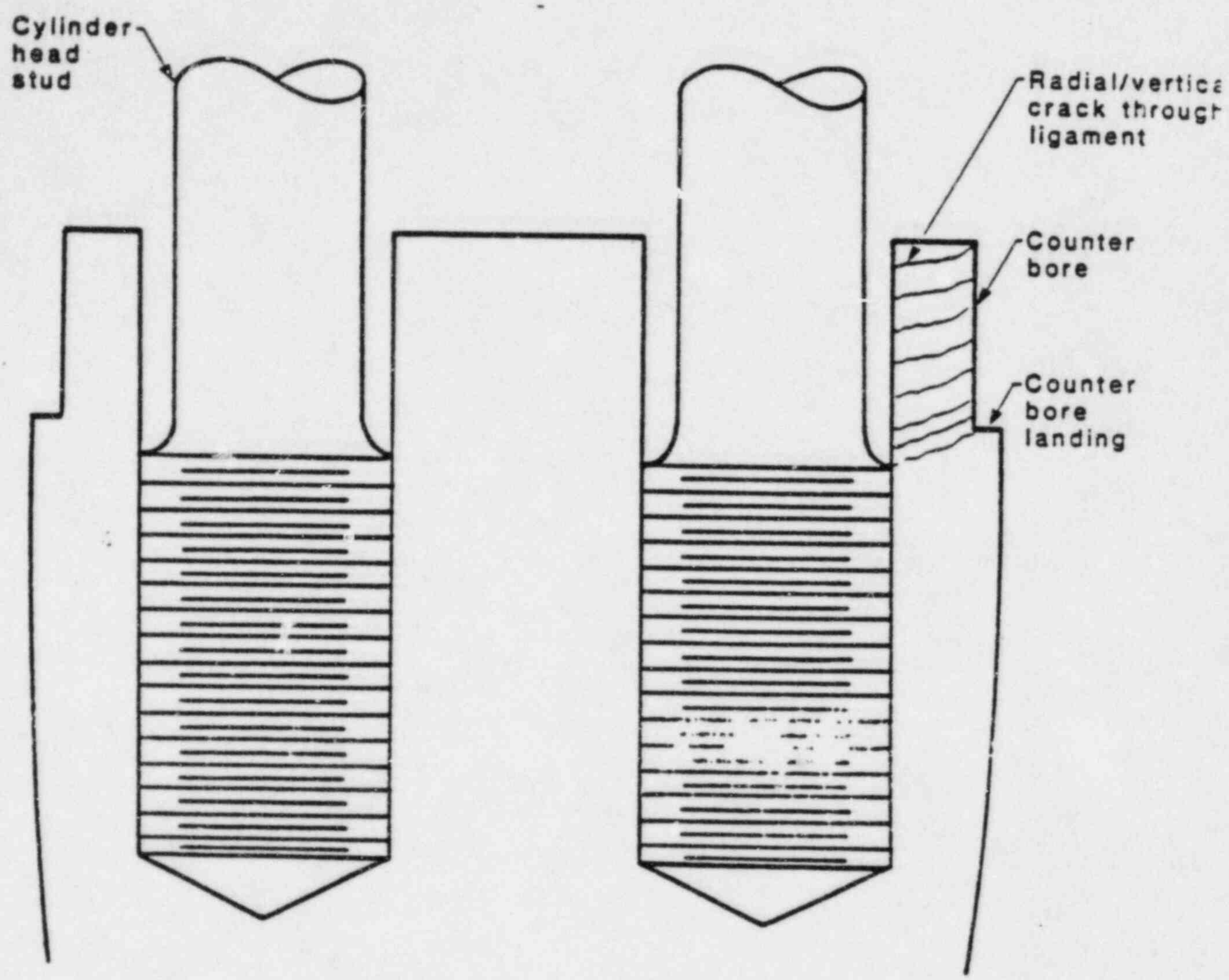

Figure 1-5. Longitudinal section between adjacent cylinders.

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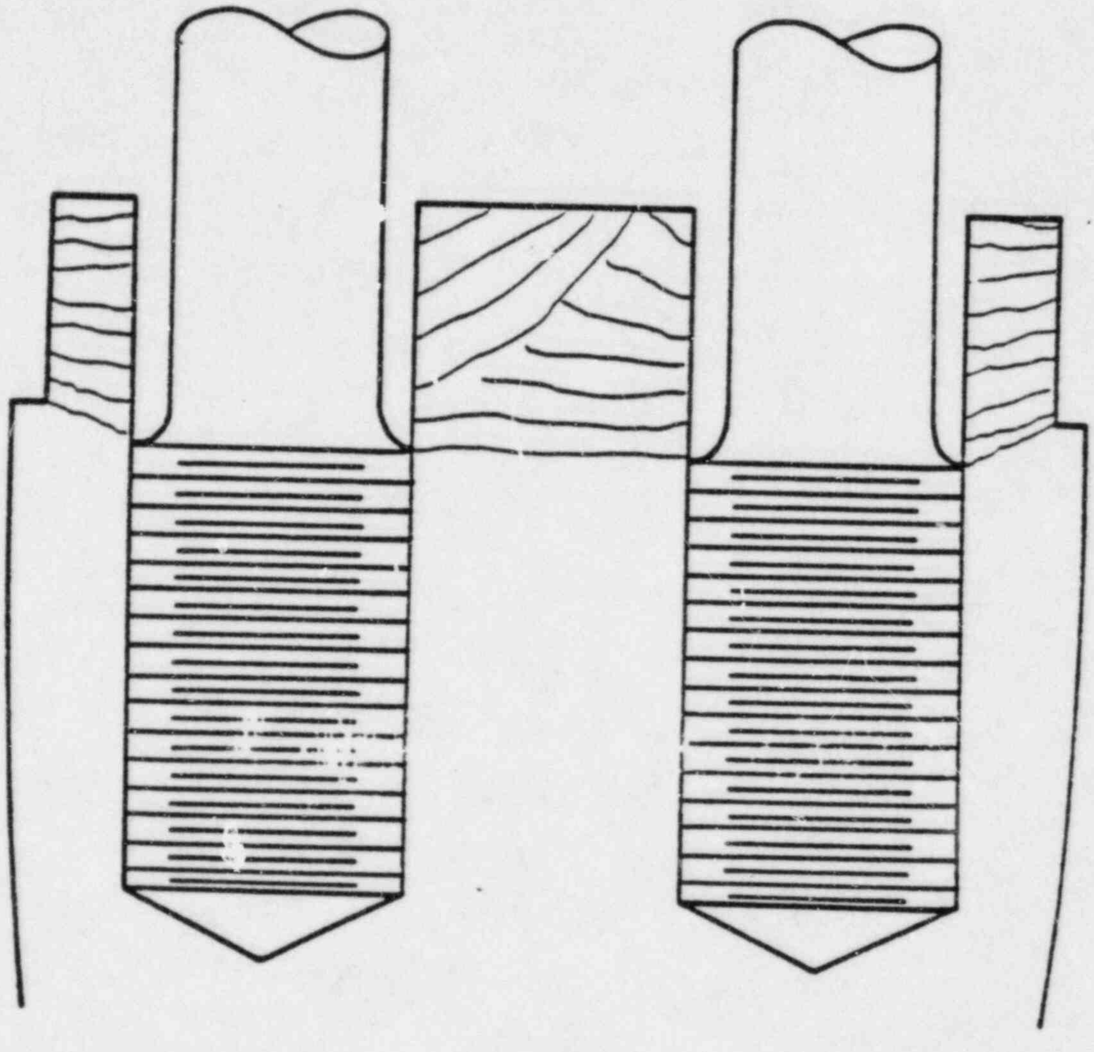


Figure 1-6. Longitudinal section between adjacent cylinders for SNPS DG103.

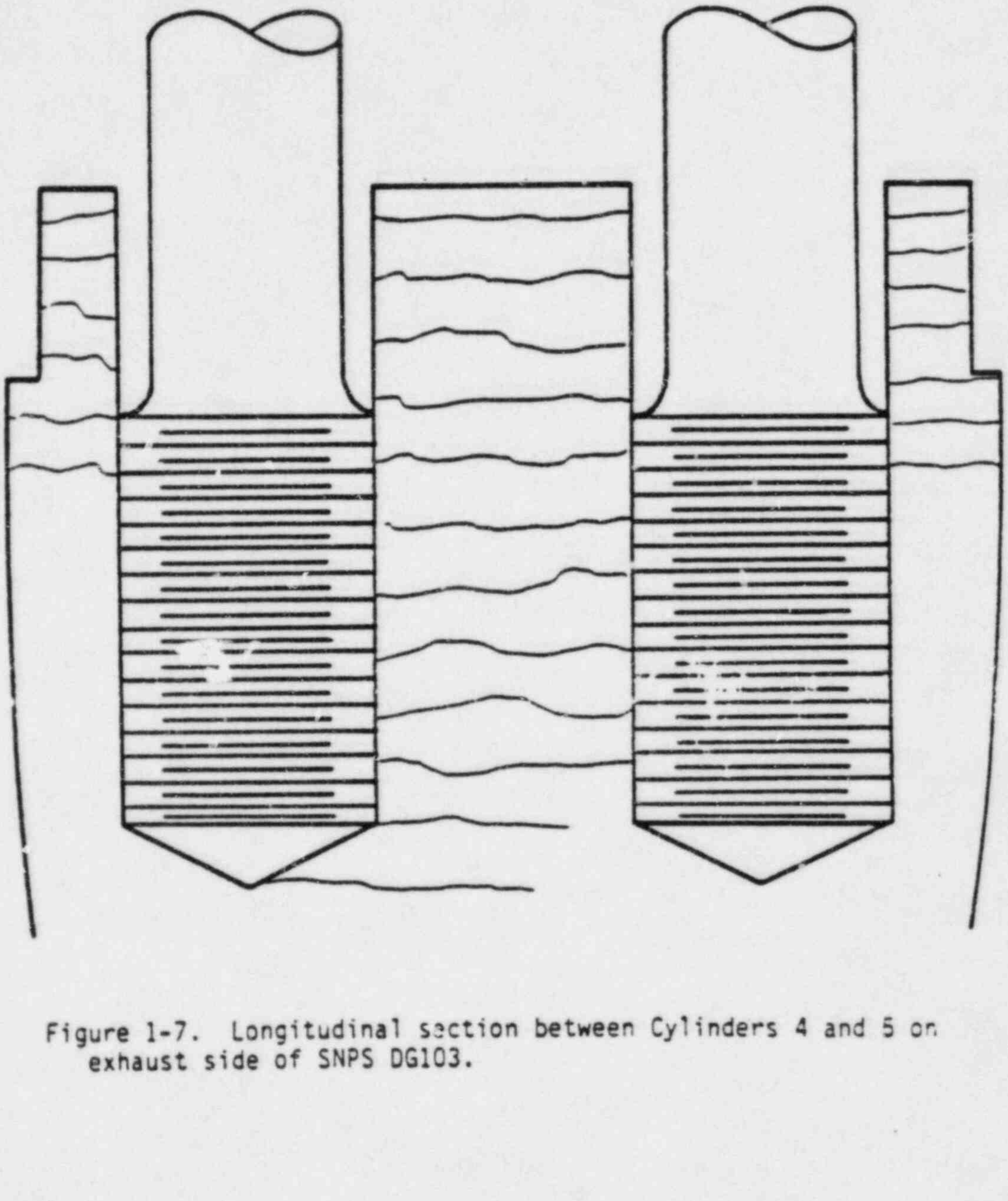
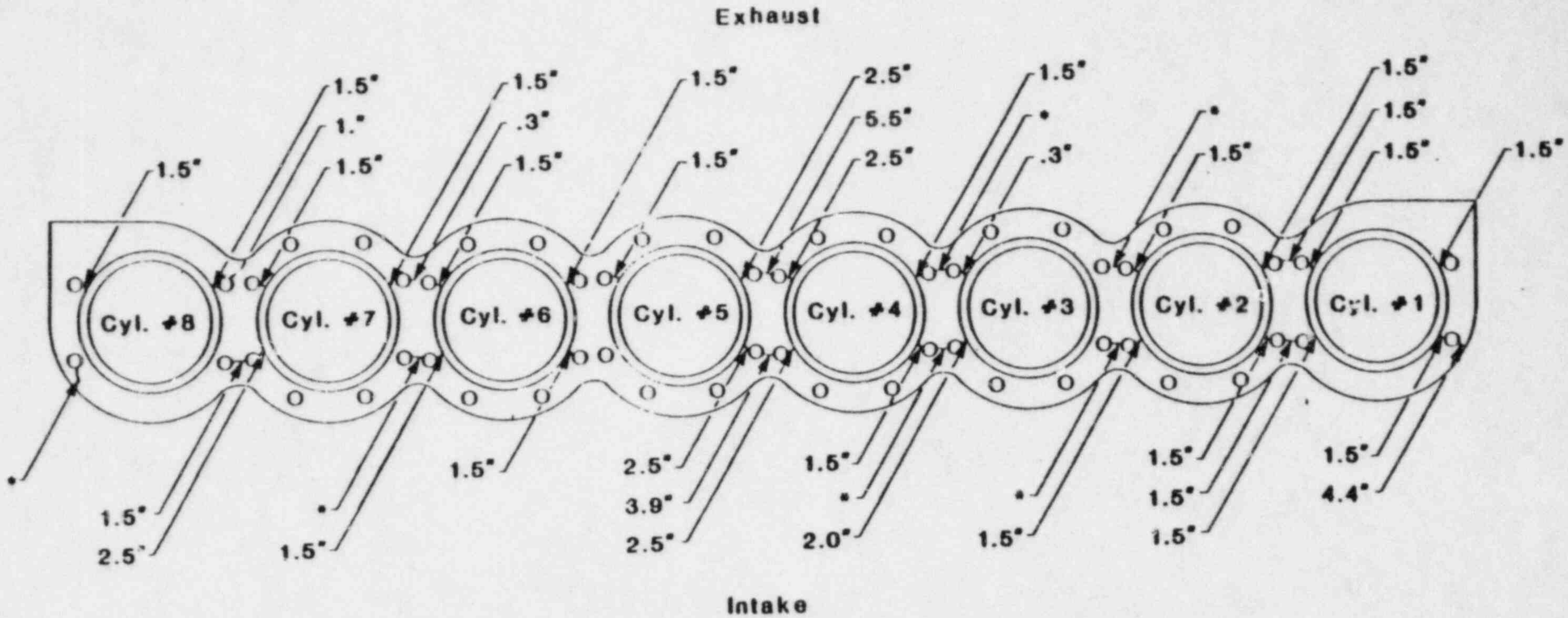


Figure 1-7. Longitudinal section between Cylinders 4 and 5 on exhaust side of SNPS DG103.



Dimensions indicate crack depth

*Top surface indication. No depth to crack measurable down stud hole

Figure 1-8. [illegible] DG103 crack map as of 4/23/84.

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(14)

Ref: Q-465

real case, the ligament crack is only about 1 $^1/_2$ inches deep, so less stress is actually transferred to the stud-to-stud region than is calculated by the model.

As in Section 3.2.2, the thermal stress is obtained by scaling the stress measured at Gage No. 13, using the model in Figure 3-11 to obtain the scaling factor. The primary assumption in this process is that the thermal stress acts in the plane of the block top, analogous to pressure. The result is 17.3 ksi = 9.7 (10.85/6.06) for 100% load.

3.3 Discussion of Stress State at Crack Sites 1 (Ligament) and 2 (Stud-to-Stud)

The stress shown in Table 3-2 can be divided into mean and alternating components for fatigue analysis. For low cycle fatigue caused by startup plus load change from 0% to a particular load level, the relevant alternating stress range is the peak stress at that load level (upper pressure band) minus the preload. This range may not be substantially different for starts from hot standby or cold starts, because the stress difference between cold preload and the lower pressure band for steady state running at zero load is less than 1 ksi, as shown by Gage No. 13 in Figure 3-6. The mean stress is the preload plus half of the range, while the alternating stress is half the range. For high frequency fatigue caused by the firing pressures, the relevant alternating stress range is that caused by firing (the band on each curve from the strain gages). The mean stress is the preload plus the thermal range plus the difference between average (mean) stress at load and the median stress in the stress band from firing. The alternating stress is half the range.

The results are shown in modified Goodman (Smith) diagrams: Figure 3-13 for ligament cracking and Figure 3-14 for stud-to-stud cracking given cracked ligaments. The curves are derived from the minimum ultimate tensile strength in thick sections, the minimum specified endurance limit (>10^6 cycles), and the stress for failure in 100 cycles (from the lowest curve in Figure 1-16). In both cracking locations, the stress state is outside the Goodman (Smith) curve for either HFF or LCF and for any load level of 90% or higher. The implication is that initiation of ligament cracks in minimum strength material

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is predicted, and given a ligament crack, initiation of stud-to-stud cracks is also predicted. Initiation could occur in less than 100 load excursions from 0 to 90% power or above and/or steady running for more than 10^6 cycles (about 100 hours) at 90% power or above if the minimum material properties are assumed. At 110% load, overload failure could occur in both locations with minimum strength material since the peak total stress is 33 ksi compared to 32 ksi minimum thick-section ultimate strength. The fact that few blocks that have run at 110% load have cracks at both locations is indicative of higher-than-minimum material properties and/or conservatism in the analysis.

The stress components in Table 3-2 are believed to be best available estimates from strain gage readings or conservative analytic scaling to key locations from gage readings, except for the preload. The preload gage readings (Gage Nos. 3 and 13) were used directly without scaling, even though the stress due to preload is probably higher near the stud hole in Crack Locations 1 and 2. This unconservative preload estimate partly compensates for conservative adjustments to the thermal stresses and for the conservatism inherent in the analysis of cracked ligaments with a plane strain model. This analysis is also conservative for engines that operate at lower temperatures and/or pressures.

Other than determining the scaling factors to get from gage locations to crack initiation sites, the analytical models were used only for insight. Reasonably good agreement between all available experimental and analytical results was obtained for several 2-D finite element and hand calculation models. However, in such a complicated case, with interacting effects of clearance gaps, 3-D geometry and loading, friction, component-to-component distortion interactions, and relatively uncertain material properties, the experimental results are judged to be more reliable than the models.

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TABLE 3-2

CONSERVATIVE ESTIMATES OF STRESS NORMAL TO CRACK FACE AT CRITICAL LOCATIONS

Location		Stress (ksi) Preload Experimental	Thermal Experimental	Pressure Range Experimental	Pressure Range Analytical	Load Level %
	TDI Gage No. 3	8.2	--	--	5.0	100
Ligament	TDI Gage No. 4	10.5	--	3.1	--	90
		10.5		3.3	5.0	100
		10.5		3.6	--	110
	Block top at stud hole Location 1	8.2*	14.1	5.9	--	90
		8.2*	14.9	6.3	9.5	100
		8.2*	18.8	6.9	--	110
Between studs (for cracked ligament)	FaAA Gage No. 13	4.3	9.2	3.4	--	90
		4.3	9.7	3.7	6.06	100
		4.3	12.2	4.2	--	110
	Block top at stud holes Location 2	4.3*	16.4	6.1	--	90
		4.3*	17.3	6.6	10.85	100
		4.3*	21.8	7.5	--	110

*Unconservative

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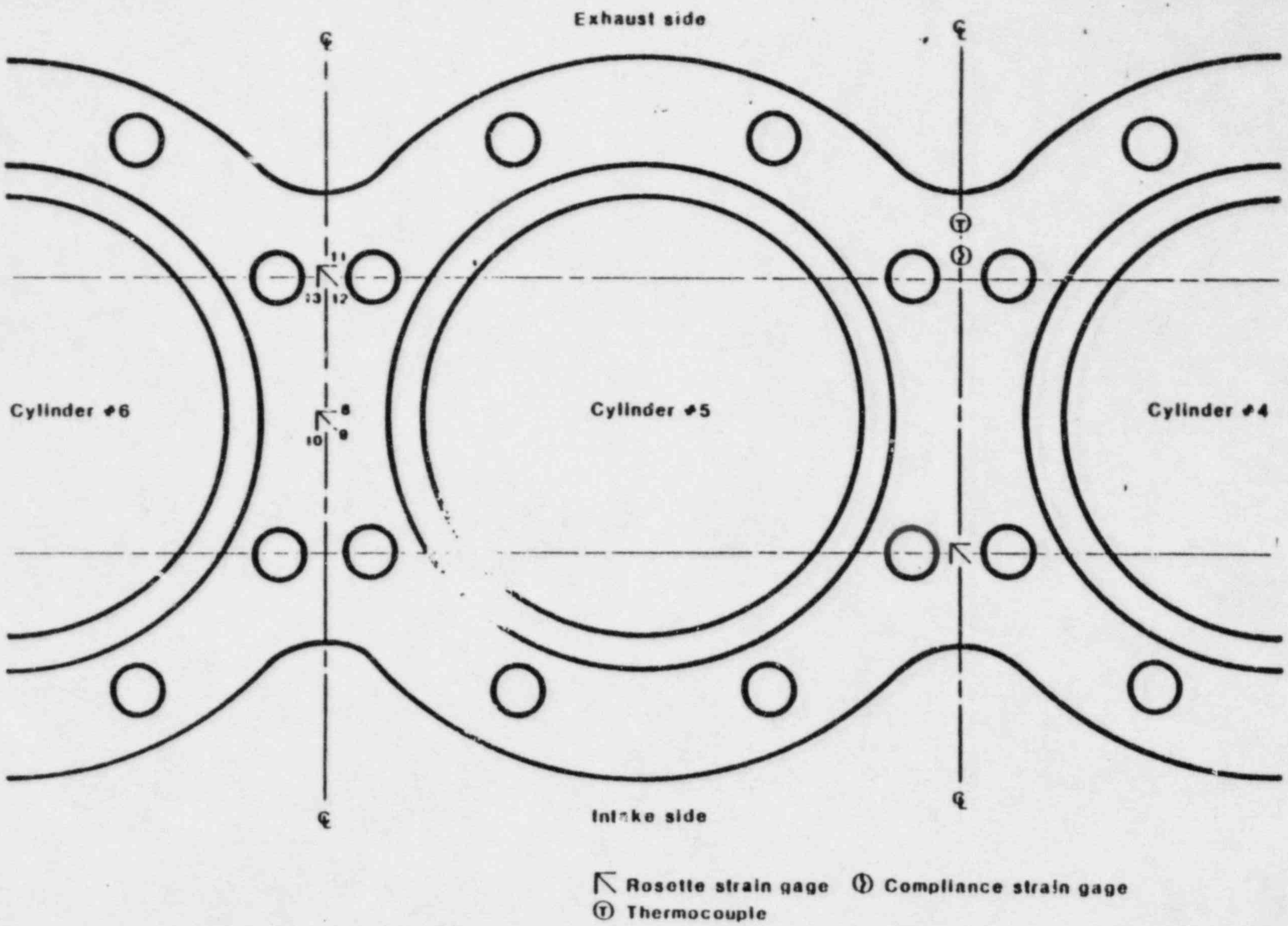

Figure 3-1. Strain gage placement.

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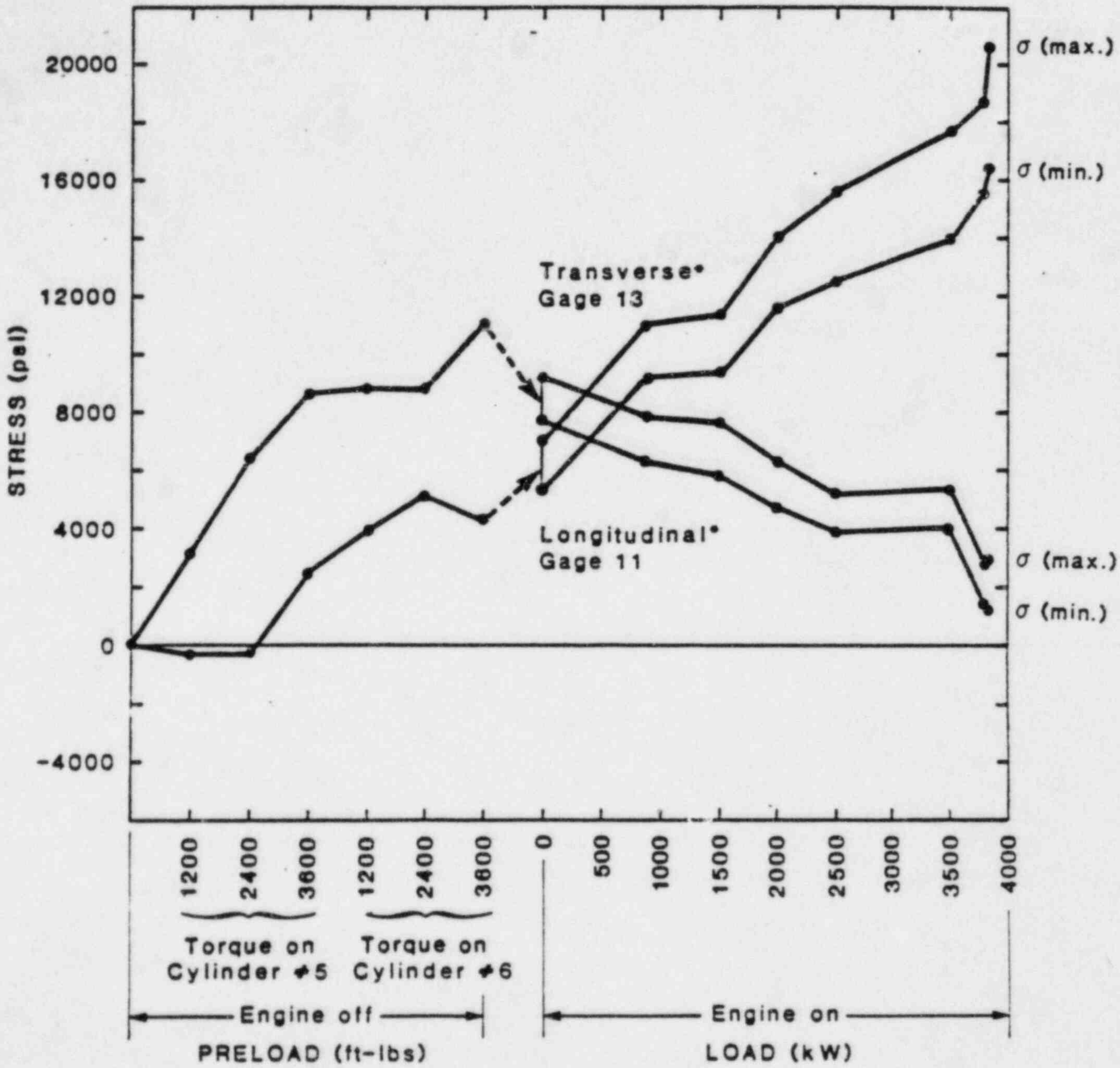

Figure 3-6. Principal stresses vs. load for Gages 11, 12 and 13 (located between studs.
*Principal stresses are located within 15° of gage axis.

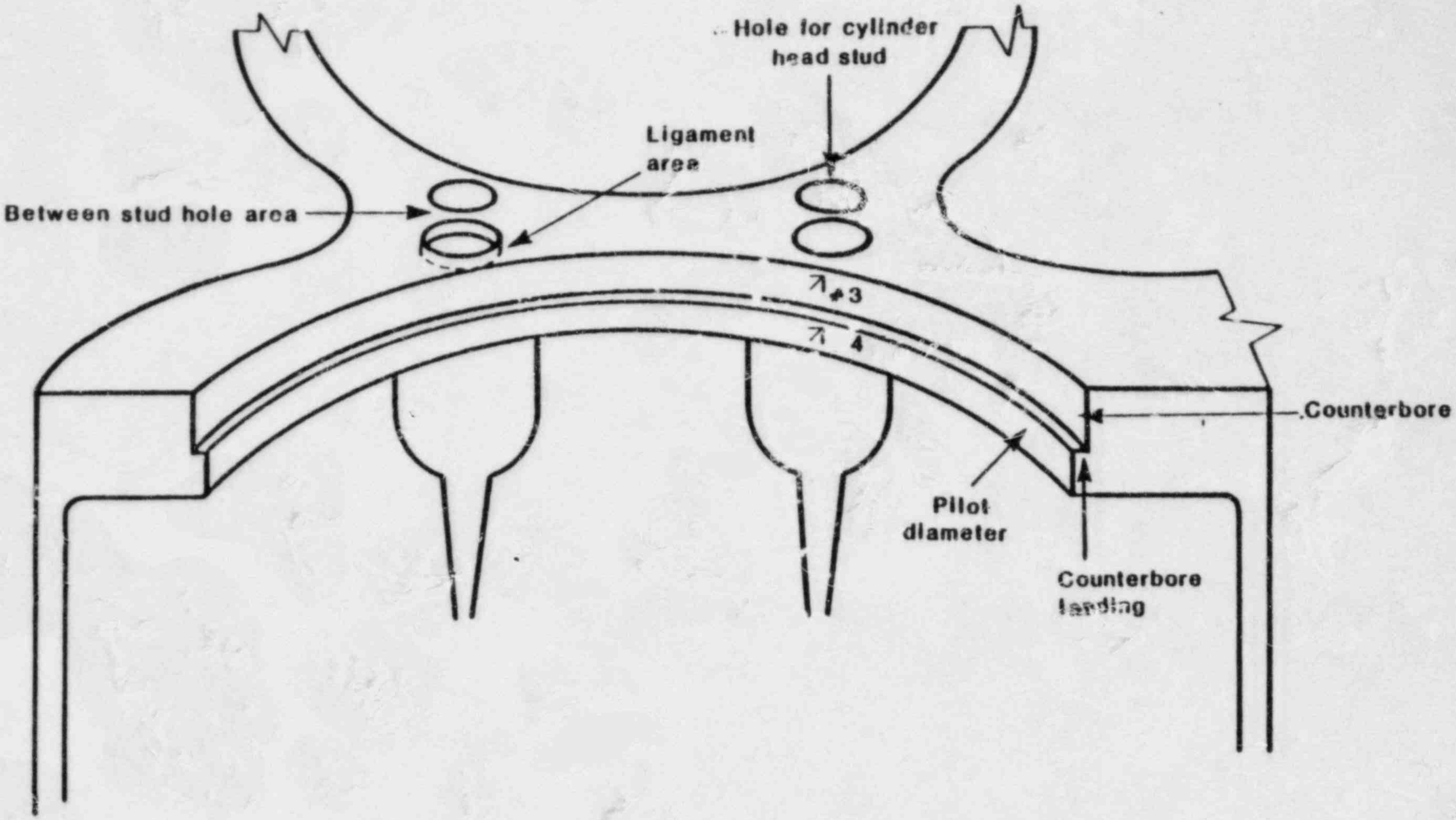

Figure [illegible]. TDI strain gage location.

Ref. 3-1.

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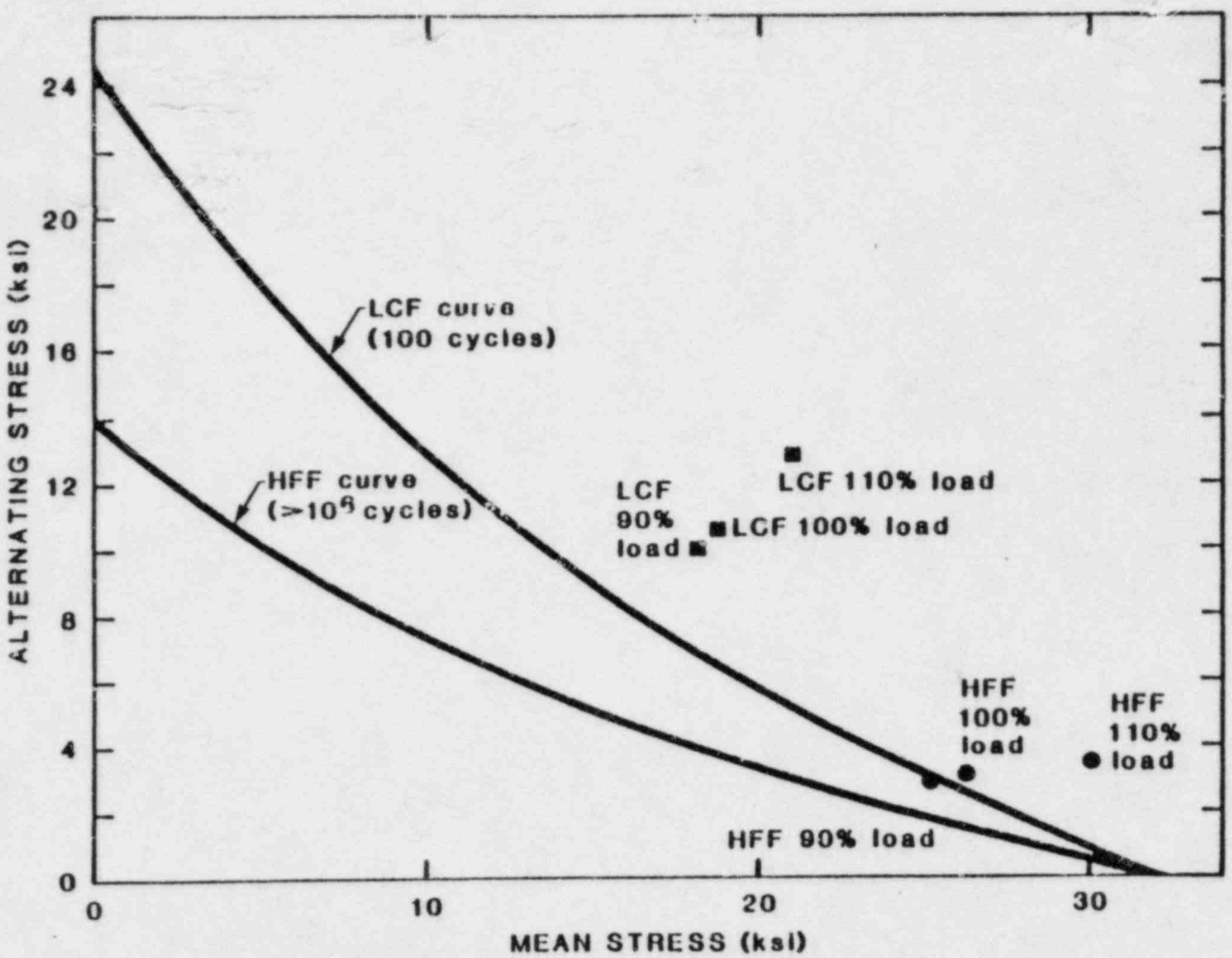

Figure 3-13. Goodman (Smith) diagram for ligament cracking.

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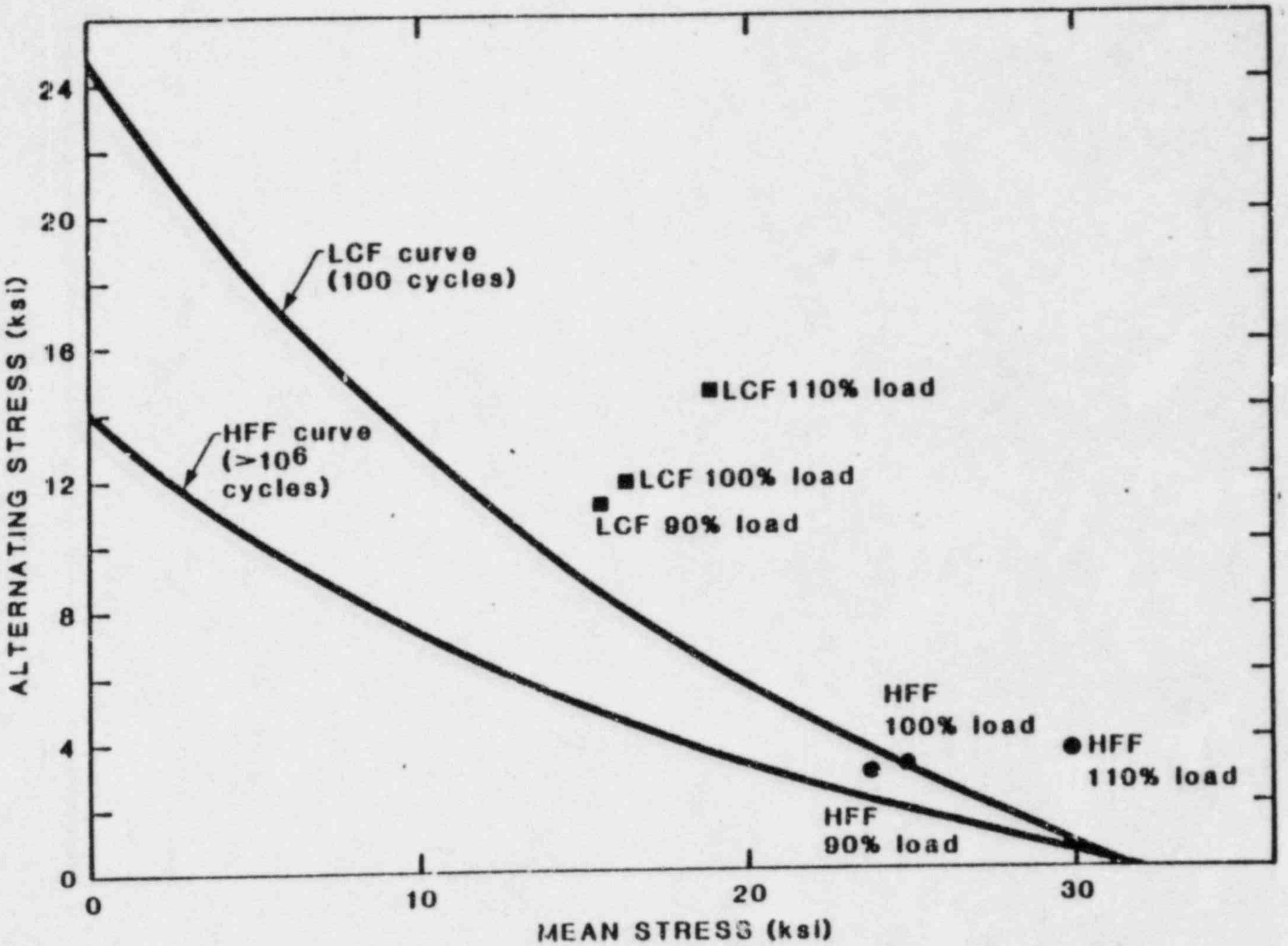

Figure 3-14. Goodman (Smith) diagram for stud-to-stud cracking.

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4.0 FRACTURE AND FATIGUE LIFE EVALUATION

4.1 Block Top Crack Initiation Damage Model

This section analyzes the initiation of block top cracks. A key part of this analysis is the observation that operation at 90% to 100% of rated load is in the fatigue initiation region of the Goodman diagrams for minimum strength cast iron as shown in Figures 3-13 and 3-14. However, the normal variability of material properties could result in no crack initiation under 90% to 100% load operating conditions. The 110% load point is far into the region where initiation is expected with minimum strength cast iron, and it is clearly more damaging relative to 100% load than 100% load is relative to 90% load. At load levels of 80% or less, the minimum acceptable Class 40 material probably will not initiate HFF cracking and will require greater than 100 startup cycles to initiate LCF cracking.

To predict the minimum amount of additional service before cracks are expected to occur between stud holes, it is necessary to consider both LCF and HFF and the current level of damage. If a particular block has operated for a substantial period of time without initiating ligament cracks, this provides an estimate of the minimum LCF and HFF damage required for ligament cracking in that particular block. Since the mean and alternating stresses for initiating ligament cracks and for initiating [illegible] stud cracks in the presence of ligament cracks are almost the same (compare Figures 3-13 and 3-14), at least the same cumulative damage will be required to initiate stud-to-stud cracks after the ligament cracks initiate and grow to a significant depth as was experienced in producing the ligament cracks.

A conservative way to estimate the current level of damage is to divide the time at load and the number of startups to load into categories, i.e., L<70%, 70<L<90%, 90<L<100%, 100<L<105%, 105<L<108%, and L>108%. For LCF, the number of startups that reached the particular load range is tabulated. After an inspection revealing no ligament cracks, subsequent operation without inspection can proceed so long as the number of additional startups in each category are less than the accumulated number at the time of the last inspec-

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micro-porosity and degenerate graphite. The appearance of the microstructure of DG103 is quite different than that of the engine blocks of DG101 and DG102.

The presence of degenerate graphite microstructure has been shown to reduce the strength of cast iron significantly [4-4, 4-5]. Specific materials testing is required to quantify any degradation in fatigue or fracture properties of the thick section block casting. A conservative projection of the cracking potential of other engines was obtained by extrapolating the experience of DG103 and assuming that other engine blocks are of equivalent material.

A block with no existing stud-to-stud cracks and material properties sufficiently better than those of DG103 should be able to complete the LOOP/LOCA requirements without any cracks as deep as the $5\frac{1}{2}$-inch crack in DG103, while continuing to run normally. Engines with better material or more favorable operating parameters or demands would have less damage. Therefore, these calculations indicate that periodic inspection for radial cracks between the stud holes, in combination with site-specific analysis of operating history, material properties, and operating stress, should assure that block cracks will not grow to a size which will impair the engine's ability to provide the power levels required during a LOOP/LOCA.

4.3 Block Material Properties

The comparison of stresses under full load operation in stud hole regions of the block top with the ultimate strength and fatigue resistance of Class 40 gray cast iron [4-6] shows that fatigue cracking of the ligament region can occur in material with minimum specified properties. On the other hand, if the ultimate strength and fatigue resistance of the block are above average for the Class 40, fatigue crack initiation may not occur without a large number of cold starts and extended operation at or near full power. The cumulative damage index approach provides a method to quantify the effects of alternative engine usage.

Clearly the block top area is not so conservatively designed that cracking will never occur, nor is it so highly stressed that ligament cracks will always occur. Under these circumstances, the cumulative time/load level/number of cold starts at which cracks develop and the rate at which they progress is strongly dependent upon the materials properties of the specific casting.

Gray cast iron is particularly sensitive to materials properties degradation due to small amounts of tramp elements, like lead. The ultimate tensile strength of thick section castings has been shown to be reduced by as much as 80% of its normal value by the presence of greater than 0.01% lead [4-4, 4-5]. These tramp elements reduce strength and ductility by modifying the normal structure of the graphite flakes to produce degenerate graphite structures with interconnected Widmanstatten (accicular) structure.

The presence of very extensive degenerate graphite microstructures can be identified by conventional metallographic examination. In-situ polishing of block top surfaces, light etching and taking of cellulose acetate (plastic) replicas for microscope examination provides a non-destructive method to detect severely degenerate casting stuctures. Small pieces of block material can also be removed for more detailed metallography and for quantitative chemical analysis to detect the presence of undesirable tramp elements.

4.4 Cam Gallery Cracks

An inspection of the emergency diesel generators at Shoreham revealed crack indications in the cam galleries of all three SNPS engines. These indications were of varying lengths, the longest being 4 1/2 inches long and 0.375 inch deep in DG103. A typical cross-section of the cam gallery is displayed in Figure 4-2, indicating the crack region. TDI installed strain gages on an experimental engine (DSR-46) at the locations of the crack-like defects and recorded the dynamic strains in a running engine. The strain gage data were reduced by TDI to obtain the mean and alternating stresses [4-7]. These stresses are reproduced here in Table 4-2. For the present analysis, stresses obtained at the Gage No. 1 location at 100% load were used.

A fracture mechanics analysis was performed to evaluate the fatigue

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Section 4 References

4-1 A. Yuen, et al., "Correlations Between Fracture Surface Appearance and Fracture Mechanics Parameters for Stage II Fatigue Crack Propagation in Ti-6 AC-4V, Metallurgical Transactions 5, p. 1833, August 1984.

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4-7 Dean T. Ripple, "R4-L6 Cam Gallery Strain Gage Test," Transamerica Delaval Inc., Engine and Compressor Division, R and D Report, FR-01-1983, Rev. June 21, 1983.

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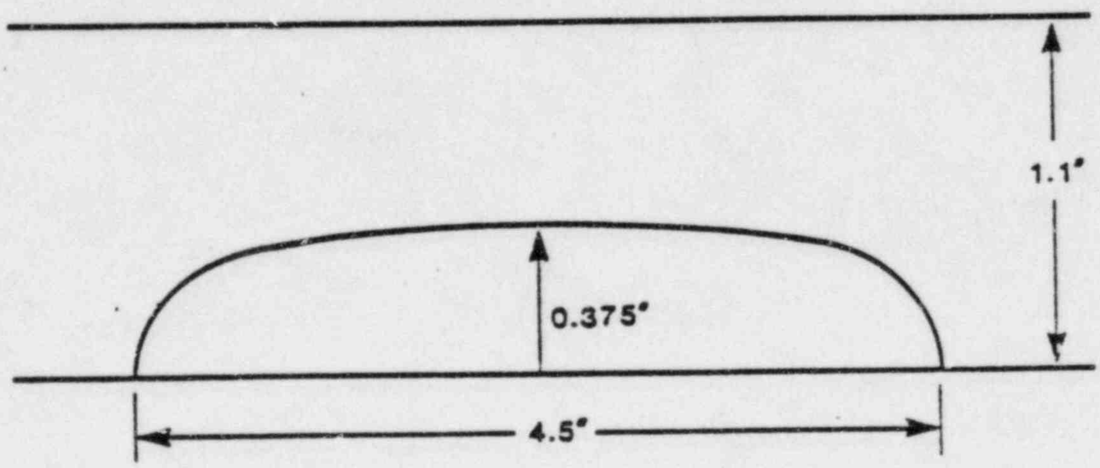

Figure 4-2. Cam gallery crack shape.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Review of operating experience with TDI R-4 and RV-4 cylinder blocks indicates that precautions are necessary to avoid the potential consequences of block top cracking between stud holes of adjacent cylinders. The results of strain gage testing, combined with two-dimensional analytical models of the block top and liner and cumulative damage estimates, provide the following conclusions and recommendations:

1. Initiation of cracks in the ligament between stud hole and liner counterbore is predicted to occur after accumulating operating hours at high load and/or engine starts to high load. These cracks are benign because the cracked section is fully contained between the liner and the region of the block top outside the stud hole circle. Field experience is consistent with both the prediction of ligament cracking and the lack of immediate consequences.

2. The presence of ligament cracks between stud hole and liner counterbore increases the stress and the probability of cracking between the stud holes of adjacent cylinders such that stud-to-stud cracks are predicted to initiate after additional operating hours at high load and/or engine starts to high load. The deepest measured crack in this region (5 $^1/_2$-inch depth) did not degrade engine operation or result in stud loosening.

3. The apparent rate of propagation of cracks between stud holes in the DG103 block at SNPS, when compared with the LOOP/LOCA requirements, indicates that blocks with ligament cracks (e.g., DG101 and DG102) are predicted to withstand a LOOP/LOCA event with sufficient margin provided that: (1) inspection shows no stud-to-stud cracks detectable between heads, and (2) the specific block material of DG103 is shown to be sufficiently less resistant to fatigue than typical gray cast iron, Class 40.

4. The block tops of engines that have operated at or above rated load should be inspected for ligament cracks. Engines such as those at Catawba and Grand Gulf that are found to be without ligament cracks can be operated without additional inspection for combinations of load, time, and number of starts that produce

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less expected damage than the cumulative damage prior to the latest inspection. The allowable engine usage without repeated inspection can be determined from cumulative damage analysis.

5. The blocks of engines that have been operated at or above rated load without subsequent inspection of the block top should conservatively be assumed to have cracked ligaments for the purpose of defining inspection intervals.

6. For blocks with known or assumed ligament cracks, the absence of detectable cracks between stud holes of adjacent cylinders should be established by eddy current inspection before returning the engine to emergency standby service after any period of operation other than no load. If crack indications are found, removal of the adjacent heads and detailed inspection and evaluation of the block top are necessary. In addition, it is necessary to ensure that the microstructure of the block top does not indicate inferior mechanical properties.

7. Engines that operate at lower maximum pressure and temperature than the SNPS engines (e.g., San Onofre) may have increased margins against block cracking that could allow relaxation of block top inspection requirements. Modifications to other parameters such as increased liner-to-block radial clearance will reduce stresses, and site specific analyses of such modification could also permit relaxation of inspection requirements.

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Appendix:

COMPONENT DESIGN REVIEW

TASK DESCRIPTION

CYLINDER BLOCK
Part No. 03-315A

Classification A
Completion Date 3/20/84

PRIMARY FUNCTION: The cylinder block comprises the framework of the liquid cooled engine and provides passage and support for the cylinder liner. The block must provide cooling water passages, provide bores to support the cam shaft assembly, and react the dynamic loads from the cylinder firing pressure and valve assemblies. For the RV engines, the cylinder block is interconnected with an engine crankcase which supports the camshaft and associated bearings. Although these are separate parts, their generic function is similar to the cylinder block of the R-48 engines and will therefore be evaluated as a unit. The liner itself forms the walls of the combustion chamber containing the high temperature gas pressure and must provide a guide for the piston motion while reacting skirt side forces without excessive wear or scuffing.

FUNCTIONAL ATTRIBUTES:

1. The cam gallery bearing supports must be designed to maintain concentricity during service and have sufficient structural strength to react the cam/valve train loads without fatigue cracking.

2. The support of the cylinder liner must maintain tight seals, react pressure and stud loads without unacceptable distortion and maintain sufficient load distribution to preclude excessive cracking in the liner counterbore (landing) due to combined thermal, gas pressure and preloaded stud induced states of stress. The cylinder head stud thread configuration is important in determining stress concentrations and stress distributions.

3. The cylinder liner itself must be sufficiently hardened to resist unacceptable wear associated with piston ring action and maintain adequate contact with the block counterbore to prevent high cycle contact stress and fretting. In addition, the compression of the head to the cylinder liner must be sufficient to avoid axial fretting of the liner within the counterbore but not so great as to cause failures of the cylinder block liner landing.

4. The cooling water distribution within the block must be sufficient to preclude overheating of the block and liner and must maintain proper flow conditions to minimize or avoid cavitation or corrosion damage to the liner.

SPECIFIED STANDARDS: None

EVALUATION:

1. Review information concerning previous cracking and distortion of the cylinder block and liners of the R48 and RV engines.

2. Review liquid penetrant inspections of cylinder block in the head stud and liner counterbore regions of the SNPS DSR-48 engines.

3. Evaluate the steady state and alternating stresses in the liner landing/head stud region and compare these to yield and endurance limits for appropriate materials. This examination must consider variations in head stud thread geometries and preload torques.

4. Evaluate the state of stress in the liner in the landing/axial seal region due to gas pressures, thermal growth and head clamping forces and compare to normal fatigue properties for liner material.

5. Evaluate critical flaw size and rate of crack growth considering combined head stud loads and thermal stresses for cracks located between head stud holes and cylinder block counterbore diameter.

6. Evaluate critical flaw size and rate of crack growth for cracks eminating from the corner of the cylinder block landing and counterbore diameter.

7. Evaluate the loading produced on the bearing supports in the cam gear gallery and verify the structural adequacy of the design.

8. Review the inspection of the sampled SNPS cylinder lines following 100 hours at 100% load for evidence of unacceptable scuffing, corrosion, cracking, or scoring.

9. Review information provided on TER DR-220.

REVIEW TDI ANALYSES:

1. Review any TDI analyses which consider stresses created in the liner counterbore area and any design changes which relate to geometry or material.

INFORMATION REQUIRED:

1. Manufacturer's drawings of R48 and RV cylinder blocks and liners, including material specifications and historical design changes.

2. Gas pressures and temperatures for R48 and RV engine designs.

3. Cylinder head stud drawings and torque specifications.

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4. Cylinder head stud drawings showing design changes.

5. Liquid penetrant inspection of cylinder block counterbore (landing) on SNPS engines.

6. Cam shaft loads due to rocker arms, pushrods and valve springs.