

# Chapter 9

## Conclusion

### 9.1 Summary

It was shown that an air mount with a parallel MR damper controlled with either a LQR Optimal, Velocity Feedback, or Acceleration Bang-Bang controller can provide very effective shock isolation for SDOF applications. Test results suggest that this hybrid isolation system could reduce transmitted accelerations below the 7 to 8 g threshold for introduction of so-called Commercial-Grade COTS equipment on ships. This has been very difficult to achieve with commercial passive mounts. Introducing Commercial-Grade COTS equipment could conceivably offer significant reductions in equipment costs. Furthermore, it was shown that the air spring/MR damper combination with either controller provides excellent isolation performance for both shock and vibration inputs simultaneously. Combining vibration and shock isolation into a single unit can offer significant advantages in terms of weight and space savings. This is particularly important in submarine applications where space is at a premium. Using semi-active control allows the isolation system to automatically adjust to variations in the mass and center-of-gravity of the supported payload. This is particularly important as electronic equipment is typically refreshed every 18 months which obviously alters the mass and center-of-gravity of the isolated equipment. This forces a re-evaluation and/or replacement of the isolation system every 18 months. This can be very costly and time consuming. Having an isolation system that automatically accounts for these variations is obviously advantageous.

It was also shown through simulation of a relatively tall, narrow equipment cabinet subjected to MDOF ship shock inputs that although the MDOF Velocity Feedback and Skyhook controllers performed poorly, the MDOF Acceleration Bang-

Bang controller provided excellent performance. The simulation results with the MRAM mounted cabinet showed significant reductions in cabinet displacements and above mount accelerations over a cabinet mounted with a traditional passive shipboard isolator. Also encouraging is the minimal cabinet rotations experienced with the MRAM. It appears that the cabinet rotations can be minimized to such an extent that sway mounts that are traditionally placed at the top of the cabinets to minimize rocking can be eliminated. Entirely base mounting an equipment cabinet is very desirable as adding sway mounts increases the difficulty of the installation considerably.

Although semi-active devices require a power source, MR devices are attractive in that they have low power requirements and without power they still behave as passive dampers. The later affords a degree of fail-safety to an MR damper-based isolation system. Another benefit of having low power requirements is that it may be possible to create a self-powered device by scavenging and storing ambient vibration energy. Having a self-powered, self-contained, combined shock and vibration isolator would be especially attractive as it would eliminate the need for external power sources and external controller connections. Furthermore, a self-contained isolation system would be much easier to backfit on existing ships.

The feasibility of self-powering was explored through the use of a PSG to convert the mechanical vibration energy to electrical energy which was then stored in an ultracapacitor stack. The results of the power scavenging experiment showed that sufficient energy could be generated with a PSG(s) and stored in an ultracapacitor stack(s) to power the MRAM through several shock events. The optimization of the capacitance versus energy storage requirements and the use of energy conversion electronics would result in considerably shorter recharge times. Further design work is necessary to "fine tune" this power scavenging concept into a usable system, but the preliminary results look promising.

## 9.2 Future Work

Several extensions to this work are proposed. 1) Expand the 3DOF model to consider variations in the CG of the supported equipment. This would be useful to determine whether variations in the equipment CG has any impact on the performance of the isolation system. 2) Design, optimize, fabricate and characterize an MR damper that is suitable for the high velocities expected in a shipboard application. There is not enough information available on the performance of these dampers at high velocities. 3) Design, fabricate and test a complete isolation system in a typical shipboard installation using a traditional MIL-S-901D test method. This demonstration would prove the performance of this system to the ship shock community in a way that simulation results cannot. As a selling tool a test of a complete system would be invaluable.