2. RECENT PROGRESS (4-1-89 to 8-90)

The main emphasis during this has been to continue development of the high frequency (to 300 MHz) instrumentation, to test the system on a prototype bending magnet, to construct the high frequency 32-channel electronics and probes, to seek industrial partners for technology transfer and commercial exploitation, and to do computer simulations for optimizing design parameters. Experience gained from tests made on a dipole magnet at Lawrence Berkeley Laboratory was extremely valuable and has resulted in substantial modifications to the original design. These, and other items are discussed briefly below.

2.1. Dipole test at Lawrence Berkeley Laboratory. A very important advance was a successful low field (0.4 T) test of our prototype 8-coil MCPMR field mapping system on a short dipole magnet. The overall success of this operation on its first trial in a dipole magnet indicated the viability of the method and its implementation. Specifically, this test demonstrated the following important points:

- The testing can be done without the high degree of magnet current regulation normally needed for NMR field testing. This feature occurs because a nearly instantaneous "snapshot" of the field is taken by recording the signal from all of the coils simultaneously. In the case of the LBL tests, magnet field fluctuations of 500 ppm did not degrade the accuracy of the measurements.
- The inhomogeneity of the magnetic field over the individual coils was larger than anticipated. This situation has led to two responses; the electronics has been modified to handle shorter free induction decay times, and extensive computer simulations have been undertaken to model the effect of field inhomogeneity and related issues on the accuracy obtained for the multipoles. This activity is described in more detail in Section 3.
- It was found that the spin-lattice relaxation of the ^{3}He sample in the chambers was an uncomfortably long 20 s. An alternative that uses a composite cell with ^{3}He and Al powder is being developed. It has the dual advantages of a short relaxation time (about 1 s.) and the ability to test at two magnetic field values with a single probe. This alternative is discussed further in Sections 2 and 3.

2.2. Advances in multipole coil probe design. The initial reason for the choice of ^{3}He as the NMR working substance was its very small intrinsic line width at cryogenic temperatures. This narrow width permits highly accurate determination of the magnetic field at each of the coils and consequent precise measurement of the multipole coefficients. The inhomogeneity of the magnet dipole field, however, produces its own broadening of the NMR line to the extent that other working nuclei with intrinsically broader lines can be considered. In particular, it appears that ^{27}Al should also work for the higher values of the magnetic field, where the effect of the intrinsic width of the NMR line is less of a limitation.

We have investigated the possibility of using the ^{27}Al resonance for higher field measurements through computer simulations of the effect of its intrinsic line width and find that it should be satisfactory for fields above 2T. This development has several important benefits with regard to the MCPMR method. It can be implemented by using a composite sample that is Al powder immersed in ^{3}He. The first benefit is that two fields can be measured with a single probe working at a single frequency, one with the ^{3}He signal at the lower field and the other with the ^{27}Al signal at the higher one. A particular implementation of this strategy is discussed in Section 3.1.

The other benefit of this step is that the ^{3}He spin-lattice relaxation time is reduced by more than an order of magnitude. This condition occurs because the relaxation of the ^{3}He spins occurs at the sample boundaries. By constricting the ^{3}He to reside in the interstices of the Al powder the surface available for relaxation is increased dramatically and the relaxation time is substantially reduced to a time on the order of 1 second (see Section 2.6). The relaxation time of the ^{27}Al spins is already 1 second or less because of nuclear relaxation by the conduction electrons.

2.3. Digital electronics. The 32 channel digital electronics and connection to the acquisition and control microcomputer used to process the signals from the receiving channels has been constructed and tested successfully.

2.4. RF electronics. Construction of the 32 channel receiver is underway. A compact pulsed rf transmitter to cover the frequencies needed for cold magnet testing has been constructed and successfully tested.

2.5. ^{3}He gas purification and handling system. A simple and reliable purification and pressurized gas handling system for the ^{3}He NMR samples and operation in short magnets has been designed and constructed. It forms the basis of a system to be designed and constructed for long magnet testing.

2.6. Sample relaxation rate improvement. A set of measurements on various restricted geometry ^{3}He nuclear spin-lattice relaxation rates was done for frequencies and temperatures appropriate for SSC dipole testing. In these measurements an epoxy cell was filled with ^{3}He and another material to add area to enhance the surface available for relaxation of the ^{3}He spins. A manuscript describing this work is being prepared for submission to an appropriate journal. In this work, several restricted geometry systems were compared: ^{3}He was introduced into a cell that was otherwise empty, into a cell filled with Al powder, into a cell filled with tightly packed cotton, and into a cell filled with tightly packed polyester film. In all of the restricted geometries used there was a substantial reduction of the relaxation rate relative to the cell with no filling material. The greatest reduction was obtained with the Al powder. For this and its usefulness as a second NMR signal, our future probes will use ^{3}He-Al powder composite samples.

2.7. Computer simulations. We have made numerous computer simulations that predict the accuracy of the multipole moment coefficient determination and other important characteristics as a function of the various measurement parameters, such as magnetic field, NMR working substance, the diameter of individual coils, and the radius upon which the coils are placed. These simulations are in progress. They are proving to be very useful for optimizing the design of the multicoil probes.

2.8. Technology transfer and commercial development. A considerable effort has been made to identify companies that are capable of and interested in commercial application of the technology developed with support of this Contract for testing SSC dipoles and other applications. This effort included participation in the IISSC90 Conference in Miami Beach, March, 1990 (see preprint of Appendix A); attendance at the ENC Conference in Asilomar, April, 1990 (NMR instrumentation topics and NMR instrumentation manufacturers), and a proposal to form a field measurement consortium was presented at the SSC Laboratory on May 16, 1990. In all of these activities, approximately 5 organizations were identified as capable and/or interested in commercial exploitation of the technology and method, either singly or as groups. The level of their interest in this technology is not yet determined. It depends on the cost of commercialization and their estimate of the market for it. At present, the most promising market is the SSC itself. It is not yet clear whether it is a viable market for the technology.

The most active approach made so far was to propose to the SSC Laboratory the formation of a magnetic measurements consulting and instrument manufacturing consortium that would cover all of the technologies and methods that have sound potential for use with SSC magnets, including the one supported under this contract. This approach was presented to members of the SSC Laboratory on May 16, 1990. Those attending interested in participating in the consortium approach included W.G. Clark, UCLA (MCPMR method and instrumentation); P. Starewicz, Resonance Research, Inc. (commercial NMR field mapping instrumentation); Janis Research, Inc.

(Cryogenic apparatus manufacturing and design); and Ian Walker, GMW Associates (manufacturers of Hall effect instrumentation; U.S. representative of Metralab, design and manufacture of NMR instrumentation for particle accelerator magnets and Danfysk, design and manufacture of rotating coil instrumentation for field mapping). On the commercial side, it has been indicated that there is interest within such a consortium in manufacturing MCPMR instrumentation, provided that there is a reasonable potential to earn profits and that the financial risk in doing so is negligible.

This consortium approach was advanced by Dr. P. Starewicz of Resonance Research, Inc. A response to him following the meeting appears in Appendix B. Some of the points raised in that letter are addressed in this proposal. The letter also indicates the revised multipole field specifications that we are using in our work.

END

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