DEVELOPMENT OF AN ELECTROMAGNETIC MICROSCOPE FOR EDDY CURRENT EVALUATION OF MATERIALS

by
Walter Podney

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To realize the advantages of SQUID technology for Air Force requirements in evaluating the integrity of airframes, SQM Technology, Inc. is developing an electromagnetic microscope that uses an array of microscopic pickup loops for imaging micro flaws in aluminium. The prototype comprises a triangular array of microscopic gradiometers that are coupled to SQUID sensors through a flexible, cryogenic umbilical, which enables convenient scanning.

Development to date shows three main accomplishments: (1) a planar azimuthal gradiometer configuration enables suppressing source interference, (2) instrument noise at drive currents of 1 A or so at frequencies below a few kilohertz is of the order of SQUID noise, and(3) a cryogenic umbilical can provide adequate cooling over a four to six foot length.

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SUMMARY

Superconductive quantum interference devices (SQUIDs) offer new technology for locating material flaws electromagnetically that promises to increase sensitivity and depth of field as well as to enhance resolution and imaging. The ultrahigh sensitivity of SQUIDs to magnetic flux allows use of microscopic pickup loops in a gradiometer configuration to give high resolution. To realize the advantages of SQUID technology for Air Force requirements in evaluating the integrity of airframes, SQM Technology, Inc. is developing an electromagnetic microscope that uses an array of microscopic pickup loops for imaging micro flaws in aluminum. The prototype comprises a triangular array of microscopic gradiometers that are coupled to SQUID sensors through a flexible, cryogenic umbilical, which enables convenient scanning.

Development to date shows three main accomplishments: (1) a planar, azimuthal gradiometer configuration enables suppressing source interference, (2) instrument noise at drive currents of 1 A or so at frequencies below a few kilohertz is of the order of SQUID noise, and (3) a cryogenic umbilical can provide adequate cooling over a four to six foot length.

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1.0 INTRODUCTION

Superconductive quantum interference devices (SQUIDs) offer new technology for locating material flaws electromagnetically that promises to increase sensitivity and depth of field as well as to enhance resolution and imaging. The ultrahigh sensitivity of SQUIDs to magnetic flux (10^{-4} flux quanta or less) allows use of microscopic pickup loops in a gradiometer configuration to give high resolution. Because their sensitivity is independent of frequency over a range from 0.1 Hz to 10 kHz, they enable using low frequencies to increase depth of field as well as operating at multiple frequencies to scan over depth. Arrays of closely spaced pickup loops can provide high scan rates and image flawed regions.

To realize the advantages of SQUID technology for Air Force requirements in evaluating the integrity of airframes, SQM Technology, Inc. is developing an electromagnetic microscope that uses an array of microscopic pickup loops for imaging micro flaws in aluminum. The prototype comprises a triangular array of microscopic gradiometers that are coupled to SQUID sensors through a flexible, cryogenic umbilical, which enables convenient scanning. A cylindrical section containing SQUID sensors at the bottom of the unit fits in the neck tube of a storage cryostat. Conductive heat transfer through the umbilical brings the pickup loops of the probe to a superconductive state about one hour or so after immersion in a bath of liquid helium. The unit is then operational.

Development to date shows three main accomplishments: (1) a planar, azimuthal gradiometer configuration enables suppressing source interference, (2) instrument noise at drive currents of 1 A or so at frequencies below a few kilohertz is of the order of SQUID noise, and (3) a cryogenic umbilical can provide adequate cooling over a four to six foot length.

2.0 INSTRUMENT DESCRIPTION

The instrument comprises three main elements: (1) sensor and probe, (2) cryogenic umbilical, and (3) detection and control electronics. Figure 1 diagrams a configuration of the probe and cryogenic umbilical that connects it to SQUID sensors immersed in a bath of liquid helium. The umbilical thermally grounds source and receiver loops in the probe to the bath. Superconductive leads threading through the umbilical couple magnetic flux from the receiver to SQUID sensors in the bath.

2.1 PROBE

Figure 2 shows an array of three coplanar source and pickup loops, spaced at apexes of an equilateral triangle, that form the probe. Each element of the array comprises a source coil encircling a receiver formed by a planar gradiometer. A pair of adjacent loops, shaped as half circles and wound in opposition, form a planar gradiometer. For perfectly circular, concentric source and receiver loops, the net flux coupled from the source to a perfectly balanced, planar gradiometer vanishes. Moreover, symmetry of the equilateral array suppresses interference between elements of the array.

2.2 CRYOGENIC UMBILICAL

The cryogenic umbilical uses copper conductor to thermally ground pickup loops to a reservoir of liquid helium, which houses the SQUID sensors. Braided copper shielding provides both a thermal radiation shield and an electromagnetic shield for NbTi leads inside the braid. A stainless steel bellows provides a flexible vacuum jacket for the copper braid.

2.3 ELECTRONICS

A sinusoidal current oscillating in the source coil drives eddy currents in test objects. Pickup loops of the gradiometer detect fluctuations in magnetic flux from the eddy currents. Residual interference coming directly from the source is suppressed by electronic feedback to the SQUID sensor.

Each element of the array operates as a balanced circuit or null detector. Electronic feedback to the SQUID sensor balances residual interference from the source and sets a null coupling between source and receiver, for azimuthally symmetric eddy currents driven by the source. A flaw perturbs azimuthal symmetry of eddy currents and so disrupts the null setting, thereby giving a signal proportional to its size.

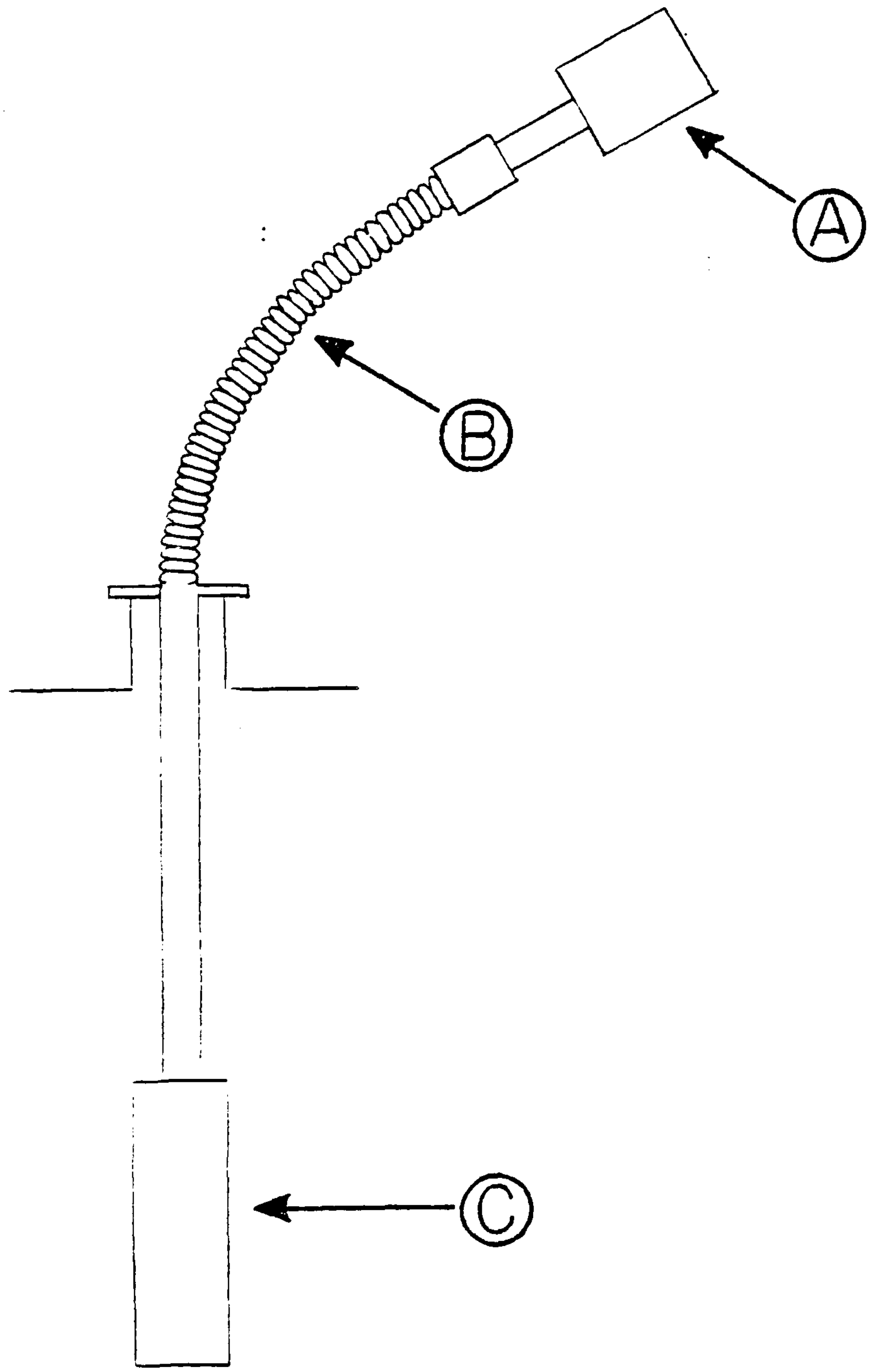

Figure 1

Diagram showing configuration of main components: (**A**) probe, (**B**) cryogenic umbilical, and (**C**) SQUID sensors .

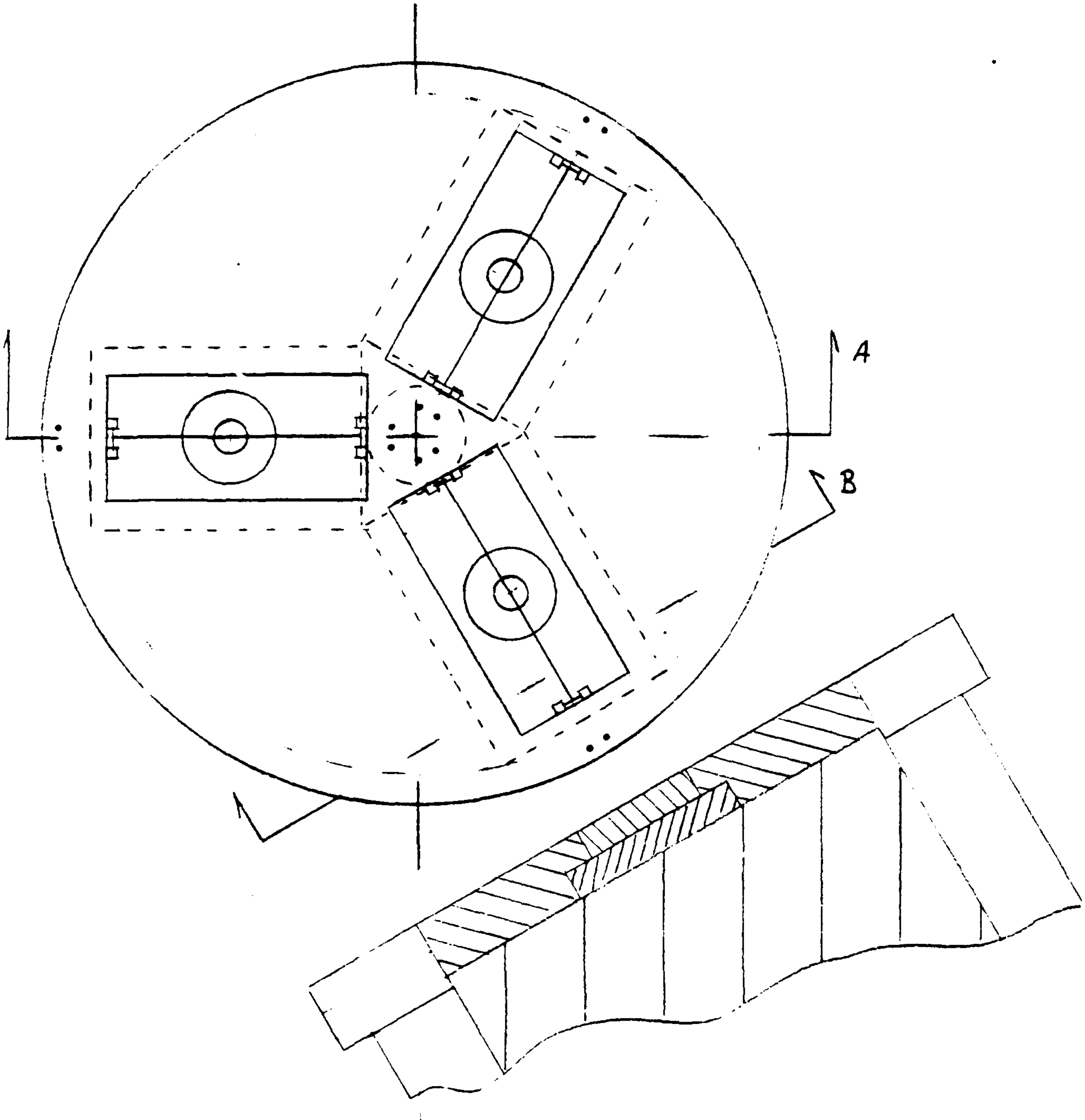

Figure 2

Array of three pairs of coplanar source and pickup loops, spaced at apexes of an equilateral triangle. Triangular symmetry of the array suppresses interference among its elements.

3.0 DEVELOPMENT PLAN

Development comprises three parallel paths that culminate in a prototype instrument. The first is development of a probe, comprising an array of three source and receiver coils coupled to SQUID sensors, housed in a remote cryostat. The second is development of a cryogenic umbilical to ground the array thermally to a reservoir of liquid helium in a remote cryostat. Third is development of electronics that drive the source, set a null, and detect perturbations of the null.

Development proceeds in stages marked by fabrication and testing of prototype elements for each path. We identify two probe elements, two umbilical elements, and three electronic elements.

3.1 PROBE DEVELOPMENT

Development of the probe comprises two stages, marked by fabrication and testing of Probes I and II.

3.1.1 Probe I

Probe I uses a single element of the array, formed by wires wound with radii expanded by a factor of four, to examine source and receiver configuration, interference from the source, and calibration constants.

Figure 3 shows the test configuration of source and receiver loops, wound on a Delrin substrate. The substrate and a SQUID sensor fit to a probe that slides in the neck of a storage dewar. The loops face upward with the SQUID sensor mounted about two inches below the substrate. A 3/8" diameter tube fits down the center of the probe. It brings test coils and material samples to the pickup loops.

3.1.2 Probe II

Probe II uses a rigid umbilical to bring source and receiver loops out of the cryostat so material samples can be tested at room temperature. It examines noise from the long leads that couple flux to the SQUID in the cryostat.

The test configuration uses a five foot length of copper tube to thermally ground a triangular array of pickup loops, patterned on a silicon substrate, to the helium bath. A thin sapphire window separates the test surface from the pickup loops 1 mm away.

3.2 UMBILICAL DEVELOPMENT

Development of the umbilical also comprises two stages, marked by fabrication and testing of Umbilical I and II.

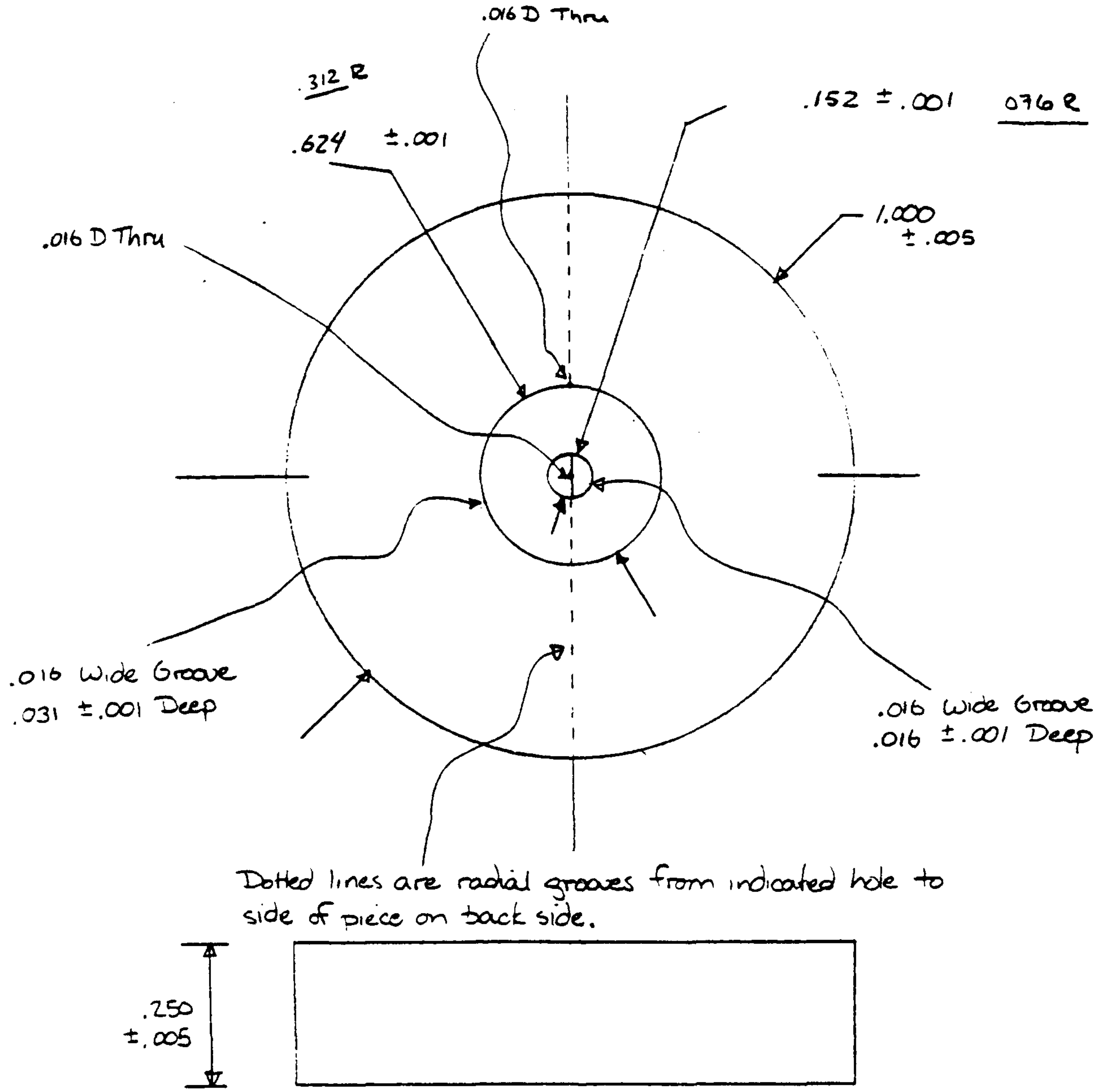

Figure 3

Test configuration of source and receiver loops wound on a Delrin substrate. Radii of source (0.312 in or about 8 mm) and receiver (0.076 in or about 2 mm) loops are four times values shown for each element of the triangular array of Figure 2. Substrate is 1 in. in diameter and 0.25 in thick. Adjacent, coplanar loops wound oppositely in the shape of half circles form a planar, azimuthal gradiometer for the receiver.

3.2.1 Umbilical I

Umbilical I examines radiation and conduction heat loads on a copper tube, 1 m or so long, with one end thermally grounded to a bath of liquid helium.

The test fixture uses a 3/4 inch diameter stainless steel tube as a vacuum jacket over copper tubes varying in diameter from 3/16 in to 5/16 in, with wall thicknesses of 1/32 in to 1/16 in. Measurement of temperature at the top of the copper tubes tells the tube dimensions needed to keep pickup loops superconductive.

3.2.2 Umbilical II

Umbilical II examines radiation and conduction heat loads on a copper braid over twisted leads of NbTi wire. Stainless steel bellows over the braid gives a flexible vacuum jacket for the umbilical.

The test fixture uses a 1 m or so long copper braided cable, attached to short lengths of copper tube at each end, to thermally ground pickup loops to a helium bath. Stainless steel bellows cover the braid. A sapphire window closes the umbilical at one end. A compression joint in the vacuum jacket below the window brings it to within one millimeter of the pickup loops.

3.3 ELECTRONICS DEVELOPMENT

Electronics development comprises two stages, marked by fabrication and testing of drive and detection electronics.

3.3.1 Drive Electronics

Drive electronics generate a sinusoidal electric current oscillating in the source coil at frequencies from 300 Hz to 3000 Hz, with a maximum amplitude of a few amperes. They also generate a quadrature component of current for nulling residual interference from the source. Stability and low harmonic distortion are the main requirements for keeping noise low.

3.3.2 Detection Electronics

Detection electronics null residual interference from the source and detect in phase and quadrature components of the signal arising from a perturbation of the null. They track residual interference from the source and adjust feedback to the SQUID sensors to achieve a null and fix feedback coefficients. Perturbation of a fixed null then gives the signal from a disturbance.

3.4 PROTOTYPE DEVELOPMENT

The prototype mates probe, umbilical, and electronics in a compact unit that uses a storage cryostat for its helium reservoir. A cylindrical section at the bottom of the unit, containing SQUID sensors, fits in the neck tube of a storage cryostat. Conductive heat transfer through the umbilical brings the pickup loops of the probe to a superconducting transition, one hour or so after immersion in a helium bath. The unit is then ready for operation.

Prototype development comprises one stage, marked by integration of probe, umbilical, and electronics and by performance testing of the integrated unit. Performance tests lead to design improvements to achieve imaging of a 10 μm flaw at a depth of a few millimeters in an aluminum plate.

3.5 SCHEDULE

Table I schedules development of Probe I and II, Umbilical I and II, drive and detection electronics, and integration and performance testing of a prototype.

TABLE I

DEVELOPMENT SCHEDULE FOR AN ELECTROMAGNETIC MICROSCOPE

TASK	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
PROBE I																								
Design	****	****	****																					
Build				****	****		**	**	**	**	**	**	**											
Test						***	**	**	**	**	**	**	**											
PROBE II																								
Design						****	****	****	****	****														
Build											****	****	****		**	**	**							
Test														****	**	**	**							
UMBILICAL I																								
Design			****	****																				
Build					****	****																		
Test							****																	
UMBILICAL II																								
Design									****	****	****	****												
Build													****	****		**	**	**						
Test															****	**	**	**						
DRIVE ELEC																								
Design						****	****	****																
Build									****	****		**	**	**										
Test											****	**	**	**										
DETECT ELEC																								
Design												****	****	****										
Build															****	****		**	**	**				
Test																	****	**	**	**				
PROTOTYPE																								
Design															****	****	****							
Integrate																		****	****		**	**	**	**
Test																				****	**	**	**	**

4.0 STATEMENT OF WORK

The statement of work included in contract F49620–90–C–0058, and repeated here, summarizes the development plan with tasks specified for development of a single element microprobe, corresponding to Probe I of the development plan, and for development of an array, corresponding to Probe II that uses a triangular array.

4.1 TASKS FOR MICROPROBE DEVELOPMENT

We first specify tasks for development of a high performance microprobe in accordance with three interrelated design and development elements, (1) probe configuration, (2) cryogenic and mechanical structure, and (3) electronics, and then for its performance testing.

4.1.1 Microprobe Configuration

Use analytical methods developed during Phase I research to specify expected performance for six drive coil and pickup loop configurations, including a first–order gradiometer, a second–order gradiometer, and a biaxial gradiometer of first and second order.

Fabricate a microprobe on a silicon or sapphire substrate in the configuration of a first–order gradiometer with dimensions set by analyses of expected performance. Fabricate additional microprobes, as determined by results of performance tests, in order to obtain high performance configurations for both single axis and biaxial gradiometers of first and second order.

4.1.2 Cryogenic Structure

Design a cryogenic umbilical cord, suited to thermally grounding a microprobe to a reservoir of liquid helium, using copper wire for heat transport or, alternatively, using a heat pipe with helium working fluid.

Fabricate a cryogenic umbilical that uses copper wire for heat transport. Use it to attach a microprobe to the liquid helium reservoir of an existing cryostat.

4.1.3 Electronics

Design and fabricate an electronic circuit to control amplitude and phase of electric current in a compensating coil that suppresses interference from the drive coil of a microprobe by a factor of 10^5.

Use electronics from our electromagnetic gradiometer to detect amplitude and phase of the pickup coil signal and to apply external feedback to a SQUID sensor in order to null interference from the drive coil.

4.1.3 Performance Tests

Fabricate a calibrated set of aluminum test plates together with a fixture suited to moving a stack of test plates at set spacings below a microprobe.

Use the test plates to measure depth of field, field of view, and resolution of a microprobe as a function of operating frequency, height of the microprobe above a test surface, and current in its drive coil. Determine its maximum useable drive current.

Use results of performance tests to improve design of a microprobe in order to obtain a higher drive current and greater resolution.

4.2 TASKS FOR ARRAY DEVELOPMENT

As for tasks for development of a microprobe, we specify tasks for development of an array of microprobes in accordance with three design elements, (1) array configuration, (2) cryogenic and mechanical structure, and (3) electronics, and for testing and demonstrating its performance.

4.2.1 Array Configuration

Use an equilateral, triangular array of three microprobes to determine the closest spacing for the array that enables nulling mutual interference from drive coils.

Fabricate a parallel array of six close–packed microprobes, separated by twice the closest spacing, on a silicon or sapphire substrate to form a prototype sensor head for an electromagnetic microscope.

Fabricate additional arrays to specifications determined by performance tests in order to obtain higher drive currents and greater resolution and to determine the closest spacing for an array.

4.2.2 Cryogenic Structure

Fabricate a cryogenic umbilical, suited to thermally grounding an array of six microprobes to a reservoir of liquid helium, using a braid of copper wire for heat transport.

Fabricate a test section of a heat pipe using a helium working fluid, suited for use as a cryogenic umbilical. Examine its performance as an umbilical for an array of microprobes.

4.2.3 Electronics

Design and fabricate an electronic circuit to control amplitude and phase of electric current in compensating coils of an array that suppresses mutual interference from drive coils by a factor of 10^5.

Use electronics from our electromagnetic gradiometer to detect amplitude and phase of signals from pick up coils of an array of six microprobes and to apply, automatically, external feedback to six SQUID sensors in order to null interference from drive coils.

4.2.4 Performance Tests and Demonstration

Use calibrated aluminum test plates to measure depth of field, field of view, and resolution of an array as a function of operating frequency, its height above a test surface, and current in its drive coils. Determine its maximum useable drive current.

Use results of performance tests to improve array design in order to obtain a higher drive current and greater resolution.

Demonstrate advanced performance of an array for resolving internal flaws by using calibrated test plates to make comparative tests with a conventional eddy current array available commercially.

5.0 STATUS AND ACCOMPLISHMENTS

Here we give a concise statement of status and accomplishments of development work, referenced to the main elements of the development plan and to tasks in the statement of work.

5.1 PROBE

Design and fabrication of Probe I are complete. Tests to date give the following: (1) residual noise of the source and receiver configuration at a null achieved with electronic feedback to the SQUID, (2) calibration of the flux transformer formed by the gradiometer pickup loops and rfi transformer, and (3) response of the gradiometer to a target coil.

Figure 4 shows noise spectra of components of the SQUID response that are in phase and in quadrature with a drive current of 0.5 A, oscillating at a frequency of 198 Hz. It shows a noise of about $8 \times 10^{-5}\,\phi_0/\sqrt{Hz}$ at a frequency near 1 Hz.

Figure 5 shows calibration of the flux transformer using a 25 turn coil, 3 mm in diameter, at a distance of 2 mm above the pickup loops. Movement of the coil on circular path with a radius of 2.12 mm about the gradiometer gives a sinusoidal response. Amplitude of the response gives a flux of $1.2 \times 10^{-2}\,\phi_0$ coupled to the SQUID for each flux quantuum coupled to the pickup loops.

Figure 6 shows the in phase and quadrature response to a shorted coil of 250 turns, with a 3 mm diameter, at a distance of 3 mm above the pickup loops. It shows that the frequency limit of the electronic feedback presently used to suppress residual interference from the source is about 2 kHz.

Design of Probe II is complete and fabrication is in progress. Probe II use a three element array of source and pickup loops, shown in Figure 3.

We identify the following accomplishments in terms of completion of tasks for microprobe configuration. Analyses of microprobe configuration are complete. They show that using the original configuration of concentric, coplanar pickup loops to form a gradiometer is impractical. Their response is sensitive to errors in configuration of the order of 10 μm. Concentric configurations giving higher order gradiometers are equally impractical.

Instead, we use an azimuthal or D–shaped gradiometer configuration. It gives excellent decoupling between source and receiver. It also eliminates the need for a compensation coil for the source coil. A feedback coil at the rfi transformer provides compensation without decreasing the source moment.

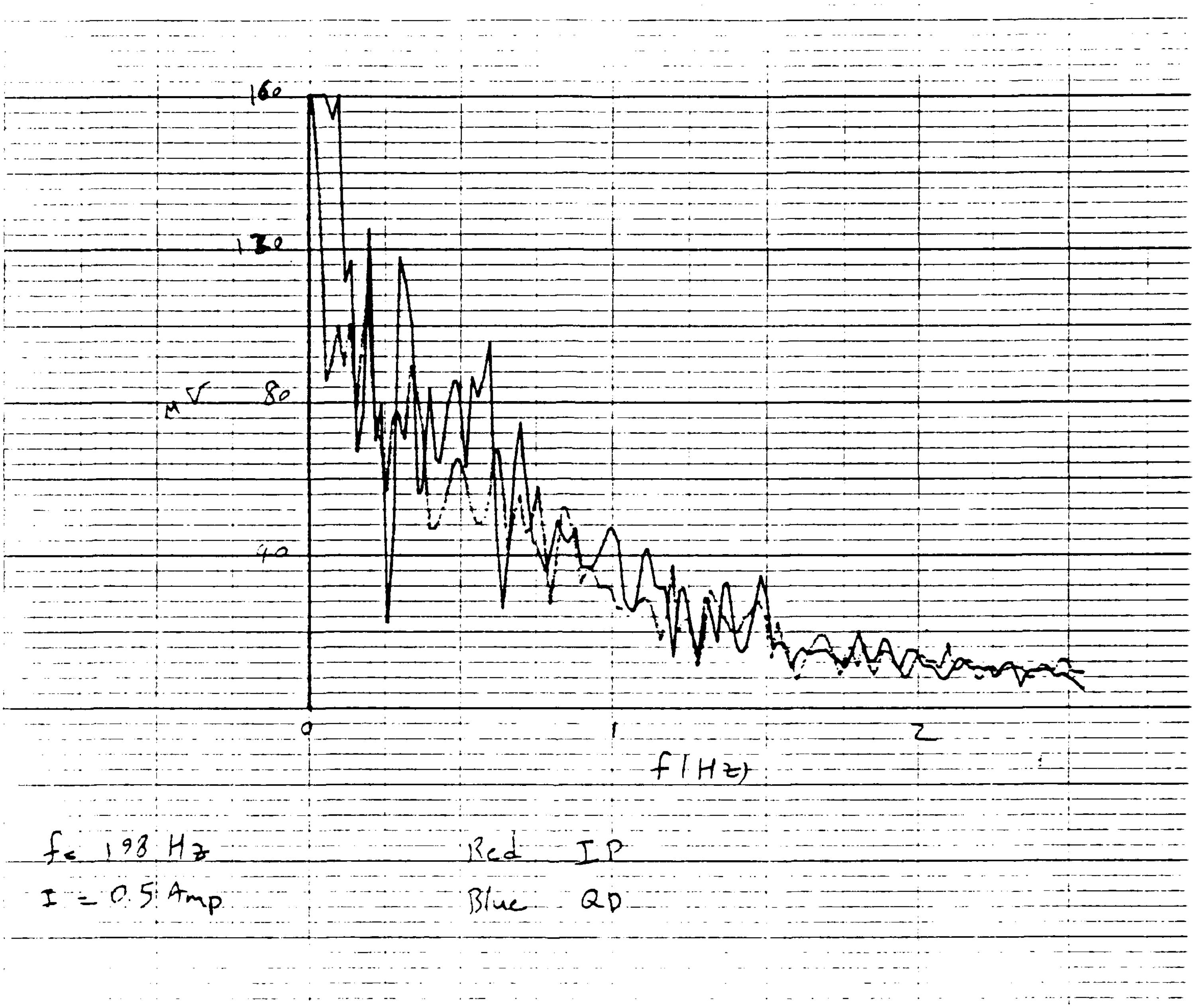

Figure 4

Noise spectra of in phase and quadrature response at a null interference between source and receiver, with 0.5 A oscillating in the source coil at a frequency of 198 Hz. The spectra overlap, with the in phase response showing somewhat greater variance. Noise increases with decreasing frequency as f^{-1}, with a value of $8 \times 10^{-5}\ \phi_0/\sqrt{Hz}$ near 1 Hz.

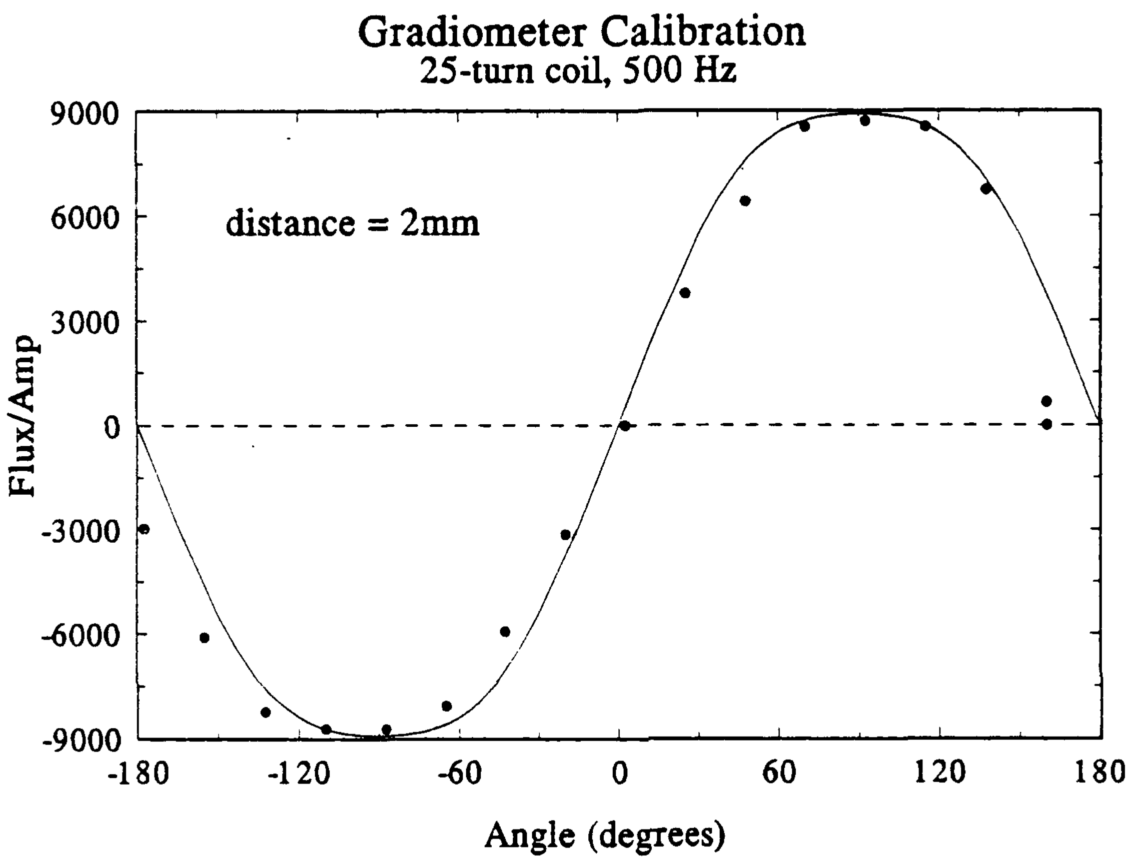

Figure 5

Calibrated response of gradiometer to current oscillating at 500 Hz in 25 turn coil 2 mm above the pickup loops, as a function of rotation angle. Zero angle marks the axis of symmetry of the pickup loops.

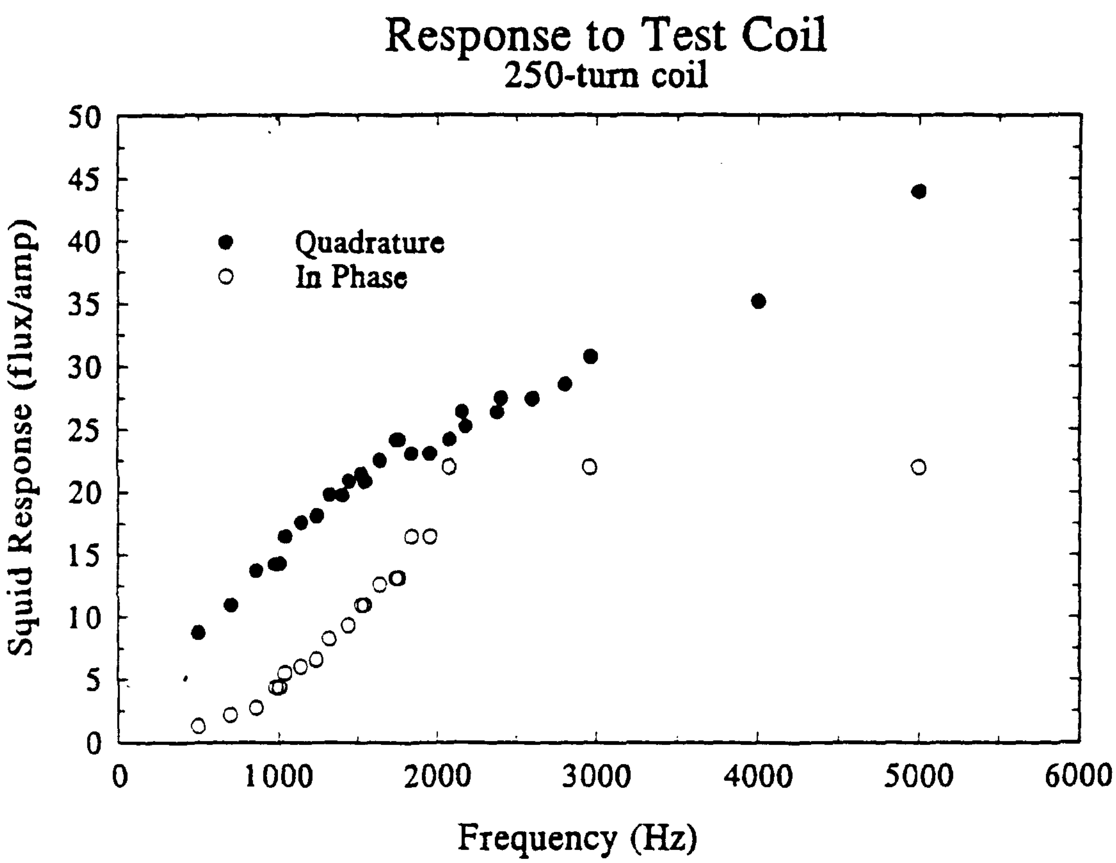

Figure 6

In phase and quadrature response from a 250 turn coil, 3 mm in diameter, at a distance of 3 mm above the pickup loops.

5.2 CRYOGENIC UMBILICAL

Design, fabrication, and tests of Umbilical I are complete. Tests show that a thermal shield provided by a copper tube 5/16 in in outer diameter with a 1/16 in thick wall requires a 4 K temperature differential over a length of four feet to transport the radiative heat load to a helium bath. A temperature of 5.4 K is achieved inside the shield at the warm end.

Design of Umbilical II is near completion. Pacific Cable and Conduit can fabricate the layered copper braid needed for a flexible umbilical.

We identify the following **accomplishments** in terms of completion of tasks for cryogenic structure of a microprobe. Design, fabrication, and tests of a cryogenic umbilical verify that conduction cooling with a copper tube, thermally grounded at one end to a bath of liquid helium, can achieve superconductive temperatures for NbTi wire over a length of four feet.

5.3 ELECTRONICS

Design, fabrication, and tests of drive electronics are complete. Tests show that an electric current of a 1 A or so can drive the source coil at frequencies below a few kilohertz without exceeding the slew rate limit of the SQUID electronics. Nonetheless, harmonic distortion adds noise at currents near 1 A at frequencies above a few hundred Hertz.
Design modifications and tests are in progress to suppress harmonic distortion and improve quality of the drive electronics.

Electronics previously used for compensation and detection of a electromagnetic gradiometer now provide a breadboard unit for detection electronics needed for a microprobe. Their frequency limit is about 2000 Hz. Design of detection electronics is in progress.

We identify the following **accomplishments** in terms of completion of tasks for drive and detection electronics needed for a microprobe. Design, fabrication, and tests of drive electronics show a current of 1 A or so, oscillating at frequencies up to a few kiloHertz, can drive the source without adding appreciable interference, provided harmonic distortion is suppressed.

6.0 PUBLICATIONS

Podney, W.N. and Czipott, P.V.,"An Electromagnetic Microscope for Eddy Current Evaluation of Materials", IEEE Trans. on Mag., Vol 27, No. 2, March 1991.

Podney, W.N. and Singsaas, A.L., "Detection of Micro Flaws in Aluminum using a Superconductive Eddy Current Probe", planned for J. Appl. Phys.

Podney, W.N. and Singsaas, A.L., "Use of an Electromagnetic Microscope for Detecting Micro Flaws in Aluminum", planned for J. NDE

Podney, W.N. and Longo, J., "A Cryogenic Umbilical for SQUID Applications", planned for J. Appl. Phys.

7.0 PRESENTATIONS

Podney, W.N., "An Electromagnetic Microscope for Eddy Current Evaluation of Materials", presented at Applied Superconductivity Conference, Snowmass, CO, 1990.

Podney, W.N., "A Cryogenic Umbilical for SQUID Applications", planned for International Cryogenic Engineering and Materials Conference, Kiev, USSR(?), 1992.

Podney, W.N., "Use of an Electromagnetic Microscope for Detecting Micro Flaws in Aluminum", planned for QNDE meeting, La Jolla, CA, 1992.

8.0 INVENTIONS AND PATENT DISCLOSURES

A patent disclosure is in process on an Electromagnetic Microscope for Eddy Current Evaluation of Materials. A specific application is identification of second layer cracks under installed fasteners.

9.0 KEY PERSONNEL

Dr. Walter N. Podney

University of California, Berkeley, Ph.D., Engineering Science, 1967;
Purdue University, B.S., Engineering Science, 1961.

Dr. Podney is founder and President of SQM Technology, Inc., a new research and technology development firm spun off from Physical Dynamics, Inc. He joined PDI in 1972 as Principal Investigator on a research problem associated with using ULF electromagnetic waves for communication undersea. He then initiated and directed a research program that developed experimental and analytical techniques for measuring and interpreting gradients of magnetic fluctuations generated by ocean waves. He participated in the Arctic Internal Wave Experiment (AIWEX), measuring magnetic gradient fluctuations from internal waves in the Arctic Ocean. Currently, he is Principal Investigator on projects he initiated to develop novel superconductive sensors for use in undersea metal detection and nondestructive evaluation of materials.

From 1969 to 1972, Dr. Podney worked at the Institute for Defense Analyses on physics of the upper atmosphere, ionosphere, and magnetosphere. At the Lawrence Livermore Radiation Laboratory from 1967 through 1969, he participated in designing fast reactor systems to provide electric power for spacecraft, and he investigated material motion and vaporization resulting from energy deposited by an X–ray pulse.

Dr. Podney is a member of the American Physical Society, the American Geophysical Union, the American Association for the Advancement of Science, and the Society of Exploration Geophysicists. He is the author of nearly 30 technical publications.

Selected Publications

Podney, W.N. and P.V. Czipott, "An Electromagnetic Microscope for Eddy Current Evaluation of Materials", IEEE Trans. on Mag., Vol 27, No. 2, March 1991.

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Podney, W.N., and R.E. Sager, Measurement of fluctuating magnetic gradients originating from oceanic internal waves, *Science* **205**, 1381–1382, 1979.

Podney, W.N., Electromagnetic fields generated by ocean waves, *J. Geophys. Res.* **80**, 2977–2990, 1975.

Dr. Alan Singsaas

University of California, Santa Barbara, Ph.D., Physics, 1984;
State University of New York, Stony Brook, M.A., Physics, 1976;
Augustana College, B.A., Physics and Mathematics, 1972.

Dr. Singsaas recently joined the staff of SQM Technology, Inc. as Research Scientist to participate in development of novel superconductive instruments for nondestructive evaluation and other applications.

From 1987 to 1990, Dr. Singsaas was Research Physicist at the Max Planck Institute for Physics and Astrophysics in Munich, West Germany, where he headed a laboratory investigating cryogenic detectors for astro–particle physics applications including the search for dark matter candidates and weakly interacting massive particles (WIMPs). Specializing in high energy physics research, the Munich Max Planck lacked a low temperature laboratory. Dr. Singsaas designed and equipped that laboratory and built a now solidly established program working on innovative cryogenic particle detectors.

As a Postdoctoral Research Associate from 1984 through 1986 at the University of Bayreuth, West Germany, Dr. Singsaas participated in studies of ^3He–^4He mixtures using NMR and other techniques. Part of that effort involved construction of a two–stage nuclear demagnetization apparatus that reached the lowest temperature ever recorded on an experimental platform, 12 μK.

His doctoral work in the laboratory of Prof. Guenter Ahlers at UCSB resulted in important contributions to both experimental and theoretical understanding of the λ transition (superfluid transition) in ^4He.

Dr. Singsaas is a member of the American Physical Society; he is coauthor of over a dozen technical publications.

Selected Publications

Frank, M., A. Singsaas, L. Stodolsky and S. Cooper, Energy transport in single superconducting grains, submitted to *Phys. Rev. B*, 1990.

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Dr. Peter V. Czipott

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Dr. Czipott is co–founder and Vice President of SQM Technology, Inc., a new research and technology development firm. As a staff scientist at Physical Dynamics, Inc. from 1984 to 1990, he participated in developing innovative superconductive instruments for undersea metal detection and for nondestructive evaluation of materials. He continues work on these programs at SQM. He has used a superconductive gradiometer to measure magnetic fluctuations caused by seismic waves, in the first field trial of a novel technique promising to detect crustal stress changes near active earthquake faults.

In 1985, during the Arctic Internal Wave Experiment (AIWEX), he measured magnetic fluctuations induced by internal waves in the Arctic Ocean. Unexpectedly interesting data from ancillary tilt measurements led him in 1989 to measure wave–induced ice tilt as part of the Coordinated Eastern Arctic Experiment (CEAREX). Results include the first unambiguous measurement of ice flexure forced by internal waves. Dr. Czipott continues to analyze the CEAREX tiltmeter data base.

Earlier, as a doctoral candidate in the laboratory of Prof. John M. Goodkind at UCSD, Dr. Czipott conceived and constructed an apparatus using the superconductive gravity meter developed in that lab to test Newton's inverse square law of gravitation on laboratory distance scales. The work forms part of the search for a fifth fundamental force. In work at UCSD emphasizing geophysical gravimetry, he contributed to studies in tidal spectroscopy and in the interpretation of aperiodic gravity variations (earthquake precursors; gravity as a monitor of geothermal reservoir recharge; the Chandler Wobble).

Dr. Czipott is a member of the American Geophysical Union and the American Association for the Advancement of Science.

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