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Paper Session II-A - Utilizing Advanced Vibration Technology to Enable Microgravity Science Operations

Dean Alhorn

Utilizing Advanced Vibration Isolation Technology to Enable Microgravity Science Operations

Abstract

Microgravity scientific research is performed in space is to determine the effects of gravity upon experiments. Until recently, experiments had to accept the environment aboard various carriers: reduced-gravity aircraft, sub-orbital payloads, SpaceShuttle, and Mir. If the environment is unacceptable, then most scientists would rather not expend the resources without the assurance of true microgravity conditions. This is currently the case on the International Space Station, because the ambient acceleration environment will exceed desirable levels. For this reason, the g-LIMIT (Glovebox Integrated Microgravity Isolation Technology) system is currently being developed to provide a quiescent acceleration environment for scientific operations. This sub-rack isolation system will provide a generic interface for a variety of experiments for the Microgravity Science Glovebox. This paper describes the motivation for developing of the g-LIMIT system, presents the design concept and details some of the advanced technologies utilized in the g-LIMIT flight design.

Introduction

The International Space Station (ISS) will soon become an active platform for performing microgravity research. Microgravity research will be conducted in various fields: Biotechnology, Combustion Science, Fluid Physics, Fundamental Physics and Material Science. These investigations have a diverse range: from protein crystal growth experiments to material solidification; from combustion synthesis to heat transfer. Many of these experiments are sensitive to accelerations in the frequency range below 1 Hz. Another requirement of some experiments is to operate with quiescent microgravity conditions for an extended duration: from hours to weeks, and in some cases, up to one month. Although the experiments on ISS will be in earth orbit, this alone does not guarantee that a microgravity environment will exist for a particular experiment. Numerous other disturbances will be present on ISS in the form of crew activity, pumps, fans, and motors from other ISS hardware and experiments. These disturbances will cause the ISS to not meet its design requirement as presented in Figure 1.

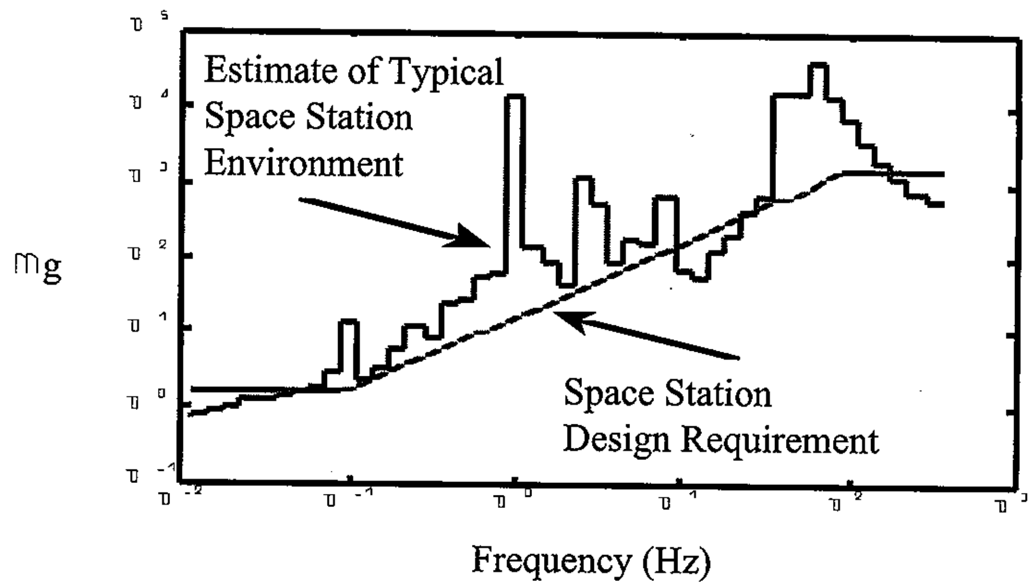

Figure 1: ISS Acceleration Levels

Figure 1 presents the anticipated acceleration levels of the ISS (root-sum-squared acceleration magnitudes) compared to the design requirement. If the microgravity experiments are operated in this anticipated environment, success will be difficult to achieve. For this reason, several active vibration isolation systems have been developed to attenuate the disturbances and provide a quiescent microgravity environment, ideally suited to a particular experiment. These systems will be described later. Although passive isolation methods would be able to attenuate the higher frequency disturbances, they are ineffective for the sub 1 Hz range. Therefore an active vibration isolation system is necessary to provide the full range of disturbance rejection for microgravity experiments.

As stated before, disturbances on the space station are numerous and are transmitted to the payload through various means. Direct crew contact, whether intentional or not, can even cause isolation systems to be ineffective. This is due to the limit on the size and power of the isolators and the amount of free "rattle-space" for the isolation system. In addition, crew activity in other areas of the station, (exercise, rack replacements, scientific operations, construction), will provide enough disturbances to be of concern to the scientist. Another direct concern for microgravity experiments is neighboring payloads generating unwanted disturbances. For this reason, a "good-neighbor" policy has been adopted by the ISS, whereby payloads are supposed to limit the emission of large disturbances to a specified vibration allocation. Even with "good-neighbors," disturbances will be directly applied to payloads requiring resources. These resources are transmitted through a set of umbilicals and might consist of the following: electrical power, data, video, vacuum and/or fluid resources for cooling or gaseous supply. Since the umbilicals transmit resources and disturbance vibrations directly to the payload, they need to be designed to be flexible as possible. If the umbilical were flexible enough, the payload could be passively isolated, but for most payloads, the umbilicals are too bulky, stiff and act as a direct path for disturbances. Therefore, sensitive microgravity experiments will require active vibration isolation.

The space station selected the Active Rack Isolation System (ARIS) to be the baseline active isolation system for the ISS. The ARIS system is designed to isolate a whole payload rack, but is unable to attenuate forces directly applied to the rack. Likewise, the "good-neighbor" policy is critical to the ARIS racks, because ARIS is unable to reject unwanted disturbances from internal payloads. To isolate only the microgravity payload, a sub-rack isolation system would be required. The Suppression of Transient Accelerations By Levitation Evaluation (STABLE) and the Microgravity Isolation Mount (MIM) are the only two existing sub-rack isolation systems, but neither of these systems is optimized for small volume enclosures, as will the case be for the Microgravity Science Glovebox (MSG) facility. For these reasons, the MSG facility has chosen not to isolate its whole rack, but instead use the g-LIMIT isolation system.

g-LIMIT Design Concept

The g-LIMIT isolation system is being designed for operations in the MSG facility and is scheduled to be launched on the UF-2 mission in November 2000. This system will be the first payload to be tested in the MSG facility. The g-LIMIT system will be initially characterized and afterwards will be available to other science investigators as a unique MSG facility resource. Although g-LIMIT is designed for use in the MSG facility, the concept is modular and can be utilized in other areas of ISS for vibration isolation applications. The g-LIMIT project arose out of a need to develop a generic system for active vibration isolation at the sub-rack or payload level. The success of the STABLE mission prompted an effort to develop an advanced system for isolating payloads. With knowledge gained from STABLE, the principle investigators have directed an effort, which has culminated in the g-LIMIT system. Figure 2 shows the g-LIMIT isolator in an exploded view to detail the internal components of the system.

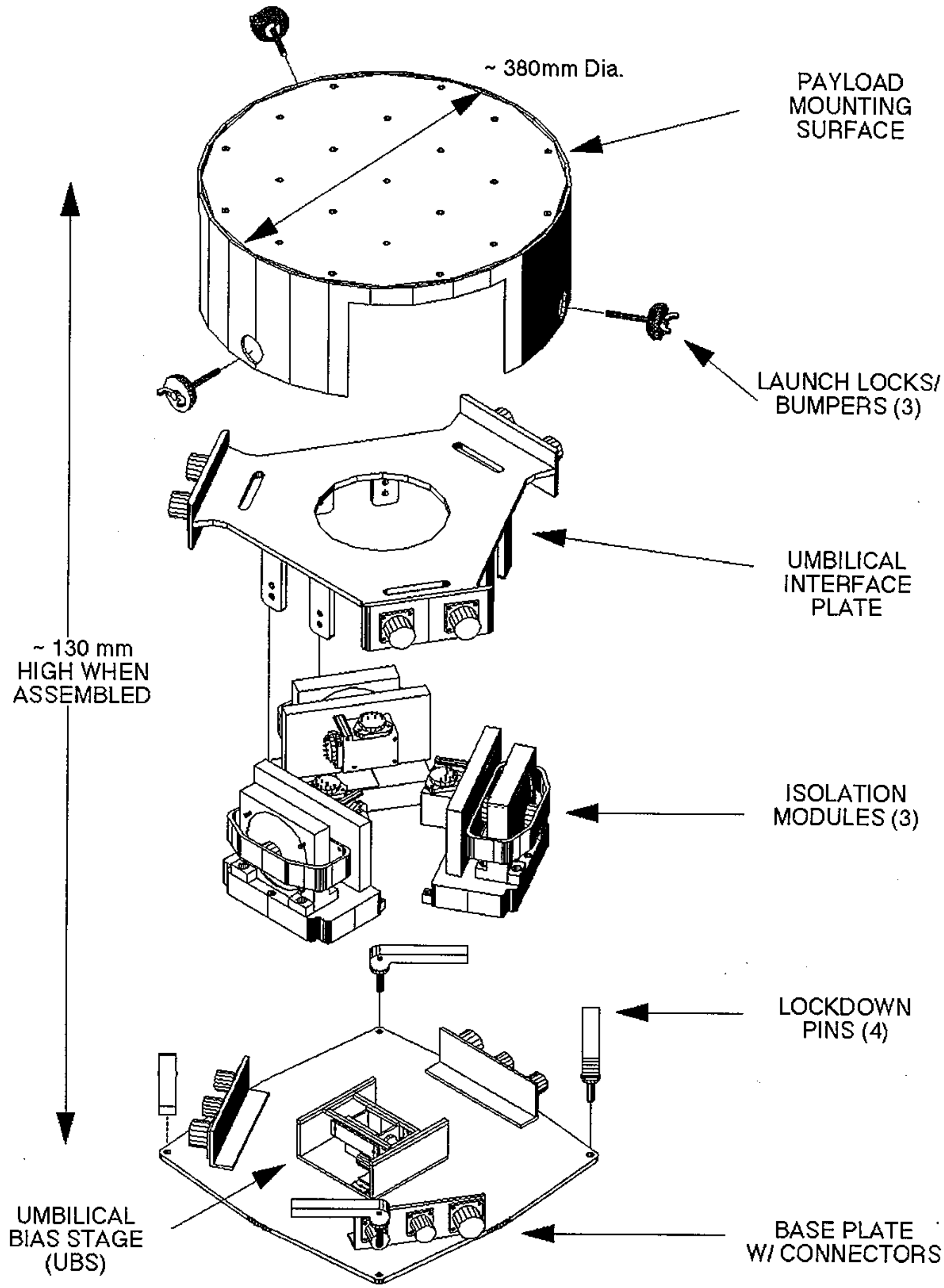

Figure 2: g-LIMIT System Isolator
(Exploded View)

The basic unit of the g-LIMIT isolation system is the Isolation Module (IM). This module is designed as complete dual-axis isolator incorporating, a dual-axis electro-magnetic actuator, two axes of acceleration and position sensing, signal conditioning and drive electronics and a DSP based digital control system. The axes of the actuator and sensors have been co-located to allow each axis to be independently controlled.

A digital control system is being implemented using high frequency acceleration control with low frequency position control. Three IM's will be integrated into the g-LIMIT isolator to produce six-axes of control. Both co-located (local) and centralized control laws will be tested to determine the most effective method for isolating the payload. Classical and modern control designs will be implemented to assess the performance and robustness of the g-LIMIT control system.

A Power and Information Processor (PIP) box (not shown) provides g-LIMIT the capability to interface to the MSG and ISS computer network. One function of the PIP is to provide power conversion from the 120V MSG supplied power to the g-LIMIT system operational voltages. When operational, the g-LIMIT system requires approximately 60 Watts peak and 25 Watts nominally. The PIP also performs overhead functions for storing data and transmitting information to an external computer for display and analysis. Finally, when implementing centralized control, the PIP would perform the control law calculations, receive sensor data and send commands to the three IM's.

The experimental payload would be secured to the top plate and the required resources would be connected to the g-LIMIT system connectors. A subset of the MSG resources is passed through from the base to the isolated portion of the g-LIMIT system using a set of flexible umbilicals. For g-LIMIT these resources include: power (+28V, +5V, ±12 V), 8-bits digital I/O, 4 bits analog input, RS422, Ethernet, and two video connections. The g-LIMIT isolation system has been designed to be transparent to the user with respect to the system interfaces. The user available structural, electrical and data interfaces are identical to those provided by the MSG facility.

Advanced Technologies

The g-LIMIT system is the evolution of vibration isolation technology originally demonstrated with the STABLE project. The g-LIMIT isolator incorporates several key technological advances while requiring minimal user interfaces. These advanced technologies and modular system design will allow the isolation system to be utilized in locations other than the MSG facility. The basic g-LIMIT concept is to supply to the experimenter a set of three isolators that can be incorporated into various carriers: lockers, drawers or other small volumes. Although this concept is currently being applied to the isolation system for the MSG facility, the modular approach provides the ability to scale the system for larger or smaller volumes. Thus, the IM then forms the basis for an off-the-shelf kit for general users to incorporate into their experiment to provide vibration isolation. Utilizing a co-located control law results in a configuration independent control system, thereby reducing the user software interface requirements.

Another novel technology incorporated into the g-LIMIT system is integral co-located position sensing. This patent-pending technology simultaneously utilizes the actuator coil as a dual axis position sensor and as an electo-magnet to provide isolation to the payload. The position sensor operates in a manner similar to a resolver. This is accomplished by adding a generator coil to the actuator backiron and exciting the coil with a high frequency signal. The excitation signal is received by the actuator coil and conditioned to provide a position signal. The incorporation of the position sensor with the actuator provides inherent co-located position and actuator axes. This technology has been further advanced to produce a patent-pending rotary position sensor for commercial applications. The dual axis position sensing system is detailed in Figure 3.

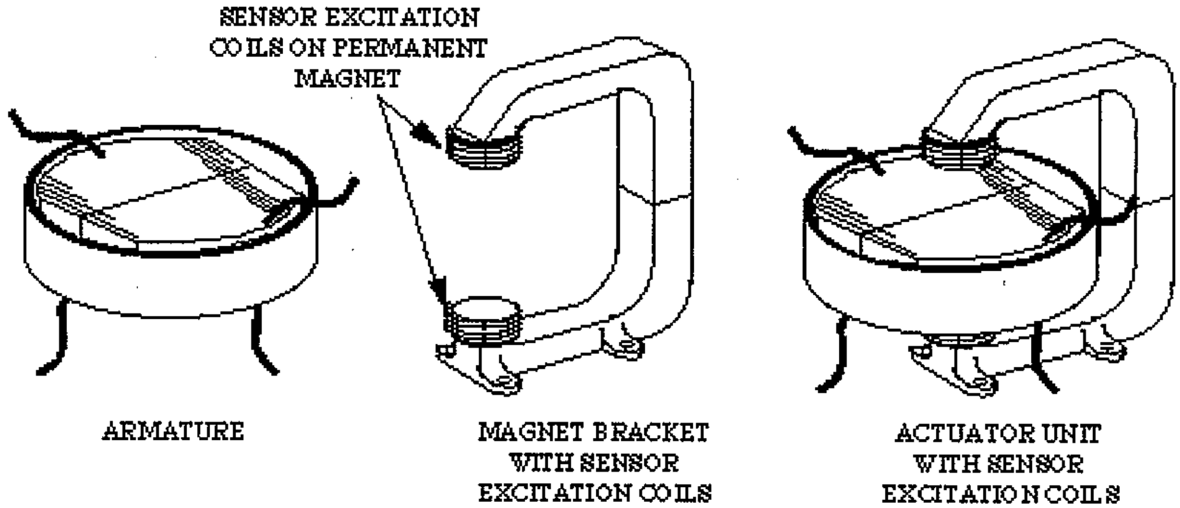

Figure 3: Patent-pending Co-located Dual-Axis Actuator and Position Sensing Technology

One drawback of designing the g-LIMIT system for modularity and optimizing for the MSG facility application is minimizing the peak actuator force. If the umbilical has enough bias to cause the top plate to move off-center, the peak actuator force might be insufficient to provide centering and control. To center the top plate requires either a constant bias force or requires the assistance of an Umbilical Bias Stage (UBS). The g-LIMIT UBS is a 3-axis translation stage, in a 400cc volume. The UBS is an active translation mechanism incorporating 3 motors with drive mechanisms and sensors with a range of ±15 mm in each axis. The base of the umbilical is attached to the UBS and the base moves in three dimensions to minimize the bias force. The net effect of the UBS is to minimize the DC power required by the actuators, minimize the actuator size and provide a greater range of vibration attenuation.

The g-LIMIT system will also have the advanced capability to generate a pristine acceleration profile while maintaining a quiescent microgravity environment. This unique capability is useful for certain microgravity investigations, such as protein crystal growth experiments. The type of acceleration environment, time response or frequency spectrum, can be user selected and g-LIMIT will respond accordingly. Finally, another advance technology, which is actually a byproduct of the g-LIMIT control system, is the ability to measure quasi-steady accelerations. These measurements are independent of the accelerometers and are thus a true representation of the inertial drag on the g-LIMIT system and can be used to measure space station drag.

Conclusion

The International Space Station will be a premier facility for microgravity research, but not without problems. To achieve a true microgravity quiescent environment on the ISS will require active vibration isolation systems. Even though ARIS has been baselined by ISS, it alone will not meet all the ISS vibration Isolation requirements and therefore the need exists for a sub-rack isolation system. The g-LIMIT system is being designed for the MSG facility to provide the necessary vibration isolation and will be tested and become operational on the UF-2 mission in November 2000. With its novel approach and advanced technology, g-LIMIT is the most advanced vibration isolation system to date. The g-LIMIT system will provide a generic capability, not only for MSG, but also as a modular isolation system for other applications on space station. Several spin-off technologies from the g-LIMIT design are under development and these will produce benefits to mankind long after the g-LIMIT project has been completed.

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