Vibration Suppression for Precision Metal Matrix Truss Structures

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Abstract

The progress on incorporating damping in metal matrix composites for precision truss structures is presented. The design, analysis, and fabrication techniques will be applicable to future space missions where dimensional precision under a severe dynamic environment is required. A testbed is described which has performance requirements similar to those of many future space missions where purely structural solutions offer little potential for mission success. Methods of analysis and system tailoring for enhanced damping are discussed. Preliminary results indicating the payoff that can be expected using damping and metal matrix composites are presented.

Introduction

Many future NASA and DoD space missions will have extremely stringent dynamic performance requirements based on a dimensionally stable structural platform. Purely structural solutions to the dynamics problems using conventional metallic or composite materials have little or no potential for meeting these criteria. Efficient solutions to the challenges posed by these future space missions will require enhanced damping implemented on a dimensionally precise structure.

One possibility which shows great promise for space missions with quiet, precise performance requirements is damped metal matrix composite (MMC) structures [1]. Metal matrix materials, with their high stiffness and near-zero coefficient of thermal expansion (CTE), exhibit very high dimensional precision, but relatively poor vibration suppression characteristics. The drawback of low damping of MMC can be overcome with the integral design of passive damping materials, such as viscoelastic materials (VEM), with the MMC.

The work described herein represents TRW's effort on the Damping and Metal Matrix for Precision Structures (DAMMPS) program. The objective of the program is to demonstrate dimensional precision for flexible structures when subjected to dynamic disturbances. TRW's approach to the problem is to incorporate viscoelastic joint dampers in series with metal matrix composite truss members. By using this approach, the amount of strain energy in the viscoelastic material can be controlled to achieve the desired level of damping. Thermal control of the viscoelastic material amounts to controlling the temperature of the joint, rather than the temperature of the entire truss member when employing constrained layer passive members.

System Description

In order to demonstrate materials and damping technology that is traceable to future space missions, it is necessary to have a testbed with dynamic characteristics that are traceable to those missions. Some of the important characteristics include strain levels, dynamic response levels, and member sizes. The precision structure shown in Figure 1 has been chosen for this work. It consists of a tripod mounted on top of three bipods. All members are constructed from P75/T6061 graphite/aluminum alloy composites. The tripod can emulate a secondary mirror metering truss or an optical sensor support structure. The bipods are similar to an optical system alignment truss or a reaction wheel assembly support structure. An optical sensor for dynamic test purposes is located at the apex of the tripod.

At the base of each leg is a modular three element joint as shown in Figure 2 [2]. The joints may be removed and replaced with viscoelastically damped joints (or fluid damped joints) to demonstrate the impact of damping on dynamic performance.

In a typical test sequence, dynamic disturbances are injected into the structure at the mid-platform or the apex of the tripod while monitoring the motions of the apex of the tripod with the optical sensor. Additional dynamic response data, such as accelerometer measurements at the mid-platform, may also be observed. The inert joints are then replaced with damped joints and the test is repeated. The impact of the damping on the dynamic performance is readily apparent by comparison the two sets of test data.

Design and Analysis Methods

Natural frequencies and strain levels traceable to future space missions can be obtained by employing MMC tubes and joint dampers with suitable stiffness values. In addition, the stiffness of the joint compared to the stiffness of the MMC tube determines the amount of strain energy induced in the VEM (i.e., the amount of damping achieved). For the three element joint damper shown in Figure 2, varying the VEM stiffness, the casing stiffness, and the machined spring stiffness changes both the equivalent stiffness of the joint and the amount of strain energy induced in the VEM. By selecting these stiffness values appropriately, the loss factor (thus the

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level of damping) can be maximized for a given equivalent joint stiffness. Furthermore, appropriate selection of the joint stiffness values can tailor the dynamic behavior of the VEM, thus the joint, at different temperatures. Figure 3 shows the calculated loss factor in the first four modes of the testbed as a function of joint temperature. Good damping is still obtained at high temperatures while performance degrades as the temperature of the VEM falls below room temperature. This behavior suggests the use of joint heaters to maintain moderate-to-high joint temperatures and avoid the low temerature loss of damping.

Dynamic performance of the testbed was analyzed using the modal strain energy (MSE) technique implemented in MSC/NASTRAN. In the MSE technique, modal loss factors are apportioned according to the strain energy participation of the mode in each of the materials [3]. Using the diagonal damping matrix obtained from the uncoupled MSE technique avoids the necessity of having to compute complex modes for dynamic response calculations [4].

Preliminary Results

Figure 4 contains a histogram of the modal damping as a function of frequency for the joint-damped testbed. Modes where axial motion of the members (thus axial motion in the joints) dominate are highly damped whereas leg bending or twisting modes are lightly damped. These lightly damped modes would have more damping if non-axial effects of the VEM in the joint were considered.

Undamped and damped PSDs of typical pointing and line-of-sight (LOS) quantities are shown in Figure 5. The disturbance used in this case was a scaled coolant flow disturbance [5] applied at the apex of the tripod. All of the modes that contribute to LOS_z have been damped while all but four of the modes that contribute to LOS_x and LOS_y have been damped. RMS levels have been lowered by factors of 2.8 to 7.7 (see Table 1).

Conclusions

A description of TRW's DAMMPS program, which is to demonstrate the viability of using damped metal matrix composites for future DoD space missions, has been given. By employing joint dampers with varying stiffnesses in a truss structure, the amount of damping in many structural modes can be predicted and controlled. The three element joint concept also has the advantage that the thermal sensitivity of the damping can be minimized. Typical performance improvements in RMS pointing errors over undamped metal matrix composites range from 2.8 to 7.7.

Acknowledgement

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References

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Table 1: RMS Response Levels Due to Coolant Flow Disturbances

Quantity	Undamped Gr/Al	Damped Gr/Al
Pointing X (μin)	1049	225
Pointing Y (μin)	1112	271
Pointing Z (μin)	16.34	2.116
LOS X (μrad)	6.993	2.263
LOS Y (μrad)	6.273	1.867
LOS Z (μrad)	.1828	.0649

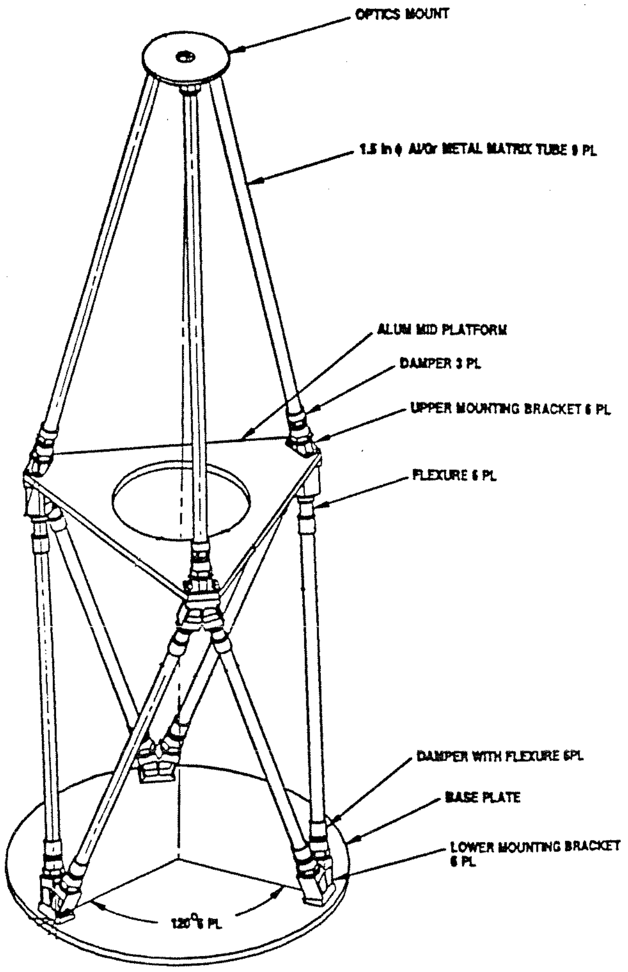

Figure 1: DAMMPS Precision Structure Testbed

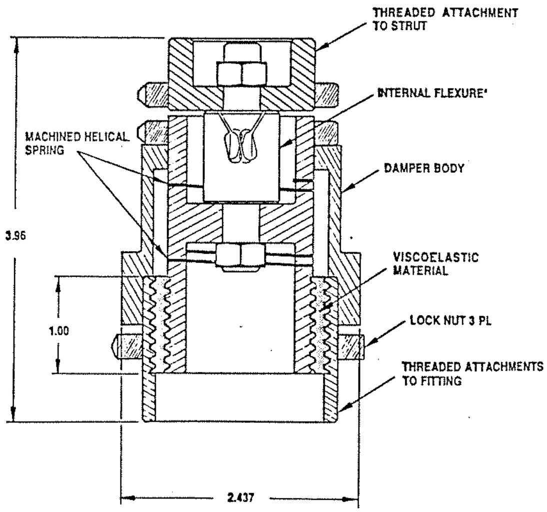

Figure 2: DAMMPS Three Element Joint Damper

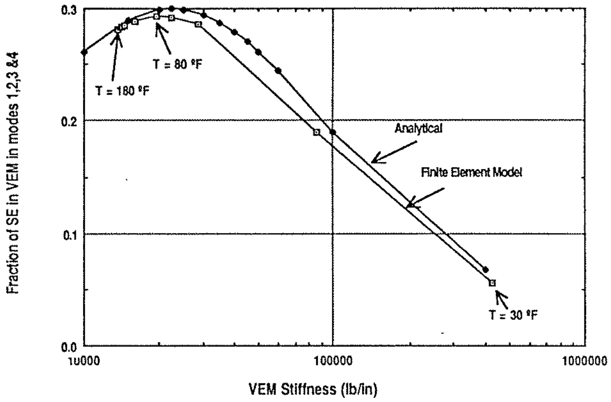

Figure 3: Loss Factor Performance Sensitivity Related to Temperature

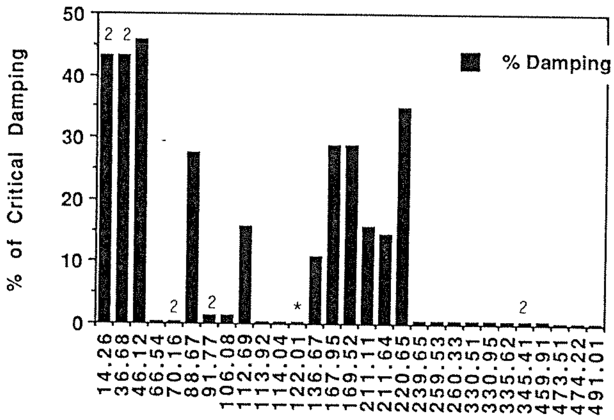

Figure 4: Modal Damping for the DAMMPS Testbed

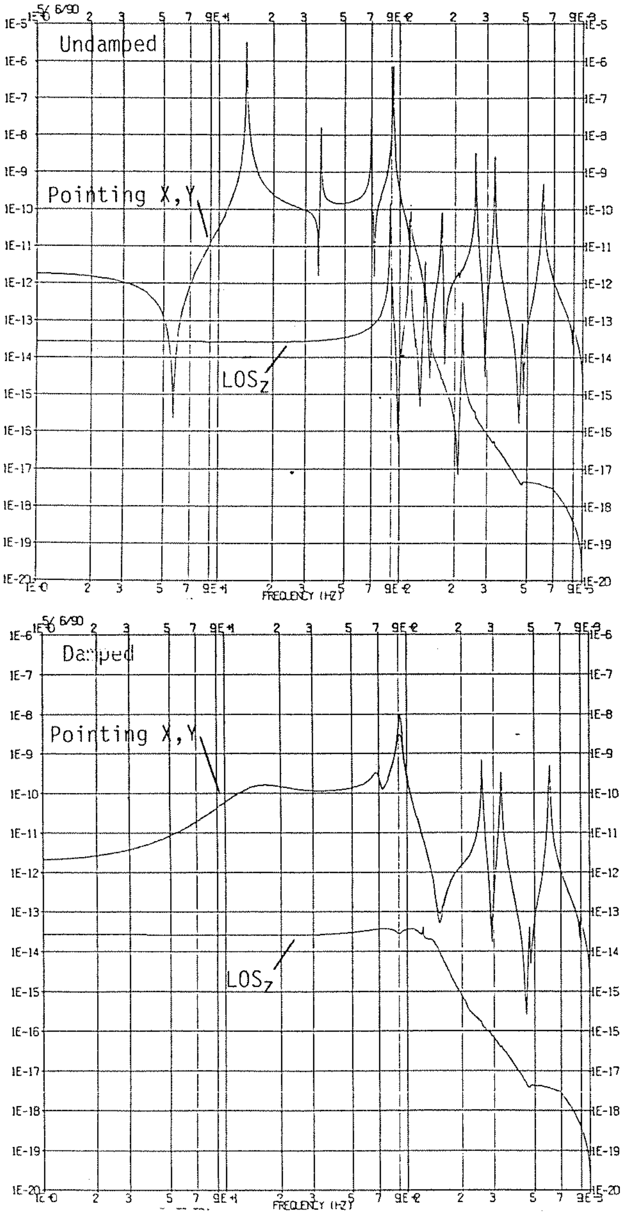

Figure 5: Undamped and Damped LOS Responses