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WANL-TME-519

Test Series A-11/G-3

TEST REPORT ON PRELIMINARY VIBRATION DATA

BASED ON TWO SINGLE ELEMENT TEST CONFIGURATIONS

(Title Unclassified)

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SUMMARY

Preliminary vibration data were obtained from various tests conducted with two different types of single element test rigs to determine the behavior of the element when subjected to internal and external flow conditions.

The results from the graphite fuel element tests or internal flow tests, showed no apparent flow induced vibration at the various pressure ratios tested. In general, the damping characteristics of an externally excited element was the same for helium flow as it was for air flow. However, the rate of decay of oscillation was less for helium than for air.

The results from the simulated single element-tie rod tests, or external flow tests, showed that vibration at various frequencies could be induced by external flow around the element. The frequencies induced were found to be a function of mass flow, pressure ratio, and rod-tube clearance.

An evaluation of the results from both tests established confidence that the behavior of a fuel element is substantially the same whether plugged or unplugged when subjected to gas flow conditions.

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INTRODUCTION

The single fuel element experiments reported herein are presented as a prelude to a series of component tests that are tentatively planned to be conducted under the NRX-A Component Test Program, in particular, the A-11 Flow Induced Vibration Tests, and the G-3, Plugged Core Flow Tests.

The purpose of these experiments was to establish the behavior of a single fuel element when subjected to internal and external flow.

Two series of experiments with different type single element test rigs were used to obtain the preliminary vibration data presented here.

The first series of experiments were conducted at various pressure ratios with air and helium gas at ambient temperatures flowing vertically upward through the flow passages of a cantilever mounted graphite fuel element with the gas exhausting directly to the atmosphere.

The second series of experiments were conducted at various pressure ratios with air at ambient temperatures flowing vertically upward around a simulated fuel element-tie rod configuration mounted inside a steel tube.

The results of these experiments were used to establish that the behavior of a fuel element is substantially the same whether plugged or unplugged when subjected to gas flow conditions.

TEST APPARATUS & INSTRUMENTATION

Graphite Fuel Element Test Rig

The graphite fuel element test rig incorporated an unfueled niobium carbide coated graphite fuel element glued into a stainless steel holding block. One end of the element was fastened to the holding block with an epoxy adhesive (Eccobond 51). This particular adhesive was selected because of its high shear strength (6000 psi). To utilize the high adhesion strength, the holding socket of the inlet block was serrated and the fuel element was notched on adjacent surfaces along a two-inch length. Six resistance type strain gauges were mounted on each of the six flats at the fixed end of the hexagonal element. By recording the resultant output of any of the two opposite mounted strain gauges, one of the three or all three possible modes of vibration could be measured.

A schematic of the graphite fuel element is shown in Figure 1. Figure 2 shows a schematic of the strain gauge bridge circuit.

Simulated Single Element-Tie Rod Test Rig

The simulated single element-tie rod test rig incorporated a 5/8" diameter aluminum rod which was made to simulate the length and approximate weight (705.5 grams) of a graphite fuel element. The aluminum rod was internally threaded on one end to adapt to a tie rod. The tie rod consisted of an externally threaded 1/8" stainless steel rod which was threaded into the aluminum rod on one end and to the base of the plenum chamber on the other. The plenum chamber was made from a 3" pipe tee, a pipe plug, and several different size reducing bushings. The aluminum rod-tie rod assembly was incased in a steel tube mounted vertically to the plenum chamber. Three, one-inch outside diameter

tubes with wall thickness of .095, .120 and .134 inches were used for the tests to obtain the various rod-tube clearance.

The test rig was instrumented with a linear variable differential transformer displacement sensor capable of measuring vibration frequencies from 0 to 300 cps. The sensor was mounted rigidly to the steel tube which was connected to the free end of the aluminum rod by a core follower attachment. Figure 3 shows a schematic of the test rig and instrumentation used for the tests. Figure 4 shows the test rig and Figure 5 shows the rig partially disassembled to show the internal components of the test rig.

TEST PROCEDURE

Graphite Fuel Element Test

Air or helium under pressure entered the vertically oriented element through the inlet plenum chamber and holding block, flowed through the passages of the element, and discharged directly to the atmosphere.

Once stable flow conditions were established at a specified inlet pressure, the output of the strain gauge bridge circuit was recorded on a Visicorder oscillograph.

To determine the damping characteristics of the fuel element under stable flow conditions, the free end of the element was purposely deflected and released to simulate external excitation.

Simulated Single Element-Tie Rod Test Rig

Air under pressure entered the plenum chamber through a flexible hose upstream of a copper tube instrumented with a total pressure probe and static pressure tap, the air flowed vertically upward between the simulated fuel element-tie rod assembly and the steel tube.

After stable flow conditions were established the output signal of the LVDT displacement sensor was recorded on a visicorder oscillograph. Later, tests were conducted where the output signal of the displacement gauge was recorded on an oscilloscope that was equipped with a polaroid camera attachment.

DISCUSSIONS AND RESULTS

In general, no flow induced vibration was experienced with gaseous air or helium under stable flow conditions when the gas flow was directed internally and vertically upward through the flow passages of a single graphite fuel element.

To determine the damping effect of the element under stable flow conditions, the free end of the element was purposely deflected and released. It was found that when the element was subjected to external excitation, it immediately tended to restore itself to its original position. The damping effect experienced was similar to a viscous type damping with the rate of decay of oscillation for helium being less than air at the same pressure ratio. This type of damping effect indicates that the rate of decay is statically and dynamically stable and varies as a function of density and mass flow. Table I compares the average response time for helium and air. A typical oscillograph trace that was recorded during one of the tests with air flowing internally and upward through the passages is shown in Figure 6. The trace shows (1) the end of a steady state stable flow test with no flow induced vibration, (2) the initial deflection of the free end of the element, attempting to obtain vibration from external excitation, and (3) the damping effect of the element following the release of the free end.

The rate of decay of oscillation of the element with helium and air flowing through the passages at approximately the same inlet pressure and initial deflection

was replotted from oscillograph traces and is shown in Figure 7.

Test data obtained from the simulated single element-tie rod tests showed that vibration was induced by external flow around a simulated element. The frequencies induced were found to be function of the pressure ratio, mass flow, and rod-tube clearance. Figure 8 and 9 show the frequency ratio, measured fundamental frequency divided by the natural frequency, at various pressure ratios and mass flows for three different rod-tube clearances. The measured natural frequency curve for the aluminum rod-tie rod assembly is shown in Figure 10 as a function of the tie rod lengths. This frequency was obtained from oscillations in still air. Figures 11 through 14 show photographs of typical frequency traces obtained with the oscilloscope and polaroid camera attachment.

CONCLUSIONS

On the basis of the results of the various series of tests reported here, the following conclusions can be drawn:

A. Graphite Fuel Element Tests

Internal flow through the element passages does not induce vibrations.

The decay time constant obtained was found to be greater for helium than for air.

B. Simulated Single Element-Tie Rod Tests

External flow through gaps surrounding a simulated fuel element can induce vibration. The frequency obtained was found to be a function of clearance, mass flow and, pressure ratio.

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C. Because vibrations could not be induced by internal flow, the behavior of a plugged fuel element is not expected to be materially different than an open element. The vibration is induced by flow in the clearances between the elements as demonstrated by the external flow experiments.

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NOMENCLATURE

f	=	measured fundamental frequency	cps
f_n	=	measured natural frequency	cps
I.D.	=	inside diameter	inches
L	=	tie rod length	inches
$\dot{m}$	=	mass flow rate	lb/sec
O.D.	=	outside diameter	inches
P_a	=	ambient pressure	psia
P_s	=	static pressure	psia
P_t	=	total pressure	psia
R/T	=	rod-tube clearance	inches
t	=	time	seconds
W	=	weight	grams
X_o	=	initial deflection	inches
X_n	=	deflection at N number of cycles	inches
τ	=	decay time constant	seconds

Figure 1

Figure 2

Figure 3

SIMULATED SINGLE ELEMENT TEST RIG

Figure 4

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SIMULATED SINGLE ELEMENT TEST RIG PARTIALLY DISASSEMBLED

Figure 5

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A TYPICAL OSCILLOGRAPH TRACE SHOWING THE DAMPING EFFECTS OF A
GRAPHITE FUEL ELEMENT WHEN SUBJECTED TO EXTERNAL EXCITATION

FLUID: AIR

PRESSURE RATIO: 6.5

Figure 6

TABLE I
RATE OF DECAY OF OSCILLATION OF A
SINGLE ELEMENT SUPPORTED AT ONE END

Gas	$\tau_{avg.}$ - Decay Time Constant
	(Seconds)
Air	3.4
Helium	5.3

τ - Time for the amplitude of the initial deflection to decrease by 63 per cent

COMPARISON SHOWING THE RATE OF DECAY OF OSCILLATION
OF A GRAPHITE FUEL ELEMENT WITH INTERNAL GAS FLOW

INLET PRESSURE: 48 PSIA
INITIAL DEFLECTION: 1/2 INCH

Figure 7

FREQUENCY RATIO VERSUS PRESSURE RATIO
FOR DIFFERENT ROD-TUBE CLEARANCE

Figure 8

FREQUENCY RATIO VERSUS AIRFLOW THROUGH A
SIMULATED SINGLE ELEMENT TEST CONFIGURATION
AT DIFFERENT ROD-TUBE CLEARANCE

Figure 9

MEASURED NATURAL FREQUENCY OF AN ALUMINUM ROD-TIE ROD
CONFIGURATION SUPPORTED AT VARIOUS TIE ROD LENGTHS

Figure 10

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TEST A-(R-1)-II

Fluid: Air
Primary Rod Diameter: 5/8" (Aluminum)
Weight of Rod: 705.5 grams

Tie Rod Diameter: 1/8" Stainless Steel
Support Tube Diameter: 1.000" O. D., 0.760 I. D.
Rod Tube Clearance: 0.068"

Pressure Ratio: 1.000
 $f = 0$ cps
Horiz. Sweep: 0.1 sec/cm
Vert. Sweep: 0.2 volts/cm
Camera Speed: 1 sec.

Pressure Ratio: 1.69
 $f = 4.88$ cps
Horiz. Sweep: 0.1 sec/cm
Vert. Sweep: 0.1 volts/cm
Camera Speed: 1 sec.

Pressure Ratio: 2.04
 $f = 6.16$ cps
Horiz. Sweep: 0.1 sec/cm
Vert. Sweep: 0.5 volts/cm
Camera Speed: 1 sec.

Pressure Ratio: 2.38
 $f = 6.85$ cps
Horiz. Sweep: 0.1 sec/cm
Vert. Sweep: 0.2 volts/cm
Camera Speed: 1 sec.

Figure 11

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TEST A-(R-1)-II

Fluid: Air
 Primary Rod Diameter: 5/8" (Aluminum)
 Weight of Rod: 705.5 grams

Tie Rod Diameter: 1/8" Stainless Steel
 Support Tube Diameter: 1.000" O. D., 0.760 I. D.
 Rod Tube Clearance: 0.068"

Pressure Ratio: 2.72
 $f = 8.2$ cps
 Horiz. Sweep: $\frac{0.1}{0.2}$ sec/cm
 Vert. Sweep: $\frac{0.2}{1 \text{ sec.}}$ volts/cm
 Camera Speed: 1 sec.

Pressure Ratio: 3.07
 $f = 8.45$ cps
 Horiz. Sweep: $\frac{50}{0.2}$ sec/cm
 Vert. Sweep: $\frac{0.2}{0.5 \text{ sec.}}$ volts/cm
 Camera Speed: 0.5 sec.

Figure 12

TEST C-(R-1)-I

Fluid: Air
Primary Rod Diameter: 5/8" (Aluminum)
Weight of Rod: 705.5 grams

Tie Rod Diameter: 1/8" Stainless Steel
Support Tube Diameter: 1.000" O.D., .810 I.D.
Rod Tube Clearance: 0.092"

Pressure Ratio: 1.000
 $f = 0$ cps
Horiz. Sweep: 0.1 sec/cm
Vert. Sweep: 0.2 volts/cm
Camera Speed: 1 sec.

Pressure Ratio: 1.69
 $f = 3.78$ cps
Horiz. Sweep: 0.1 sec/cm
Vert. Sweep: 0.2 volts/cm
Camera Speed: 1 sec.

Pressure Ratio: 2.04
 $f = 4.54$ cps
Horiz. Sweep: 0.1 sec/cm
Vert. Sweep: 0.2 volts/cm
Camera Speed: 1 sec.

Pressure Ratio: 2.38
 $f = 5.87$ cps
Horiz. Sweep: 0.1 sec/cm
Vert. Sweep: 0.2 volts/cm
Camera Speed: 1 sec.

Figure 13

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TEST C-(R-1)-I

Fluid: Air
Primary Rod Diameter: 5/8" (Aluminum)
Weight of Rod: 705.5 grams

Tie Rod Diameter: 1/8" Stainless Steel
Support Tube Diameter: 1.000" O.D., .810 I.D.
Rod Tube Clearance: 0.092"

Pressure Ratio: 3.06
 $f = 6.75$ cps
Horiz. Sweep: $\frac{0.1}{0.2}$ sec/cm
Vert. Sweep: volts/cm
Camera Speed: 1 sec.

Pressure Ratio: 3.41
 $f = 7.15$ cps
Horiz. Sweep: $\frac{0.1}{0.2}$ sec/cm
Vert. Sweep: volts/cm
Camera Speed: 1 sec.

Pressure Ratio: 3.76
 $f = 7.5$ cps
Horiz. Sweep: $\frac{0.1}{0.2}$ sec/cm
Vert. Sweep: volts/cm
Camera Speed: 1 sec.

Pressure Ratio: 4.45
 $f = 10$ cps
Horiz. Sweep: $\frac{0.1}{0.2}$ sec/cm
Vert. Sweep: volts/cm
Camera Speed: 1 sec.

Figure 14

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