AD-A160 641   DEVELOPMENT OF ELECTRONIC CONTROL OF A SUPERCONDUCTING GRAVITY GRADIOMETER(U) MARYLAND UNIV COLLEGE PARK DEPT OF PHYSICS AND ASTRONOMY   H J PAIK ET AL. SEP 85   1/1

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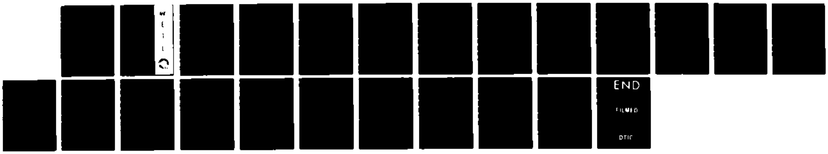

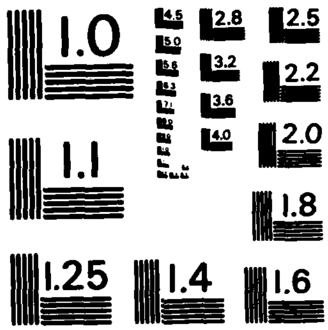

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AD-A160 641

Development of electronic control of a superconducting gravity gradiometer

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September 1985

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Another report generated under the same contract is ETL–0398, Electronic Feedback Control of Mass-Spring Systems, by Qin Kong.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Feedback control network	SQUID
Gravity gradiometer	Superconductivity
Magnetic switch	Three-axis gradiometer
Shielded transformer	Vacuum oven
Spring-mass system	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report discusses the development of a three-axis superconducting gravity gradiometer and a six-axis superconducting accelerometer for geological and navigational applications.

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PREFACE

This document was generated under contract DACA72–84–C–0004 for the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, by the Department of Physics and Astronomy, University of Maryland, College Park, Maryland. The Contracting Officer's Technical Representative was Dr. Hans G. Baussus Von Luetzow.

The work done under this contract is documented in three progress reports and a final report.

CONTENTS

PROGRESS REPORT

DEVELOPMENT OF A SENSITIVE SUPERCONDUCTING GRAVITY GRADIOMETER FOR GEOLOGICAL AND NAVIGATIONAL APPLICATIONS

NASA Contract NAS8-33822

Army/Corps of Engineers DACA 72-84-C-0004

Principal Investigators: H. J. Paik and J.-P. Richard

August 1, 1984 to October 31, 1984

Status Summary

Army/Corps of Engineers:

1. The passive vibration isolation system for the gradiometer has been redesigned and tested.

2. Progress has been made on the cold damping feedback network.

NASA:

3. A vacuum system for the high temperature heat treatment process required for parts of the three-axis gradiometer has been designed.

4. Work is continuing on the three-axis gradiometer.

5. Tests on the magnetic superconducting switch are nearing completion.

Activities and Results

1. Vibration isolation:

Past test results indicate that the noise level of the single-axis gradiometer is a result of angular motion noise. For this reason we have redesigned the passive vibration isolation system to increase the rigidity to angular motion. In the past quarter, this system was tested and appears to be performing as intended. The first tests of the three-axis gradiometer will be made using this isolation system in addition to active isolation.

2. Cold damping:

Electronic cold damping of the gradiometer's resonant peak to prevent overloading of the SQUID electronics has been tested. In this case the feedback signal is applied to the modulation coil of the SQUID sensor, whereas in previous tests the feedback signal was applied to the gradiometer platform. An attenuation of 40 dB was achieved using this method.

3. Vacuum oven:

The vacuum system used to house the high temperature heat treatment facility is no longer available. Consequently, a dedicated vacuum system with a water cooled vacuum chamber is being designed. The system will use a number of surplus parts (diffusion pump, roughing pump, water cooled baffle, etc.) to reduce costs. The primary design criteria are a temperature of 1800° c with a vacuum of 10^{-7} torr.

4. Three-axis gradiometer:

In order to avoid further delay in the assembly of the three-axis gradiometer, the necessary parts will be subjected to an initial heat treatment at an outside location. We plan to have all parts completed by January 1985.

5. Magnetic superconducting switch:

Though vanadium appears to have the necessary properties for the magnetic superconducting switch (low critical field and a critical current greater than 10 A), making a high current junction between vanadium and niobium is difficult. However, by placing a number of vanadium-niobium joints in parallel, sufficient critical currents can, apparently, be obtained.

6. Travel:

Dr. M. V. Moody attended the 17th International Conference on Low Temperature Physics at Karlsruhe, West Germany and presented two papers. Also, Dr. H. J. Paik and Dr. H. A. Chan presented a paper at the Applied Superconductivity Conference in San Diego.

Plans for Next Period

1. Completion of parts for the three-axis gradiometer.

2. Assemble a high temperature vacuum oven.

3. Completion of a preliminary design for the magnetic superconducting switch.

PROGRESS REPORT

DEVELOPMENT OF A SENSITIVE SUPERCONDUCTING GRAVITY GRADIOMETER

FOR GEOLOGICAL AND NAVIGATIONAL APPLICATIONS

NASA Contract NAS8-33822

Army Corps of Engineers DACA 72-84-C-0004

Principal Investigators: H. J. Paik and J.-P. Richard

November 1, 1984 to January 31, 1985

Status Summary

Army Corps of Engineers:

1. Tests of a force rebalance feedback system have been performed.

NASA:

2. Heat treatment of the proof mass suspension springs has been done at Stanford University.

3. The new superconducting circuit to be used in the three-axis gradiometer has been analyzed.

4. Tests are being performed on a transformer designed to isolate the SQUID sensors for RF interference.

5. Most of the components for the vacuum oven have been obtained

6. A number of new SQUID systems have been tested at 2.1 K.

Activities and Results

1. Force rebalance:

Tests of a force rebalance feedback system have been done at room temperature. In these tests the resonant frequency of a spring-mass system was increased from 7 Hz to 60 Hz. A similar system will be incorporated into the new gradiometer design to increase the dynamic range and the linearity of the instrument.

2. Proof mass suspension springs:

The niobium springs for the proof mass suspension have been thinned by electrode EDM to 0.010" thickness. The springs were then sent to Stanford University where they were annealed at 1340°C for three hours in a vacuum oven. Due to a temperature control problem, three of the springs were damaged. The remaining units are being cut by wire EDM to form the folded cantilever suspensions.

3. Analysis of the three-axis gradiometer circuit:

The new circuit to be used in the three-axis gradiometer has been analyzed for common mode balance, signal detection, and temperature sensitivity. The analytical results for common mode balance and signal detection are similar to those of the prototype gradiometer. The temperature sensitivity is partially cancelled out in the balancing procedure for common mode acceleration. The remaining sensitivity to temperature can be passively balanced out by incorporating an additional coil into the circuit.

4. Shielded superconducting transformer:

A superconducting transformer in which the primary is isolated from the secondary by a thin layer of copper (or other normal metal) is being tested. The purpose of the copper is to eliminate effectively the coupling at high frequencies and, thus, shield the SQUID input from RF interference. Preliminary results look promising.

5. Vacuum oven:

The water cooled container for the high temperature vacuum oven has been completed. A delay in the shipping of some of the components has postponed the assembly of this system until next quarter.

6. New SQUID systems:

A number of new SQUID systems were ordered with the specification that they be operated at 2 K; however, since the manufacturer does not have the facilities to test the systems at this temperature, the tests must be performed in our laboratory. Out of four SQUIDs tested at 2 K, none performed satisfactorily. Consequently, we are exchanging these SQUIDs and, temporarily, giving up on the idea of operating the SQUIDs at 2 K.

Plans for Next Period

1. Continue the investigations of active feedback.
2. Begin assembly of the new gradiometer.
3. Assemble the vacuum oven.
4. Continue test on the shielded transformer.

PROGRESS REPORT

DEVELOPMENT OF A THREE-AXIS SUPERCONDUCTING GRAVITY GRADIOMETER

AND A SIX-AXIS SUPERCONDUCTING ACCELEROMETER

NASA Contract NAS8-33822
Army Contract DACA 72-84-C-0004
Air Force Contract F19628-85-K-0042

for the period of

February 1, 1985 to April 30, 1985

Principal Investigator: H. J. Paik

Department of Physics and Astronomy
University of Maryland, College Park, Maryland

NASA: THREE-AXIS GRAVITY GRADIOMETER

STATUS SUMMARY

1. Work is continuing on the fabrication of the three-axis gradiometer.
2. Substantial progress has been made on the error analysis of the three-axis system.
3. Appropriate step is taken to incorporate the negative spring to the present design.

ACTIVITIES AND RESULTS

1. Three-axis gradiometer:

   Fabrication of the components for the three-axis gradiometer is continuing. The proof mass suspension springs have been heat-treated at Stanford University and are presently being cut by wire EDM, which is the final step in fabrication. These springs should be delivered in mid-May. The accelerometer housings have been returned to EBS Machining for the final precision cut. The primary task at this point is to wind the numerous multilayer coils necessary for the superconducting circuitry. A new more efficient method of winding double layer pancake coils has been developed.

2. Analysis of gradiometer errors and dynamics:

   A complete error analysis for the three-axis gravity gradiometer is being done. Beginning with the general expression for a platform moving with respect to an inertial reference frame, the fundamental error sources for a gravity gradiometer are being completely analyzed. A more rigorous analysis of the new detection circuit for the three-axis gradiometer has been made. As a result of this analysis, an optimal configuration of the sensing, levitation and feedback coils has emerged.

3. Modification of the Three-Axis Gradiometer:

The thorough system analysis undertaken during this quarter suggested desirability of incorporating the superconducting negative spring into the three-axis gradiometer at this time rather than at a later stage, as originally proposed. It has been found that the negative spring not only improves the gradient sensitivity but also enables a wideband common mode balance by precision relative tuning of the resonance frequencies of the two component accelerometers along each axis. Additional machining and fabrication required for this change is expected to delay the project by about six months. In the long run, however, it will save money and speed up the progress toward testing the final flight model by at least a year by eliminating another phase of constructing and testing an improved prototype at a later stage.

4. Meetings:

Professor Paik has given presentations on the three-axis gravity gradiometer and the six-axis accelerometer at the Annual Gravity Gradiometer Conference held at the Air Force Academy, Colorado Springs, Colorado on February 12, 1985, and at the Pacific Coast Gravity Meeting, Caltech, Pasadena, California on March 2, 1985.

PLANS FOR NEXT PERIOD

1. Wind the double layer pancake coils and various superconducting transformers.
2. Modify niobium proof masses and machine coil forms for the negative springs.
3. Complete the error analysis.

ARMY: ELECTRONIC CONTROL OF THE GRADIOMETER

STATUS SUMMARY

1. Work has been done on the analysis of the feedback network for the three-axis gradiometer.
2. Components necessary for the feedback on the three-axis gradiometer are being designed and tested.

ACTIVITIES AND RESULTS

1. Feedback network analysis:

   Analysis of the feedback network of the three-axis gradiometer has indicated that this network can introduce excessive coupling between the common mode and differential mode signals. In order to reduce this coupling, the addition of dedicated feedback coils into the circuitry is necessary. These additional coils have made it necessary to develop techniques for winding multilayer coils.

2. Design and test of feedback components:

   In addition to the multilayer coils, special transformers are being designed to be used in the feedback network. These transformers are made primarily of superconducting materials with the primary and secondary separated by a normal conductor. The superconductors permit coupling down to dc, whereas the normal metal isolates the secondary from high frequency noise in the room temperature feedback electronics. A preliminary design has a cut-off frequency of approximately 250 Hz with a 3 dB roll-off.

PLANS FOR NEXT PERIOD

1. Continue the work on active feedback.

AIR FORCE: SIX-AXIS ACCELEROMETER

STATUS SUMMARY

1. Components for the six-axis accelerometer are being machined.
2. A six-axis shaker is being designed.

ACTIVITIES AND RESULTS

1. Six-axis accelerometer:

   The components for the six-axis accelerometer are being machined at a fully automated commercial machine shop with the exception of the proof mass. The fabrication of the proof mass requires more development effort and has therefore been kept for inhouse machining. The niobium pieces that will be assembled into the single proof mass have been rough machined and stress relieved. A defect in the material has been found, however, in the form of porosity which could trap magnetic flux and cause excessive damping in the accelerometer circuit. It is planned to machine a new proof mass out of a different stock of niobium.

2. Six-axis shaker:

   A further study of the method of calibration for the six-axis accelerometer has identified a need to have a rather sophisticated shaker which can apply known accelerations to the accelerometer in the six degrees of freedom independently. In order to avoid undesirable mixing of signals, the orthogonality and symmetry are important in the shaker. A precision six-axis shaker, which can shake the integrated assembly of the six-axis accelerometer and the three-axis gradiometer, is being designed. The incorporation of the shaker into the test apparatus requires a cryostat and a cryostat insert of an increased diameter. The additional budget required to manufacture the shaker and to obtain a larger cryostat and insert will be submitted to the funding agency as soon as reliable cost estimates are available.

PLANS FOR NEXT PERIOD

1. Complete the fabrication of the mechanical components for the accelerometer.
2. Complete the design of the six-axis shaker and the cryostat insert.

FINAL TECHNICAL REPORT

DEVELOPMENT OF ELECTRONIC CONTROL OF SUPERCONDUCTING GRAVITY GRADIOMETER

U.S. Army Contract DACA 72-84-C-0004

for the period of June 20, 1984 - April 20, 1985

Principal Investigator: Ho Jung Paik

Department of Physics and Astronomy

University of Maryland, College Park, MD 20742

A superconducting gravity gradiometer employs mass-spring systems to convert gravity signals into mechanical displacements, which modulate persistent currents in a superconducting circuit. The resulting magnetic field is then detected with a low-noise current-to-voltage converter called SQUID (Superconducting QUantum Interference Device). The low dissipation coefficient in the superconducting transducer, which is responsible for low Brownian motion noise, accompanies with undesirable high Q resonance peaks. The amplification of the ground seismic noise at the resonance frequencies of the gradiometer can then severely limit the dynamic range of the system.

The research goal in the ten month period of this contract was to approach the problem in two directions. 1) Isolate the gradiometer platform from the seismic motions of the ground, and 2) Apply "cold damping" to high Q suspension modes of the gradiometer proof masses. Passive spring-mass vibration filters are not practical to build at the low signal frequencies (<1Hz) and passive damping would increase the Brownian motion noise. Therefore, we had to develop active feedback techniques for both of these approaches.

A new wideband superspring concept, which circumvents practical difficulties arising from an extra mode introduced by the sensing accelerometer in the usual superspring scheme, has been suggested by Dr. H. A. Chan of our research team. In the new scheme, the displacement of the platform is measured relative to the ground to avoid the need of an accelerometer and thus a wideband vibration isolation is accomplished. We have analyzed this system and demonstrated the wideband superspring.

We have also analyzed the feedback control network for active damping of the gradiometer and developed special active narrowband filter. The SQUID output is bandpass filtered around a particular resonant mode and integrated to obtain 90^0 phase shift. The resulting signal is then fed back to the gradiometer sensing circuit with a proper polarity to actively "drive down" the resonance. Ideally, a feedback force should be applied to the proof mass through a separate transducer circuit. Since additional superconducting coils are not available in the prototype superconducting gradiometer, we had to apply the feedback current to the SQUID input or to apply a feedback force to the gradiometer platform. However, the two eigenmode frequencies (common mode and differential mode) were only 1 Hz apart in the prototype superconducting gradiometer.

The closeness of these resonances introduced undesirable cross coupling of these two modes in the feedback circuit. Nevertheless, a limited but sizeable reduction in Q of 40dB was obtained by using standard filters. A coherent filter with an extremely narrow bandwidth was consequently constructed and is being tested.

The progress in the electronic control of the superconducting gravity gradiometer has been reported in the three quarterly reports (10/31/84, 1/31/85, 4/30/85). The detailed analysis, design of the apparatus and discussion of experimental results have been reported in Mr. Q. Kong's M.S. thesis titled "Electronic Feedback Control of Mass-Spring Systems." Work is continuing to improve the feedback circuits and to apply the "force rebalance" feedback as well as the above two feedbacks to the new three-axis gradiometer under construction.

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