NASA CR-202201

Superconducting Magnets Used as a Magnetic Bumper/Tether System

Final Technical Report

to

NASA-Johnson Space Center

Regional University Grant Program

Contract #NAG 9-822

UH Account # 1-5-53101

August 1, 1995 - July 31, 1996

Prepared by Roy Weinstein
Roy Weinstein
Prof. Physics
University of Houston

JSC Colleagues: Dr. Dickey Arndt
Dr. Kumar Krishen
Dr. Leo G. Monford, Jr.

Date Submitted: September 6, 1996

Location: BPDG, Room 632 SR1
Univ. of Houston
Houston, TX 77204-5506

Tel. (713) 743-3600
FAX (713) 747-4526
e-mail weinstein@uh.edu

Final Report NASA-JSC

Contract #NAG 9-822

The proposal presented to NASA for the Regional University Grant reported on herein, contained two major goals, development of new materials, and a continuation of tests on a magnetic bumper/tether for spacecraft docking.

I. Materials

A. The U/n Method

It was proposed to improve the materials used to make superconducting trapped field (permanent) magnets. During the period of the grant several improvements were made in materials processing. In our previous study, the most striking improvement was achieved by development of a new type of pinning center.(1) A small amount of U^{235} was added to the superconductor. This was finely dispersed by milling techniques, and then irradiated with thermal neutrons to induce the reaction

$$U^{235} + n \rightarrow \text{fission} \qquad \text{Eq. 1}$$

The resulting fission fragments create columnar damage regions about 20μm long and 50 A° in diameter, which act as pinning centers. It is these long thin columnar centers which improve the materials. We refer to this process as the U/n method.

This material is presently the best bulk superconductor available. During the past year we made further controlled tests on the U/n method to optimize the process.

We performed an irradiation at the Texas A&M Reactor on 12 U^{235} samples and 12 placebos, and tested the materials at the Texas Center for Superconductivity at UH. The major purpose of this experiment was to determine the optimum fluence of neutrons. This was found to be $(8\pm1)\times10^{16}$ n/cm^2. We also determined that the residual radiation in a magnetic disk 2 cm diam x 0.8 cm is about 1-10 μc. As a comparison we note that the amount of radioactivity in a commercial smoke alarm is 1 μc. This level of radioactivity is about 100 times <u>below</u> that of previous radiation techniques. The presence of samples in this test with no U, and with U^{238}, allow us to cleanly separate the effects of U^{235}.

The optimization experiments will continue on processing variables (a) total mass of added U and (b) mass ratio of U^{235}/U^{238}.

We believe that the U/n method is the most promising on the world scene for producing high J_c, and high trapped field. Using this method, a single trapped field magnet 2 cm diam. x 1 cm, at 77K, traps a field of 2.1 Tesla. This is over 5 times the field of a very good permanent ferromagnet. Higher fields are available at lower temperatures (e.g., 5 Tesla at 65K). Four such disks trap a field of 3.1 Tesla.

B. The Method of Chemical Uranium

In the course of studying the U/n method we noted that some improvement in the superconducting critical current, J_c, and in the trapped field, B_t, was obtained *prior to irradiation*. This effect can only be due to the action of Uranium as a chemical, and not to its nuclear properties.

We followed this accidental discovery by studying J_c, and B_t as a function of the mass of U added.

Fig. 1 shows the early results of this test. The trapped magnetic field and J_c are increased by over 60% when 0.8% U (wt.) is added.

We have identified two new compounds, which form when U is added to $Y_{1.6}Ba_2Cu_3O_{7-\delta}\,Pt_{0.05}$ (Y123). These are compounds of UPtBaYO and UBaYO. The former is formed until all of the Pt is bound. Then the latter compound forms.

This new discovery will be presented soon.(2,3) Our group continues these studies by a study of a matrix of points with variables x = % Pt and y = %U. In addition we are investigating chemical substitutes for Pt and U.

The chemical U results are of great interest because they produce excellent magnets with essentially no radioactivity.

C. New International Collaboration, and Accolade

The attractiveness of both the U/n method, and the Chemical U method, has resulted in an exciting collaboration. At UH we will pursue optimization of these methods in Y123 and in Sm123. At ISTEC, Japan, Masato Murakami, Director of Div. VII of ISTEC, will pursue Nd123. Prof. S.X. Dou of Univ. of Wollongong in Australia will pursue BiSCCO, presently the best candidate for superconducting wire. Prof. Harald Weber of the Atom Institut of the Univ. of Austria (Vienna) will test all compounds. The production of materials for which each of the collaborators is responsible is probably the best in the world.

In Spring 1996 the ARO published its annual list of 10 exciting results in materials science. Our 1995-96 work, reported in our last RUG report, was chosen as the #2 result on the ARO list.

D. Publications

Two papers are being presented at conferences on the chemical pinning centers discovered this year.(2,3) Two additional papers are being presented on advances in the U/n pinning centers discovered during last year's NASA-RUG grant.(4,5)

II. Magnetic Bumper/Tether

A. Extension of Tests on Y123-SmCo System

The second goal of the RUG study was continued development of a soft docking device, based upon superconducting trapped field magnets. The system applies to two approaching spacecraft. An electromagnet is mounted on the front of one craft, and an area of superconductor is on the front of the other. As the two craft approach, the superconductor is cooled in zero magnet field, and the electromagnet is turned on.

An experimental apparatus was developed last year to measure the repulsive "bumper" force which occurs as the two craft near each other, and the force which occurs after they magnetically "bounce" off one another. As described below the latter force is *attractive*, and results in a tethering of the two craft.

The apparatus developed measures force vs. distance using transducers, and computer logging. The apparatus continued to evolve, during the period of this grant, via the addition of motor drives, and lateral force measuring devices. Development of this apparatus continues to date, via the replacement of the ferromagnets, on one of the two "spacecraft" with electromagnets.

Fig. 2 shows the forces which occur during the collision.(6,7) There is a repulsive force upon approach. Upon retreat there is first a repulsive force which, a small distance away, evolves into an attractive force. The magnitude of the attractive force increases as $R \equiv B_{Fe}/B_{superconductor}$ increases, until a limit is reached at about R=2. Because of this attractive force, the system can be designed to achieve a large bumper force followed by *automatic* tethering.

In our tests, single Y123 magnets were used, and the most desirable ferromagnet, an electromagnet, was simulated by a permanent SmCo magnet. Extrapolating our results on the small Y123-SmCo system to a more sizable bumper (e.g., 1 m^2) we find bumper forces of well over 10 tons are achievable.(6,7)

Last year we also investigated large matrices of small Y123 magnets.(6) We found that the range of the forces are comparable to the size of the array. For a 1m^2 array, bumper action at 50 cm is feasible, and is, we believe, a reasonable distance.

Our newer results show that the original kinetic energy of the collision is almost entirely converted to magnetic energy. An hour after the collision, 15% of the initial kinetic energy is still trapped as magnetic field. 85% of the initial kinetic energy has been converted first to magnetic energy, and then to heat, at varying rates given by the "creep" mechanism.(6,7)

It appears at this stage of development that the magnetic bumper/tether may indeed provide a practical docking mechanism, either primary or backup. Funding will be requested from NASA to perform a scale model test, in space.

B. Publication

The development of the bumper/tether was reported at an international conference on superconductivity(6), and at a NASA sponsored conference on applications of levitation(7).

III. References and Publications

1. R. Weinstein, J. Liu, Y. Ren, I.G. Chen, V. Obot, R.P. Sawh, C. Foster and A. Crapo, Invited Paper, "Effects of High Energy Irradiation of MT Y123 on J_c, Trapped Field, Creep, and the Irreversibility Line," Proc. International Workshop on Superconductivity, Kyoto, Japan (June 1994).

2. R. Weinstein, R. Sawh, Y. Ren, "New Chemical Pinning Center," International Symposium on superconductivity, Sapporo, Japan (October 1996).

3. R. Weinstein, R. Sawh, Y. Ren, "Chemical Pinning Centers Including Uranium," MRS 1996 Fall Meeting, Boston (December 1996).

4. R. Weinstein, R. Sawh, Y. Ren, J. Liu, "Isotropic, Short, Columnar Pinning Centers," Internat. Sympos. on Supercon. Sapporo, Japan (October 1996)

5. R. Weinstein, R. Sawh, Y. Ren, J. Liu, "Fission Fragment Pinning Centers," MRS 1996 Fall Meeting, Boston (December 1996).

6. D. Parks, R. Weinstein, R.P. Sawh, and G. D. Arndt, "A Magnetic Bumper Tether System Using ZFC Y123," Proc. of the 1995 International Workshop on Superconductivity, pg. 148, Wailea, Maui, Hawaii (June 1995).

7. R. Weinstein, D. Parks, R-P Sawh, V. Obot, J. Liu and G. D Arndt, "A Magnetic Bumper-Tether System Using ZFC Y123, " Proc. of the 3rd International Symposium on Magnetic Suspension Technology (NASA, NHMFL) Tallahassee (December 1995)

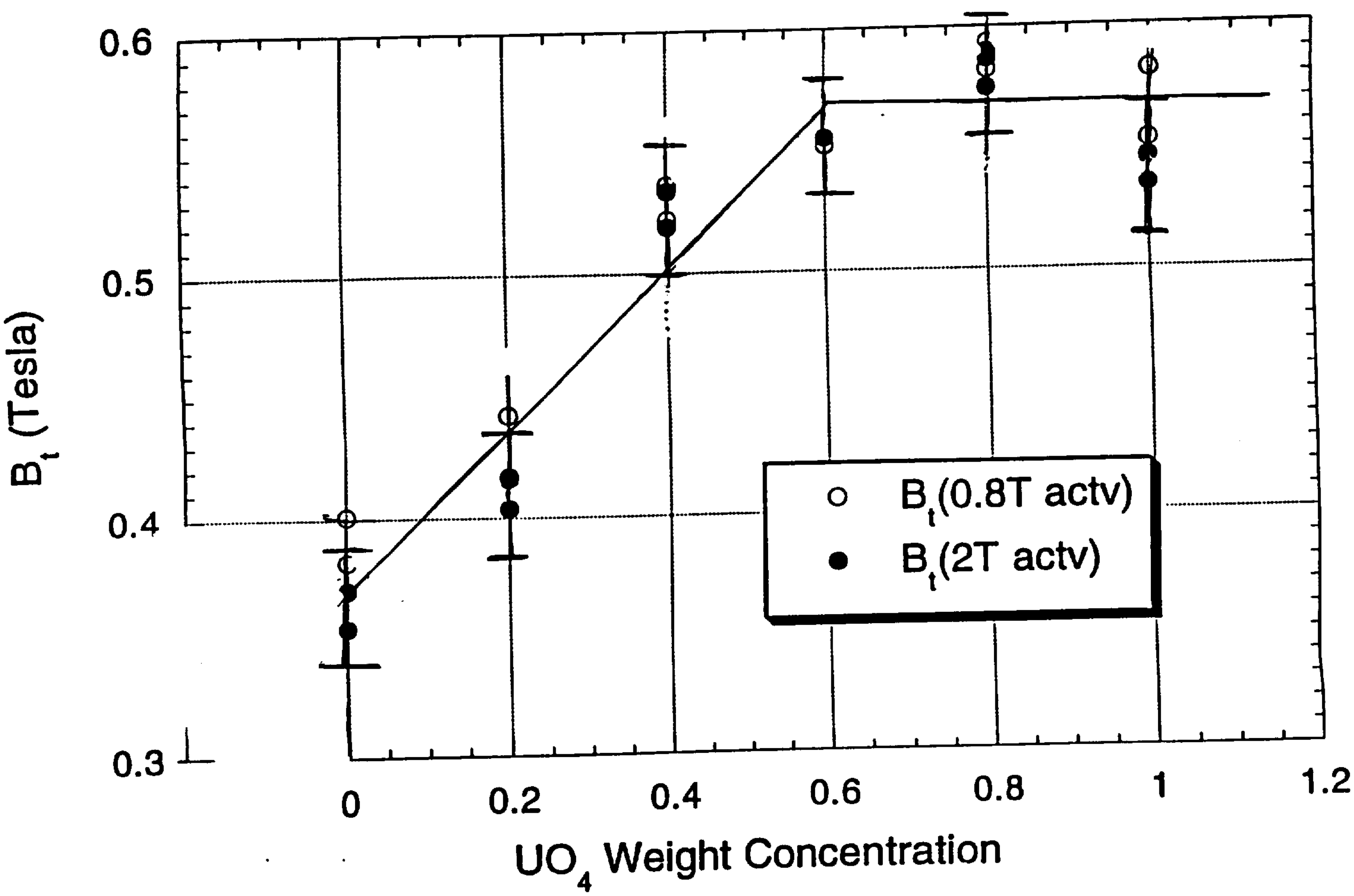

Fig. 1 Initial results on a new class of chemical pinning centers. Uranium is added to $Y_{1.6}Ba_2Cu_3O_{7-\delta}Pt_{.05}$. Compound of UPtYBaO is formed. Trapped field B_t increases as more U is added,until all Pt is used up.

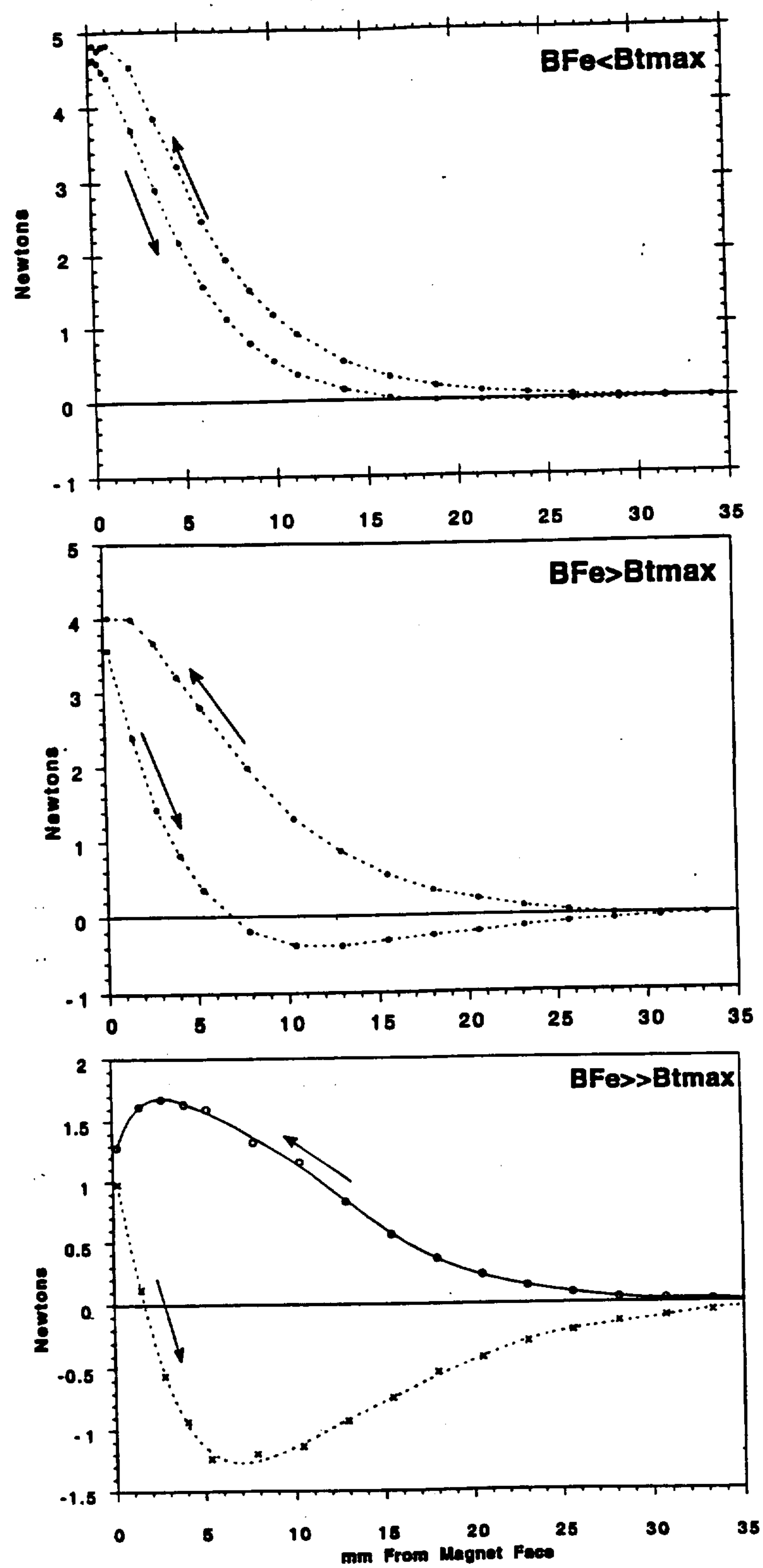

Fig. 2. Operation of a small bumper tether using Y123 and a SmCo magnet. Tether force varies from zero (top) to maximum (bottom) as B_{SmCo} is increased. Forces shown here will increase 5 fold for an electromagnet in place of the SmCo.