

Testing in a Combined Vibration and Acceleration Environment

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Abstract

Sandia National Laboratories has previously tested a capability to impose a 7.5 g-rms (30 g peak) radial vibration load up to 2 kHz on a 25 lb object with superimposed 50 g acceleration at its centrifuge facility. This was accomplished by attaching a 3,000 lb Unholtz-Dickie mechanical shaker at the end of the centrifuge arm to create a "Vibrafuge". However, the combination of non-radial vibration directions, and linear accelerations higher than 50g's are currently not possible because of the load capabilities of the shaker and the stresses on the internal shaker components due to the combined centrifuge acceleration. Therefore, a new technique using amplified piezo-electric actuators has been developed to surpass the limitations of the mechanical shaker system. They are lightweight, modular and would overcome several limitations presented by the current shaker. They are 'scalable', that is, adding more piezo-electric units in parallel or in series can support larger-weight test articles or displacement/frequency regimes. In addition, the units could be mounted on the centrifuge arm in various configurations to provide a variety of input directions. The design along with test results will be presented to demonstrate the capabilities and limitations of the new piezo-electric Vibrafuge.

Background

The combined vibration and linear acceleration environment has been an area of interest for component function and qualification for re-entry scenarios. These two environments have historically been tested separately on mechanical shakers and centrifuges for the respective vibration and static loads. However, there is uncertainty regarding the possible synergistic effects of the two superimposed environments. Therefore, there is considerable interest in testing in the combined environment for test units up to 25 lb with vibration loads up to 30 g-rms and linear acceleration loads up to 100 g's.

Past work has been attempted to combine these environments by mounting a 3,000 lb mechanical shaker to the end of the 29 ft centrifuge arm at the Centrifuge Facility [1] in the Validation and Qualification Sciences Experimental Complex at Sandia National Laboratories (Figure 1). The shaker armature was preloaded using airbags between the bottom of the shaker head and shaker body as well as preloading the unit and fixture assembly with nylon straps to the centrifuge structure. This was in addition to the DC current supplied to the armature through the coil to load center the armature. There was some success for test units weighing 25 lb or less with a superimposed 50 g static load imposed by the centrifuge and a transverse 7.5 g-rms vibration load between 20 and 2,000 Hz. In addition, a similar test was performed at 70 g static load with a 5 lb test unit and was stopped because the cooling system for the mechanical shaker failed. Testing was also done to combine a vertical vibration load on the centrifuge [2] using a multiple direction vibration fixture shown in Figure 2. Results of this testing demonstrated a 3 g-rms vibration for a 5 lb test unit in a 40 g static load. No further tests were conducted with the 3,000 lb mechanical shaker. In summary, the limits of these aforementioned mechanical systems were primarily associated with the air cooled system and internal components of the mechanical shaker (armature, coils, etc.) when under linear acceleration environments at or above 50 g's.

In order to overcome these limitations for future testing, a piezo-electric shaker system is proposed because it eliminates the issues associated with failure of internal components in the mechanical shaker when under high linear acceleration loads. In addition, a variable load centering technique was employed to balance the increased load of the test unit felt by the shaker system while under the linear acceleration.

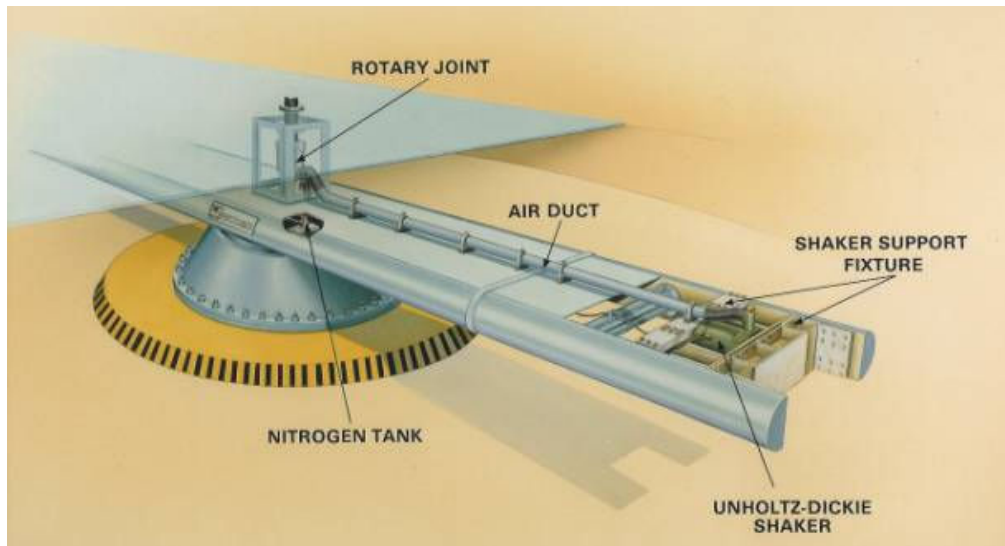


Figure 1. 29 ft Centrifuge with 3,000 lb shaker assembly mounted to arm.

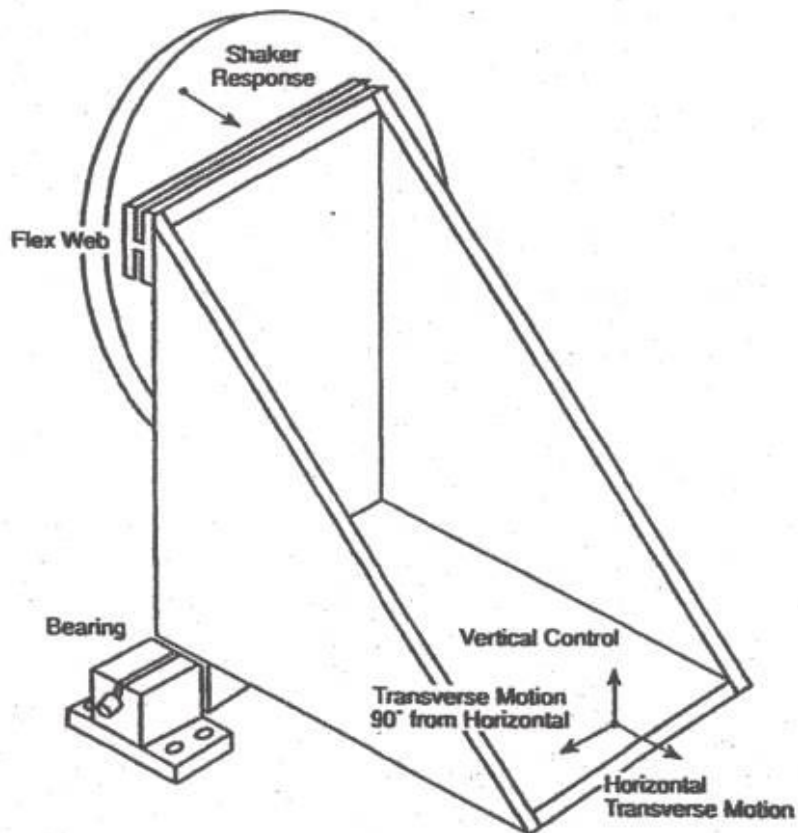


Figure 2. Multiple direction vibration fixture.

Experimental Setup

Several unique designs were implemented for the development of the new vibrafuge. These include the use of piezo-electric actuators, a variable load centering technique, vibration system control and monitoring, control/return signal routing via RF and slip rings, and possible individual actuator control. The following describes the integrated system setup.

The piezo-electric shaker system was composed of four Adaptronics Inc. APA95ML amplified actuators, each driven by an Adaptronics Inc. LA75C linear amplifier. These actuators have been used in helicopter blade vibration control systems in up to 2,000 g linear acceleration environments [3]. Each actuator can drive 450 lb between 300 and 2000 Hz. Therefore, the assembled shaker has an 1,800 lb capacity. The maximum stroke of the actuators is 100 μm . The maximum vibration loads are defined by stroke, frequency, unit weight, and total shaker capacity. Figure 3 shows the shaker assembly and test unit used during development of the new vibrafuge.

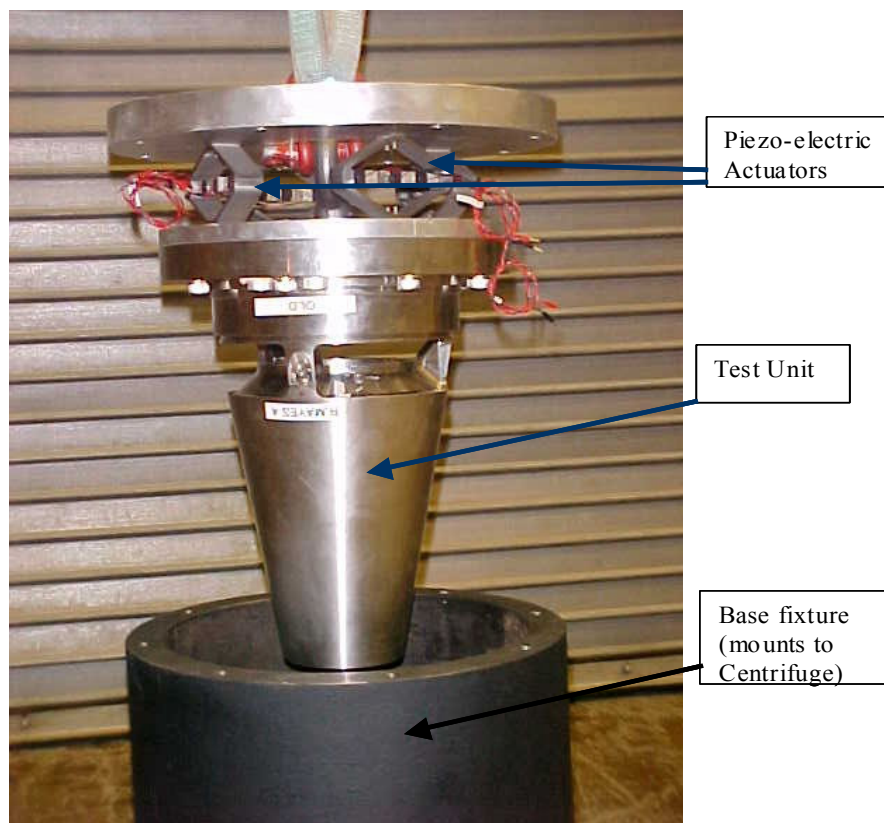


Figure 3. Test assembly showing 4 actuators in shaker fixture with 22 lb test unit.

The voltage range required to drive the complete stroke ($\sim 100 \mu\text{m}$) of the actuators is -20 to $+150\text{V}$. The LA75C amplifiers supply this drive voltage by amplifying ($\times 20$) an input control signal of between -1 and 7.5V . To center the stroke of vibration, the actuators are pre-loaded with a DC offset between 50 and 65V . This offset may be supplied as part of the input control signal or may be manually set on the amplifiers. A waveform generator supplying a control signal was used to input a 600Hz , 3V peak-to-peak (3Vpp) sine wave riding on a 2.5V DC offset. This control signal would result in a 600Hz , 60Vpp , 50V offset drive signal. Alternatively, the same control signal minus the 2.5V offset could result in the same drive signal to the actuators by manually adjusting a 50V offset directly into the amplifiers. This lends itself well to other sources of control signals that may not have offset capabilities, such as when generating random Power Spectral Density (PSD) environments.

The variable load centering technique utilizes a counterweight to balance the weight of the test unit at any linear acceleration up to 100 g's (Figure 4). The load centering structure consists of a 5-inch diameter, 1-inch wall thickness steel pipe attached horizontally across the centrifuge arm. Nylon rigging strap rated at 6,500 lb was attached to the base of the shaker fixture (22 lb), around the load-centering column, and to the 25 lb counterweight (Figures 4 and 5).

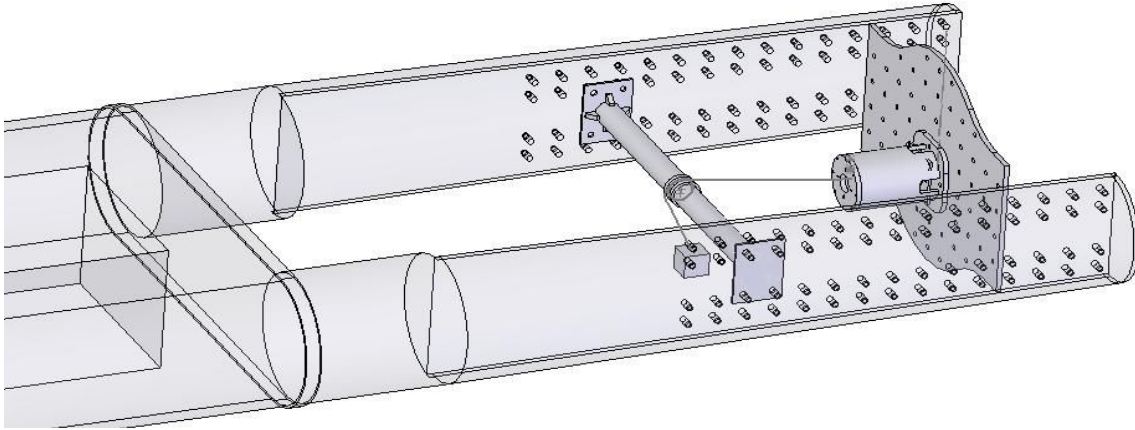


Figure 4. Schematic of shaker assembly, load centering column and counter weight on Centrifuge arm.

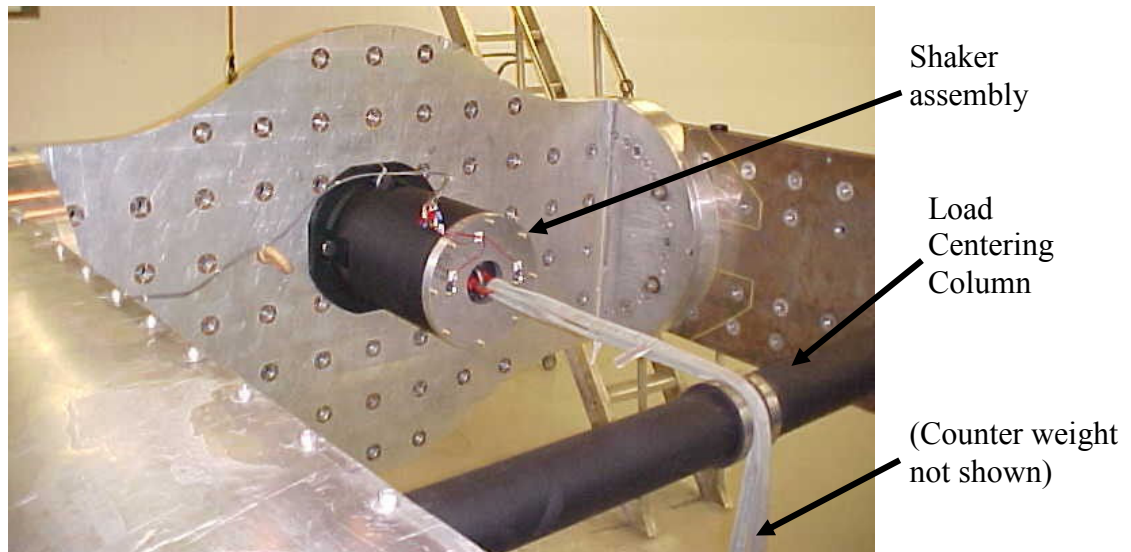


Figure 5. Shaker assembly with load centering column.

Finite element analysis was performed to determine the maximum linear acceleration that the load-centering column could withstand due to the force from the test unit and counter weight and the increased load on the column itself from the static centrifuge load (Figure 6). Therefore, the 100 g constraint is due to the limitations of the load-centering column attached to the centrifuge.

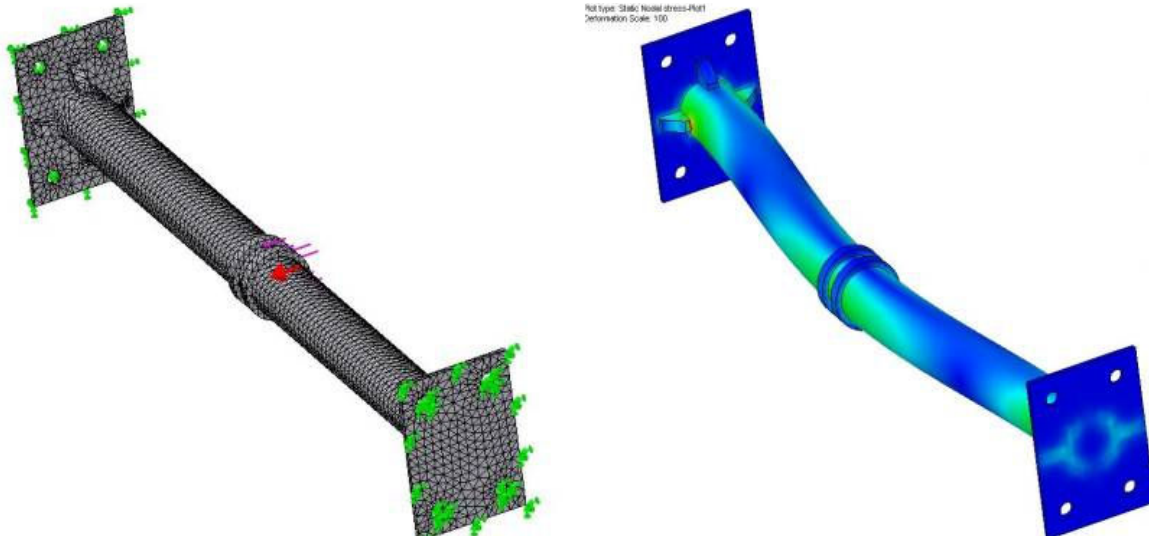


Figure 6. Analysis of load centering column.

Results

Preliminary testing of the actuators and actuator shaker assembly was done on the bench-top to determine compatibility with the control system, thermal limitations, and frequency-load limitations. The system was then mounted to the centrifuge and tested with combined environments.

Bench-top Testing

Thermal limits given by the manufacturer for the actuators was 65 C. Therefore thermal tests were done to determine how long it took the actuators to approach 65 C during similar load and frequency scenarios expected in the Vibrafuge testing. Figure 7 shows thermal couple data from the surface of one of the ceramic cells in the actuator during a 500 Hz, 50 g peak vibration for a 2 lb load. At 200 s the temperature was approaching the 65 C limit. The results of thermal testing show that the shaker should not be operated for more than 3 minutes under similar conditions. Since a DC offset from the amplifier must be used with the random control system, care must be taken to not overheat the actuators while waiting for the centrifuge to reach the required linear acceleration environment. To address this issue a remote switching box will be added to switch and monitor drive voltage to individual actuators. Also temperature will be monitored to prevent overheating.

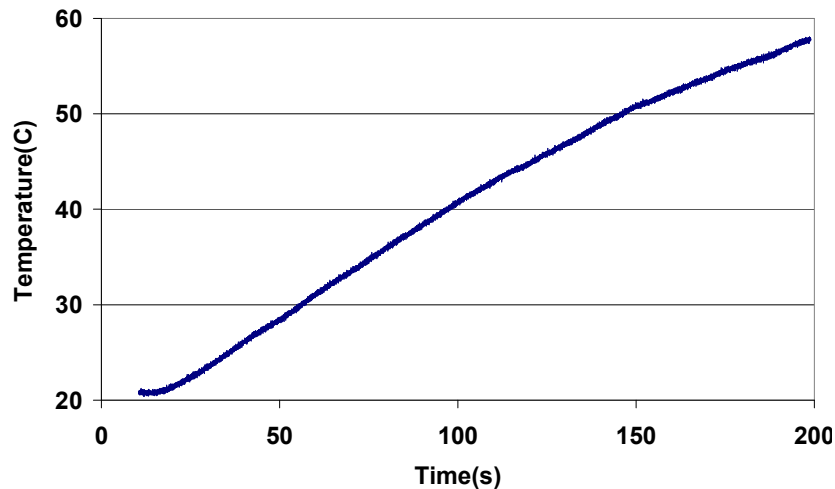


Figure 7. Temperature (C) vs. time (s) for 2 lb test unit at 500 Hz and 50 g peak vibration load.

Random Signal Control

The control system used for testing was a Spectral Dynamics single channel Jaguar system. Tests were done using an arbitrary random PSD profile on single and multiple actuators. Results for a single, unloaded actuator are shown in Figure 8.

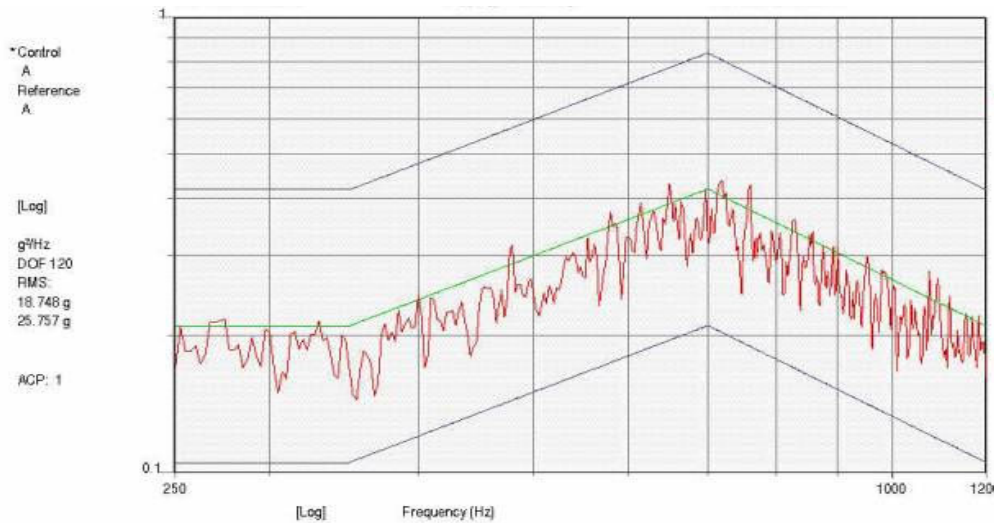


Figure 8. Results for arbitrary random PSD (green line) for a single, unloaded actuator.

Tests done for multiple actuator assemblies were more difficult to achieve the desired PSD for the same single actuator test because of resonance created by the additional fixturing necessary to combine the actuators into one shaker system. Figure 9 shows results for a dual actuator assembly using the same PSD shown in Figure 8. This test shows that the overall levels achieved in the single actuator tests were not obtainable. For frequencies slightly above 600 Hz, the system exceeded the required level and at 900 Hz, the system was “force starved” and could not achieve the required level. If the problematic frequencies were removed from the PSD, the results would show increased g^2/Hz levels like that shown in Figure 8. Similar results for four actuator assemblies and different fixtures were also found. However, the problematic frequencies were different for each new assembly.

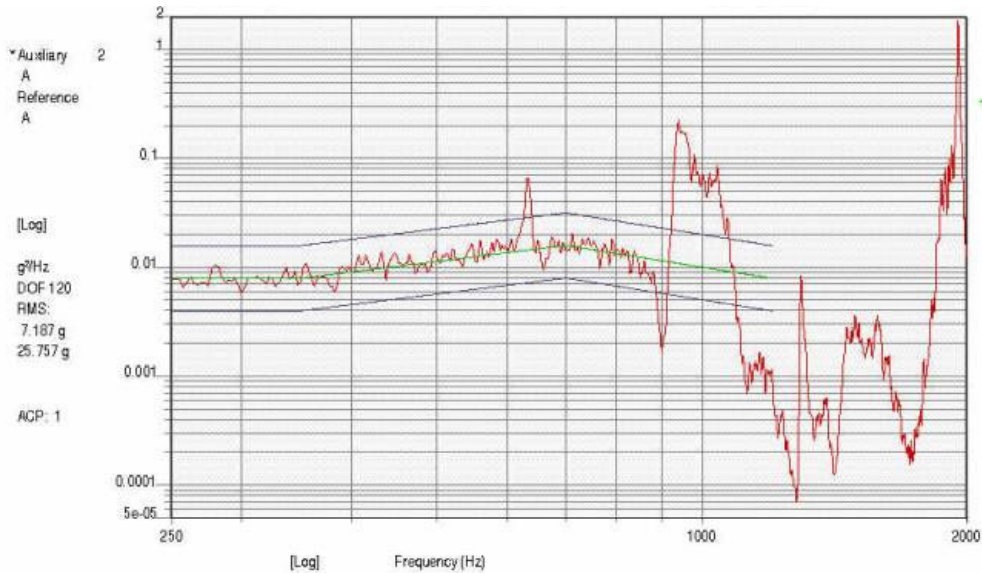


Figure 9. Results for arbitrary random PSD (green line) for a dual actuator assembly.

Vibrafuge Testing

The four-actuator assembly shown in Figure 3 was mounted to the centrifuge arm as shown in Figures 4 and 5. Tests were conducted at linear accelerations of 10, 20, 40, 50, 60, 70, and 75 g's with combined vibration environments of 300 and 600Hz. An Agilent model 33250A waveform generator was used to supply the 300 and 600Hz sine waves used as input control signals. A 3Vpp level and 2.5V offset were used for each test. This amounts to 40% of the voltage or stroke capacity of the actuators. Endevco Model 2221D piezoelectric accelerometers and Model 133 signal conditioners were used to measure the physical vibration of the test unit. A Hi-Techniques Win600 data acquisition system was used to collect accelerometer data.

The load centering technique was successful, all components survived, and results showed no discernable difference in the vibration response of the 22 lb test unit at different linear acceleration levels. Figure 10 shows results for the 600 Hz vibration tests at various linear accelerations. There are large spikes (not shown) at the beginning of each trace that represent the times at which the input control signals were energized. This causes the actuators to immediately shift-to-center as a result of the offset. The actuators stabilize from the initial start-up in under 10 ms. In all cases, about 23 g peak-to-peak at 600 Hz were measured. For the 70 g case there was a small 500-600 Hz signal recorded before the control signal was started. This is most likely due to small vibrations generated by the centrifuge at this speed. However, this did not seem to affect the shaker results at 70 g's. In addition, the nylon strap used for load centering did not adversely affect the shaker output at high linear accelerations at which loads were approaching 1500 lb in the strap. This is because the strap was able to quickly dampen the vibration due to nylon's 15-20% elongation properties and did not transfer the vibration to the load centering column or counterweight.

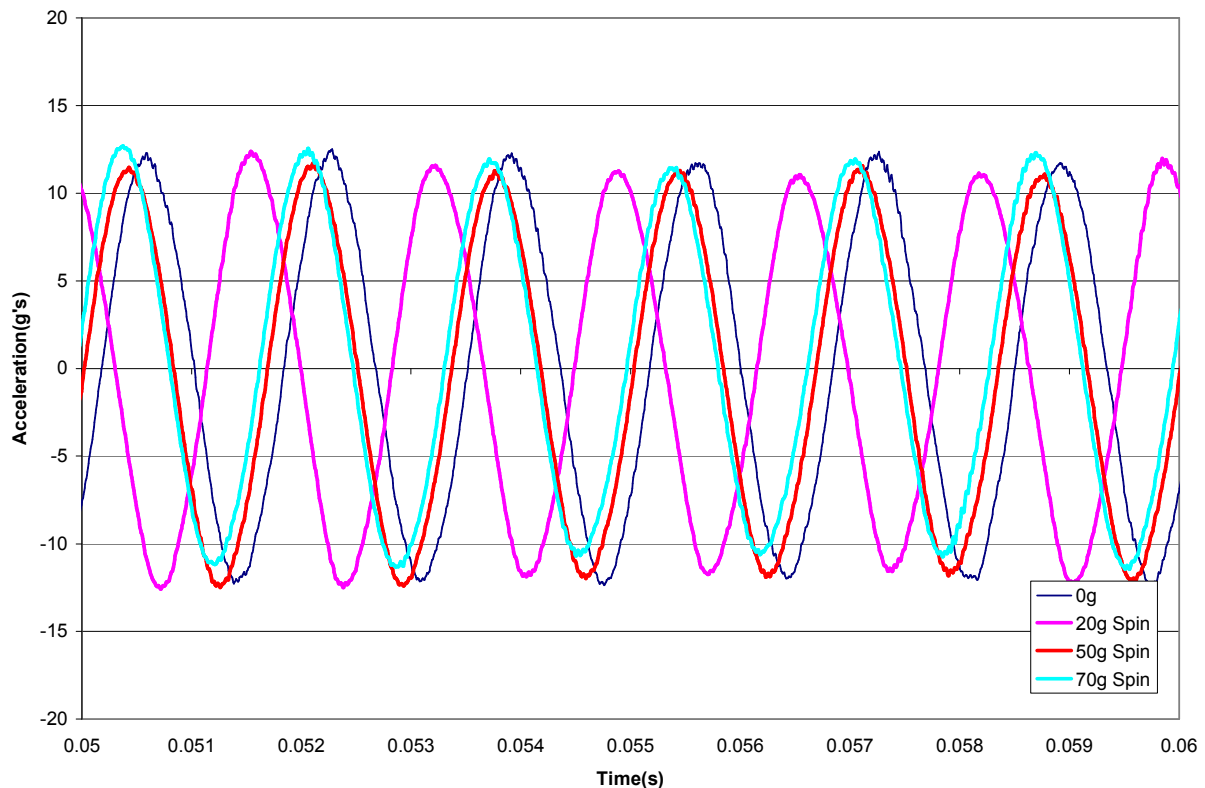


Figure 10. 22 lb Test unit vibration with 600Hz, 3Vpp, 2.5 V offset control signal.

Conclusions

The piezo-electric actuators and variable load centering technique were successful in providing a combined vibration and linear acceleration environment that significantly surpassed the capabilities of the previously reported mechanical Vibrafuge. Since the actuators allow for a scalable system, more could be utilized to drive units of larger weights than that reported here. Limitations of the new system are primarily due to the small stroke of the individual actuators and with multiple-actuator drive systems integrated with single channel random control. A multiple channel control system will be investigated and employed for future testing to expand the vibration environment capability. In addition, vibration at lower frequencies (larger actuator stroke) and in non-transverse axes will be implemented and tested in the combined environment.

Acknowledgements

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References

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- 3) Leconte, P., M. Hughes. Experimental Assessment of an Active Flap Device. American Helicopter 58th Annual Forum. 2002.