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WANL-TME-1987
APRIL 1970

DATA ITEM T-119

PARTIAL CORE

VIBRATION TEST RESULTS (U)

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FINAL REPORT

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PARTIAL CORE

VIBRATION TEST RESULTS.(U)

FINAL REPORT

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ABSTRACT

(U) Current lateral support system designs have resulted in a system which has a core natural frequency of 10 Hz or lower. Previous testing of these designs have been frequency limited to 10 Hz and above due to displacement limitations of vibration exciter equipment, even though the critical "G" loads are expected to occur in practice at lower frequencies. The purpose of this test was to investigate the low frequency characteristics of the lateral support system.

(U) A flat seal design was tested for simplicity of test and analysis of friction damping phenomena. The results from this development test can be applied to the current lateral support system utilizing angled seals since both systems employ friction damping in the same manner. The analytical model used for predicting the system response was verified as a suitable tool for design purposes. The test has also demonstrated that large core motion can occur at resonance when the input "G" is sufficient to "break friction" between the core and reflector.

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1.0 INTRODUCTION (U)

(U) This report details the test results from the Partial Core Vibration Test, Reference: Test Scope 63DE-209-0. The test was performed in accordance with Test Plan EM-7778. The objectives of the test were to investigate the low frequency response of the lateral support system to dynamic inputs. The critical environmental "G" loads are expected to occur at low frequencies.

1.1 TEST IDENTIFICATION (U)

(U) The following documentation applies to this test:

1.1.1 Type of Report (U)

(U) This is a final report.

1.1.2 Applicable Test Documents (U)

(U) Test Scope 63DE-209-0 - Test Plan EM-7778.

1.1.3 Functional Category of Testing (U)

(U) Development ECC-677559 (supersedes ECC-677563).

1.1.4 Contractor (U)

(U) Westinghouse Astronuclear Laboratory, Contract Number - NE 729F88, Date of Submission: December 13, 1969.

1.1.5 Test Facility (U)

(U) Engineering Mechanics Laboratory.

1.2 PURPOSE OF TEST (U)

(U) The purpose of this test was to investigate the low frequency characteristics of the lateral support system. The specific areas of interest were to:

- (U) 1. Provide an experimental model to establish whether the current lateral support system analysis techniques are sufficiently accurate to justify extension to hardware analysis.
- (U) 2. Determine if friction breakaway is frequency independent at low frequency.
- (U) 3. To determine the vibration response at low frequencies.
- (U) The required test results are to determine:
 - (U) 1. Breakaway "G" level for frequencies from 5 to 15 Hz.
 - (U) 2. Relative displacement core/reflector for input "G" levels varying between one and five "G" in the frequency range from 5 to 15 Hz.

1.3 GLOSSARY OF TERMS (U)

(U)	Friction Damping	-	Solid type damping caused by the rubbing between two surfaces
(U)	"G"	-	Abbreviated form of acceleration-one "G" = 386 inch/second ²
(U)	Input "G" Level	-	Input acceleration as measured on the reflector (See Figure 3.3)
(U)	Core "G" Level	-	Core acceleration as measured on the core (See Figure 3.3)
(U)	Breakaway "G" Level (Friction Breakaway)	-	Minimum input "G" level required to cause relative motion between core and reflector

2.0 REFERENCES AND ASSUMPTIONS (U)

(U) A flat seal design was tested. This design was chosen because an angle seal system requires a structure to guide the core thereby complicating extraction of pertinent information. Prior publications of these results can be found in report DRM 51627, "Test Report - Partial Length Core Low Frequency Vibration."

(U) Previous publications describing tests of similar systems are:

- (U) 1) WANL-TMI, 1884, Vibration Test - A6 Type Lateral Support System
- (U) 2) WANL-TME-550, Static and Dynamic Tests of the NRX-A Single Helical Spring Lateral Support System
- (U) 3) WANL-TME-980, Partial Length Core Vibration Tests-Impregnated Inner Reflector
- (U) 4) WANL-TMI-1913, Static and Vibration Test of R-1 Flat Seal Type Lateral Support System

3.0 (CRD) DESCRIPTION OF TEST ARTICLE (U)

(U) A schematic of the test setup is shown in Figure 3.1. A cross section of the Lateral Support System is shown in Figure 3.2.

(CRD) The partial length core is supported in the outer reflector ring by two rows of flat seals with each row containing a one-piece outer seal constructed of Carb-i-tex 700 and twelve 30° inner seal segments. The lateral support spring rate provides a 3.2 p.s.i. equivalent bundling pressure with a calculated undamped system natural frequency of 10.4 Hz.

(U) The outer reflector is mounted on a linear bearing support. Input forces are applied utilizing two 10,000 lb. Ling 310 Thrusters. Resonant drive rods were used to achieve the required high input displacements (five "G" at five Hz represents a displacement of four inch D. A., while the maximum thruster displacement capability is one inch D. A.).

(U) The resonant drive rod concept consists of inserting a coil spring between the thruster and reflector. By sizing the drive rod spring rate (K) to provide a system first natural frequency in the range of from 5 to 10 Hz, it was possible to achieve a large displacement at the reflector with a smaller input from the thruster. Two sets of springs were used providing natural frequencies of seven and nine Hz. A photograph of the test setup is shown in Figure 3.3.

(U) The resonant drive rod employs five springs mounted in parallel. By removing springs, the system was tuned at each frequency in the range from five to seven Hz.

(U) Transducers were used to measure input acceleration (reflector), core acceleration and relative displacement between the core and reflector. The data was recorded on tape and on a pen recorder. The instrumentation is tabulated in Table 3.1.

TABLE 3.1
INSTRUMENTATION (REFER TO FIGURE 3.3)

Measurement	Location	Type	Model Number	Comments
Input Acceleration	Reflector	Crystal Accel.	Endevco 2219	Strain gage accelerometer added at low frequency < 9 Hz to insure accuracy
		Strain Gage Accel.	CEC 4-202-001	
Core Acceleration	Core	Crystal Accel.	Endevco 2219	Strain gage accelerometer added at low frequency < 9 Hz to insure accuracy
		Strain Gage Accel.	CEC 4-202-001	
Relative Displacement Core-Reflectr.	Core/Reflectr.	DCDT	Collins SS 288	
Input Displacement	Drive Fixtures	Potentiometer	Pacific Scientific 4 101119-0	Became inoperative during test and was dropped

LEGEND
RD = Displacement Transducer (Relative
Between Core and Reflector)
A = Accelerometer

Figure 3.1. Partial Core Test Setup

Figure 3.2. Lateral Support System

Figure 3.3. Test Setup

4.0 SUMMARY OF TESTS (U)

4.1 NARRATIVE (U)

(U) It was found that the breakaway "G" level did not change significantly at low frequency. The breakaway "G" level was measured to be approximately 2.2 "G" throughout the frequency range from 5 to 15 Hz. The resonant frequency of the system was measured to be near 10.5 Hz. The system response was typical of the classic friction-damped system. At resonance, the relative displacement increased rapidly for small changes in input levels above breakaway.

4.2 TEST CONDITIONS (U)

(U) Discrete frequency dwell tests were performed at each frequency between 15 and 5 Hz, starting at 15 Hz, at input levels varying between one and five "G". The input level was increased in .2 "G" increments until breakaway occurred (breakaway defined as initiation of relative motion). Upon achieving breakaway, the input level was increased in .5 "G" increments to five "G" or until a relative displacement of 200 mils single amplitude was measured. In the frequency range from 15 to 13 Hz, the test system was driven directly by the thrusters. In the range from 12 to 5 Hz, (large input displacements required) the resonant drive rods were used.

(U) At 11 Hz, the relative displacement jumped rapidly as the input was being increased from 4.0 to 4.1 "G". The relative displacement exceeded 200 mils (limit established prior to test to avoid impact and possible damage to test hardware) and the core impacted before the test could be stopped. Eight plunger pins were broken (Figure 4.4) as a result of the impact. These pins were replaced and the test continued. One thruster began rocking in its base at five Hz and the test was discontinued at an input level of 3.5 "G" for fear of damaging the thruster.

4.3 TEST RESULTS (U)

4.3.1 Recorded Data (U)

(U) A plot of relative displacement versus frequency is shown in Figure 4.1. A plot of relative core displacement divided by absolute input displacement is shown in Figure 4.2. Data traces are shown in Figures 4.3, 4.5 and 4.6. All original data is available in Engineering Mechanics storage. The plunger pins which were broken when the core accidentally impacted on the reflector are shown in Figure 4.4.

4.3.2 Discussion of Data (U)

(U) The breakaway "G" level was independent of frequency, always occurring at approximately 2.2 "G". It can be seen in Figures 4.1 and 4.2 that the system resonant frequency occurred near 10.5 Hz. Near resonance a small change in input level caused a large relative displacement response. This phenomena is illustrated in Figure 4.3 at 11 Hz. As the input level was increased from 4.0 to 4.1 "G", the relative displacement suddenly jumped, in this case, causing impact. This phenomena can occur in a friction damped system. The response waveshapes are typical of a friction damped system, stop motion at low input levels, typical acceleration waveshapes, etc. Some typical data at six and nine Hz is shown in Figures 4.5 and 4.6.

(U) The flat portion of the relative displacement traces represent stop motion; i.e., for that portion of the vibration cycle, the dynamic forces across the friction damper are insufficient to break friction; the damper locks, and the relative motion remains constant. It can also be noted that both the reflector acceleration and core acceleration are non-sinusoidal in response to a sinusoidal driving force. These waveshapes are typical of a simple friction damped system and are also shown in Analog Computer studies as reported in WANL-TME-513, Lateral Vibration Studies of the G-1 Core Assembly Tests.

(U) As in the past tests involving carbitex seal rings, some graphite dust was generated as a result of rubbing between the seals. This dust is shown in Figure 4.7.

(U) The data in Figures 4.1 and 4.2 shows a rise in relative displacement on frequencies below 8 Hz which appears to indicate a pseudo resonance. This phenomena does not seem to be physically plausible and is not in agreement with analytical predictions as discussed in Section 5. Although the exact reason for this questionable data at low frequency is not known at this time, WANL believes the data to be the result of low frequency limitations of the test equipment rather than representative data attributable to partial core phenomena.

(U) Subsequent to this test, WANL has purchased vibration equipment which does not have the low frequency and amplitude limitations previously encountered in vibration testing. Using this new state-of-the-art equipment, WANL presently plans to further investigate this low frequency, high G response of an R-1 lateral support design during the partial core vibration testing tentatively scheduled for CY '71.

Figure 4.1. Relative Displacement Versus Frequency at Selected Input "G" Levels

Figure 4.2. Relative Displacement/Input Displacement Versus Frequency

Figure 4.3. Core Excursion at 11 Hz

ENGINEERING MECHANICS LABORATORY

W59849

Date 4-15-69 Data Pg. 2333673Test No T.S. 209 Run No _____Specimen PARTIAL CORETest PARTIAL CORE LOW FREQ.
VIBRATION TEST

*Indicates number
of pins broken at
this location.

Direction of Test

Figure 4.4. Broken Pins Resulting From Impact

Figure 4.5. Typical Data Trace 6 Hz

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Figure 4.6. Typical Data Trace 9 Hz

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Figure 4.7. Graphite Dust Generated During Test

5.0 ANALYSIS (U)

(U) The breakaway load G_{ba} , was computed for various coefficients of friction μ with the results shown in Figure 5.1. The test data shows a breakaway load factor of 2.2 "G's". From Figure 5.1, this corresponds to an average coefficient of friction of .185 which agrees almost exactly with the value of .18, assumed for analysis purposes.

(U) In order to predict the general lateral support system response, an analytical solution of a base excited friction damped system was performed. The analysis was used to predict relative displacement, core to reflector, versus input "G" level.

(U) The dimensionless parameters governing the theoretical response are plotted in Figure 5.2. One should note that the input displacement X_1 which varies linearly with input "G" at constant frequency is contained in both the ordinate of the figure Y/X_1 and the motion parameter $\lambda = P/KX_1$ where P is the total friction in the system, K is the system spring rate, Y is the relative motion and X is the input displacement. Therefore, as the input "G" level and input displacement are increased at any frequency, the parameter λ decreases.

(U) Figure 5.2 was used to generate the analytic test predictions shown in Table 5.1. For any given frequency and harmonic input "G" level, the value of Y/X_1 can be obtained for the value of λ corresponding to the input "G" level. It should be noted that the analytical predictions are everywhere conservative for frequencies above 8 Hz. As previously discussed in Section 4.3.2, the test data below this frequency is questionable and is probably a result of low frequency limitations of the test setups. The analytical predictions shown in Table 5.2 show a steady decline of the parameter Y/X_1 and the relative displacement, Y , with decreasing frequency at any "G" level for the lower frequencies.

(U) Good qualitative agreement was obtained between the test and analysis results above 8 Hz with all the phenomena normally expected to occur in a classical friction damped system being indicated by both. The analysis results are more conservative above 8 Hz. For example, near resonance, core impacting occurred on test at four "G" whereby this impact was

was predicted analytically near three "G's". The fact that the dynamic coefficient of friction varies with position, velocity and temperature could be partly responsible for this difference. Also, a harmonic input force was used to drive this test while the analysis model considers a harmonic motion input.

TABLE 5.1
 ANALYTICAL RESULTS (REF: FIGURE 5.2)

$P/K = .2$ (System natural frequency computed at 10 HZ)

f (HZ)	G_{in}	X_1 (IN)	$P/(KX_1)$	Y/X_{1SS}	Y(IN)
12	4	.2717	.7361	.285	.0772
	4.5	.3057	.6542	.300	.095
	5.0	.3397	.5888	.326	.111
11	4.	.3234	.6184	2.4	.776
	4.5	.3638	.5498	↑ increasing out of bounds ↓	↑ increasing out of bounds ↓
	4.8	.3881	.5153		
10	5.0	.4042	.4948		
	4.	.3913	.5111	↑ increasing out of bounds ↓	↑ increasing out of bounds ↓
	4.5	.4402	.4543		
9	4.8	.4696	.4259		
	5.0	.4891	.4089	2.25	1.07
	4.	.4831	.4140		
8	4.5	.5435	.3680		
	4.8	.5797	.3450	1.20	↓ .73
	5.0	.6039	.3312		
7	4.	.6114	.3271		
	4.5	.6878	.2908	1.30	↓ 1.00
	4.8	.7337	.2726		
6	5.0	.7643	.2617		
	4.	.7986	.2504	.80	.63
	4.5	.8984	.2226		
5	5.0	.9982	.2004		
	4.	1.0870	.1840	.44	.48
	4.5	1.2228	.1636		
4	5.0	1.3587	.1472		
	4.5	1.7609	.1136	.29	.51
	5.0	1.9565	.1022		
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Figure 5.1. Breakaway Load Factor Versus Coefficient of Friction

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Figure 5.2. Y/X_1 vs f/f_n

6.0 CONCLUSIONS (U)

(U) The results of this test show that the breakaway "G" factor and lateral support spring rate can be adequately predicted. While the response after breakaway is not apparently easy to predict due to the manifold friction effects, the analytical solution is conservative and is, therefore, adequate for design of the lateral support system.

(U) Future testing and analysis are required to support and complete our understanding of low frequency dynamic responses. These studies are planned as part of the R-1 reactor partial core component test.

TITLE	
	Partial Core Vibration Test Results	
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ABSTRACT <p>Current lateral support system designs have resulted in a system which has a core natural frequency of 10 Hz or lower. Previous testing of these designs have been frequency limited to 10 Hz and above due to displacement limitations of vibration exciter equipment, even though the critical "G" loads are expected to occur in practice at lower frequencies.</p> <p>The purpose of this test was to investigate the low frequency characteristics of the lateral support system.</p>		
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