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Develop and Test an Internally Cooled, Cabled Superconductor for Large Scale MHD Magnets

Test Plan

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TEST PLAN

INTRODUCTION

The experimental program will be carried out with subscale conductors consisting of subelements of the proposed full-scale conductor. The basic element of a cable is a triplet which is simply a bundle of three wires twisted together. The first tests will be to determine the stability of these cable subelements using two different conductor designs. One will consist of three wires, each of which will be a multifilamentary composite. The other will consist of three wires in which only one of the three strands is a multifilamentary composite while the other two strands are pure copper. The overall copper-to-superconductor ratio in each of these triplets will be approximately the same. Preliminary tests have indicated that the latter configuration (the two copper strands and one composite strand triplet) will have the same performance as the triplet in which all three strands contain superconductor. If detailed tests confirm this indication, it will be possible to reduce the manufacturing cost of the proposed full-scale ICCS conductor substantially.

The first subscale cable to be tested will have 27 strands (9 triplets). This ICCS configuration in the finished condition will have overall dimensions of approximately 4 mm dia. The stability, quench propagation and internal pressure dynamics of this conductor will be tested in both short sample and small coil configurations in the background field of the high field test facility at MIT's National Magnet Laboratory. Results of these tests will be compared with predictions. We anticipate that the correlation between predictions and experimental results will be adequate to proceed with the procurement of long-term materials for the full-scale test conductor.

Full-Scale Test

The proposed baseline design assumes as 486-strand conductor encased in a stainless-steel sheath having overall dimensions of approximately 2.5 cm square. An approximately 15 m length of this conductor will be wound into a coil in a configuration closely duplicating the actual operating environment of a large-scale MHD magnet. This coil will be tested while monitoring its performance with respect to stability, quench propagation and pressure dynamics.

The final test performance analysis will include definition of the program, time, and cost to fully develop the manufacturing technology required for minimum risk construction of a large-scale MHD magnet.

Predictive Analysis

An attempt will be made to predict analytically the performance of the subsize conductors in the test configuration described in the next section. This analysis will address problems of transient stability having sudden energy inputs in the range of 100 microseconds to 100 milliseconds and steady-state stability having energy inputs over long periods of time (1 s to steady state). The maximum amount of energy that can be input into the conductor without causing a quench will be measured, and energy margins (mJ/cm^3) will be compared to predictions.

Similiarly, maximum hot-spot temperatures and pressures will be measured and compared.

The analysis will consider the differences in both electrical and thermal contact resistances between the two configurations; the slight differences in overall copper-to-superconductor ratios in the two triplet configurations, and also the inherently different filament sizes in individual strands (or strand in the case of the 2 and 1 cable) and therefore, different critical currents in the superconductor.

SCHEDULE

Tests will be performed in accordance with the schedule set forth in the Management Plan dated July 24, 1986.

SUBSCALE TESTS

Transient Stability

Good transient stability is one of the principal advantages of ICCS conductors. In the proposed geometry, at least 80% of the wire periphery is in contact with the coolant. Wire diameter is small and a large heat transfer area is thus achieved. Coolant is single phase, supercritical He. Under steady-state conditions a modest flow of supercritical helium through the high surface area ICCS conductor provides adequate stability. Under transient (0.1 to 100 ms) heating conditions ICCS cooling is dramatically enhanced by the so-called "Kapitza heat transfer,"[1] making transient stability uniquely independent of coolant flow.[3]

The purpose of this series of proposed experiments is to evaluate the limits of transient stability, in candidate, subsize, copper-stabilized NbTi ICCS test conductors. Figure 1 shows a 3.5 m length of a 27-strand, stainless-steel-sheathed ICCS conductor, wound into a noninductive test coil. Figure 1 also shows electrical terminations (top) and coolant couplings (left of terminations). The placement of the test coil is illustrated in Fig. 2. It can be seen here that the coil sits in the annulus between a set of two concentric pulse coils. Figure 2 illustrates electrical systems and instrumentation while Fig. 3 shows the helium system schematically. To provide the required transient heating, a capacitor is discharged into the pulse coil set. A double pulse used for Nb_3Sn is shown in Fig. 4. The double pulse was needed for the Nb_3Sn test conductor, because of its higher energy margin. Critical energy input for Nb_3Sn and NbTi cabled superconductors is compared in Fig. 5. Our expectation is that the proposed NbTi ICCS conductors will have adequate transient stability for DC applications, such as MHD.

Protection

Transient stability assumes the sudden (0.1 to 100 ms) release of energy, able to drive the superconductor temporarily into its normal, resistivity state, but followed by recovery. Since heat transfer between wire and coolant is very high, the duration of the resistive heating period is extremely short. It is therefore postulated that transient recovery is so short that current transfer to the "all-copper" strands does not take place. The question is therefore: "What is the minimum amount of stabilizing copper which must be included in close proximity to the superconducting filaments?"

In the case of protection, on the other hand, it is assumed that the conductor has ceased to be superconducting. Current must transfer to the (now) less-resistive stabilizing copper, located in both the multifilamentary strand and in the pure copper strands. Since adequate voltage is available under these conditions, we hypothesize that the "all-copper" strands will participate fully in the protection process.

To protect ICCS from overheating, it must be provided with the following:

(i) An adequate amount and quality of stabilizing copper to minimize heating during shutdown. The quality of the copper is defined in terms of the effective Residual Resistivity Ratio (RRR). RRR = 100 is readily available.

(ii) A "quench detection" system designed to detect the existence of a normal zone anywhere within the coil winding.

(iii) A switch to cut off the DC power supply.

(iv) A shunt connected "Dump Resistor" to absorb the magnetic stored energy and provide an adequately short current-decay time constant, to limit the ICCS conductor "Hot-Spot" temperature to a safe value.

A "Protection" test of the subsize ICCS test conductor can be readily carried out by voltage measurement across the full (3.5 m) length of the conductor as it is driven into a quench.

Specific Test Conductor and Test Characteristics

Two 3.5-m-long, 27-strand ICCS test conductors will be fabricated. Type A will consist of 27 identical strands of a 0.510 mm diameter wire with a 7:1 Cu:NbTi ratio. Type B will consist of 9 strands of a 0.510 mm diameter wire with a 1.35:1 Cu:NbTi ratio and 18 strands of a 0.510 mm diameter pure copper wire, arranged in nine (9) wire triplets, each consisting of one NbTi/Cu strand and two pure Cu strands. The overall Cu:NbTi ratio for this cable is thus 5.2:1. Each cable will now be double wrapped with 0.025 mm thick stainless steel foil and will be reduced to a 3.4 mm diameter bundle. Each cable will then be pulled through a 3.5 mm ID stainless steel tube with an 0.38 mm thick wall. The encapsulated conductor will then be drawn down to a tube of 4.05 mm OD, thus ensuring a 34% He fraction in the cable.

The round, 4.05 mm diameter conductor will then be wound into a single layer, 83 mm ID noninductive (bifilar) coil, designed to fit in the annular space between two existing, coaxial pulse coils and will be secured within the pulse coil assembly by means of paraffin wax potting.

The two test-coil assemblies will be mounted on support probes for insertion into an existing LHe-cooled, LN_2-shielded dewar. Special precautions must be taken to provide structural support of the coil assembly, due to large eccentric forces generated. Both ends of each conductor will be terminated for low-loss connection to 2,000 A current leads as well as helium plumbing connectors.

Operating characteristics of the two test conductors are as follows:

<u>CONDUCTOR</u>	<u>A</u>	<u>B</u>	
Critical Current (I_{crit}) @ 5 T	810	1,125	A
Critical Current (I_{crit}) @ 8 T	459	720	A
Multifilamentary strand Cu:NbTi ratio	7:1	1.35:1	
Overall Cu:NbTi ratio	7:1	5.2:1	

<u>EXPECTED ENERGY MARGIN</u>				
Limit at I_{op}/I_{crit}	=	0.8	0.8	
Namely I_{op}	=	367.	576	A
at B = 8 T		50	35	mJ/cm^3

Test operations will be carried out as follows:

The test coil is first mounted on its probe an then inserted into the appropriate (150 mm OD) dewar. The dewar is then inserted into the background field coil at the Francis Bitter National Magnet Laboratory. This is an 8 T peak on-axis solenoid of Bitter plate construction. After appropriate cooldown and dewar backfill with liquid helium, the background field is raised to the desired field level. Field levels of interest will range between 4 and 8 teslas. Helium pressure in the ICCS conductor itself will be maintained at 2.5 to 3 atm. - that is, in a supercritical, single phase state. Cooldown without mass flow between test runs is assured since the ICCS conductor is immersed in a liquid helium bath.

Our objective is to determine the energy margin (Q) of an ICCS conductor operating at a given field (B) as well as at a given current level (I_{op}). After having established the appropriate field, B, the procedure then calls for the establishment of the operating current, I_{op}. The transient energy pulse is delivered to the ICCS conductor inductively by means of the pulse coil set (see Figs. 2, 3 and 6). In order to energize the pulse coil, a capacitor must be charged to some predetermined level (such as 100 V). The test run takes place with the discharge of the capacitor into the pulse coil. This will be done using a half-cycle (single) pulse, lasting 100 ms. The amount of energy which is inductively coupled into the test coil is known from extensive calibration tests. Voltage taps across the test conductor will indicate whether or not the conductor recovers or goes normal (quenches). Several discharge runs must be performed to narrow the range between recovery and nonrecovery.

It is expected that transient stability of the Type A ICCS test conductor will be higher than that of Type B, because all strands have copper in intimate contact with the superconductor. Since MHD conductors usually operate under steady state, DC conditions, the Type B conductor, however, should have adequate transient stability. It also has the minimum Cu:Sc ratio identified by the previous design and performance requirements analysis. It thus represents a minimum cost configuration. Separate "ramp" tests, in which the current will be ramped up from zero to maximum current at different, ever increasing rates, will also be performed. The objective of this test will be to determine whether or not there is any significant "Lorentz Compaction Heating" during magnet energization.

REFERENCES

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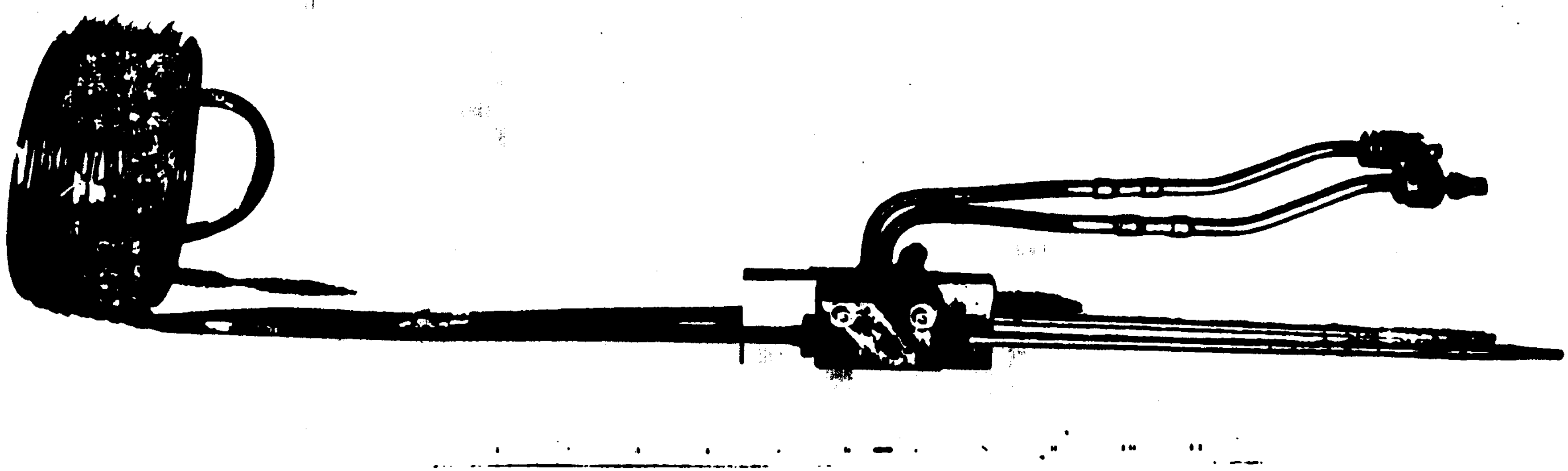

Figure 1. Stability test coil of subsize conductor showing bifilar winding and current terminations and helium connections.

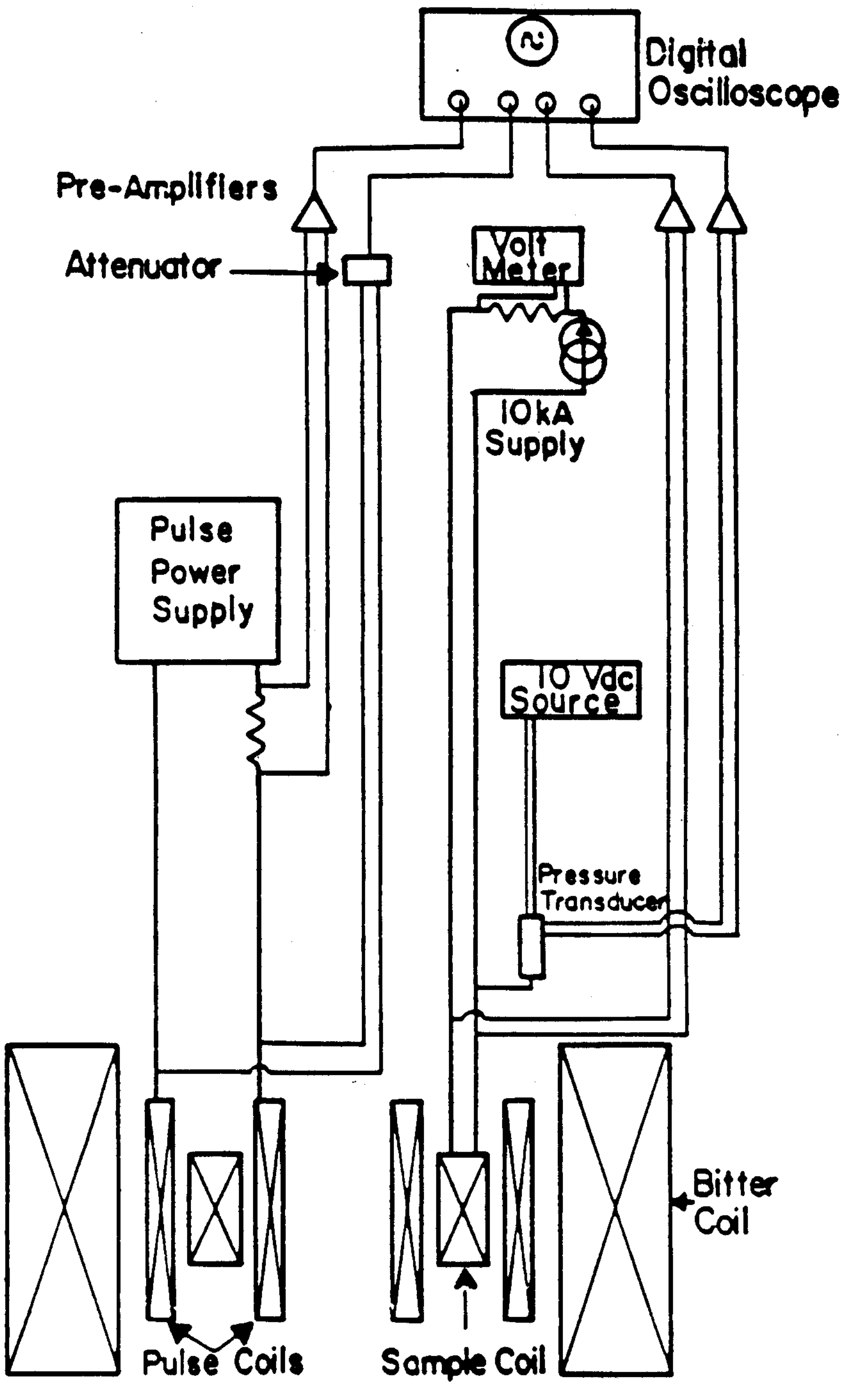

Figure 2. Schematic of the instrumentation and experimental set-up.

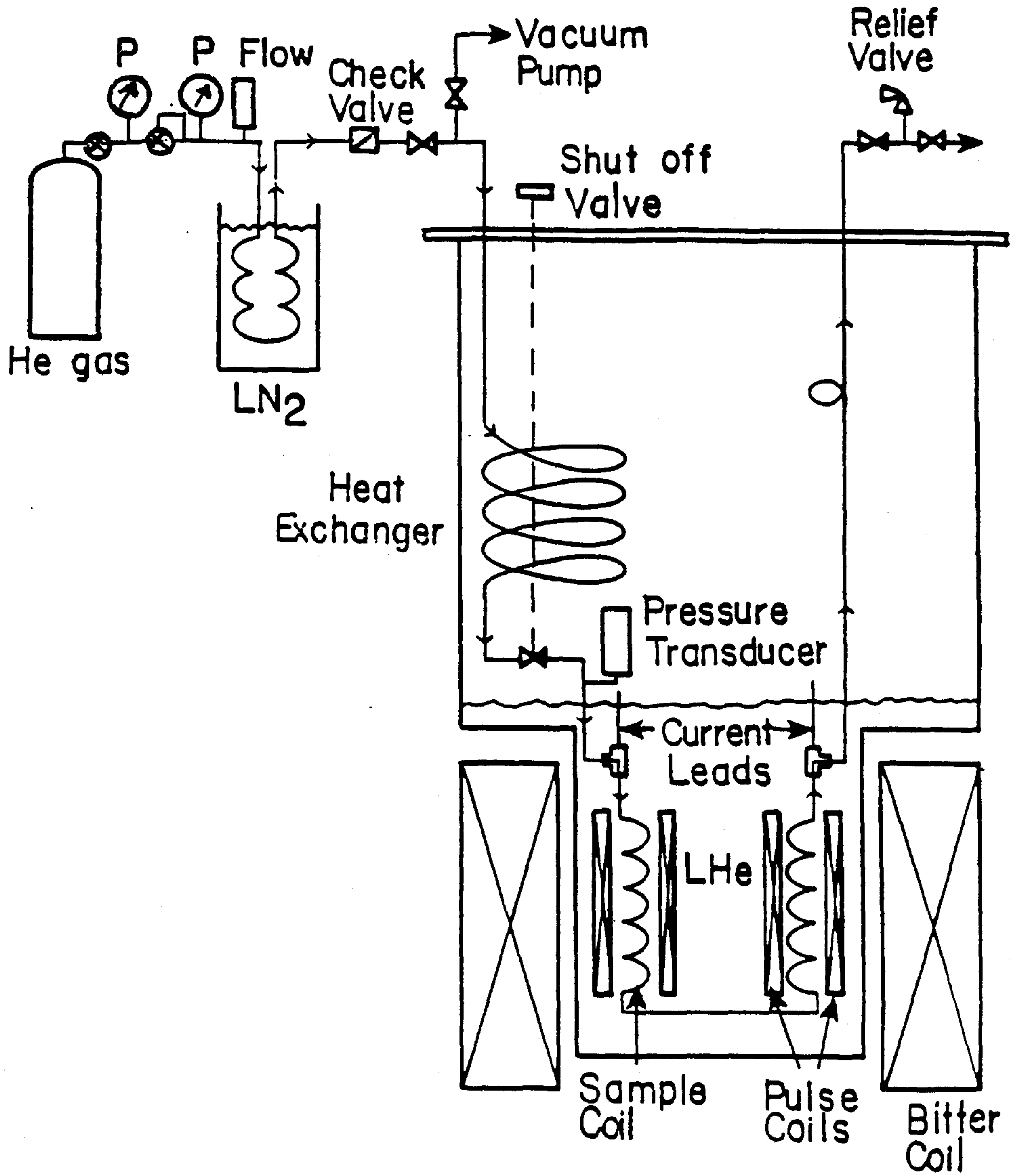

Figure 3. Schematic of the helium flow circuit.

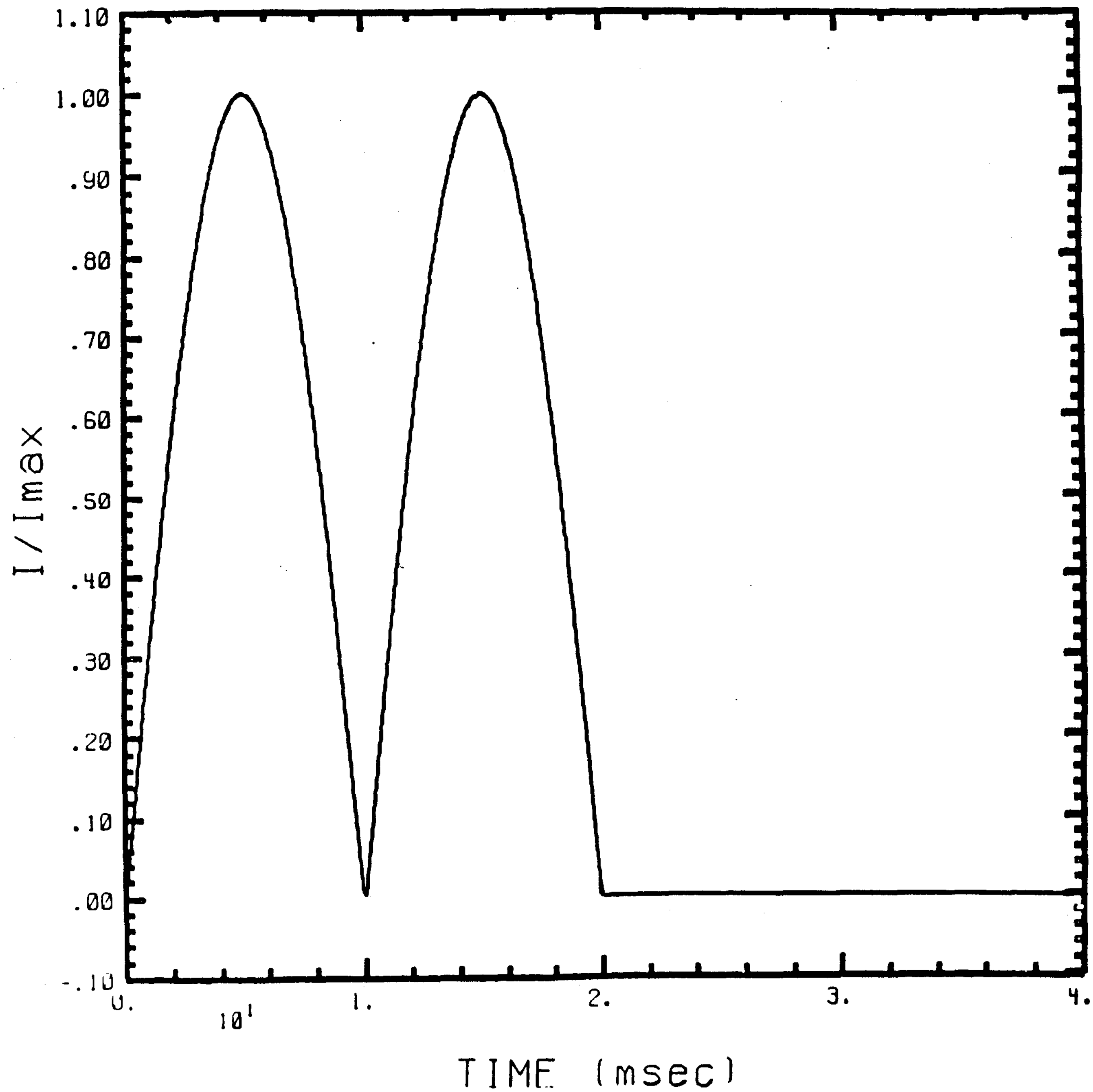

Figure 4. Inductive pulse. The double pulse was used for Nb_3Sn ICCS. A single pulse (Δt = 100 ms) would be used for NbTi.

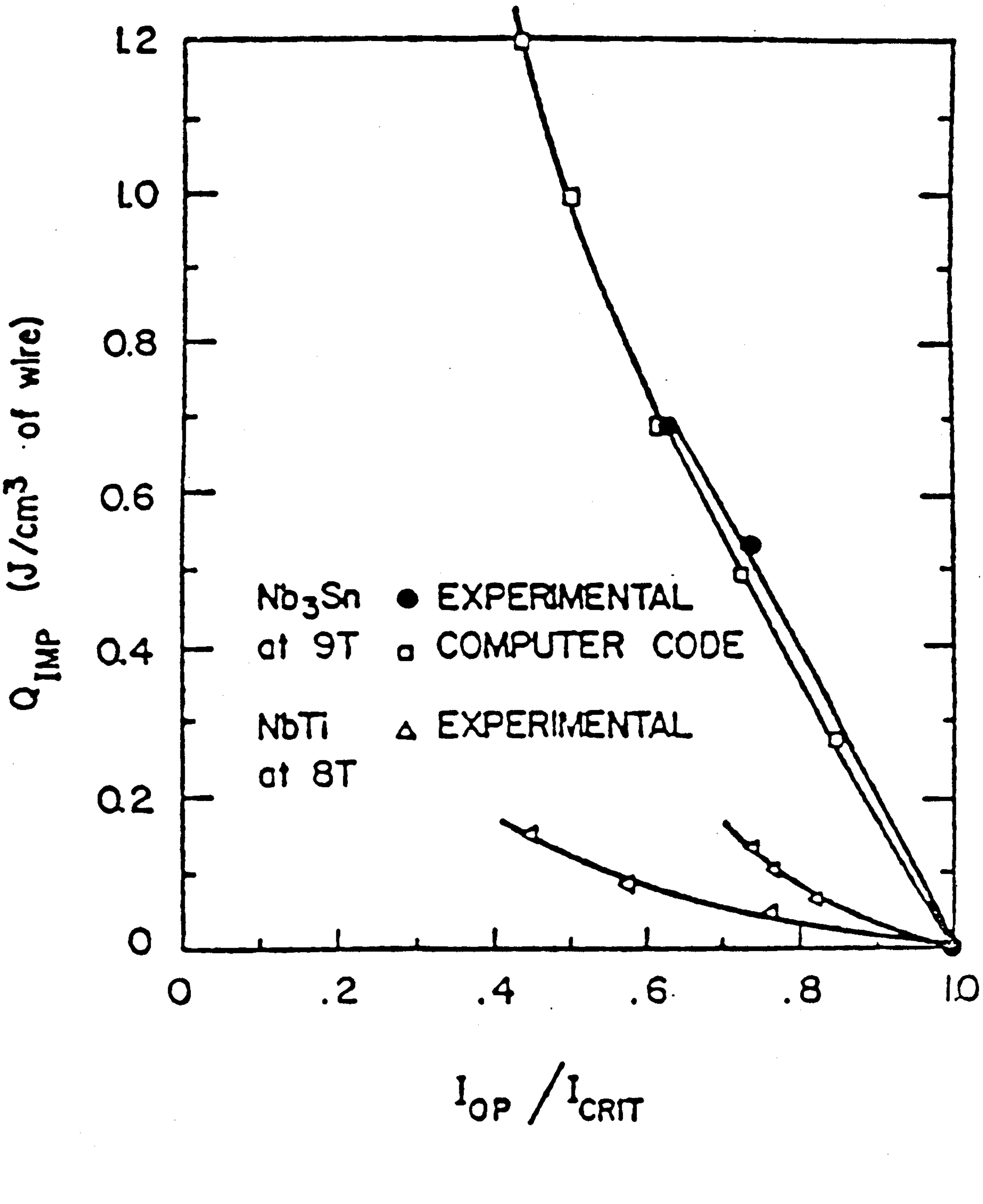

Figure 5. Critical energy input for NbTi and Nb_3Sn cabled superconductors.

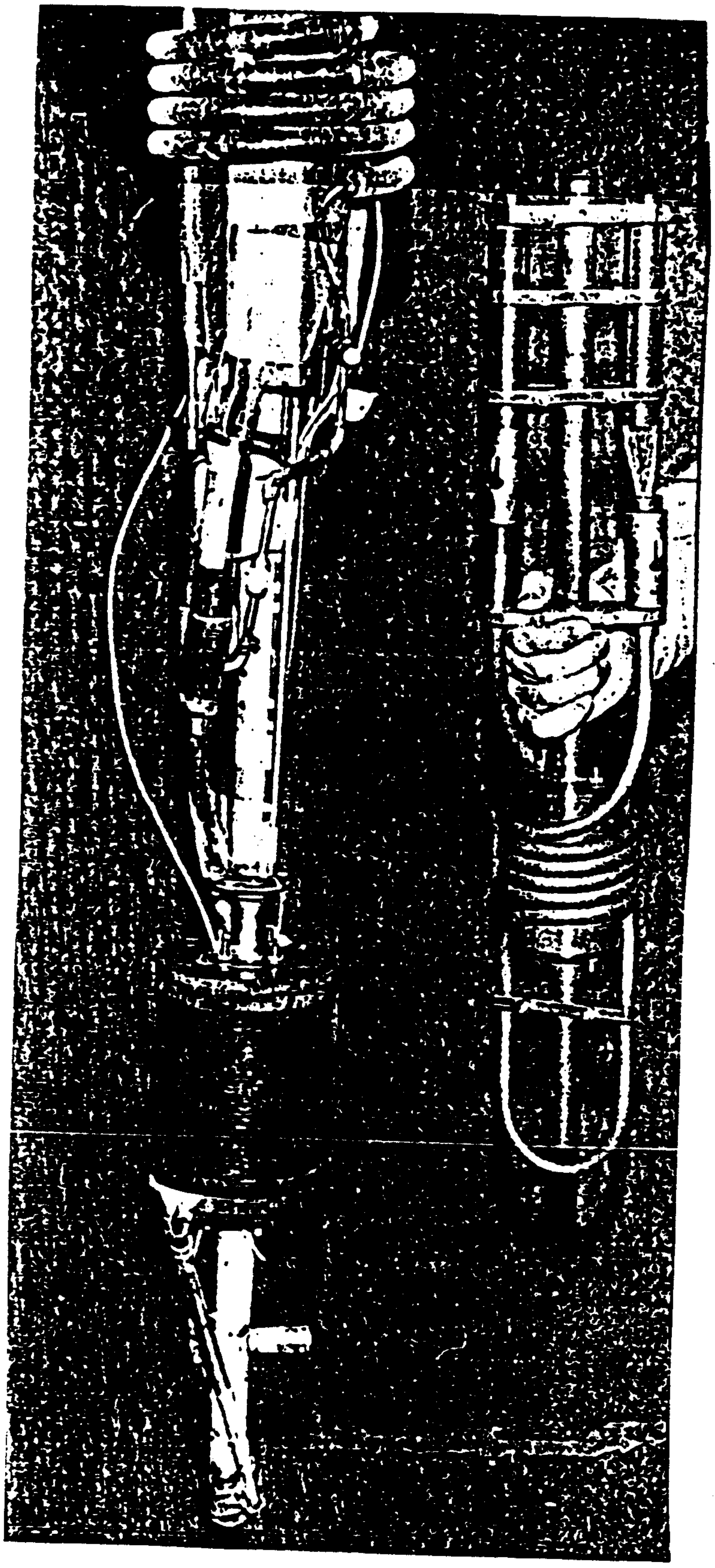

Figure 6. Six-inch-scale test coils: (i) NbTi test coil in pulse coil set – left, and (ii) test coil without pulse coil – right.