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WANL-TME-823

September 1964

CORE TIE ROD SIMULATING EXTREME
OPERATING CONDITIONS
(Title Unclassified)

EML-16 WR No. 41:41:04-36W

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Astronuclear Laboratory
Westinghouse Electric Corporation

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1. SUMMARY

- 1.1 The calculated mean stress for a tie rod with zero offset and maximum axial load of 820 lb was found to be approximately 85,000 psi. This calculation is for an Inconel 750 tie rod - the same type tie rod as used in the NRX-A2 reactor. During simulated reactor offset conditions, the maximum stresses sustained by this tie rod occurred, as would be expected, at the threaded end fillet (about 5/8 of an inch from the end) and also at the point where the tie rod enters the cluster plate which is approximately 5-1/8" from the threaded end. The simulated load conditions are specified in detail in 5.1. With a 0.200 inch offset and the maximum axial load of 820 lb, the maximum localized stresses induced in the above loaded locations are well beyond the yield strength. Actually, at this same axial load yielding will occur in the tie rod at less than 0.100 inch offset. The tie rod can be offset approximately 0.175 inches before yielding will occur with an axial load of 600 lb. After the first cycle at maximum load and offset conditions practically no further yielding was evident after 25 additional cycles.
- 1.2 The test data indicates that the tie rod will perform satisfactorily during the life of the reactor. The tie rod experienced 38,000 cycles with maximum offset (0.200 inches) superimposed on the steady maximum axial load (820 lb) before failure. These cycles were applied at cryogenic temperature at each of 4 offset values. If this durability is typical of all tie rods, the safety factor is considerable, since the maximum anticipated offset is substantially less and the maximum number of cycles are less than 100 at this condition.

2. INTRODUCTION

- 2.1 The wide extremes of temperature experienced in the operation of the NERVA reactor, especially during startup and shutdown, will, due to thermal growth and the variable coefficients of expansion in the different material used, induce severe stresses in the components. There is concern that bending stresses imposed on the already highly stressed tie rod could induce premature failure in the tie rod, which would then adversely affect successful reactor operation. Tests were conducted to substantiate analytical work and prove that the tie rods will perform satisfactorily under the extreme load conditions encountered during reactor startup and shutdown.
- 2.2 This test was considered a prerequisite for the NRX-A test and the report satisfies all the objectives of EML-16 Test Specifications.

3. PURPOSE

- 3.1 The purpose of this test is to determine the stress distribution in the core tie rod at specified conditions of displacement and axial load, and the structural integrity of the tie rod subjected to extreme (simulated) operating conditions for a limited number of cycles.
- 3.2 To determine the fatigue life of the tie rod when cycled laterally over the maximum range.

4. OBJECTIVES

- 4.1 Determine the stress distribution in the core tie rod due to specified displacement and axial load.
- 4.2 Determine if the tie rod will fail during a specified number of axial load and laterally displaced cycles at cryogenic temperature.

- 4.3 Determine the life expectancy of a tie rod subjected to extreme operating conditions and environmental operating temperature.

5. CONCLUSIONS

- 5.1 The maximum stress in the tie rod at zero off-set and 820 lb axial load is approximately 85,000 psi. This condition exists when the rod is stretched an additional 0.046 in. with 600 lb axial preload on the tie rod. The 0.046 in. represents additional displacement due to thermal restraint and support plate deflection.*
- 5.2 A lateral displacement (bending) of the tie rod at the cluster plate bushing induces severe stresses at the thread fillet and also at the cluster plate split bushing as shown by the strain distribution curves in Figure 4. Up to axial loads of 400 lb, the peak bending stress is approximately the same at these two end points. As the axial load is increased, the bending strains induced by lateral displacement increases sharply at the threaded end while remaining essentially the same at the bushing. At the maximum load of 820 lb, with an offset of 0.200 in., the measured strain at the thread end fillet is more than 7,000 microinches, well beyond the yield strength of the tie rod material. The accumulated bending tension strain only at this point may be twice this value as shown in Figure 5.
- 5.3 Yielding was found to occur in the tie rod at 820 lb axial load with 0.100 in. offset and at a lower axial load of 600 lb with 0.175 in. offset. It can be assumed that the tie rod can be operated safely below these limits for extended periods. At the higher axial load (820 lb) and lateral displacement (0.200 in.) the tie rod was cycled

* WANL-TME-568, "Stress Analysis: NRX-A Cluster Tie Rod".

for 38,000 cycles in cryogenic temperature (-320°F) before failure. Failure occurred approximately 5-1/8 in. from the threaded end where the tie rod enters the split bushing. There was considerable evidence of fretting which creates a strength reduction factor and thus contributing to early crack initiation.

- 5.4 Interference between tie rod and preload spring occurs under the maximum offset condition. We are of the opinion that this condition results from loose fitting tolerances in the attachment hardware seat and centering hub of the split bushing. This condition occurs at a point where the bending stress is very low.
- 5.5 Fretting between the tie rod and the split bushing creates a strength reduction factor severe enough to cause the tie rod to fail under cyclic loading in the bushing where the measured strain is approximately 30 per cent of the strain value at the thread fillet.

6. RECOMMENDATIONS

- 6.1 As noted in the results, wear occurred on the tie rod due to the friction of the rod in contact with the preload spring when the tie rod was cycled at 0.200 in. offset. The factors responsible for this condition to exist apparently were the very loose fitting tolerances of the spring in the attachment hardware (bolt, Part No. 977D774) and the centering (split) bushing, Part No. 963B343. It is suggested that these components could be redesigned to provide a closer fit. This would involve increasing the diameter of the split bushing (spring) end, and decreasing the diameter of the bolt (spring) seat.
- 6.2 If long periods of vibration are anticipated the problem of fretting corrosion of Inconel 750 in contact with the aluminum bushing material may become critical. The fatigue strength may be reduced by a factor of 3 or more.

7. TEST SPECIMENS AND COMPONENTS

7.1 Two core tie rods (Part No. 944C732H01, Serial Nos. V305 and V386) of Inconel 750 material, were instrumented with strain gages, placed back to back in the same plane, as shown in Figures 3 and 6 for the determination of stress distribution in the core tie rod at specified lateral displacements and axial loads. Budd Strain Gage, Type C6 1x1 - M50A, Lot No. A8-FBB-2 were cemented to the rod at the locations shown in Figure 3. A third tie rod (V326) was instrumented with two gages for calibration purposes.

7.1.1 Included in the test setup was support plate attachment hardware including; the centering bushing, Part No. 944C407H02; split bushing, Part No. 963B343; tie rod holder, Part No. 977D774; tie rod nut, Part No. 963B338; preload spring, Part No. 963B484, and the tie rod holder nut, Part No. 945C463. It was necessary to modify the tie rod holder as shown in Figure 8 to permit routing of strain gage lead wiring. All these parts were used to duplicate reactor assembly and loading conditions.

8. TEST EQUIPMENT

8.1 The test specimen used to determine the stress distribution in the tie rod, as shown in Figures 1 and 2 consisted of a test rig (ref. Drawing NT 700971) used in conjunction with the Wiedemann Testing Machine. The test rig simulating the core support plate (shown in cross section in Figure 7) was designed to provide offset (bending of 0 to 0.250 in. in the tie rod with a simultaneous axial load provided by Wiedemann

Testing Machine. The offset was induced at the split bushing (point A of Figure 7) which is approximately 5-1/8 in. from the tie rod threaded end. Displacement was accurately controlled with the aid of a dimensional gage mounted on the crossarm of the tensile machine (Figure 4). Strain gage readout equipment used for this test is shown in Figure 1.

- 8.2 The offset cycling could be accomplished by two different means: (1) by hand if the cycling was to be in one plane, and (2) rotation of the housing of the test fixture, thus subjecting the entire circumference of the tie rod to the maximum cyclic bending stress. The rotation of the housing sets up a wobbling action of constant amplitude. See Figure 7. Liquid nitrogen was controlled from a dewar into the fixture.

9. RESULTS

- 9.1 Maximum stress, in a tie rod subjected to offset bending with axial load, as determined by the stresscoat crack pattern and strain gage readout, occurred at the base of the thread fillet (5/8 to 3/4 in. from the end) and at the split bushing (approximately 5-1/8 in. from the end). Figure 4 illustrates the strain values at various conditions at axial load and offset. Yielding occurred in the tie rod at 820 lb axial load with 0.100 in. offset and also at lower axial load of 600 lb with 0.175 in. offset. Yielding was evident both at ambient and cryogenic temperatures (-320°F).
- 9.2 The tie rod performed satisfactorily when subjected to reactor environmental temperature (-320°F) and maximum possible lateral displacement (0.20 in.). The tie rod was cycled at cryogenic temperature in the same plane for 25 cycles with offset varying between 0 and 0.067 in. and axial

load between 50 lb and 820 lb; then again for 25 cycles each at 0 to 0.100 in., 0 to 0.150 in., and 0 to 0.200 in. offset with axial loads varying between 50 lb and 820 lb. These load conditions resulted in a permanent set (bend) in the tie rod at the centering bushing due to yielding in the tie rod. Each cycle consisted of; (1) offset, (2) load axially, (3) unload, and (4) return offset to 0.

9.3 The structural durability of the tie rod was found to be excellent with respect to long life under severe operating conditions. The tie rod was subsequently offset cycled at -320°F for over 38,000 cycles with a constant maximum anticipated axial load of 820 lb and offset varying from 0 to 0.200 in. before failure occurred. The rod fractured approximately 1/16 in. inside the split bushing where fretting was rather severe (Ref. Figure 11). The break occurred in an area where the measured strain was less than 1/3 the strain at the thread end.

9.4 It was found that severe wear occurred between the tie rod and the pre-load spring during cycling at 0.200 in. offset due to moving contact between these parts. The wear on the tie rod, measuring about 6 to 10 mils of the diameter occurred at about the second coil of the preload spring (bolt end) as shown on Figures 11 and 12. Although this worn section of the tie rod was weakened due to the reduced cross section, failure did not occur because of the lower induced stresses at this point.

10. TEST PROCEDURE

10.1 Stresscoat to indicate direction and location of maximum stress point was applied to the tie rod as shown in Figure 9 before the rod was assembled in the test rig and installed in the Widemann Testing Machine. An axial load of 200 lb and offset of 0.250 in. was imposed on the rod after which the rod was removed from the rig for observation

of the crack (stress) pattern in the stresscoat.

- 10.2 The tie rod, instrumented as shown in Figure 6, was installed in the machine as shown in Figures 1 and 7. Various conditions of axial loads and offsets were applied to the rod at ambient temperature to determine strains under these conditions. Difficulties were at first encountered in routing of gage lead wires and it was necessary to modify the tie rod bolt (Figure 8) for passage of the lead wires. The strains determined from these tests are graphically illustrated in Figure 4. A plot of load and offset versus cumulative bending tensile strain in Figure 5 illustrates yielding effects due to overloading (loading beyond the elastic limit) of the rods.
- 10.3 Single plane cyclic testing at cryogenic temperature was accomplished by offsetting the rod, applying axial load, removing offset, and finally releasing the axial load. The tie rod was cycled (Figure 1) for 25 cycles each at 0.067 in. offset, 0.100 in. offset, 0.150 in. offset, and 0.200 in. offset, with a maximum axial load of 820 lb. The 820 lb axial load was determined by first applying a 600 lb axial load and then stretching the tie rod an additional 0.046 in. which represents additional elongation in the peripheral rod as a result of support plate deflection, friction and thermal growth.
- 10.4 Offset cycling was applied at cryogenic temperature (-320°F) to determine the structural durability of the tie rod under the most severe operating conditions anticipated during reactor operation. A variable speed gear-motor rotated the fixture by means of a V-belt drive as shown in Figure 10 at a speed of 260 revolutions per minute with the offset at 0.200 in. and a steady axial load of 820 lb. The wobbling action induced in the tie rod also approximately simulates a torsional displacement of the core.

FIGURE 1

Tie Rod Test Setup

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FIGURE 2

Tie Rod Test Rig

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FIGURE 3

Strain Gage Locations

FIGURE 4

Strain Distribution Under Various Offset Conditions

FIGURE 5

Strain History at Threaded End of Tie Rod
Due to Axial and Offset Loading

FIGURE 6

Showing Strain Gages on Tie Rod

FIGURE 7

Cross Section of Tie Rod Offset Test Rig

FIGURE 8

Modified Tie Rod Bolt

TIE ROD OFFSET TEST
(STRESSCOAT APPLICATION)

FIGURE 9

Stresscoated Tie Rod

FIGURE 10

Variable Speed Drive for Torsional Bending

FIGURE 11

Tie Rod Fractured End Showing Fretting at Break

FIGURE 12

Fractured Tie Rod