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SHORT SAMPLE TEST OF SOME SUPERCONDUCTING WIRES

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We tested some superconducting wires at Fermilab and the test results and some experiences are reported here. Similar tests were also done by other members of Fermilab[1]. The short sample test will be continued in the future.

The present short sample test equipment, which was originally built and used by J.R. Purcell at Argonne for Fermilab 15-foot Bubble Chamber wire, was resurrected recently and used for the reported job. The principle of this system is reported in the paper by J.R. Purcell and H. DesPortes[2].

1. Setup

The superconducting magnet used to provide a magnetic field for the sample wires is an air-core bending magnet. It is mounted vertically and the sample wire is inserted into its center hole. The magnet bore radius is about 1" and its length is about 2 feet. This magnet can go up to 49 kG. The central field value was measured by a calibrated search coil and an integrator. The coil is potted completely with epoxy at the central region, and covered with Vaseline at the ends. Partly due to the inefficient cooling and partly due to the old type wire, its stability is not good, especially at high field. It takes typically 12 minutes to reach 36 kG (250 A) from start and an additional 13 minutes to go up to 47 kG (325 A). Especially in this later period the power supply voltage should be inched up very slowly and carefully. Otherwise the magnet will quench. The Oxford instrument power supply was used to excite this magnet.

The sample is excited through a DC transformer. The primary is a coil of 363 turns and connected to a 10 volt, 100 amp power supply. The secondary is a one-turn coil consisting of a half inch by a tenth inch superconducting wire and a sample wire. The current in this loop is monitored by a pick-up coil and an integrator. Three sample holders were made and intercalibrated.

The sample is usually made out of a 5-foot long wire. The wire is bent at the center and two halves are glued together tightly with epoxy. The end is shaped into a dog-bone shape with an average radius of 3/8 inch. If the sample is not already insulated electronically, glass tape is wrapped around the sample and glued with a thin layer of epoxy. The other two ends are soldered to the corresponding ends of the main secondary coil with 50-50 solder, using copper plates that fit around sample and part of secondary. All pieces are pretinned, clamped together, heated and any spaces are filled with solder.

The sample is placed in a slot of a cylindrical aluminum holder. A stainless steel plate is also placed in the slot and pressed against the sample to hold it still. The sample is made long enough to place both ends outside the magnetic field. Therefore only the central straight section is subject to the strong magnetic field.

With this system we can excite the sample up to 8000 A with the modestly small power supply and small power lead. This is a big advantage of this system. The secondary loop is a closed system and has an inductance L and a resistance R. The resistance comes mainly from the soldering joints. The time constant of the loop is typically 10 to 200 sec, depending mainly on the resistance of the joint and type of wire. This keeps the current changing during measurement. Therefore the detailed observation of the transition is not easy, though not impossible.

The current in the sample is constantly monitored and special attention is paid to when the sample quenches. Also we observed the voltage across both ends of the sample. It gives a voltage spike just before the sample quenches. We can estimate the difference is less than a few percent in current values. The current is usually excited up to the quench value in 5 to 10 sec.

2. Procedure

A sample was measured by increasing its current at certain magnetic fields set by the dipole magnet. The magnitudes of the magnetic field were usually 21.4, 28.6, 35.7, 42.8, 46.5 kG. These values corresponded to the current value of 150, 200, 250, 300, 325 Amp of the power supply of the magnet. At 35.7 kG, the current flow in the sample was reversed and measured both ways. With one sample of MCA wire the sample was rotated mechanically by 90° and the corresponding quench values were measured at four positions of 0°, 90°, 180°, and 270° at 35.7 kG.

In the early stage, the mechanical holder for the sample was not rigid enough and part of the wire moved during excitation and quenched. After both side pieces of the sample wire were glued with BIPAX epoxy, we could avoid this effect.

The resistance of the soldering joints between the sample and the secondary loop wire affected the time constant of the secondary loop. We reduced the resistance by clamping the sample wire between a copper plate and the secondary and soldering it securely, thus providing a bigger cross section of copper at joints. In some trial runs we cut the sample into halves and soldered the ends instead of making a dog-bone shape, but we eliminated it because of extra resistance there.

3. The Effect of Self Field

When excited the sample wire generates a self-magnetic field in addition to the magnetic field due to the dipole magnet. If the average distance of the two wires is d cm, the rough average field on the other wire is $H = I/(5d)$, where I is the current in Ampere through the sample and H is given in Gauss. For $d = 0.254$ cm, $H \simeq 0.79 \times I$, and if $I = 3000$ A, $H \simeq 2.4$ kG, which is about 5% for 50 kG. Its effect is very high at low field, e.g. H_c is 5.5 kG for $H = 14.3$ kG.

Actually the superconducting wire is made of many fine filaments and distributed over some area. The filaments are twisted along the length, so the average distance should be calculated more carefully or maximum field should be considered. But in most cases we just take the distance between the center of two conductors. For the flat BNL wire a little calculation is needed, and the following equation is used:

$$H_V = \frac{1}{5}\frac{I}{W}\log\left(1+\left(\frac{W}{2d}\right)^2\right),$$ where W is the width of the wire.

One important thing is a similar effect happens at the innermost conductor of a layer of coil. The other conductors have cancelling effects from both sides, but the innermost one has only adverse effect from the next one. There is local peak field of 2 - 3 kG due to this effect.

4. <u>The effect of orientation of wire to external magnetic field.</u>

The sample is most stable and gives highest quench current values when the self field is oriented so that its direction is opposite to the external field (called Normal Position). The orientation when the self field adds to the external field, is most unstable and gives lowest values for quenching current (called Reversed Position). The 90° and 270° positions give intermediate values. An example is shown in the data for MCA wire.

5. <u>The Experimental Data</u>

The experimental data are listed in the table and shown in Figs. 1 and 2. The external magnetic field is given by H. The average correction field due to the transport current through a sample is shown by H_c. The corrected field in the sample is denoted by $H_{corrected}$.

There is some range in the quench current value at a given field value and the maximum quench current is given as I_q. J_c is calculated from that value and the cross-sectional area of superconducting material.

We tested three MCA wires. They are solid wires with a cross section of 0.150" by 0.075". MCA-1 is not prekeystoned. MCA-2 and MCA-3 are prekeystoned, and show almost the same data. MCA-3 is a sample for Magnet #9. I_q for MCA-1 is lower by about 12% than others. This difference may be due to prekeystoning process or some other effect. MCA-1 had an extra solder joint.

The BNL wire is a thin but wide braided wire and one used for a model magnet of ISABELLE. The model magnet's operating current is 3780 A at 45 kG. The measured I_q is higher than that by about 200 A. Its data are very stable and show a very small range of quench value. Supercon-1 is the sample wire for Mag #6 A. Supercon-2 is actually the average value of seven samples for Magnet #6 C. The variation among them was fairly small so only the averaged values are given. I_q for Supercon-2 is lower by 11% than that of Supercon-1. They are cables of seven strands, which are bonded together with solder. With this structure it is hard to make a good joint. That is the reason why the time constants are low.

Two kinds of Furukawa wires are tested. They are three element conductors using cupro-nickel, and are rectangular solid ones. Furukawa-2 (Type B) is better than Furukawa-1 (Type A), and may be better than Supercon-2. But it is not as good as its company data, which says I_q is 3840 A at 50 kG. This discrepancy may be due to the difference in the measurement method. Furukawa wires have lowest slopes in I-H curves. Type A has a cupro-nickel outside sheath, which makes the time constant very low. It may be necessary to scrape it off to make a good joint.

The value of J_c, which is current density in superconducting material, and effective current density I_e in conductors are listed below. BNL wire has the highest I_q value, but its I_e is rather the lowest.

Wire	$H_{corrected}$ (kG)	J_c (kA/cm^2)	Area (cm^2)	I_e (kA/cm^2)
MCA-3	44.0	135	0.072	45
BNL	44.2	150	0.12	33.5
Supercon-1	43.4	130	0.072	41.4
Supercon-2	44.5	114	0.072	36.5
Furukawa-2	44.3	121	0.070	41.6

Acknowledgement

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References

1. B.P. Strauss and D.F. Sutter, Private communications
2. J.R. Purcell and H. DesPortes, Rev. Sci. Instrum., 44, 295 (1973)

Data

MCA-1 June 12, 1974

Cross Section .38x.19 cm Area .072 cm^2 d .26 cm

Normal to SCW 2:1

H(kG)	Posi	I_q(amp)	J_c(A/cm^2)	τ(sec)	Range(v)	H_c(kG)	$H_{corrected}$	Comments
14.3	Nor	7190	3.00×10^5		8.6-11.8	5.5	8.8	Not Prekeystoned
21.4	Nor	5970	2.49×10^5		7.2-9.8	4.6	16.8	1st Sample, used two pieces of wire with solder joint instead of one piece with loop
28.6	Nor	4750	1.98×10^5		5.5-7.8	3.7	24.9	
35.7	Nor	3840	1.60×10^5		5.3-6.3	3.0	32.7	
35.7	Rev	3230	1.35×10^5		4. -5.3	2.5	38.2	
35.7	90°CW	3350	1.40×10^5		5.3-5.5	2.6		
35.7	90°CCW	3290	1.37×10^5		4.9-5.4	2.5		

MCA-2 August 9, 1974

Cross Section .38x.19 cm Area .072 cm^2 d .26 cm

Normal to SCW 2:1

H(kG)	Posi	I_q(amp)	J_c(A/cm^2)	τ(sec)	Range(v)	H_c(kG)	$H_{corrected}$	Comments
21.4	Nor	6560	2.73×10^5	126	8.4-9.3	5.1	16.3	
28.6	Nor	5430	2.26×10^5	117	7.4-7.7	4.2	24.4	Prekeystoned
35.7	Nor	4580	1.91×10^5	119	6.1-6.5	3.5	32.2	One piece of wire with loop
35.7	Rev	3950	1.65×10^5	183	5.2-5.6	3.0	38.7	
42.8	Nor	3670	1.53×10^5	125	5.0-5.2	2.8	40.0	
46.5	Nor	3240	1.35×10^5	131	4.4-4.6	2.5	44.0	

MCA-3 Start of #29 for Magnet #9 August 10, 1974

Cross Section .38x.19 cm Area .072 cm^2 d .26 cm

Normal to SCW 2:1

H(kG)	Posi	I_q(amp)	J_c(A/cm^2)	τ(sec)	Range(v)	H_c(kG)	$H_{corrected}$	Comments
21.4	Nor	6490	2.70×10^5	176	7.7-9.2	5.0	16.4	
28.6	Nor	5360	2.23×10^5	190	6.4-7.6	4.1	24.5	Prekeystoned
35.7	Nor	4440	1.85×10^5	162	5.8-6.3	3.4	32.3	
35.7	Rev	3810	1.59×10^5	164	5.2-5.4	2.9	38.6	
42.8	Nor	3670	1.53×10^5	177	5.0-5.2	2.8	40.0	
46.5	Nor	3240	1.35×10^5	182	4.5-4.6	2.5	44.0	

BNL July 4, 1974

Cross Section* 1.9x.064 cm Area .12 cm^2 d .10 cm

Normal to SCW 1.25:1

H(kG)	Posi	I_q(amp)	J_c(A/cm^2)	τ(sec)	Range(v)	H_c(kG)	$H_{correct}$	Comments
28.6	Nor	6210	2.32×10^5	185	10.1-10.2	2.2	26.4	
35.7	Nor	5180	1.93×10^5	65	8.4-8.5	1.9	33.8	Very stable
35.7	Rev	4870	1.82×10^5	86	7.9-8.0	1.8	37.5	
42.8	Nor	4320	1.61×10^5	96	7.0-7.1	1.6	41.2	
45.7	Nor	4020	1.50×10^5	78	6.5-6.6	1.5	44.2	

*Loose braid actually 186 wires each with .008 inch diameter.
Area of cross section of wire is .0603 cm^2.

Supercon-1 At end of 1st spool June 22, 1974

Cross Section** .19x.38 cm Area .072 cm^2 d .26 cm

Normal to SCW 1:1

H(kG)	Posi	I_q(amp)	J_c(A/cm^2)	τ(sec)	Range(v)	H_c(kG)	$H_{corrected}$	Comments
28.6	Nor	4380	$1.90x10^5$	26	7.0-7.2	3.4	25.2	
35.7	Nor	3720	$1.62x10^5$	26	6.0-6.1	2.9	32.8	
35.7	Rev	3350	$1.46x10^5$	25	5.1-5.5	2.6	38.3	
42.8	Nor	3170	$1.38x10^5$	28	5.1-5.2	2.4	40.4	
45.7	Nor	2980	$1.30x10^5$	28	4.7-4.9	2.3	43.4	

Supercon-2 Ave. of seven samples for Magnet #6C August 12, 13 & 14, 1974

Cross Section** 19x.38 cm Area .072 cm^2 d .26 cm

Normal to SCW 1:1

H(kG)	Posi	I_q(amp)	J_c(A/cm^2)	τ(sec)	Range(v)	H_c(kG)	$H_{corrected}$	Comments
21.4	Nor	4800	$2.09x10^5$	22	6.1-6.6	3.7	17.7	
28.6	Nor	3980	$1.73x10^5$	23	5.1-5.5	3.1	25.5	Seven samples are prepared the same (by manufacturer and at Fermilab). In all cases the results were very close.
35.7	Nor	3350	$1.46x10^5$	24	4.3-4.6	2.6	33.1	
35.7	Rev	3040	$1.32x10^5$	26	3.8-4.2	2.3	38.0	
42.8	Nor	2840	$1.23x10^5$	24	3.7-3.9	2.2	40.6	
46.5	Nor	2630	$1.14x10^5$	24	3.4-3.6	2.0	44.5	

**Cable of seven strands. Area of SCW is .023 cm^2.

Furukawa-1 Type A August 31, 1974

Cross Section .19x.38 cm Area .072 cm^2 d .26 cm

Normal to SCW 1.81:1

H(kG)	Posi	I_q(amp)	J_c(A/cm^2)	τ(sec)	Range(v)	H_c(kG)	$H_{corrected}$	Comments
21.4	Nor	4160	$1.62x10^5$	13	5.2-5.9	3.2	18.2	
28.6	Nor	3530	$1.38x10^5$		4.5-5.0	2.7	25.9	This sample and the next were reported by the manufacturer to have high quench currents. In our tests the quench values had more variation.
35.7	Nor	3240	$1.26x10^5$	15	4.4-4.6	2.5	33.2	
35.7	Rev	2890	$1.13x10^5$	15	4.0-4.1	2.2	37.9	
42.8	Nor	2680	$1.05x10^5$	14	3.5-3.8	2.1	40.7	
46.5	Nor	2610	$1.02x10^5$		3.4-3.7	2.0	44.5	

Furukawa-2 Type B August 31, 1974 d .26 cm

Cross Section .19x.37 cm Area .070 cm^2

Normal to SCW 1.91:1

H(kG)	Posi	I_q(amp)	J_c(A/cm^2)	τ(sec)	Range(v)	H_c(kG)	$H_{corrected}$	Comments
21.4	Nor	4620	$1.92x10^5$	67	5.0-6.2	3.6	17.8	
21.4	Rev	4170	$1.73x10^5$	72	5.3-5.6	3.2	24.6	
28.6	Nor	3950	$1.64x10^5$		4.8-5.3	3.0	25.6	
35.7	Nor	3500	$1.46x10^5$		4.4-4.7	2.7	33.0	
35.7	Rev	3200	$1.33x10^5$		4.0-4.3	2.5	38.2	
42.8	Nor	3060	$1.27x10^5$		3.7-4.1	2.4	40.4	
46.5	Nor	2910	$1.21x10^5$	76	3.5-3.9	2.2	44.3	

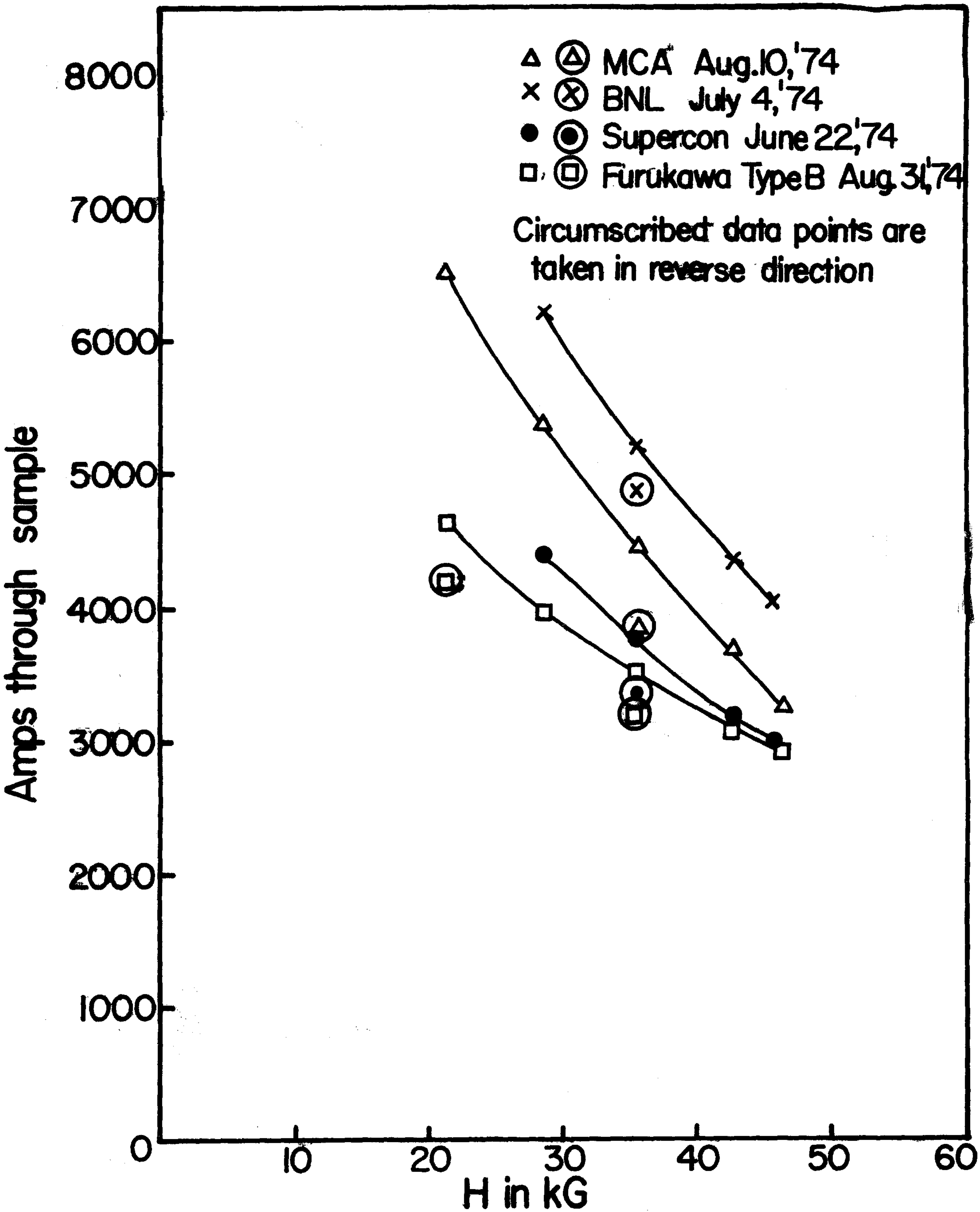

Fig. 1 Quench Current vs External Field H

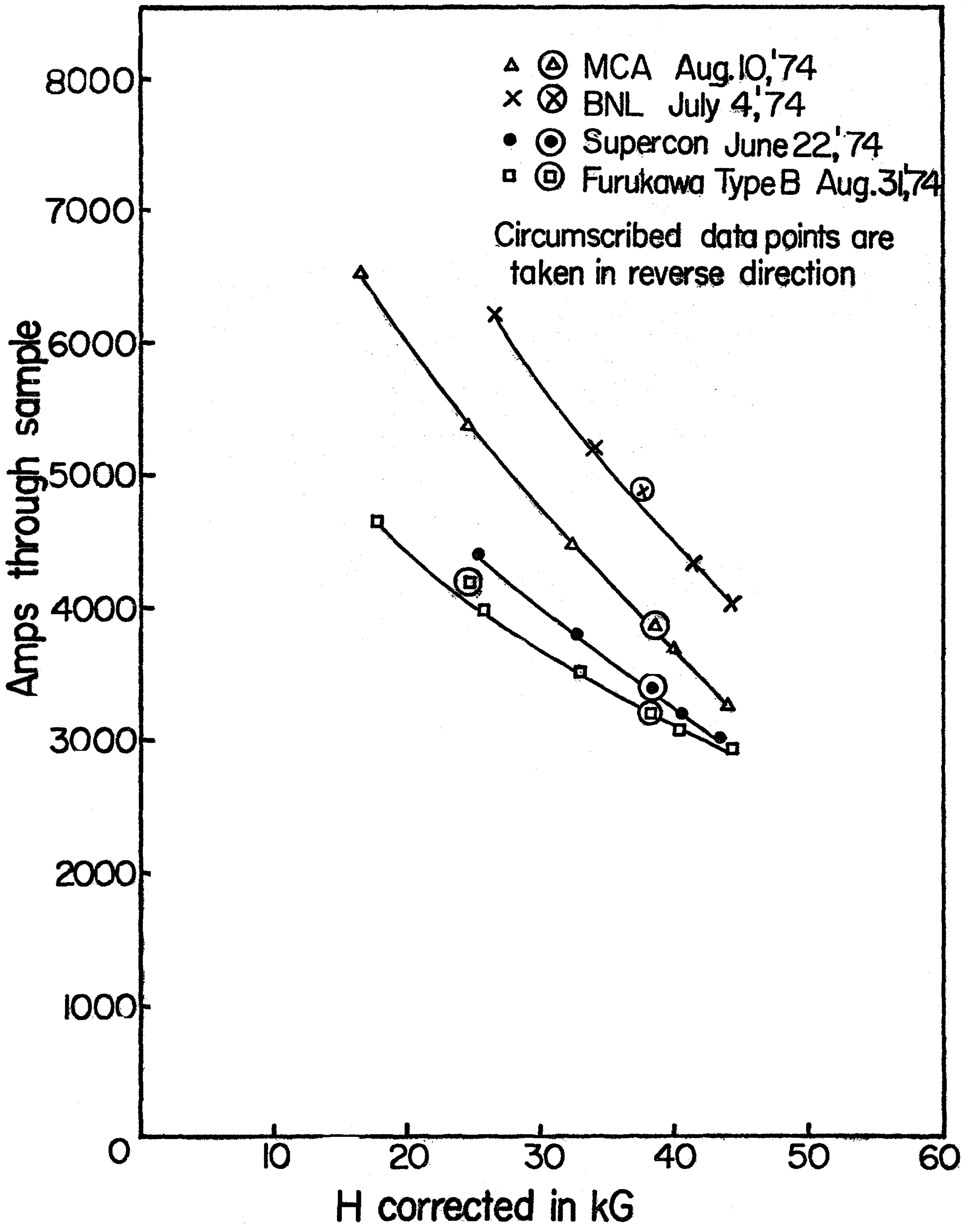

Fig.2 Quench Current vs Corrected Field