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**DESCRIPTION of the LARGE-GAP MAGNETIC SUSPENSION SYSTEM (LGMSS)
GROUND BASED EXPERIMENT**

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INTRODUCTION

The purpose of this paper is to provide an overview of the Large Gap Magnetic Suspension System (LGMSS) ground-based experiment. An outline of the paper is presented in figure 1. A description of the experiment, as originally defined, and the experiment objectives and potential applications of the technology resulting from the experiment will be presented. Also, the results of two studies which were conducted to investigate the feasibility of implementing the experiment will be presented and discussed. Finally, a description of the configuration which was selected for the experiment will be described and a summary of the paper presented.

PRESENTATION OUTLINE

- **Experiment Description**
- **Objectives**
- **Applications**
- **Feasibility Studies**
- **Selected Concept**
- **Summary**

EXPERIMENT DESCRIPTION

The LGMSS ground-based experiment, as originally defined, is shown schematically in figure 2. It consists of a cylindrical suspended element which has a core composed of permanent magnet material embedded in it. Levitation forces and control forces and torques are produced on the permanent magnet core by air core electromagnets which are required to fit within an eight foot by eight foot square by four foot high volume. The core is suspended a total distance of three feet above the top surface of the electromagnet volume. In addition to the permanent magnet core, the suspended element also contains an array of LEDs and associated electronics and power supply. The LEDs are embedded in the surface of the suspended element and provide active targets for a photogrammetric optical position measurement system which is being developed at Langley Research Center (ref. 1). Each LED target is imaged by a cylindrical lens on a linear Charge Coupled Device (CCD) sensor. Position and orientation of the model is determined from the position of the projected target images. There are two sensors per sensing unit and a total of eight sensing units which are positioned symmetrically about and approximately six feet above the suspended element. The optical position measurement system provides six-degrees-of-freedom position information for the control system.

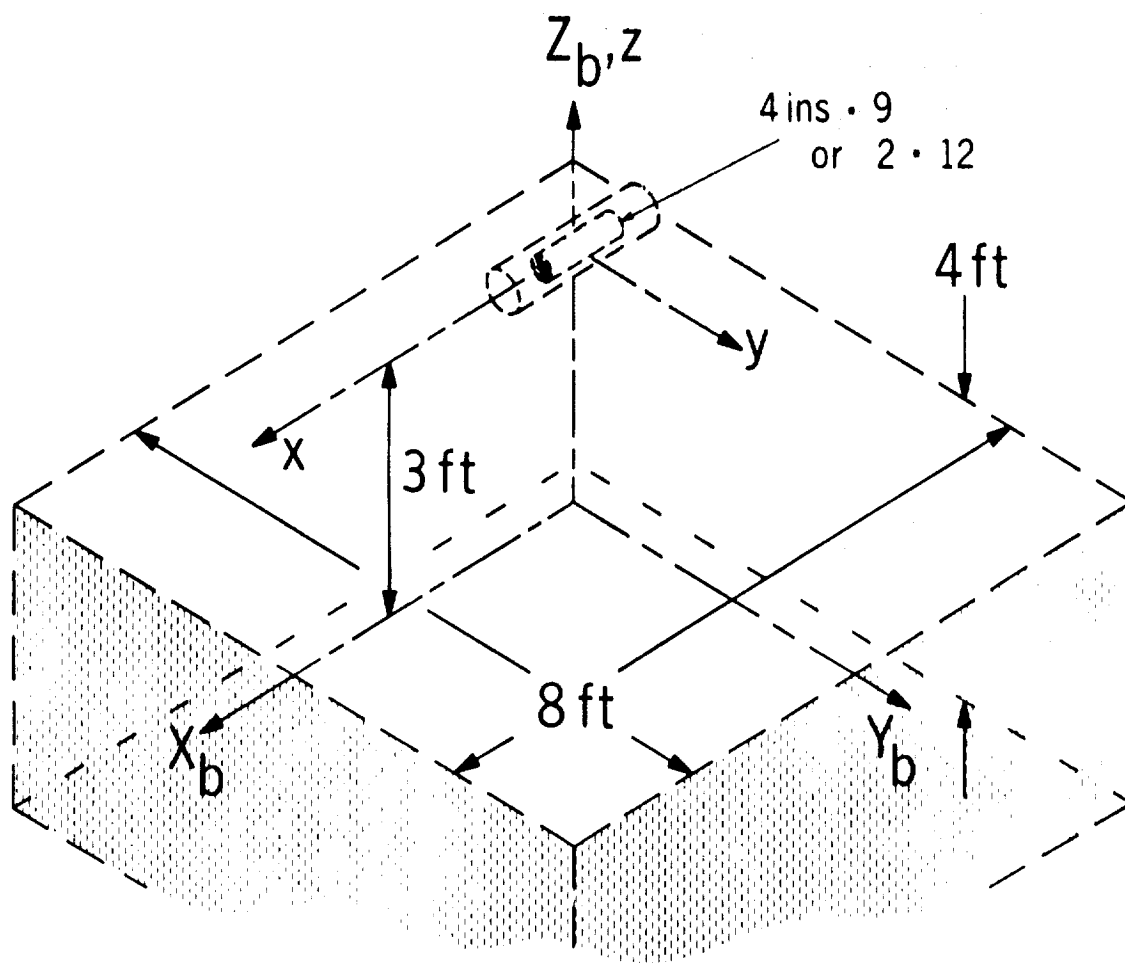


Figure 2. - Experiment Definition

EXPERIMENT OBJECTIVES

The objectives of the LGMSS ground-based experiment are to investigate the technology issues associated with magnetic suspension, accurate suspended element control, and accurate position sensing at large gaps and suspended element control over large angles (fig. 3).

OBJECTIVES

- **Investigate Technology Issues Associated with:**
 - **Magnetic Suspension at Large Gaps**
 - **Accurate Position Sensing at Large Gaps**
 - **Accurate Suspended Element Control at Large Gaps**
 - **Suspended Element Control Over Large Angles**

TECHNOLOGY APPLICATIONS

The technology which should result from the LGMSS experiment has potential applications in a wide range of areas including microgravity and vibration isolation systems, magnetically suspended pointing mounts, large-angle magnetic suspension systems for advanced actuators, wind tunnel magnetic suspension systems, and remote manipulation/control/positioning of objects in space (fig.4).

APPLICATIONS

- **Potential Applications of Technology Include:**
 - **Microgravity and Vibration Isolation Systems**
 - **Magnetically Suspended Pointing Mounts**
 - **Large-Angle Magnetic Suspension Systems for Advanced Actuators**
 - **Wind Tunnel Magnetic Suspension Systems**
 - **Remote Manipulation/Control/Positioning of Objects in Space**

FEASIBILITY STUDIES

After defining the LGMSS experiment, two studies were performed to verify the feasibility of building a system to meet the experiment requirements and to investigate approaches to implement it. One study was performed by Madison Magnetics, Inc. and resulted in a proposed configuration of five electromagnets mounted in a planar array (ref. 2). This approach was designated the five-coil approach. The other study was performed by SatCon Technology Corporation and resulted in a proposed configuration of six electromagnets mounted in a planar array. This approach was designated the six-coil approach.

Five-coil system.- A summary of the Madison Magnetics study is presented in figure 5. An important conclusion was that the implementation of the LGMSS experiment was feasible. The proposed implementation is shown schematically in figure 6 and consists of a planar array of five electromagnets mounted in a circular configuration. Since the LGMSS requirement is for five-degrees-of-freedom control, this represents the minimum number of actuators. The electromagnets are conventional liquid-helium cooled superconductors and combine the functions of levitation and control. The magnetization vector is horizontal (parallel to the long axis of the core) and the system is capable of providing 360 degrees yaw (rotation about the vertical axis) control.

FEASIBILITY STUDIES

- **Five-Coil System (Summary)**
 - **Feasible**
 - **Minimum Configuration**
 - **360 Degree Yaw Control**
 - **Horizontal Magnetization Vector (Parallel to Long Axis of Core)**
 - **Combined Superconducting Levitation and Control Coils**

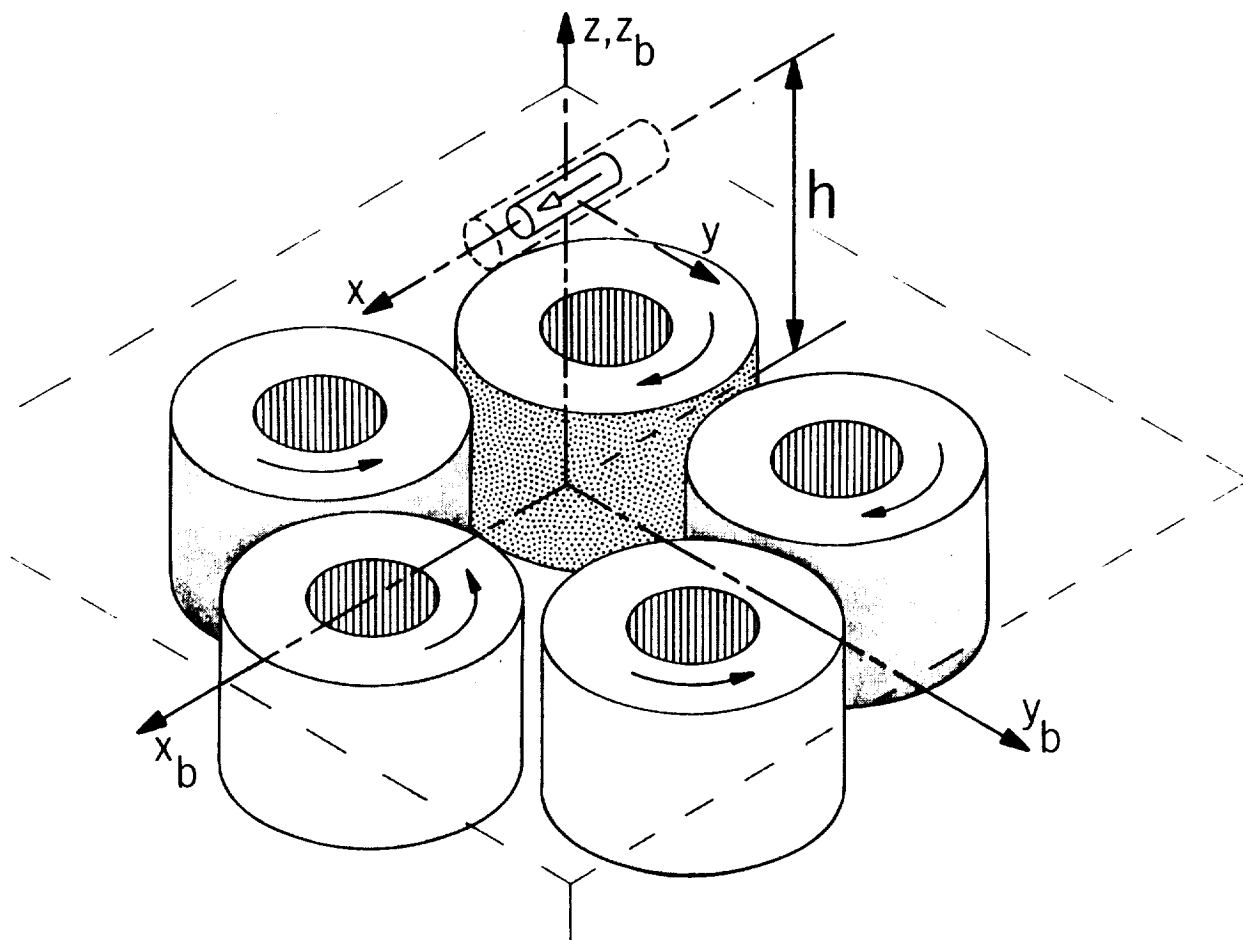


Figure 6. - Schematic Representation of Five-Coil System

FEASIBILITY STUDIES (Cont.)

Six-coil system.- A summary of the SatCon study is presented in figure 7.

SatCon also concluded that it was feasible to implement the LGMSS experiment. Their proposed approach is shown in figure 8 and consists of a planar array of six electromagnets mounted in a circular configuration. The two approaches are similar with the major differences being in the control approach and the number of coils. The six-coil configuration also uses electromagnets which are conventional liquid-helium cooled superconductors and which combine the functions of levitation and control. The magnetization vector is horizontal (parallel to the long axis of the core) and the system is capable of providing 360 degrees yaw control. The main reasons for adding a sixth coil were control system related. The six coil system results in a symmetrical configuration and also results in an overspecified system from the standpoint of control inputs. The sixth coil could be fitted in the allowable volume without a significant increase in total Ampere-turns.

FEASIBILITY STUDIES (CONTINUED)

- **Six-Coil System (Summary)**
 - **Feasible**
 - **Symmetric Configuration**
 - **Overspecified (Control Inputs)**
 - **360 Degree Yaw Control**
 - **Horizontal Magnetization Vector (Parallel to Long Axis of Core)**
 - **Combined Superconducting Levitation and Control Coils**

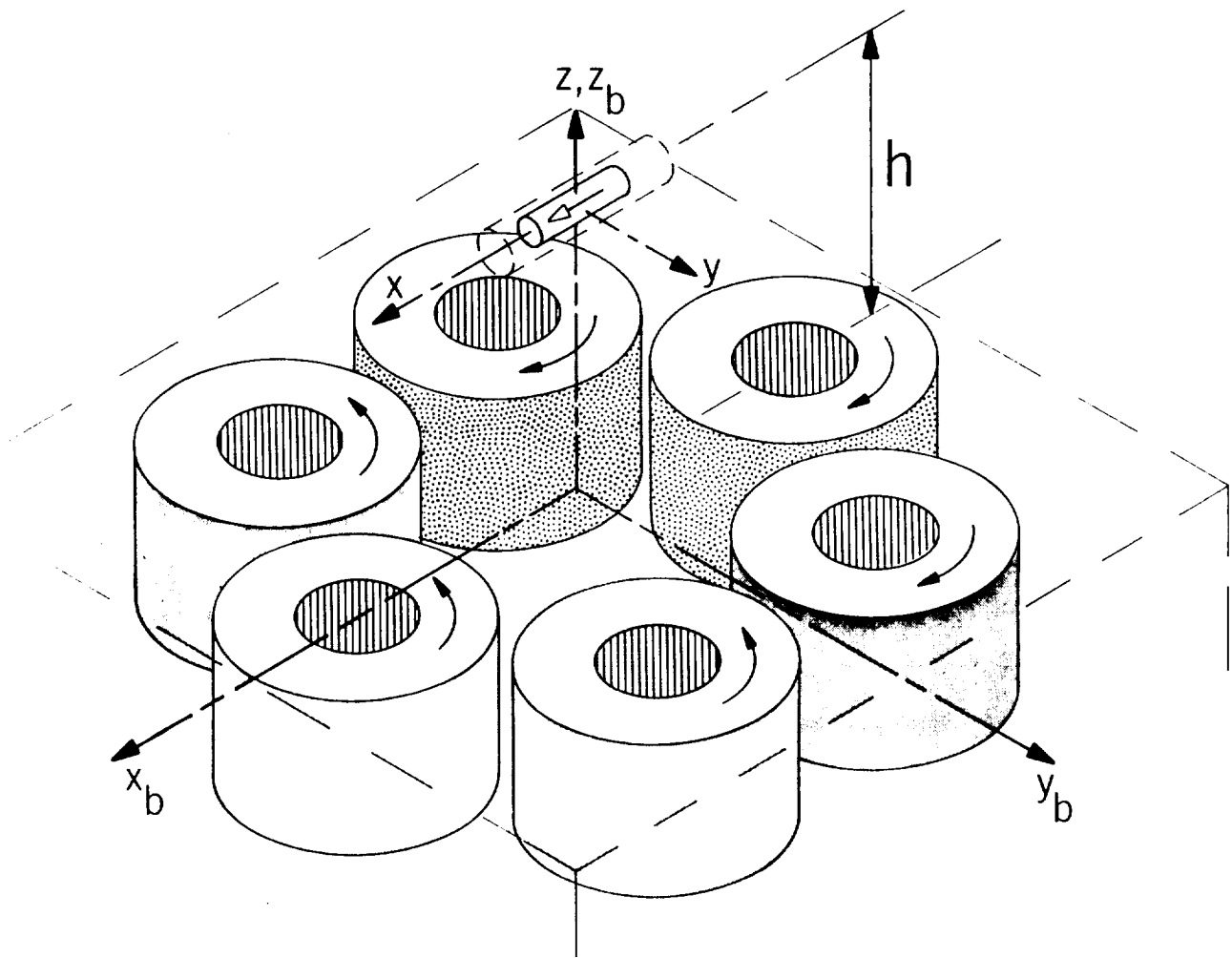


Figure 8. - Schematic Representation of Six-Coil System

SELECTED CONFIGURATION

As a result of the feasibility studies and further in-house studies, the requirements for the LGMSS experiment were refined and a decision was made to procure the design, fabrication, installation, and test of an LGMSS. A competitive procurement effort resulted in the selection of a configuration proposed by Intermagnetics General Corporation. This configuration is shown schematically in figure 9. As shown in the figure, there are two large concentric levitation coils and a separate set of control coils. The levitation coils are superconducting coils which are operated in the persistent mode. In the persistent mode, a superconducting coil is charged up to a certain current value and the terminals are shorted through a persistent mode switch. Since the superconductor has zero resistance, the current continues to flow, or persist, in the coil. In the configuration shown, the coils have currents flowing in opposite directions. The control coils are shown in a generic configuration since the contract is in the design phase and a final configuration has not been selected. The control coils are conventional room temperature coils.

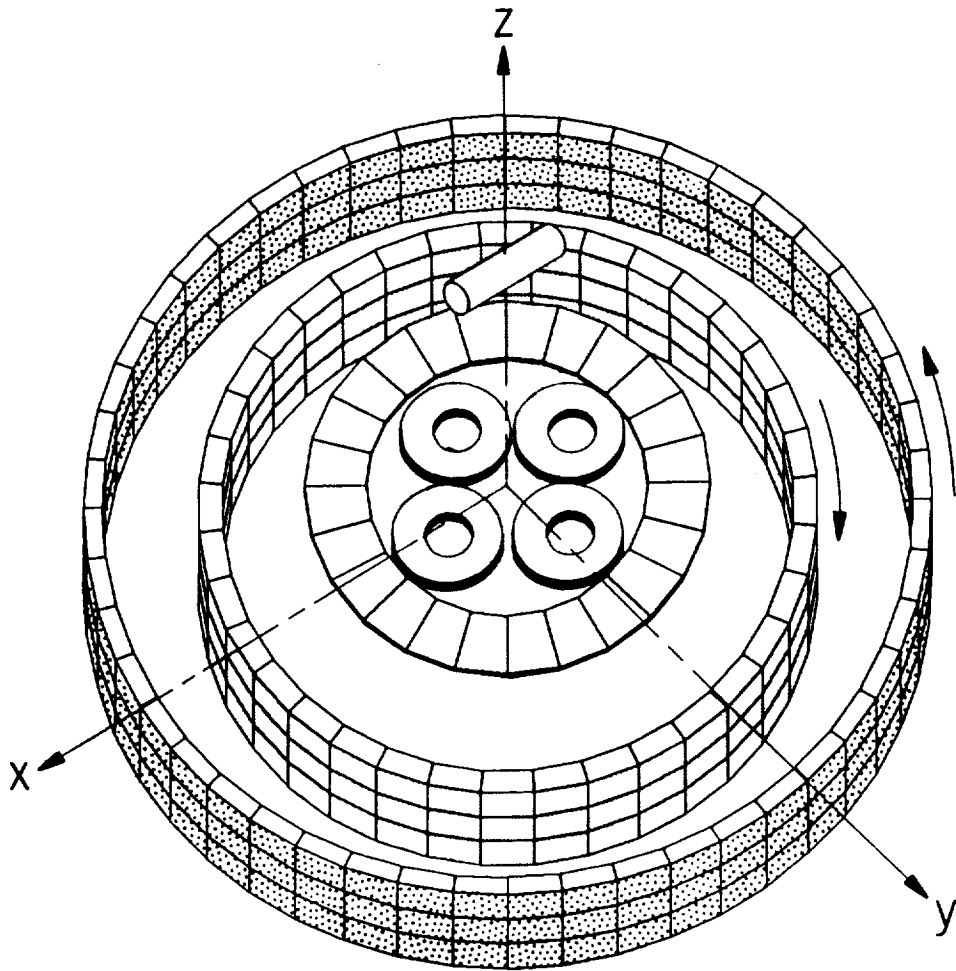


Figure 9. - Schematic Representation of Selected Configuration

SELECTED CONFIGURATION (Cont.)

Figure 10 shows the levitation coils and permanent magnet core in more detail. As shown in the figure, the magnetization vector of the core is vertical (perpendicular to the long axis). By adjusting the persistent-mode currents to the correct values, a vertical field and gradient can be produced at the location of the core which will produce a stable levitation force and also a stable torque about the roll and pitch axes. Required control forces and torques are provided by the separate control coils. Yaw torque in this configuration is provided by producing a second-order gradient (gradient of a gradient) along the long axis of the core in the x-y plane. It should be noted that this configuration has the potential for providing active roll control.

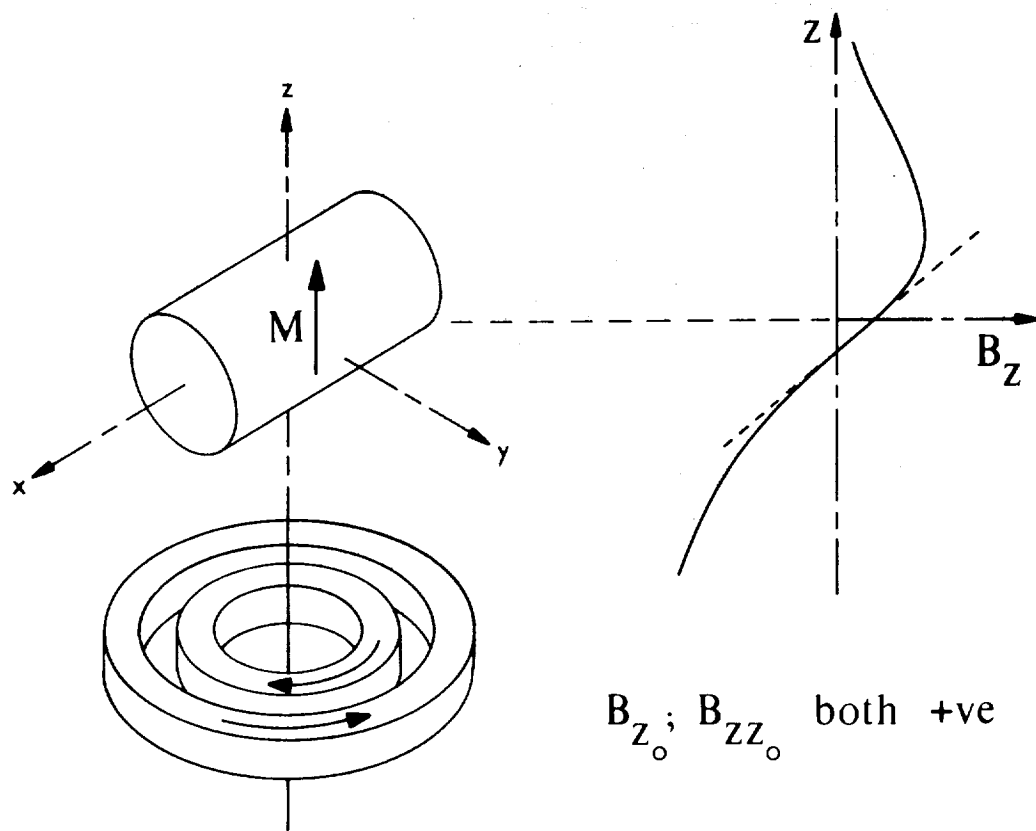


Figure 10. - Levitation Approach For Selected Configuration

SUMMARY

In summary (fig. 11), an LGMSS ground-based experiment has been defined and two studies performed to investigate the feasibility of implementing the experiment. Both studies concluded that implementation was feasible and a decision was made to procure the design, fabrication, installation, and test of an LGMSS. A competitive procurement effort resulted in the selection of a configuration proposed by Intermagnetics General Corporation. The configuration utilizes a permanent magnet core with a vertical magnetization vector (perpendicular to the long axis of the core), superconducting levitation coils and room temperature control coils, and has the potential for six-degrees-of-freedom control.

SUMMARY

- **Configuration for LGMSS Ground-Based Experiment Selected**
 - **Vertical Magnetization Vector (Perpendicular to Long Axis of Core)**
 - **Superconducting Levitation Coils and Room Temperature Control Coils**
 - **Potential for Six-Degrees-of-Freedom Control**
- **Design Phase Complete by End of 1990**
- **System Delivery and Acceptance by End of 1991**

REFERENCES

1. Welch, Sharon S; and Clemmons, James I., Jr.: The Optical Position Measurement System for a Large Gap Magnetic Suspension System (LGMSS). Presented at the Aerospace Applications of Magnetic Suspension Technology Workshop, NASA Langley Research Center, Hampton, VA, September 25-27, 1990.
2. Boom, R.W.; Abdelsalam, M.K.; Eyssa, Y.M.; and McIntosh, G.E.: Repulsive Force Support System Feasibility Study. NASA CR-178400, October 1987.