Viscoelastic Material Properties in a High Pressure Environment

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Viscoelastic Material Properties in a High Pressure Environment

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Abstract

Hardware representative of viscoelastic damping material in a cavity in a spinning jet engine blade was investigated. Specimens representing jet engine fan blades were analyzed, designed, fabricated and spun to establish that elastomer filled cavities can be designed for service in high-g environments. It was also shown that such systems can be analyzed using conventional finite element analysis. Spin rates of 7500 RPM were achieved which at a radius of 14 inches resulted in a g-level of 22,400 in the outer edge of a constrained viscoelastic material (VEM) damping treatment. Static strain readings were taken for the cavity walls. Dynamic testing was conducted and some excitation and response vibration data was acquired during spin. The elastic constants and elastomeric properties such as shear modulus, youngs modulus, bulk modulus, and Poisson's ratio of the VEM were also experimentally investigated in the laboratory. Initial results from these investigations are reported upon here.

Introduction

Augmentation of vibration damping in rotating blades of jet engines is of particular interest for improving high cycle fatigue life. In most potential vibration damping applications, the achievement of damping of realistic hardware in a laboratory setting is reasonably easy; the accomodation of the many other practical design issues such as material compatability, manufacturing and servicing can be challenging. Free layer damping surface coatings are susceptible to creep under centrifugal loading and erosion under airflow. Embedding the VEM in a cavity has the possibility of eliminating these undesirable effects. The cavity/cavities can be located and the walls sized such that damping is provided in target vibration modes through shear strain energy in the viscoelastic material. An investigation by Gordon and Hollkamp (1995) included a simplified analysis of hydrostatic pressure in a rigid wall container under body forces and indicated a great dependence on Poisson's ratio and the possibility of cavity rupture. Analysis of VEM material enclosed in flexible walls conducted in this research indicated significantly less pressure loading.

The primary concern is the hydrostatic-type loading due to the body forces in a high-g rotational field which can deform or rupture cavity walls. Strictly speaking, the term "hydrostatic" pertains only to fluids. In actuality, damping, or energy dissipation, requires that a viscoelastic material be deformed in shear. As a first approximation, the VEM is considered to be thermo-rheologically simple (trs) material. For vibratory energy dissipation, the VEM must be exercised in the transition region defined by a temperature and a frequency. The high-g spin loading occurs at static conditions, or zero reduced frequency. Under these conditions, the VEM behaves as if it were a rubbery material, where it possesses elastomeric properties. Elastomers are solids with values of elastic constants significantly lower than metals; they may be "nearly incompressible" or have Poisson's ratio approaching a value of one-half. Under non-rotating conditions, one state of stress and strain exists; upon subjection to spinning conditions, the VEM will creep over time into another state of stress and strain. Provided a satisfactory design is achieved, this final state will be one of small strains in comparison to the initial condition. Until some of the more obvious issues are resolved, it seems appropriate to analyze the polymer as a soft, linear elastic, homogenous, isotropic solid undergoing small strains and to treat any containing walls as flexible.

Laboratory Measurements

In order to help resolve some of these issues and provide input to design efforts, a series of tests were planned and performed in the laboratory in addition to spin testing. Specifically the elastic constants (shear modulus, youngs modulus, bulk modulus, and Poissons ratio) and elastomeric properties of the VEM were experimentally investigated. Testing was based on cylindrical specimens of various lengths for several types of viscoelastic materials. Each sample was placed in an instrumented test rig (see Fig. 1) and the applied force, change in length and change in circumference was measured.

In the first configuration, called “Interfacial Slip”, careful attention must be made to maintaining a perfectly lubricated slip boundary conditions. If this is acheived constant radial expansion occurs accross the test specimen as shown in Fig. 2. From this it is theoretically possible to extract the Youngs modulus as well as the Poisson’s ratio which is dependent on the radial compliance. Unfortunately maintaining the boundary condition proves quite difficult in reality. Additionally, the measurement accuracy for the radial circumfrence is required to be about 1 mil (0.001 inches). This was possible in calibration efforts on well defined stepped aluminum cylinders but on the VEM the methods used were only accurate to approximately 10 mils. The Poisson’s ratios of approximately 0.4 that were extracted from these results are lower than the values normally assumed for VEMs. Alternatively, by bonding a so called “poker chip” specimen to rigid end pieces it is possible to deform the specimen into another well defined shape, a barrel, and extract an estimate of Poisson’s ratio from the measured axial compliance. Implementing this procedure yielded values of 0.48, 0.494 and 0.482 for different types and lengths of viscoelastic materials which are closer to the normally assumed values.

Spin Testing

In addition to laboratory measurements, spin testing was performed to measure the effects of actual high centrifugal loads on viscoelastic material. While two different blade geometries were tested, only one is reported upon here. Called the viscoelastic pocket blade, it was 8.0” wide 13.25” long and 0.150” thick. The lower 1.25” was held in a clamped boundary condition, giving an effective length of 12.0” or an aspect ratio of 1.5, similar to fan blades. The blade itself consisted of two thin plates, one 0.100” thick and the other 0.050” thick. The thicker base plate had two 0.050” deep pockets hollowed out to allow the placement of viscoelastic material which was cast in place. The top plate had the same basic geometry and bolting pattern as the base plate. For spin testing, one pocket was filled with PR 1564, one of the viscoelastic materials that was tested in the laboratory setting, and the other pocket was left empty. The plates were then epoxied together using Dexter Hysol 9330.30 and bolted for additional security in case of epoxy seperation. The assembled flat blade was then instrumented with seven strain gages (type SK-06-062AP-350 from the Micro-Measurements Division of the Measurements Group, Inc.) and 1 set of 2 chordwise Lead ZirconateTitanate (PZT) patch excitors (ACX Quickpack QP20W) epoxied onto the top and bottom of the blade. Arrangement of the pockets, the excitation PZT patches, and strain gage placement is given in Figure 3. Photographs of the front and back of the blade are shown in Fig. 4 and 5.

After initial testing in the laboratory to determine unspun dynamic behavior and compare it to an otherwise identical blade with no viscoelastic treatment (Fig. 6), the blade was balanced with its hub and counter-balance (see Fig. 7 for a view of a pre balance assembly) and installed in a spin pit at the Test Devices Hudson, Massachusetts facilities. The test set up is shown schematically in Fig. 8. The blade was spun up in 2500 RPM steps from 0 to 7500 RPM as planned. Static strain was measured at these intervals and the blade was spun back down to zero. A second series of measurements were done in 1000 RPM steps from 0 to 5000 RPM with additional tests at 2500 and 5500 RPM. The results were consistent with one another and to predictions from finite element modeling as shown in Figures 9 and 10. From these results it can clearly be seen that while the presence of the VEM in one pocket did increase the measured strain, it was by a small and predictable amount.

It was also attempted to measure the dynamic response of the blade due to excitation provided by the PZT chordwise actuators. Due to a high level of cross talk between the PZT’s and strain gages (the source of which is still under investigation) this proved difficult. A modified Frequency Response Function (FRF) was generated by exciting the PZT and blade with a burst of pseudorandom band-limited noise of short duration and averaging the resulting blade dynamics as measured with the strain gages without the presence of high level cross talk (See Fig. 11). By coupling the measured data with estimates from the FE design model, it was possible to find several natural frequencies in the lower frequency range. For one of these it also proved possible to excite the mode with a pure sine wave form allowing the measurment of the cross-talk free ringdown after halting excitation (Fig. 12).

Summary

This paper documents the initial results of ongoing efforts to understand the behavior of viscoelastic materials under centrifugal loading. This effort is based on a multipronged approach of understanding the response of the material itself to high body force loading, developing accurate design methodologies and experimentally validating these predictions with testing under centrifugal loads. This work was initiated in response to earlier analysis that indicated that constrained layer viscoelastics might suffer from a type of hydrostatic effect leading to bulging of constrainment layers. Initial results reported here, both numeric and experimental, do not indicate this effect. With careful analysis and design, it appears possible to succesfully design constrained layer damping treatments for jet engine blades, at least from the standpoint of centrifugal forces.

Acknowledgements

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References

R. W. Gordon and J.J. Hollkamp, "A comparison of damping treatments for gas turbine blades," SPIE Smart Structures and MaterialsConference, 1995.

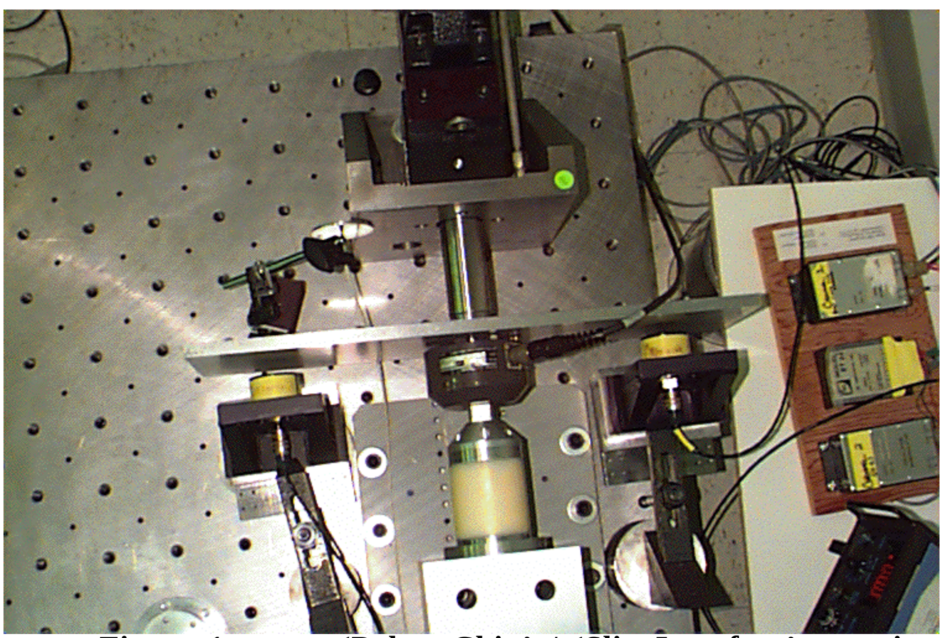
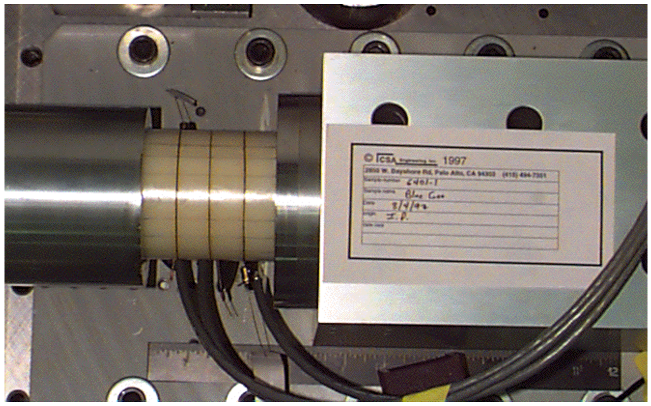


Figure 1: 'Poker Chip' / 'Slip Interface' test rig



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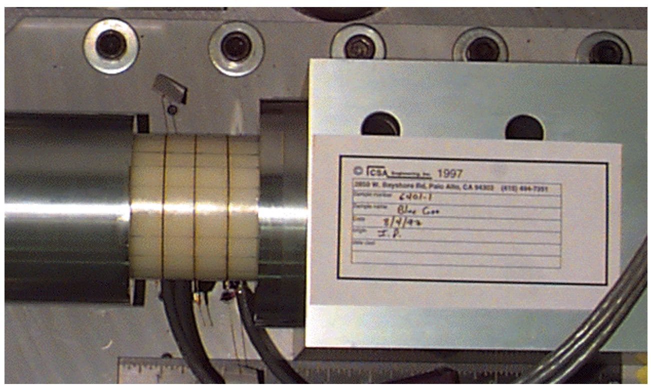

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Figure 2: Example 'Slip Interface' deformations

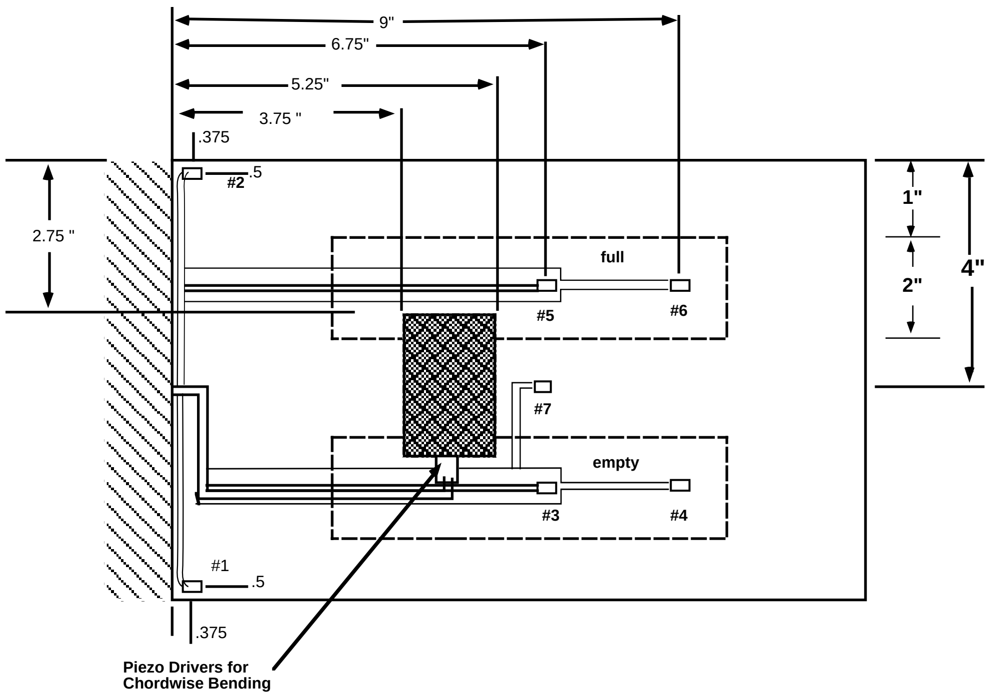

Figure 3: Viscoelastic pocket blade schematic

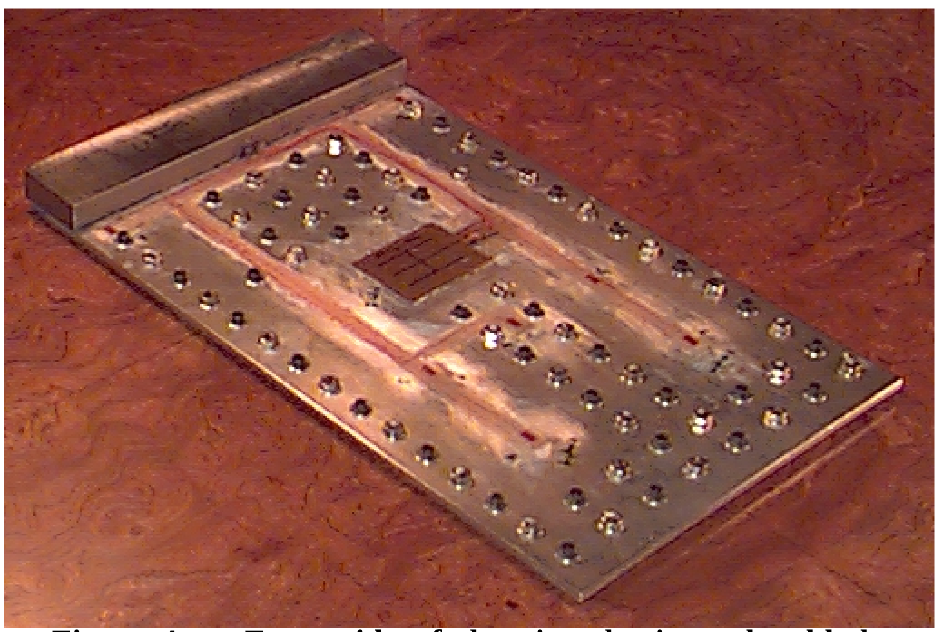

Figure 4: Front side of the viscoelastic pocket blade

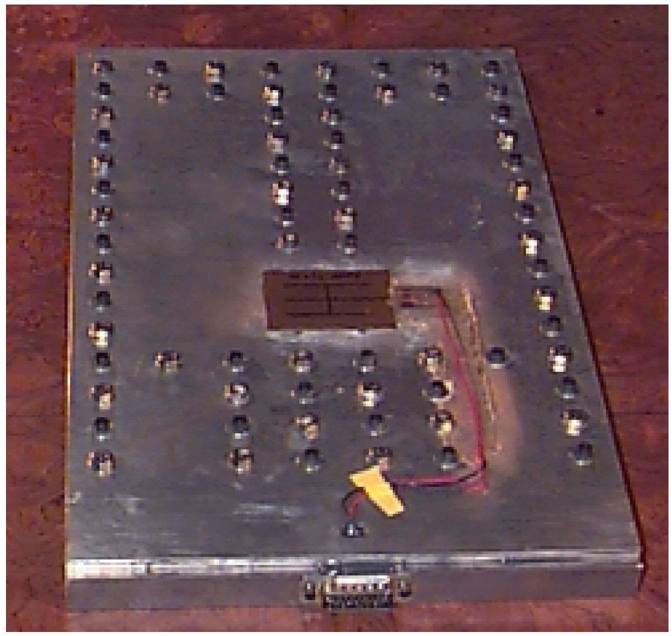

Figure 5: Back side of the viscoelastic pocket blade

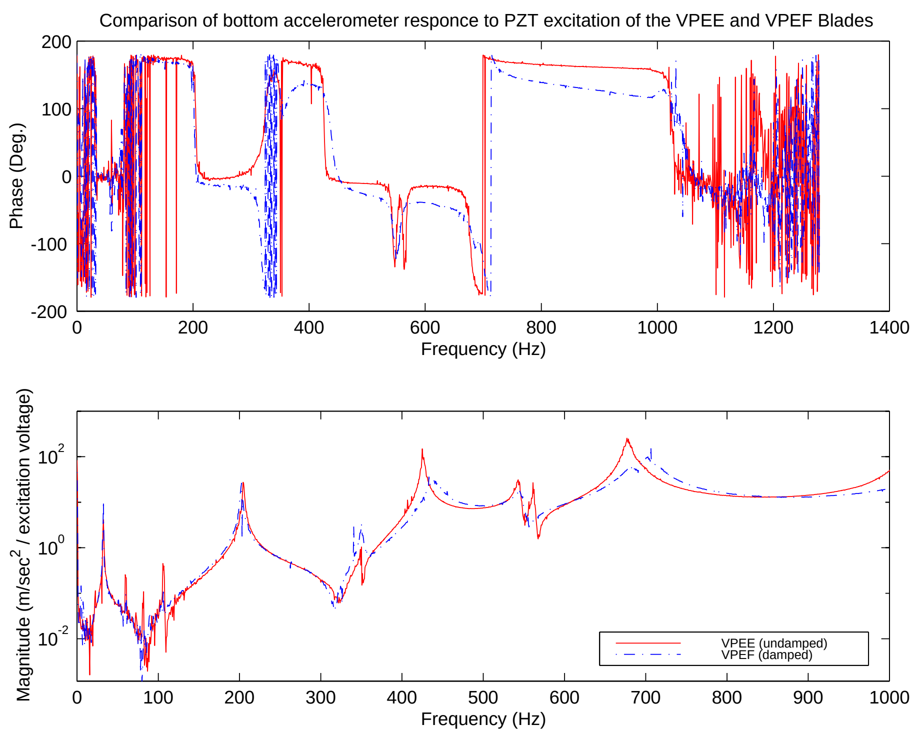

Figure 6: Unspun frequency response functions comparing the response of the damped and undamped blade to PZT provided excitation

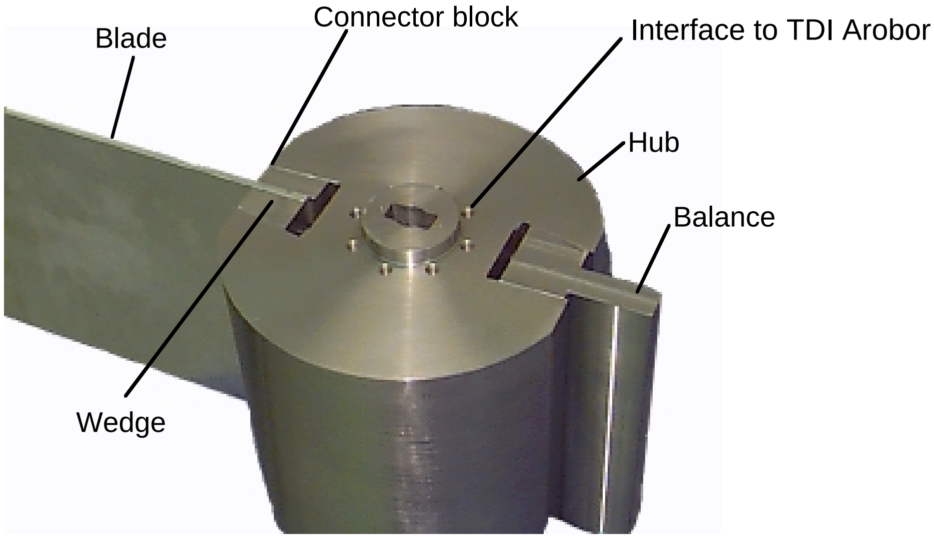

Figure 7: Blade/hub/counter balance assembly

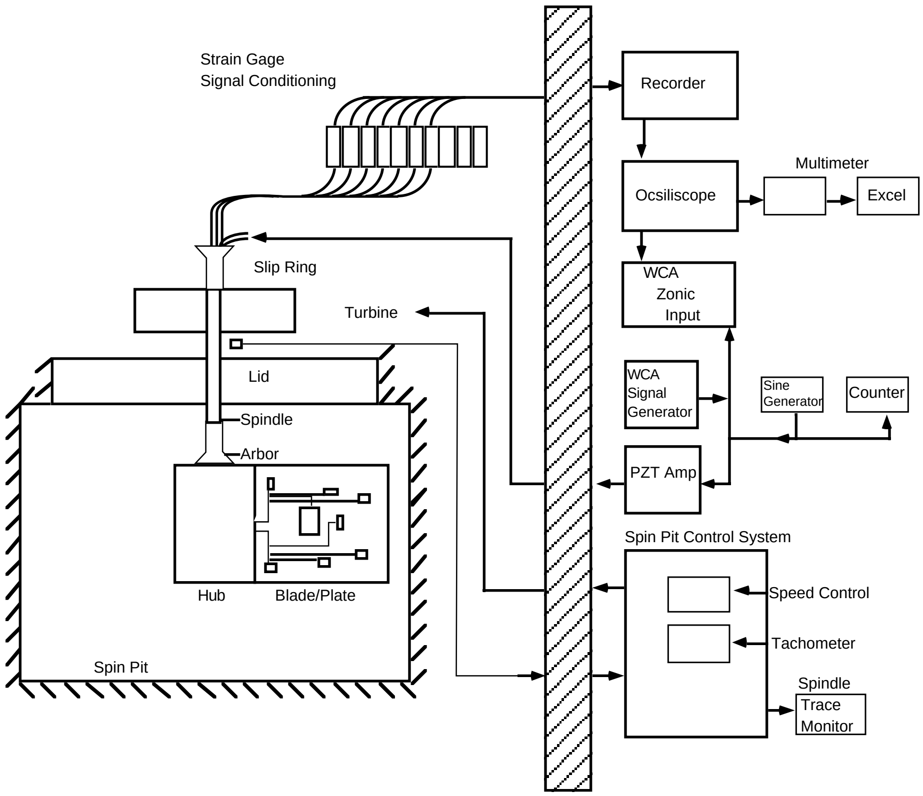

Figure 8: Schematic of spin test set up

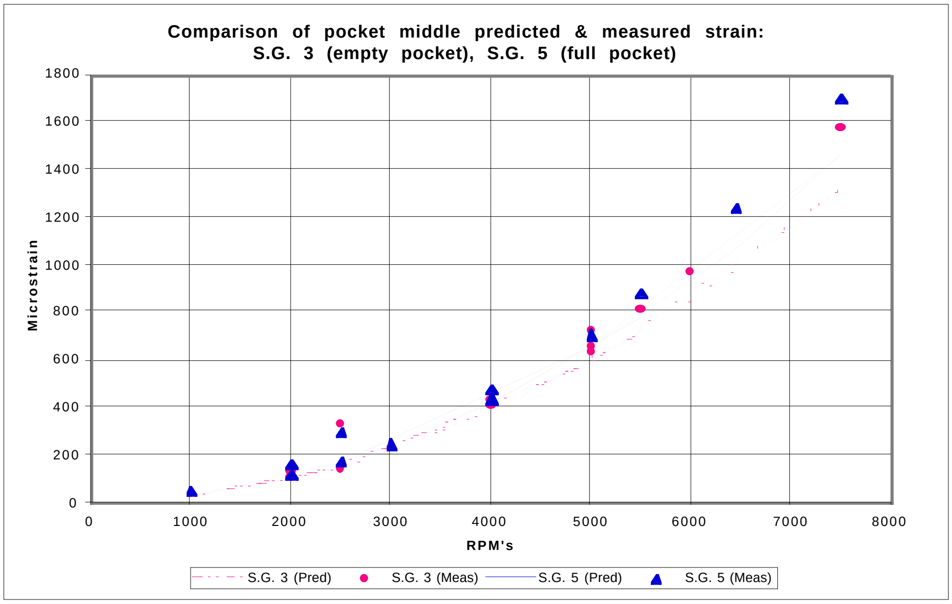

Figure 9: Measured vs. predicted strain gage measurements for strain gages at the pocket middle

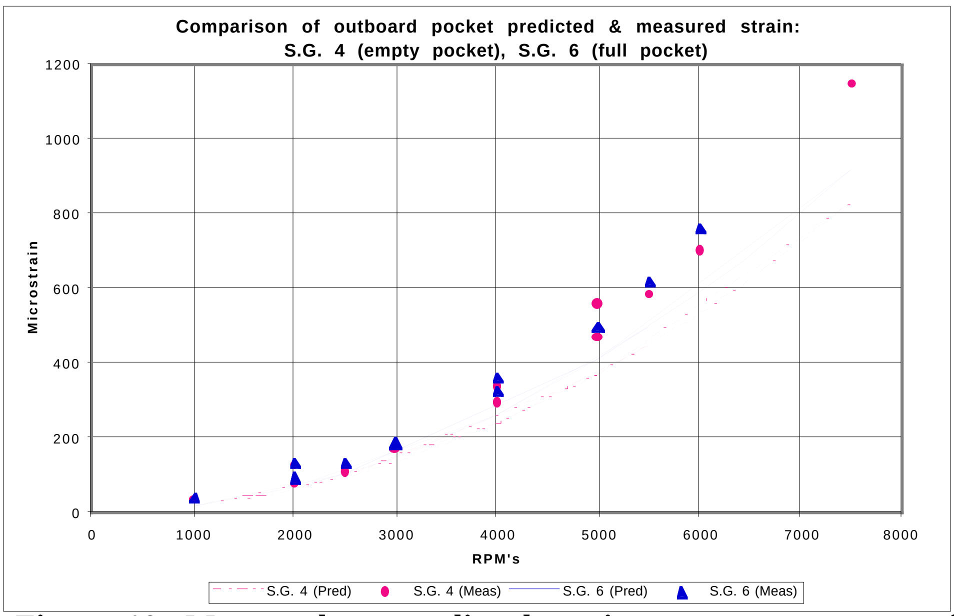

Figure 10: Measured vs. predicted strain gage measurements for strain gages at the pocket outer edge

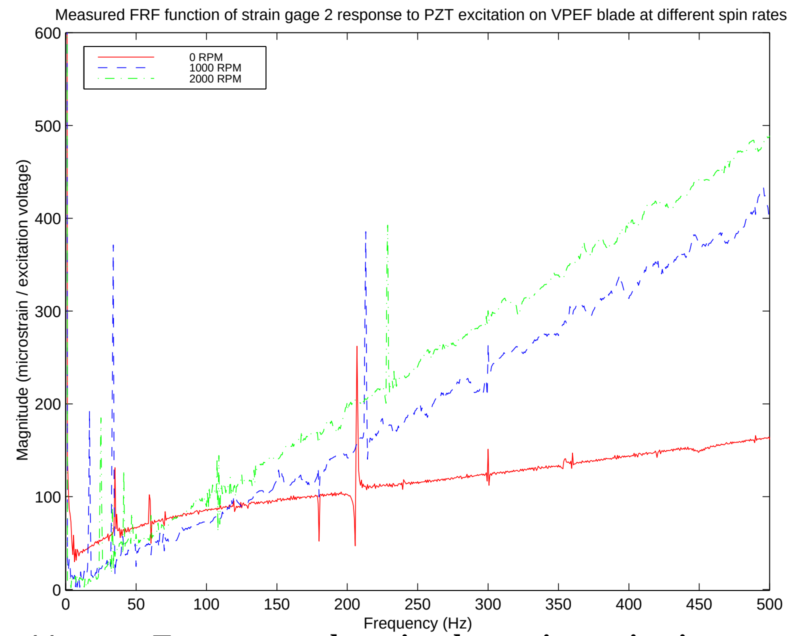

Figure 11: **Frequency domain dynamic excitation results on the viscoelastic pocket blade**

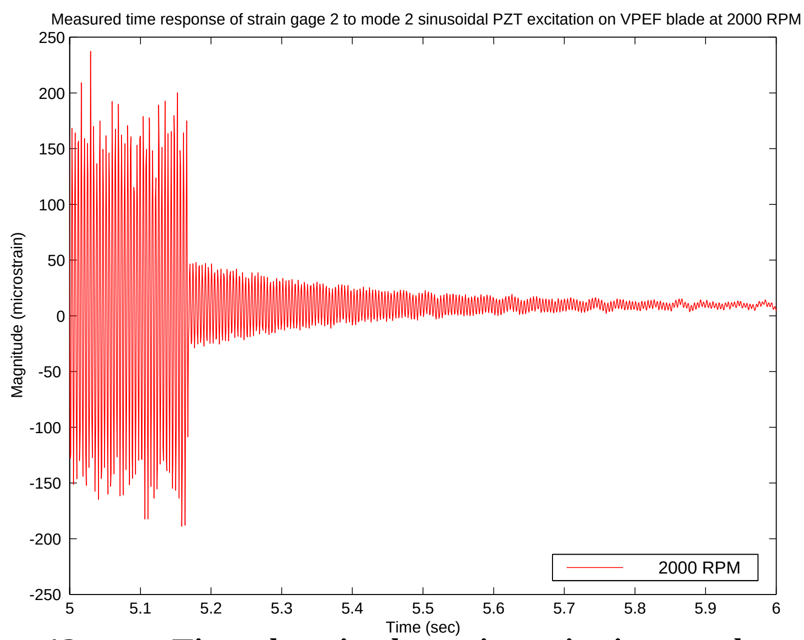

Figure 12: **Time domain dynamic excitation results on the viscoelastic pocket blade**