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Submitted By:
Westinghouse Electric Corporation
Astronuclear Laboratory
P. O. Box 10864
Pittsburgh 36, Pennsylvania

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Prepared by:

G. H. Davis
Engineering Mechanics

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C.R.D.

Chang-Kep Kim 10/17/63
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Approved by:

C-K Kim 10/17/63
C-K Kim, Supervisor (Date)
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D. Wiebe 11/24/63
D. Wiebe, Manager (Date)
Engineering Mechanics
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PRELIMINARY REPORT

A-6 TIE ROD TEST

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ABSTRACT

Static tensile tests, conducted on NRX-A and backup tie rods at temperatures ranging from -320°F to 1250°F, show results similar to published data except at temperatures approaching 1200°F, where test values were significantly less.

Preliminary axial fatigue tests conducted on NRX-A tie rods at various preload and alternating loads, and at ambient and 900°F temperatures, have demonstrated 10^5 cycle endurance limits considerably in excess of anticipated design loads.

In preliminary tests, the relationship between lateral vibration resonant frequency and axial tensile load has been practically independent of the tie rod temperature for the range -320°F to 900°F.

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INTRODUCTION

A confirmation of the mechanical properties and resonant frequencies for both instrumented and regular tie rods using Inconel X-750 and its backup material, Inconel X-718, has been desirable since the initial design was proposed.

The specific components referred to are more precisely identified as follows:

1. Rod, Tie, 0.110 Diameter, Fuel Cluster Assembly, WANL Dwg. 944C732. (Instrumented tie rod of Inconel X-750, specified for NRX-A reactors)
2. Rod, Tie, Instrumented, 0.122 Diameter, Fuel Cluster Assembly, WANL Dwg. 945C524. (Instrumented tie rod of Inconel X-750, specified for NRX-A reactors)
3. Rod, Tie, 0.110 Diameter, Fuel Cluster Assembly, WANL Dwg. 945C568. (Regular non-instrumented tie rod of backup material, Inconel X-718)
4. Rod, Tie, Instrumented, 0.122 Diameter, Fuel Cluster Assembly, WANL Dwg. 945C567. (Instrumented tie rod of backup material, Inconel X-718)

The A-6 series of tests was initiated to provide developmental data on the tie rod strength at simulated operational environments, as well as to investigate manufacturing variables and provide quality assurance and

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reliability data on tie rod operational life.

This report covers the static and dynamic tests performed thus far on production quality hardware. The complete scope of work to be accomplished in this series of tests is more fully described in WANL-TNR-095.

The results of tests discussed in this report should be useful in determining maximum permissible tie rod preloads and design temperatures. Tests involving cluster assemblies will benefit from the tie rod fatigue and resonance data.

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PURPOSE

The purpose of the tests described in this report is to determine the suitability of both tie rod designs (regular and instrumented) and both tie rod materials (Inconel X-750, the specified material, and Inconel X-718, the backup material) for NRX-A reactor use.

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TEST DESCRIPTION

The tests are divided into three groups which are static, dynamic (axial), and dynamic (lateral).

Static tensile tests were conducted at room temperature, -320°F , 900°F , and approximately 1200°F . A standard tensile machine was used for all static tests. The -320°F temperature was produced on the tie rod by immersion in LN_2 suitably contained to provide uniform cooling of the entire specimen. High temperature tests were conducted by using the tie rod specimen itself, insulated from ambient air currents, as a resistance element.

Axial, dynamic fatigue tests at both ambient and high temperature (900°F) conditions have been conducted previously on both the Haigh Machine (a standard fatigue machine adapted for tie rods) and the Weidemann-Baldwin Tensile Test machine which is in common use.

Tests were conducted at discrete preloads of 300, 500, and 70 lb. Alternating loads, commencing with ± 150 lb and increasing in 100 lb increments (always maintaining a sufficient preload to insure that the specimen tie rod is always in tension) were applied to the specimen until the maximum load was obtained that the tie rod could withstand for 100,000 cycles without yielding. The same procedure was followed in both ambient temperature, and high temperature (900°F) testing.

Lateral vibration tests were conducted in a test fixture specially fabricated for this particular test. The tie rod, situated horizontally,

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was fixed at one end and a tensile load, measured through a load cell, was applied at the other end. A 1 lb force maximum electro-mechanical generator, placed at either end of the tie rod, was used to induce tie rod vibration. An identical generator placed at the other end of the tie rod was used as a transducer to measure the resulting amplitude. The resonant frequency condition (maximum amplitude) for each tensile load was readily determined by varying the input generator frequency and noting maximum generator transducer output. The low temperature testing was accomplished by bathing the specimen in LN₂ vapor and following the procedure outlined above. High temperature testing (900°F) was performed by using the tie rod specimen as a heating element (as in static tests) and following the ambient temperature procedure.

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CONCLUSIONS

Static Tensile Tests

Static tensile tests, using at least two samples for each point, are in good agreement with the 0.2% yield strength and ultimate tensile strength data published in the WANL Materials Handbook, except at 1150°F and above, where test results are lower. Tests at -320°F, ambient temperature, and 900°F conducted on single specimens of instrumented tie rods of Inconel X-750 material, production quality, show results very similar to those obtained for regular rods of the same material (see Table 1, and Figures 7 and 8, Test Results and Data).

Dynamic and Axial Fatigue Tests

Preliminary data on axial dynamic fatigue tests conducted at ambient temperature on Inconel X-750 tie rods indicate a modified Goodman Diagram as shown in Figure 11, Test Results and Data. Note that the specimen tie rod must be maintained in tension; hence, the curve may not be extended past static load equal to alternating load.

Lateral Vibration Resonant Frequency Tests

Preliminary data on the NRX-A regular tie rods at temperatures from -320°F to 700°F, and tensile loads from 100 to 500 lb, showed less than 3% variation in resonant frequency; hence, the resonant frequencies obtained at ambient temperature are representative of values at the temperature

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extremes. This indicates a constant Young's Modulus, within the equipment accuracy, over the temperature range considered (see Fig. 12, Test Results and Data).

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RECOMMENDATIONS

Static tensile tests at temperatures in the range of -320°F to 900°F temperature range for regular tie rods of Inconel X-750, and Inconel X-718 production quality material, should be continued for adequate statistical correlation. Temperatures above 900°F must be investigated in more detail up to the maximum expected temperature of approximately 1300°F using statistically valid samples (in this case, approximately five tie rod specimens, per 50°F increment from 900°F to 1300°F) for both Inconel X-750 and Inconel X-718 material. Instrumented tie rods of both materials should be tested in statistically sufficient samples for the entire temperature range of -320°F to approximately 1300°F .

Dynamic axial fatigue tests should be conducted on samples of all four combinations of tie rod designs and materials of production quality with preloads, alternating loads, and test temperatures specified in detail in WANL-TNR-095 until enough data is obtained for adequate statistical correlation. In addition, dynamic axial fatigue tests at -320°F should be performed toward possible failure of threads, or heads, during operation, particularly for the instrumented designs.

Lateral vibration resonant frequency tests of at least three samples of each type of tie rod should be continued. Since this test is

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non-destructive, specimens are available for further use.

Dimensional tolerance limits of tie rods of both materials should be evaluated by static and dynamic tests as described in this series in order to reduce cost.

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TEST SETUP

The series of A-6 tests are divided as follows:

Static Tensile Tests:

A-6-1 Tie Rod Tests, Room Temperature, Static Tensile

A-6-2 Tie Rod Tests, Low Temperature (-320°F), Static Tensile

A-6-3 Tie Rod Tests, High Temperature (900°F and above),
Static Tensile

Dynamic Axial Fatigue Tests:

A-6-4 Tie Rod Test, Room Temperature, Static and Alternating Load

A-6-5 Tie Rod Test, High Temperature (900°F), Static and Alternating Load

Lateral Vibration Resonant Frequency Tests:

A-6-6 Tie Rod Test, Lateral Vibration

Static tensile tests at all temperatures were conducted on the Wiedemann Baldwin Tensile Machine using different end fittings for mounting the specimen at each temperature condition (see Figs. 1, 2, 3, and 13). The specimen tie rods (Fig. 13) are visible only in the room temperature test setup (Fig. 1). The head end of the tie rod is always mounted uppermost, in a support cone, which in turn is mounted on a top plate and an extension cylinder. In Fig. 2, Low Temperature Test Setup, the LN_2 container is shown in the process of filling the tube enclosing the

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tie rod specimen. This tube is rigidly attached at the bottom, the thread end of the specimen, and is free to move at the top head of the tensile machine. The potentiometer pyrometer leads shown are attached to chromel-alumel thermocouples on the specimen to determine temperature. Four thermocouples are used in both the low and high temperature tests. Thermocouples are mounted approximately 2 in. and 20 in. from each end and are continually monitored to obtain both end and central specimen temperatures. The strain gage extensometer is just visible beneath the moving head. The automatic recorder is shown at the far right. Fig. 3, the high temperature test setup, shows the induction reactor used to provide power to heat the specimen (the specimen itself is used as the heating element). Approximately 30 amperes heats the specimen to 900°F. Note the insulation between the moving head and the tube end fitting which effectively isolates the specimen. An extensometer operating on the same principle as the strain gage clips, but with an extended range, is pictured beneath the moving head. An ammeter and potentiometer pyrometer, and a thermocouple switching box are also visible.

Axial fatigue tests have been conducted at both room temperature and high temperatures (900°F) on the Haigh Machine (Fig. 4). This machine mechanically preloads the tie rod, suitably mounted with threads uppermost, then produces an alternating load electromagnetically at 120 cps. The instrumentation used with the room temperature tests enabled continual monitoring of both the tie rod preload and alternating load via strain

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gages mounted on the specimen.

Specimen temperature was provided by resistance heating, using the tie rod specimen as the element. The power supply was attached through the lead cables shown at the head and on the armature. The head was electrically insulated from the rest of the machine.

Additional axial tie rod fatigue tests were conducted on the Wiedemann-Baldwin Tensile Machine at 3 cpm, 900°F, and on a Sonntag SF-1-U at 30 cps, room temperature.

The lateral vibration test used the same load fixture (Fig. 5) at all temperatures. The low test temperature was obtained by pouring LN₂ into the fixture. The high temperature was obtained, as in the static tensile test, by passing a current through the specimen (resistance heating). Loads were applied through a load cell monitored with a strain gage indicator. Temperatures during environmental tests were monitored using chromel-alumel thermocouples adjacent, but not touching the specimen, as the resonant frequency would be affected. Instrumentation used to induce and monitor resonant frequency is shown in Figs. 5 and 6.

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TEST PROCEDURE

Static Tensile Tests

The following methods of testing for the three categories of Test A-6-1, A-6-2, and A-6-3, have a common tensile procedure. The only differences are in the end fittings and the procedures used to monitor and obtain test temperatures. The following test procedures were used for each category.

A-6-1 Room Temperature Static Tensile Tests

1. Measure and record the tie rod overall length from the underside of the head to the end of the tie rod. Measure and record the tie rod shank diameter at several places along the length.
2. Place the tie rod specimen in the tensile test machine as shown in Fig. 1.
3. Load the tie rod specimen as noted below using a strain rate less than 0.1 in./min.
 - a) 0 to 500 lb and return to 0, recording continuously load vs. strain with strain gage clips. Dial gage readings are to be recorded at fifty pound increments as a verification of recorder strain indications.
 - b) 0 to 550 lb and return to 0, recording continuously load vs. strain. Dial gage readings are to be recorded at fifty pound increments as a verification of recorder strain indications.

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4. Load the tie rod specimen to failure at a strain rate of less than 0.1 in./min. to yield, then at less than 1.0 in./min., recording continuously the load vs. strain. Dial gage readings are to be recorded at 100 lb increments to 600 lb, then at 50 lb increments to fracture, or the limit of travel of the dial gage, as a verification of recorder strain indications.
5. Measure and record the final tie rod length at several places along the length and the tie rod shank diameter at the fracture site and remote from the fracture site.

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A-6-2 Low Temperature (-320°F) Static Tensile Test

1. Measure the tie rod overall length from the underside of the head to the end of the tie rod.
2. Attach suitable thermocouples in an approved fashion, 2 in. and 20 in. from each end (4 thermocouples total).
3. Place the tie rod specimen in the tensile test machine, and attach required equipment.
4. Allow LN_2 to flow into the tube fixture until temperature equilibrium is obtained. Thermocouple temperature indications remaining within 10°F over a five minute period shall be considered temperature equilibrium. If necessary to maintain temperature, a small flow of LN_2 may be used. Maintain a record of temperature vs. time until equilibrium is reached. Care should be taken not to permit the tensile load to build up on the specimen tie rod during cooldown.
5. Load the tie rod specimen as noted below using a strain rate of less than 0.1 in./min.
 - a) 0 to 500 lb, return to 0, recording load vs. strain continuously with a strain gage extensometer. Dial gage readings at 50 lb increments should also be recorded, if the extensometer cannot be used.
 - b) 0 to 550 lb return to 0, recording load vs. strain continuously with

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a strain gage extensometer. Dial gage readings at 50 lb increments should be recorded, if an extensometer cannot be used,

6. Load the tie rod to fracture at strain rate less than 0.1 in./min. to yield, then at a rate less than 1.0 in./min., recording continuously load vs. strain with a strain gage extensometer. If an extensometer cannot be used, dial gage readings shall be recorded at 100 lb increments to 600 lb, then at 50 lb increments to fracture, or to the limit of travel of the dial gage. At fracture, measure and record the final tie rod length and the final tie rod shank diameter. The shank diameter shall be measured at both the fracture site and away from it.

A-6-3 High Temperature (900°F and 1340°F) Static Tensile Tests

The following procedure applies to the test at each temperature:

1. Measure and record the tie rod overall length from the underside of the head to the end of the tie rod. Measure and record the tie rod shank diameter at several places along the length.
2. Attach suitable thermocouples in a fashion approved by the test engineer 2 in. and 20 in. from each end (4 thermocouples, total).
3. Place the tie rod specimen in the tensile test machine. Attach required equipment.
4. Apply current to the tie rod specimen until equilibrium test temperature (900°F or 1340°F) is obtained. Equilibrium temperature is here defined as

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consecutive five minute thermocouple indications of temperature within 10°F on each central thermocouple.

5. Load the tie rod specimen as noted below, using a strain rate less than 0.1 in./min.
 - a) 0 to 500 lb and return to 0, recording continuously with a strain gage extensometer load vs. strain if an extensometer cannot be used. Dial gage readings at 50 lb increments shall be recorded.
 - b) 0 to 550 lb and retrun to 0, recording continuously load vs. strain with a strain gage extensometer. If an extensometer cannot be used, dial gage readings at 50 lb increments shall be recorded.
6. Load the tie rod specimen to failure at a strain rate of less than 0.1 in./min. to yield, then less than 1.0 in./min. to fracture, recording load vs. strain continuously with an extensometer. If an extensometer cannot be used, dial gage readings shall be recorded in 100 lb increments to 600 lb, then at 50 lb increments to fracture, or to the limit of travel of the dial gage.
7. At fracture, measure and record the final tie rod length and the final tie rod shank diameter (see step 1). The shank diameter shall be measured at both the fracture point and at some distance remote from the fracture point.

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Comments - General Static Tensile Test Procedure

1. It is desirable that dial gage readings be taken during all tests, even when using extensometers of a satisfactory range. They verify the load-strain recorder and serve as a substitute in the event of recorder malfunction.
2. In order to facilitate testing, hysteresis tests may be deleted if the first five specimens of each material and design show no discernible hysteresis.

Axial Fatigue Tests

A-6-4 Tie Rod Test, Room Temperature

1. Measure and record the tie rod overall length and shank diameter at several places.
2. Approximately 2 in. from the head end of the tie rod, install two suitably sized dynamic strain gages (180° apart) to read axial strain.
3. Install the tie rod in the Haigh Fatigue Test Machine, then attach the strain gages to the instrumentation and read zero values.
4. Set the preload spring to the desired value.
5. Turn the test machine on.

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6. Adjust the hand wheel to center the armature. The strain gage readings converted to load should agree with the preload value.
7. Adjust coil current to the desired value of alternating load, as determined from a conversion chart. Dynamic strain gage readings converted to alternating load should agree with values obtained from coil current conversions. Run the test to fracture or for one hour, monitoring strain, coil current, and preload (temperature changes of the test specimen will change the preload the center position of the armature is indicated on a gage and adjustable with the handwheel).

For this test, the arbitrary preload values to be used are 300, 500, and 700 lb. The alternating load values to be used are:

300 lb preload - ± 250 lb

500 lb preload - ± 150 lb
 ± 250 lb
 ± 350 lb

700 lb preload - ± 150 lb
 ± 250 lb

In order that a fewer number of specimens be used, the specimens shall be tested at the highest alternating loads first. Tests at a given preload shall be conducted until the alternating load yielding a specimen life of at least one hour is obtained.

No more than one test shall be run on each tie rod specimen.

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8. At the conclusion of the test, measure the tie rod overall length from the underside of the head to the threaded end of the rod and the shank diameter (if fracture occurred, both the fracture diameter and a diameter remote from the fracture must be measured).

The test procedure for the Sonntag SF-1-U Machine used on some tests is essentially the same, except that alternating loads are preset and applied mechanically, rather than electrically.

A-6-5 Tie Rod Test, High (900°F) Temperature

1. Measure and record the tie rod overall length and shank diameter at several places.
2. Approximately 3 in. from the head end of the tie rod, install two suitable sized strain gages (180° apart) to read axial strain.
3. Install the tie rod in the test machine, then attach the strain gages to the instrumentation and read zero values.
4. Set the preload spring to the desired value using strain gages to check.
5. Attach chromel-alumel thermocouples approximately 2 in. from each end of the tie rod specimen and approximately 20 in. from each end of the tie rod.
6. Adjust the resistance heating power supply to the approximate current necessary for the specimen temperature desired. Monitor the thermocouples until temperature equilibrium is obtained (consecutive 5 min. readings within 10°F on each central thermocouple). Make fine adjustments as required on the resistance heating power supply to reach and maintain

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the required specimen temperature as determined by the temperature readings of the two central thermocouples. The temperature to be used in this test at each preload is 900°F).

7. Turn the test machine on.
8. Adjust the handwheel to center the armature. The strain gage readings converted to load should agree with the preload value.
9. Adjust coil current to the desired value of alternating load, as determined from a conversion chart. Dynamic strain gage readings converted to alternating load should agree with values obtained from coil current conversions. Run the test to fracture, or for one hour, monitoring strain, coil current, and preload (temperature changes of the test specimen would change the preload).

For this test, the arbitrary preload values to be used are 300, 500 and 700 lb. The alternating load values to be used are:

300 lb preload - ± 250 lb

500 lb preload - ± 150 lb
 ± 250 lb
 ± 350 lb

700 lb preload - ± 150 lb

In order that the fewest specimens be used, they shall be tested first at the highest alternating loads. Tests at a given preload shall be conducted until the alternating load load yielding a specimen life of at least one hour is obtained.

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No more than one test shall be run on each tie rod specimen.

10. At the conclusion of the test, measure the tie rod overall length from the underside of the head to the threaded end of the rod and the shank diameter (if fracture occurred, both the fracture diameter and the diameter remote from the fracture must be measured).

Lateral Vibration, Resonant Frequency Determination

A-6-6 Tie Rod Test, Lateral Vibration

A. Ambient Temperature Tests

1. Mount the tie rod in the fixture using a cone, pyrolitic graphite cup, and an insulating washer under the tie rod head, and attach the threaded end into the transition block. Slip the load cell and fitting into the transition block and attach the other end of the cell to the threaded adjustment shaft.
2. Zero the load cell on the strain indicator, then using the calibration provided with the load cell, apply a 100 lb tensile load.
3. Tighten the transition load clamps and attach loading wires from the generators to the tie rod as close as possible to each end.
4. Using an oscillator-amplifier system capable of discrete 0.1 cps changes of frequency, determine the resonant frequency of the tie rod as determined by maximum voltage output on the generator acting as a transducer.

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5. Increase the tensile load in 100 lb increments to 500 lb total load and repeat Step 4 above. The transition hook clamp will have to be loosened before adjustments can be made in the tensile load.
6. Release the load, and check that no drift occurred in the load cell or the tie rod.

B. Low Temperature Tests (-320°F)

1. Repeat Step 1, Ambient Temperature Tests.
2. Install thermocouples near the ends of the tie rod in close proximity to the tie rods.
3. Add LN_2 to the test fixture trough. Monitor the thermocouples with a potentiometer pyrometer until equilibrium temperatures are indicated in the range of 280°F to -320°F (equilibrium is here defined as consecutive five minute readings within 10°F on each thermocouple). Be sure allowance is made for tie rod thermal contraction by releasing the load as specimen temperatures decrease.
4. Repeat Steps 3 through 6 of Ambient Temperature Tests. Monitor temperatures throughout testing, adding LN_2 as required.

C. High Temperature (900°F) Tests

1. Repeat Step 1, Ambient Temperature Tests, and Step 2, Low Temperature Tests.

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2. Attach power cables at either end of the test fixture and apply current through the tie rod specimen (the load end of the tie rod is insulated from the fixture, and the generator armature and end wires are insulated from the generator body; hence, current applied passes through the tie rod only). Adjust the induction reactor power supply to the approximate current necessary for the specimen temperature desired (900°F). Monitor the thermocouples and maintain a slight tensile load until temperature equilibrium is obtained (consecutive readings 5 min. apart within 10°F on each thermocouple). Make fine adjustment as required to maintain the required specimen temperature of 900°F.
3. Repeat Steps 2 through 6, Ambient Temperature Tests.

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TEST RESULTS AND DATA

Static Tensile Tests

A curve is presented in Figs. 7 and 8 of the yield strength and ultimate tensile strength values obtained thus far (see Table 1 for average values obtained, and summaries of static tensile test data (A-6-1, A-6-2, A-6-3) in Tables II, III, and IV. These values compare well with WANL Materials Handbook Data, and with subsequent room and LN₂ temperature tests conducted on simulated tie rods (identical head and thread, but shorter length) by the Materials Section (see WANL-TME-563) except at temperatures approaching 1200°F. The limited number of tests conducted in the temperature range 1150°F to 1250°F show results that are lower than WANL Materials Handbook Data indicates. For this reason, tests originally planned at 1340°F (the expected temperature where 0.2% yield strength equalled design load for the Inconel X-750 material) were modified in an attempt to bracket this range. Arbitrary temperatures of 1150°F and 1250°F maximum specimen temperature (nominally 1200°F) were selected on the basis of a single test as the region indicating fall-off of the Inconel X-750 curve of 0.2% yield and ultimate strength with temperature.

Hysteresis determinations were performed on NRX-A tie rods at all test temperatures. However, results indicated that loading and unloading the tie rod from 0-500 lb-0 or 0-550 lb-0 involved no hysteresis within the accuracy of the indicating and recording instruments available and at the strain rates

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employed. Identical results have been obtained in limited room temperature testing of the tie rods of Inconel X-718. The hysteresis test will be discontinued in the NRX-A Tie Rod Test. Testing of representative samples of Inconel X-718 tie rods at -320°F, 900°F, and 1200°F will be conducted. Identical results would eliminate the hysteresis test on this material, also.

Elongation and reduction of area values obtained are consistently lower than published values for both materials, at all temperatures. The limited number of instrumented tie rods tests have shown slightly lower values than those obtained for regular tie rods of the same material. This difference in values at room temperature conditions is due to the extreme test specimen length (see Figs. 9 and 10). Data shows, however, as in 0.2% yield strength and ultimate strength curves, that corresponding decrease in percentage of elongation for NRX-A tie rods occurs approximately 150°F lower than Handbook values indicate.

The method of heating the tie rod specimen (the resistance of the tie rod to a current flow heats up the rod) has no effect on the elongation of the rod; the maximum percentage reduction of area may be lessened due to arcing and consequent beading of the fractured end.

Measurements made on the regular tie rod specimens after tensile tests showed a variation of diameter indicating most of the reduction of area occurred over a length of between 12 and 25 in. No effort was made to map

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the exact diameter variation because:

1. Yield strength is the criteria for failure, not ultimate strength; hence actual failure occurs before diameter variations could be noted.
2. Fracture locations were random for regular tie rods, therefore, tests procedure or test fixtures were not causing this variation.
3. This nonuniform reduction of area along the length is expected with such long tensile specimens.

In all cases of calculation of percentage of elongation, the overall length of the tie rod from the underside of the head to the end of the tie rod was used as the base (original) length. Percentage reduction of area of instrumented tie rods assumed a uniform reduction of both inside and outside diameters, that is, the nominal percentage of reduction of area calculation was.

$$\text{Nominal \% Reduction of Area} = 1 - \frac{(D)^2}{n^2} \times 100;$$

(Initial Diameter)

the corresponding maximum percentage of reduction of area calculation was similar:

$$\text{Max. \% Reduction of Area} = 1 - \frac{(D)^2}{f^2} \times 100.$$

(Initial Diameter)

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The methods used to obtain 0.2% yield strength and ultimate strength were standard, that is

$$\frac{\text{Load at 0.2\% Permanent Set}}{\text{Original Area}} = 0.2\% \text{ Yield Strength.}$$

The load at 0.2% permanent set was determined graphically and by using dial gage readings.*

The portion of threaded end of the tie rod specimen remaining unengaged was controlled only on room temperature tests. The long tube used for environmental tests prevented this at other temperatures. It is felt that since the net area of the shank is less than the net area of the threaded portion, even on instrumented rods, static tensile test results were not affected.

Axial Fatigue Tests

Preliminary axial fatigue tests have been conducted on NRX-A tie rods at room temperature using the Haigh Fatigue Machine. Poor control of

*The increment of change of dial gage reading is determined at lesser loads, and then subtracted from readings taken at yield. The 0.2% permanent set (0.120 in. in this case) and the corresponding load are then determined where the total yield equals 0.120 in.

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preload and alternating load became an inherent property of this machine with its conversion to use for tie rod tests; hence resulting tests did not necessarily follow the preloads and alternating loads dictated in WANL-TNR-095. High temperature (900°F) tests on this machine have been limited to a total of two tests at relatively low alternating loads for the same reasons. Three tests at 3 cpm for 100 cycles were conducted at 900°F on the Wiedemann-Baldwin machine on instrumented NRX-A tie rods. No axial fatigue tests have been conducted to date on either regular, or instrumented tie rods of Inconel X-718 material.

The available data has been summarized in Fig. 11; a modified Goodman Diagram for approximately 100,000 cycles. This limit was arbitrarily selected as being a reasonable test time to determine operational tie rod failure and the initial tests were not intended to find the more common 2×10^6 cycle, or 10^7 cycles endurance limit. Points are included from tests conducted on two NRX-A instrumented tie rods at Westinghouse Research and Development Center. Samples were subjected to continued tests at higher peak loads if failure did not occur under initial loading conditions. Hence, the total points on the diagram may be higher than the total number of specimens tested (setting up the specimens in the Haigh Machine caused loss of some specimens). For this reason, data must be considered preliminary until more specimens are tested under a single loading condition.

Only two fatigue fractures were observed, and both were on the in-

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strumented tie rods. The other failures consisted of yielded specimens from loading conditions sufficiently high to cause static yielding, rather than fatigue fracture, for the number of load cycles employed. The two fatigue fractures observed (see Fig. 14) showed that peak stresses were quite high, as only a very small area of fatigue crack propagation occurred before failure took place (see WANL-TME-563).

Individual specimens in Tables II and III, marked "X" in Columns A-6-4 and A-6-5 have loading conditions, total cycles, and results of axial fatigue tests summarized.

Lateral Vibration Resonant Frequency Test

Preliminary test results at -320°F ambient temperature, and 900°F in two specimens of regular NRX-A design are shown in Fig. 12 (see also Table II, Column A-6-6 for numerical data). Only fundamental resonant frequencies have been obtained. The full range of frequency will be completed at a later date, as will testing of other type of tie rods (instrumented Inconel X-750 and both designs fabricated from Inconel X-718).

The power inputs used are sufficient to drive the center of the tie rod to a double amplitude of 0.031 in (higher power input causing 0.125 inch DA will also, be used). However, the generators used do not have sufficient force (the generator rating is 1 lb force) to produce a significant bending stress on the tie rod under axial load; hence, the sole

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purpose of this test is to establish the relationship of frequency vs. tensile load at temperatures of -320°F , ambient temperature, and 900°F . The variation in frequency among test temperatures seems random and due to experimental error. The maximum variation obtained for either specimen between two temperatures at any tensile preload was less than 3%.

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1. "Metallurgical Evaluation of NERVA NRX-A Tie Rod Fabrication Process", by D. Harrod. WANL-TME-563.
2. "WANL Materials Handbook".
3. "NRX-A Component Test Program". WANL-TNR-095.

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FIGURE 1

Static Tensile Test - Ambient Temperature Test Setup

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FIGURE 2

Static Tensile Test - Low (-320°F) Temperature Test Setup

FIGURE 3

Static Tensile Test - High (900°F and 1200°F) Temperature

FIGURE 4

Axial Fatigue Test - Ambient and High (900°F) Temperature
Test Setup

FIGURE 5

Lateral Resonant Frequency Test-Setup and Instrumentation

FIGURE 6

Lateral Resonant Frequency Test Setup - Method of Axial Loading

FIGURE 7

0.2% Yield Strength versus Temperature, Inconel X-718 and
Inconel X-750 Tie Rods

FIGURE 8

Ultimate Tensile Strength versus Temperature, Inconel X-718
and Inconel X-750 Tie Rods

FIGURE 9

% Elongation, Regular and Instrumented Tie Rod - Inconel X-750

FIGURE 10

% Elongation, Inconel X-718 Tie Rods

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FIGURE 11

Modified Goodman Diagram, Inconel X-750 Tie Rods

FIGURE 12

Lateral Resonant Frequency versus Axial Tensile Load -
Ambient Temperature

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FIGURE 13

Regular and Instrumented Tie Rods - Outline Drawing

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FIGURE 14

Axial Fatigue Fractures, Inconel X-750 Instrumented Tie Rods,
Specimen Nos. B-343 and B-344

TABLE 1

Comparative Values, Regular and Instrumented Tie Rods Average Test Results and
WANL Materials Handbook

.2% Yield Strength

Test Results	-320°F	Ambient Temperature	900°F	1200°F range 1150°F 1250°F	
Tie Rod, Regular	122,000 psi	99,700 psi	91,300 psi	83,000 psi	60,000 psi
Inconel X-750 Tie Rod, Instrumented	103,000 psi	108,800 psi	92,400 psi	-----	-----
Inconel X-750 Material Handbook Minimum	103,000 psi	85,000 psi	85,000 psi	80,000 psi	71,500 psi
Inconel X-750 Tie Rod, Regular	188,600 psi	160,300 psi	149,000 psi	120,600 psi	87,000 psi
Inconel X-718 Materials Handbook Minimum Inconel X-718	185,000 psi	155,000 psi	140,000 psi	130,000 psi	120,000 psi

UTLIMATE TENSILE STRENGTH

Test Results	-320°F	Ambient Temperature	900°F	1200°F range 1150°F 1250°F	
Tie Rod, Regular Inconel X-750	181,000 psi	163,000 psi	147,000 psi	95,000 psi	63,000 psi
Tie Rod, Instrumented, Inconel X-750	202,500 psi	175,000 psi	147,000 psi	-----	-----
Materials Handbook Minimum Inconel X-750	170,000 psi	140,000 psi	120,000 psi	90,000 psi	80,000 psi
Tie Rod, Inconel X-718	242,000 psi	207,000 psi	173,000 psi	129,400 psi	92,000 psi
Materials Handbook Minimum Inconel X-718	225,000 psi	190,000 psi	170,000 psi	155,000 psi	140,000 psi

TABLE II
X-750 REGULAR TIE RODS (A 6 TESTS)

SPECIMEN NUMBER	STATIC TENSILE			DYNAMIC		TEST TEMP. °F	.2% YIELD STRENGTH psi x 10 ³	ULTIMATE STRENGTH psi x 10 ³	% RED. IN AREA		% ELON- GATION	PRELOAD pounds	ALTERNAT- ING LOAD pounds	CYCLES x 10 ³	REMARKS	AXIAL LOAD pounds	RESONANT FREQUENCY, cps			DATE
	-1	-2	-3	Axial	Lat.				nom	max							-310°F	room temp.	900°F	
A-8						X										100 200 300 400 500 500	32.36 45.92 55.18 63.54 70.61 71.41	33.77 46.57 56.17 64.45 71.94	37.69 45.93 54.33 63.52 69.86	9/30
A-9			X				1240	52,000	25.5	1.6					1275°F max					9/16
A-15				X			Amb.					350	130	216,000						8/26
				X			Amb.					590	270	180,000						8/26
A-16			X				900	92,300	30.0	10.5					932°F max					9/16
A-17		X					-320	118,556	23.8	14.5										9/21
A-20			X				900	90,300	28.6	11.9					914°F max					9/16
A-22			X				1100	87,113	1.3	.2					1170°F max					9/16
A-25				X			Amb.					250	137	216,000						8/27
				X			Amb.					350	122	194,000						8/27
		X					-320	132,989	19.1	13.7										9/20
A-48	X						Amb.	101,000	15.8	9.7										8/21
A-65	X						Amb.	102,000	12.5	10.4										8/21
A-75	X						Amb.	100,500	15.8	13.2										8/21
A-275		X					-320	117,010	28.6	13.6										9/24
A-281					X		900					675	165	286,000						9/19
			X				1250	68,041	3.9	1.3					1262°F max					9/25
A-287				X			Amb.					590	270	180,000	Yielded					9/17
			X				1150	-----	3.9	2.2					1195°F max					9/25
A-290				X			Amb.					250	200	286,000	Mach. Failed					9/17
A-309					X										*(91.5 lb at -285°F on this point)	100 200 300 400 500	30.03* 45.25 55.31 63.71 71.27	32.97 45.43 55.40 63.42 70.70	31.210 45.676 55.108 61.489 71.352	10/2
A-327			X				Amb.					700	150	132,000	Mach. Failed					9/30

TABLE III
INCONEL X-750 INSTRUMENTED TIE RODS

SPECIMEN NUMBER	STATIC TENSILE			DYNAMIC			TEST TEMP. ° F	.2% YIELD STRENGTH psi x 10 ³	ULTIMATE STRENGTH psi x 10 ³	% RED. IN AREA		% EL- ONGAT.	PRELOAD pounds	ALTERNAT- ING LOAD pounds	CYCLES x 10 ³	REMARKS	AXIAL LOAD pounds	RESONANT FREQUENCY, cps			DATE
				Axial	Lat.	-310°F												room temp.	900°F		
	-1	-2	-3	-4	-5	-6				psi	nom							max.			
B-343				X			-320* R. T.*						700 500	+ 150 + 350	120 30	Failed 5/32" from the thread					10/3 10/4
B-344				X			R. T.* -320*						660 625 700	+ 140 + 125 + 150	216 108 113	No Failure No Failure No Failure					9/30 10/3 10/3
				X			R. T.						660	+ 350	141	Failed in thread					10/4
B-345				X	X		900 R. T.						500 700	+ 250 + 155 - 131	.1 216	No Failure No Failure					9/30 9/30
					X		900 R. T.						500	+ 250	.1	No Failure Failure 1" from thread					9/30 10/2
B-346				X			R. T.						500	+ 250	216	No Failure					9/30
					X		900						500	+ 250	.1	No Failure					9/30
B-347	X						R. T.	105.5	174.5	----	18.1	9.0				Test performed for Quality Control Failure 5/16" above thread					9/30
B-348						X											100 200 300 400 500	33.69 46.34 56.22 64.39 71.37	33.33 45.94 55.73 63.85 71.12	32.78 45.70 55.19 63.44 70.85	10/5
B-349			X				900	92.4	147.0	6.5	25.4	6.0				Fracture 2" From Thread					10/2
B-350		X					-320	118.0	202.5	11.2	14.3	11.2				Failure approximately 1/4" from thread					10/2
* These tests were conducted at Westinghouse Research Laboratory on Sonntag Fatigue Machine, Model SF 1-U.																					

* These tests were conducted at Westinghouse Research Laboratory on Sonntag Fatigue Machine, Model SF 1-U.

TABLE IV
INCONEL X-718, REGULAR AND INSTRUMENTED TIE ROD TESTS (A-6)

SPECIMEN NUMBER	STATIC TENSILE			DYNAMIC			TEST TEMP.	.2% YIELD STRENGTH	ULTIMATE STRENGTH	% RED. IN AREA		% ELON- GATION	PRELOAD	ALTERNAT- ING LOAD	CYCLES	REMARKS	AXIAL LOAD	RESONANT FREQUENCY, cps			DATE
				Axial	Lat.																
	-1	-2	-3	-4	-5	-6												°F	psi x 10 ³	psi x 10 ³	
B-1 (reg)	X						Amb.	161,000	210,300	8.9	22.3	9.5									9/23
B-5 (reg)	X						Amb.	159,000	209,300	9.0	23.8	7.9									9/23
B-6 (reg)		X					-320	190,200	240,200	7.9	22.3	8.8				Fractured 1-3/8" from head					9/23
B-10 (reg)			X				1150 nom	120,600	129,400	2.0	23.8	2.8				1165°F max Fractured 8" from head					9/25
B-11 (reg)			X				900 nom	153,100	175,300	7.1	17.5	5.7				940°F max Fractured 3- 21/32" from thread					9/24
B-12 (reg)			X				1250 nom	87,000	92,000	3.5	34.0	1.8				1267°F max Fracture 31- 1/2" from head					9/25
B-13 (reg)			X				900 nom	145,400	170,100	2.6	22.3	4.7				945°F max Fracture 3- 1/8" from thread					9/24
B-16 (reg)		X					-320	187,100	243,300	5.4	20.8	6.8				Fracture 1- 3/8" from head					9/23
B-306 (inst)	X						Amb.	161,000	202,000	9.6	27.4	8.9									9/23