N94- 35843

# High Temperature Superconductors for Magnetic Suspension Applications

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## SUMMARY

High temperature superconductors (HTS) hold the promise for applications in magnetic levitation bearing, vibration damping and torque coupling. Traditional magnetic suspension systems require active feedback and vibration controls, in which power consumption and low frequency vibration are among the major engineering concerns. HTS materials have been demonstrated to be an enabling approach towards such problems due to their flux trapping properties. In our laboratory at TCSUH, we have been conducting a series of experiments to explore various mechanical applications using HTS. We have constructed a 30 lb. model flywheel levitated by a hybrid superconducting magnetic bearing (HSMB). We are also developing a levitated and vibration-damped platform for high precision instrumentation. These applications would be ideal for space usages where ambient temperature is adequate for HTS to operate properly under greatly reduced cryogenic requirements. We will give a general overview of these potential applications and discuss the operating principles of the HTS devices we have developed.

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This work is supported in part by DARPA Grant No. MDA 972-90-J-1001, and the State of Texas.

# INTRODUCTION

Many applications can be enhanced by reducing mechanical drag as well as structural vibration, utilizing magnetic levitation. Systems using active suspension such as electrical feedback controls or complex pneumatic gas bearing systems lack efficiency. However, the benefits of levitation have greatly increased the durability and life of such devices. Passive magnetic levitation has existed for many years at low temperature (liquid He), but not until recently has it been shown to be economically feasible to implement these laboratory devices into practical systems [1-5]. The introduction of high temperature superconductors (HTS) such as $YBa_2Cu_3O_{7-d}$ (YBCO) has opened up a new opportunity for the passive levitation approach which was not thought possible before. Now a simple permanent magnet can physically levitate a mass with 60 psi pressure in all six degrees of freedom at 77K. Being a type II superconductor, YBCO exhibits the unique properties of flux pinning and flux creep effects which can be used to damp unwanted mechanical vibrations. Many simple structures such as levitated platforms and high-load bearings have started to be developed using the hybrid magnet-superconductor concepts.

Although HTS materials technology has progressed significantly, even higher levitation or suspension and stiffnesses will be needed to incorporate these superconducting bearings into a wider range of applications. High load levitation can be achieved in a passive bearing system composed of strong permanent magnets, except for the inherent instability as stated in Earnshaw's theorem [6]. Such instability can be overcome by the presence of a field-trapped HTS. The HTS pins the flux lines and hence resists any change of interior magnetic inductions. In this report we will present the hybrid superconducting magnetic bearing (HSMB) design which circumvented the unstable magnet/magnet interactions by using a high quality melt textured YBCO superconductor [7]. The HSMB design allows for the greater stiffness values and maintains a much higher static load capacity than the traditional simple zero-field cooled magnet/superconductor bearing based on the Meissner effect. Small units of a prototype flywheel energy storage system and a vibration-damping platform using the hybrid design have been constructed in our laboratory. A brief comparison of material properties with the performance of the hybrid bearings will be given.

# EXPERIMENTAL

The prototype flywheel (Figure 1) with a diameter of 11.9 in. and 30 lb. in weight was constructed of aircraft aluminum alloy. At the axis of the flywheel are two embedded permanent magnets that serve as the main magnetic bearings. The magnet on the top was used to lift most of the weight of the flywheel and at the same time assist in radial stability. The bottom magnet (double dipole) acted as a stabilizer against the magnet/magnet radial and axial instability. The double dipole consists of a ring magnet surrounding an equal surface area dipole magnet but of opposite axial magnetization in the center of the ring. A static and dynamic force measurement system [8] incorporating an elastic beam with strain gauges was attached to the double dipole permanent magnet used in the flywheel. The double dipole permanent magnets were made of NdBFe rare earth magnet material having dimensions of 1.9 cm long and 3.81 cm diameter and a surface field of 0.495 T. This cantilever beam was fixed to a motorized X-Y stage controlled by a computer. The bending of the

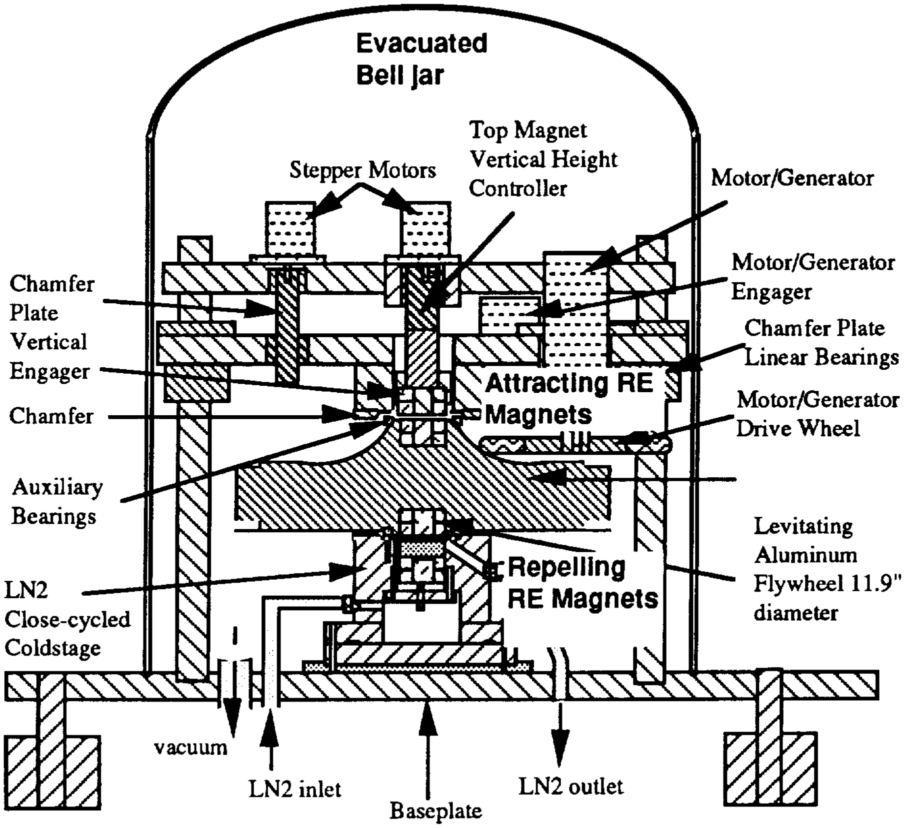

Figure 1: Line drawing of the flywheel being levitated by RE magnets and stabilized by HTS.

beam was sensed by strain gauges from which output voltages corresponding to the strain in the bent beam were monitored. A calibration was then done to correlate the strain gauge voltage with the forces which produced the beam bending. With the same setup, a mirror was fixed to the end of the beam directing a laser to a position-sensitive optical detector. The signal from the optical detector was put through a spectrum analyzer to measure the damping qualities of the HTS. A stationary cold stage held fixed on an optical table was used to cool the HTS immersed in liquid nitrogen (T=77 K). The HTS material used in the measurements has dimensions of 8.89 mm thickness and 38.26 mm diameter. All measurements were conducted under field cooled conditions (FC), which implies a trapped field. Force and stiffness data were taken for both radial and axial directions on the thrust bearing configuration.

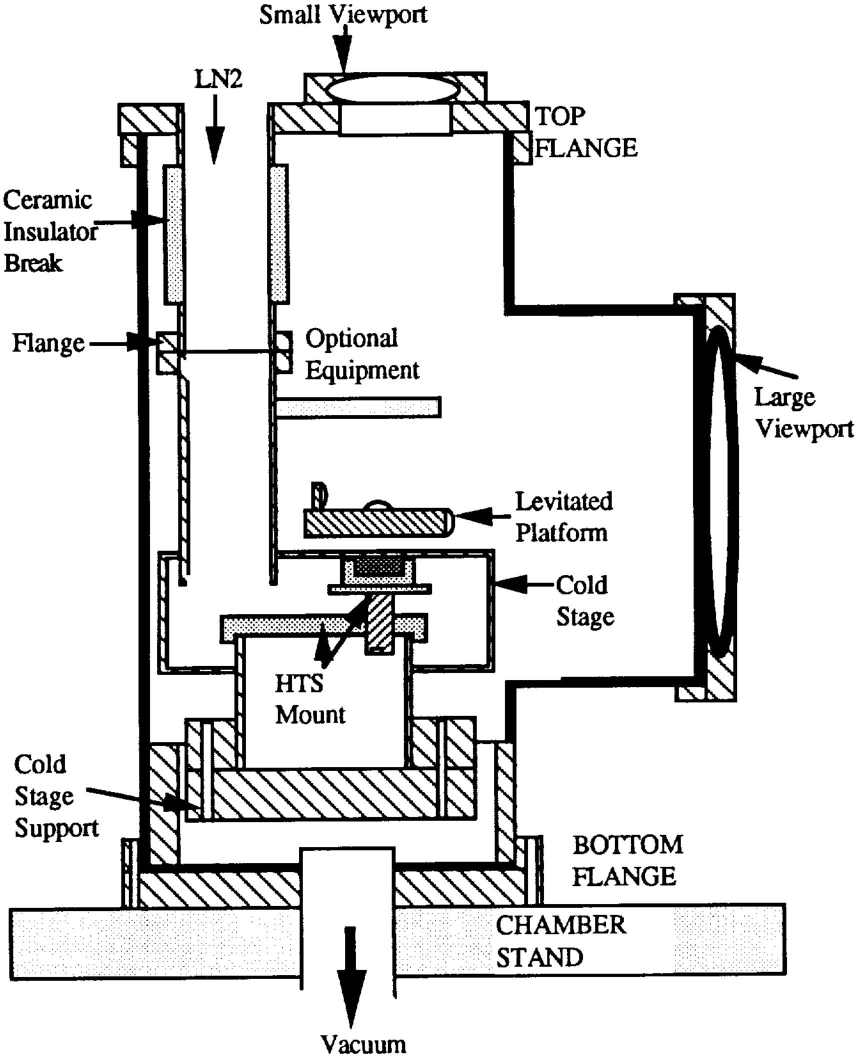

Figure 2: Line drawing of the levitated vibration-damped platform inside high vacuum chamber.

A vibration-damping platform (Figure 2) was made of an array of permanent magnets field cooled over an HTS disk inside a vacuum chamber. Spherical mirrors, a laser and a two dimensional displacement sensor were used to obtain non-contact vibration characteristics of the levitated stage. In the center of the stage is a magnet which lifts the extra weight while the HTS stabilizes and damps out the vibration.

## RESULTS

Figure 3 is a plot of radial force hysteresis for small to large displacements when the YBCO disk is in the FC state. In the FC case the radial magnetic stiffness was observed to be slightly amplitude dependent. However, the hysteresis area would increase as a function of changing amplitude because of the flux motion inside the superconductor. This flux motion exhibits an

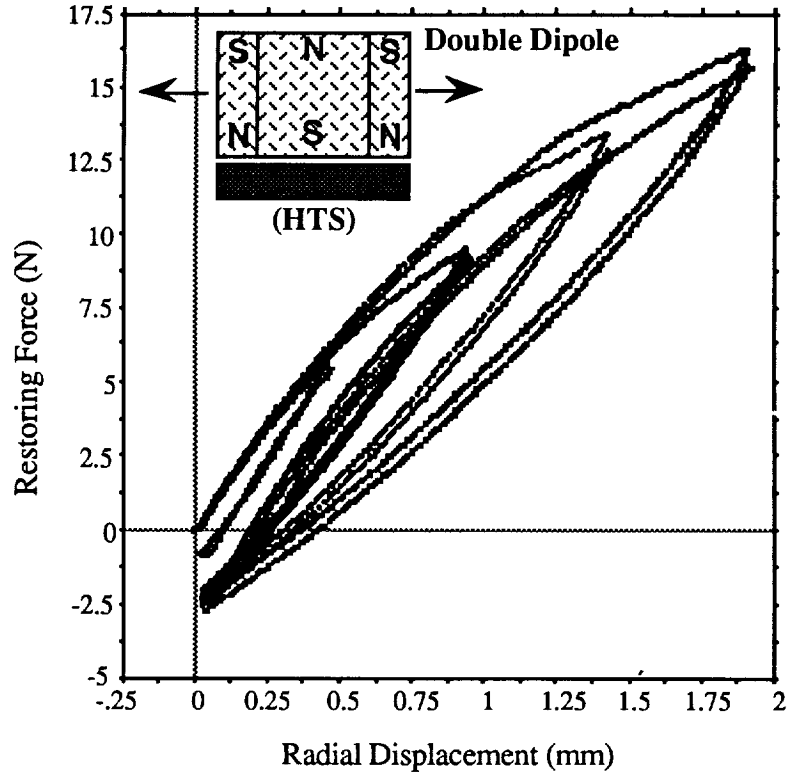

Figure 3: Radial force hysteresis over changing amplitudes. Note the larger area for larger displacements is attributed to flux motion (flux depinning) in the superconductor.

energy loss which in turn acts as a damper when low frequency vibration occurs. In table 1, the radial magnetic stiffnesses are compared between the single dipole and the double dipole under these same conditions. Also shown in table 1 is a comparison of the effects of superconducting grain size on stiffness when the HTS is measured on both faces of a bulk YBCO sample. The superconductor measured was produced by a seeded and melt-textured process that produced samples having a grain size of approximately 1.32 in.$^2$ through the length. In figure 4, the vibration characteristics for the double dipole configuration are shown in comparison with the free beam vibration.

| Sample | Double Dipole Rad. N/mm | Single Dipole Rad. N/mm | Double Dipole Axl. N/mm | Single Dipole Axl. N/mm |
|---|---|---|---|---|
| YSM88top | 7.6452 | 3.4441 | 15.9338 | 13.2320 |
| YSM88bottom | 8.5235 | 3.2300 | 20.5569 | 16.3550 |
| YSM57 | 6.4125 | 2.1153 | 16.9015 | 11.5855 |

Table 1: Magnetic stiffnesses of different HTS samples compared to single and double dipoles.

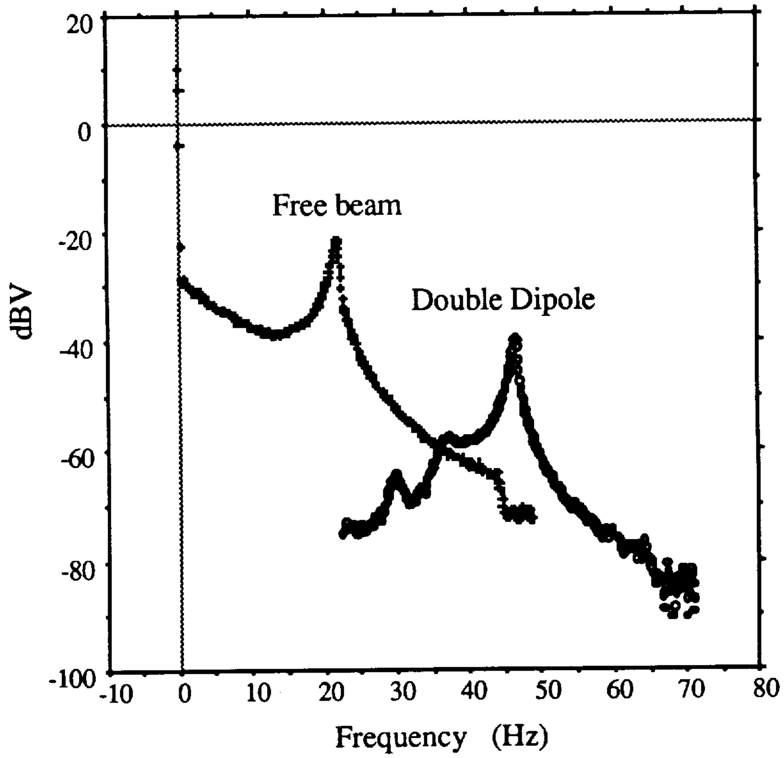

Figure 4: Vibration spectrum of a double dipole field cooled over a HTS compared to nonsuperconducting state.

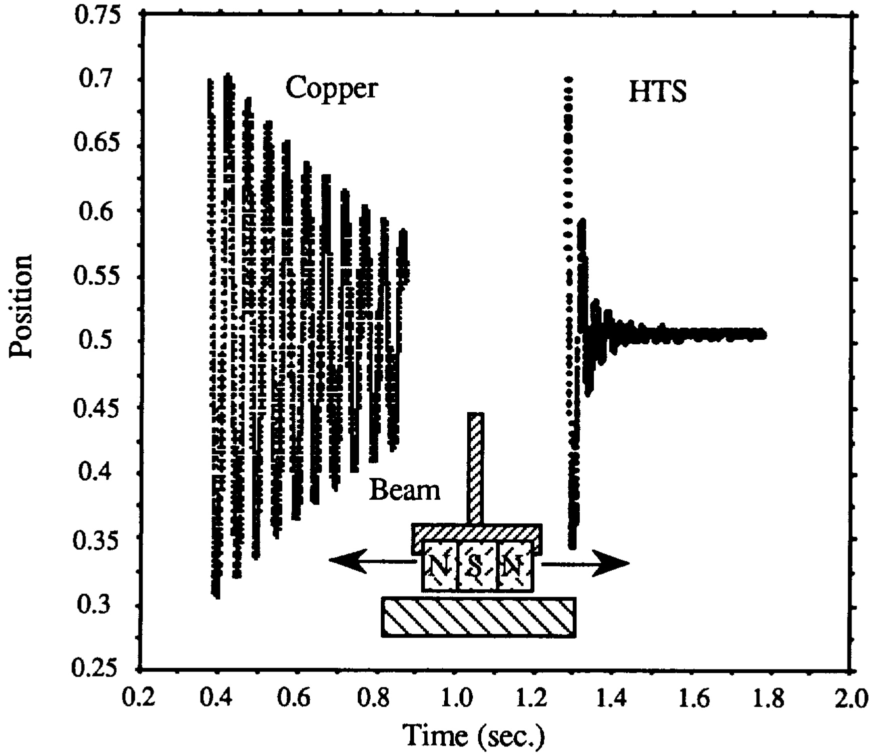

Figure 5: Vibration damping comparison between copper and HTS; the HTS damped the same impulse amplitude in 0.15 sec. compared to > 5.0 sec for the copper.

Figure 5 demonstrates the difference between copper and HTS damping by a multipole array of magnets attached to a vibrating beam. Using the frictionless behavior of magnets and HTS, it is possible to construct a totally decoupled system instead of a spring damper demonstrated here in this system.

## CONCLUSION

It is apparent that the HSMB allows the ability and improvement in superconducting bearings. The HSMB design appears to be a good candidate for the flywheel energy storage device. Furthermore, the double dipole demonstrated higher stiffnesses in both the axial and radial directions above that of the conventional single dipole over HTS, due to its increased magnetic field gradient. The superconductor also has proven to be a good damper against unwanted low frequency vibration.

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