national accelerator laboratory

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SHORT SAMPLE TEST DATA V

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The final configuration for the wire for the Energy Saver/Doubler magnets has been determined. This is an unsoldered cable made up from 23-strands. The nominal size of the wire is 50 by 300 mils, but actual size may vary upward in one or both dimensions by one to eight mils. Each strand is 27 mils in diameter and is tinned with Stay Bright solder. We have been testing this type of cable since last fall. The data on some old cable tests and some recent ones are described separately.

I. Set-Up

The current range for testing 23-strand cable is from 4000A to 6000A in an external field of 50 to 60 kG. The magnetic force on a sample during test is much stronger than that previously reported for smaller samples.[1] The 23-strand cable is not soldered therefore the individual strands are not held rigidly. The cable is turksheaded into a rectangular shape thus increasing its rigidity and packing factor.

For the above reasons it was necessary to make a new stronger sample holder as shown in Fig. 1. The radius of curvature at the top is 1-1/8 inches. The total estimated force on the cable is 322 lbs at 50 kG with 5000A current. The direction of the force is normal to the plane of a sample and perpendicular to the axis of the solenoid coil. After both ends of a cable sample are soldered to the individual power leads the sample is stretched uniformly using two tensioning bolts. The optimum torque is about 80 in-lb on 3/8 inch diameter 16 threads/inch bolts. The estimated force on the cable is 23 lbs at each end. Both ends of a sample are soldered to the power lead over six inches on a flat machined copper surface. After being assembled and stretched the sample is coated with Vaseline to prevent any movement between strands.

We experienced some instability when testing one cable. With that wire we could not get reasonable stable data until we soldered the sample all along the length. With some cables we measured short sample data at different ramp speeds of the current through the sample. The resulting data are shown in Fig. 2. Due to heating in the leads when they are carrying more than 4000A we got smaller values for slower rates. Reasonable values for our operation were around 800A/sec and the liquid helium level should be roughly 12 inches above the top of the joint.

Another type of sample holder was made for testing single strand wires as shown in Fig. 3. With this we can test three samples on one sample holder. This helped to speed up testing time and reduced helium usage.

II. Data

Single strands from five companies and cables from four companies have been tested. Two of the companies have not made single strands up to specifications and they have not made any cable. One other company sent a sample of cable but has never sent any single strands.

For the three companies which have supplied us with both single strand and 23-strand cable, the single strand current density is always equal to or higher than that of the cable. The current density in the cable is from 3% to 13% lower than the average of that in the single strand. Some exceptionally good strands are as much as 20% higher than the average single strand value. There are very few exceptionally bad strands.

For single strands a current density in the superconductor of 185 kA/cm^2 in a field of 5T is specified. The wires from the three companies have performed at 50 kG as follows:

Single Strand of 27 Mil Dia.

	Airco	MCA	IGC
Range in J_c (kA/cm^2)	203-160	227-154	230-170
Average J_c (kA/cm^2)	178	190	198
Average I_c (A)	235	250	260

Cables of 23-Strands, 300 Mil x 50 Mil

	Airco	MCA	IGC
Range in J_c (kA/cm^2)	168-154	189-170	196-171
Average J_c (kA/cm^2)	163	177	178
Average I_c (A)	4950	5350	5400

All of the above wires are supposed to be made with identical materials, but information from the manufacturer indicates slight differences, particularly with regards to copper to superconductor ratio. This should be 1.8:1 but varies up to 1.9:1.

Another company, Supercon, has only submitted single strands of wire with a copper to superconductor ratio of 1:1. These have had critical current densities of about 180 kA/cm^2. A single 23-strand cable from Furukawa has been tested and the data on it, with a bias field of 5T, were critical current-4790A and critical current density-184 kA/cm^2. The detailed data are shown in Table I. This data is typical of the initial 23-strand wires. Typical short sample curves are shown in Figs. 4 and 5. In all of these data actual values of I_c and J_c are given at quench current where the resistivity is less than 10^{-12} ohm-cm. Single strands show current sharing less than 2% and 23-strand cables less than 1%.

A resistivity ratio was measured for only one cable. The ratio of 300°K to 10°K was 43. This is the same value as was found earlier for 17-strand cables when many samples were tested.[2]

III. Self Field Effect

As mentioned in the previous section the single strands usually have a higher current density by 3 to 13% than that of 23-strand cables made from these strands. This phenomenon is partially due to the self field of this wire.

A single strand has a diameter of 27 mil and the self field at the surface is given by the following equation:

$$H_S = \frac{I}{5r}$$

where I = 240A, r = 0.0343 cm, and H_S = 1.4 kG

A 23-strand cable has a rectangular overall dimension of 0.3 inch x 0.05 inch. The self field was calculated using a simple program.[3] The self field value for each strand is shown in Fig. 5 for a current of 240A/strand where the cable was assumed to be an infinitely long straight wire. When the external field is perpendicular to the wide surface of the cable, which is the case for out test set-up, the maximum self field is 5.1 kG at one side of the cable in that field direction. If we assume the current is not being transferred from one strand to the other the maximum current is determined by that field value. The cable is twisted so all 23-strands are under that field at some point.

The difference in the field values between a 23-strand cable and single strand is 3.7 kG. A typical 23-strand cable shows a decrease of 2.4%/kG around 50 kG in the short sample test data as seen in Fig. 4. The increase of 3.7 kG in field value gives 8.7% decrease in short sample test data. This value is an estimated upper value and agrees with the observed values. A similar effect due to opposing currents was previously reported.[4]

IV. Recent 23-Strand Cables

The first samples of cable received from MCA and IGC had current densities of 185 kA/cm^2 or greater at 50 kG. The most recent samples from these companies have been in the range of 170 to 175 kA/cm^2. The recent Airco cable is about 3-5 kA/cm^2 lower than initial samples with the exception of one keystoned sample which had a current density of only 154 kA/cm^2. Their data are listed in Table II. Recent single strands have also showed a decrease in current density but in most cases it has not been as significant ($\lesssim$5%) as that in the cables.

A single sample of cable with a copper-nickel can and an interfilament matrix of copper has been received from Airco and tested. Single strands had a nominal 27 mil diameter and a ratio of CuNi:Cu:S.C.::0.7:1.1:1.0. The current density was approximately 80% of the standard Airco cable.

V. Test of Untwisting 23-Strand Cables

By untwisting the wire a half pitch it is possible to easily move from the inside to the outside layer when winding two layer coils. This test was done at the request of G. Biallas and K. Koepke.

Six adjacent samples from a single reel were tested. Two of these were used as controls. In the other four the wire was untwisted over about a 5 cm length.

Only one of the four samples did not show erratic behavior after untwisting; however, after soldering all samples quenched consistently within a few percent of the control samples. Untwisting causes no damage to the wire but it makes containment very difficult. The erratic behavior was due to motion between the strands causing early quenching. By soldering, the strands were held in place relative to each other and containment of the total cable was relatively easy.

VI. 20 Mil Strands and Cable Made From Them

About 70 single strand samples of wire with a 20 mil diameter were tested. The wires are made by IGC and are identical to the 27 mil cables but have an additional drawing from 27 to 20 mils. I_C averaged about 145A and J_C about 205 kA/cm^2 at 50 kG. The variation in J_C was from 190 to 228 kA/cm^2. This is better than the 27 mil strands which have been received recently.

Three cables made from these 20 mil diameter strands have also been tested. The cables are made from 17-strands and are about 33x197 mils. At 50 kG they range in I_C from 2040A to 2170A and in J_C from 169 kA/cm^2 to 179 kA/cm^2. This gives an average value of about 85% of the single strand current, but J_C is a little better than our recent IGC 23-strand cable.

References

[1]M. E. Price and R. Yamada, Short Sample Test of Superconducting Wire, IEEE Tran. Nucl. Sci., NS-22, 1190 (1975).

[2]M. E. Price et al., Short Sample Test Data IV, TM-587, June 26, 1975.

[3]Program for this calculation was written by J. E. Pachnik.

[4]R. Yamada et al., Short Sample Test of Some Superconductin re, TM-523, September 30, 1974.

TABLE I

Characteristics of 23-Strand Cables Used for 1-Foot Model Magnets

	Airco	MCA	IGC	Furukawa
Fermilab ID No.	314	309	303	302
Reel No.	84	82	80	81
Size (mil)	51x303	51x303	51x308	50x301
Strand Dia (mil)	27	26.8	26.8	25
Cu/Sc Ratio	1.8:1	1.8:1	1.85:1	1.8:1
Filament No/Strand	2200	2200	2200	2300
Filament Size (μ)	8.7	8.7	8.7	7.9
Magnet No.	E1-20	E1-17	E1-19	E1-18
At 50 kG				
I_c (A)	4850	5580	5570	4790
J_c (kA/cm^2)	162	187	190	184
J_{eff} (kA/cm^2)	49	56	55	49
At 60 kG				
I_c (A)	3930	4560	4520	3950
J_c (kA/cm^2)	131	153	154	152
J_{eff} (kA/cm^2)	39	46	45	41
Resistivity Ratio			43	

TABLE II

Typical Recent Wire Data of 23-Strand Cables

	Airco	MCA	IGC
Fermilab ID No.	347	355-B	338-C
Reel No.	95	93	91-C
Size (mil)	50x302	52x308	52x303
At 50 kG			
I_c (A)	4860	5230	5200
J_c (kA/cm^2)	160	172	172
J_{eff} (kA/cm^2)	50	51	51
At 60 kG			
I_c (A)	4010	4330	4240
J_c (kA/cm^2)	132	143	140
J_{eff} (kA/cm^2)	41	42	42

	Airco-CuNi
Fermilab ID No.	320
Reel No.	88
Size (mil)	51x303
At 50 kG	
I_c (A)	3820
J_c (kA/cm^2)	128
J_{eff} (kA/cm^2)	38
At 60 kG	
I_c (A)	3160
J_c (kA/cm^2)	106
J_{eff} (kA/cm^2)	32

FERMILAB ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
11			

SUBJECT: 23 STRAND CABLE SAMPLE HOLDER

NAME: B. Fuller / B.K. Barger

DATE: 7/8/76

REVISION DATE:

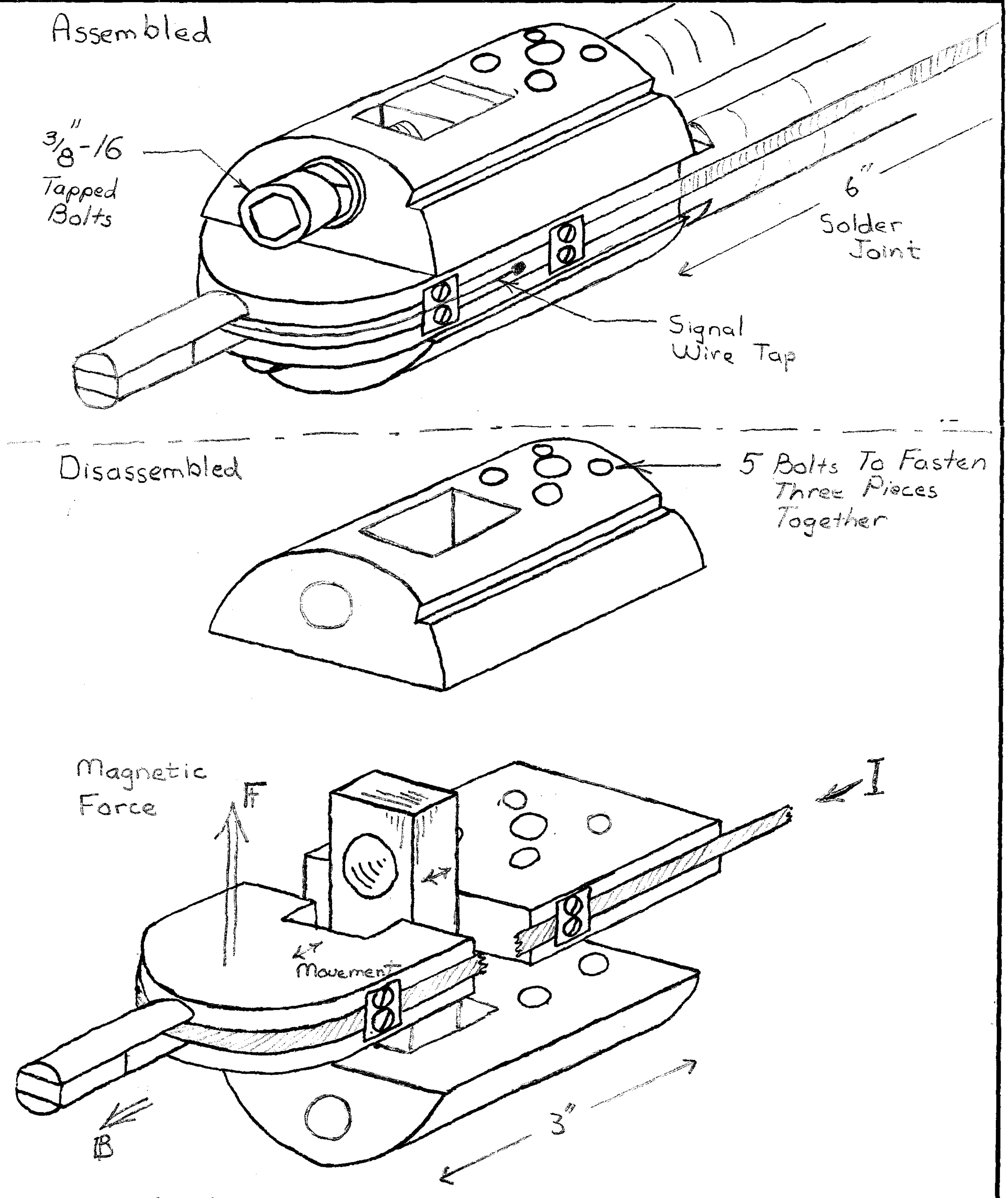
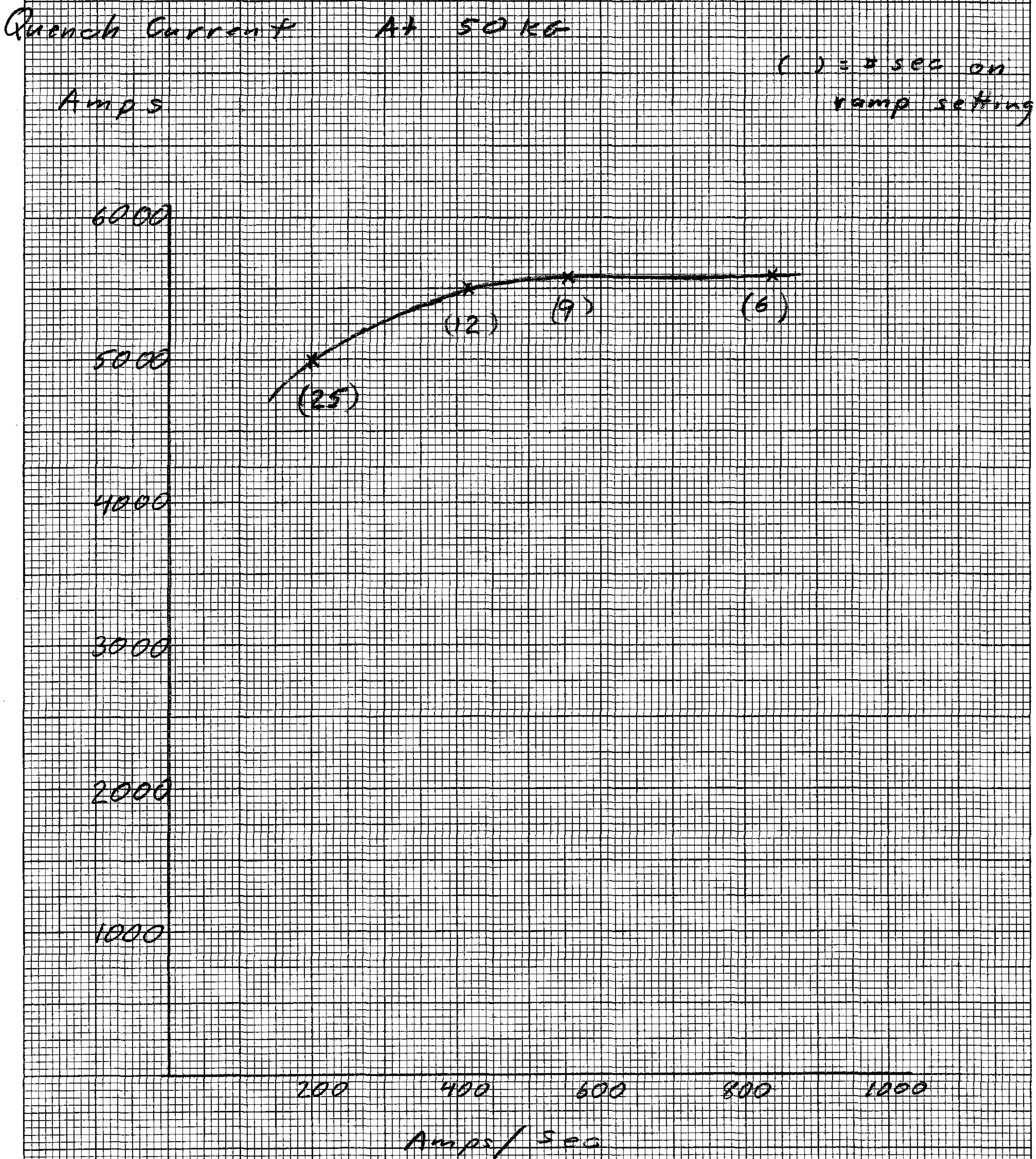


Fig. 1 Short Sample Test Holder For 23 Strand Cable

Feb 5, 1976

Fig. 2 Ramp Rate vs. Quench Current

IGC 23 strand wire



FERMILAB **ENGINEERING NOTE**

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
11			

SUBJECT: Three Single Strand Sample Holder

NAME: B. Fuller / M.E. Price

DATE: 7/8/76

REVISION DATE:

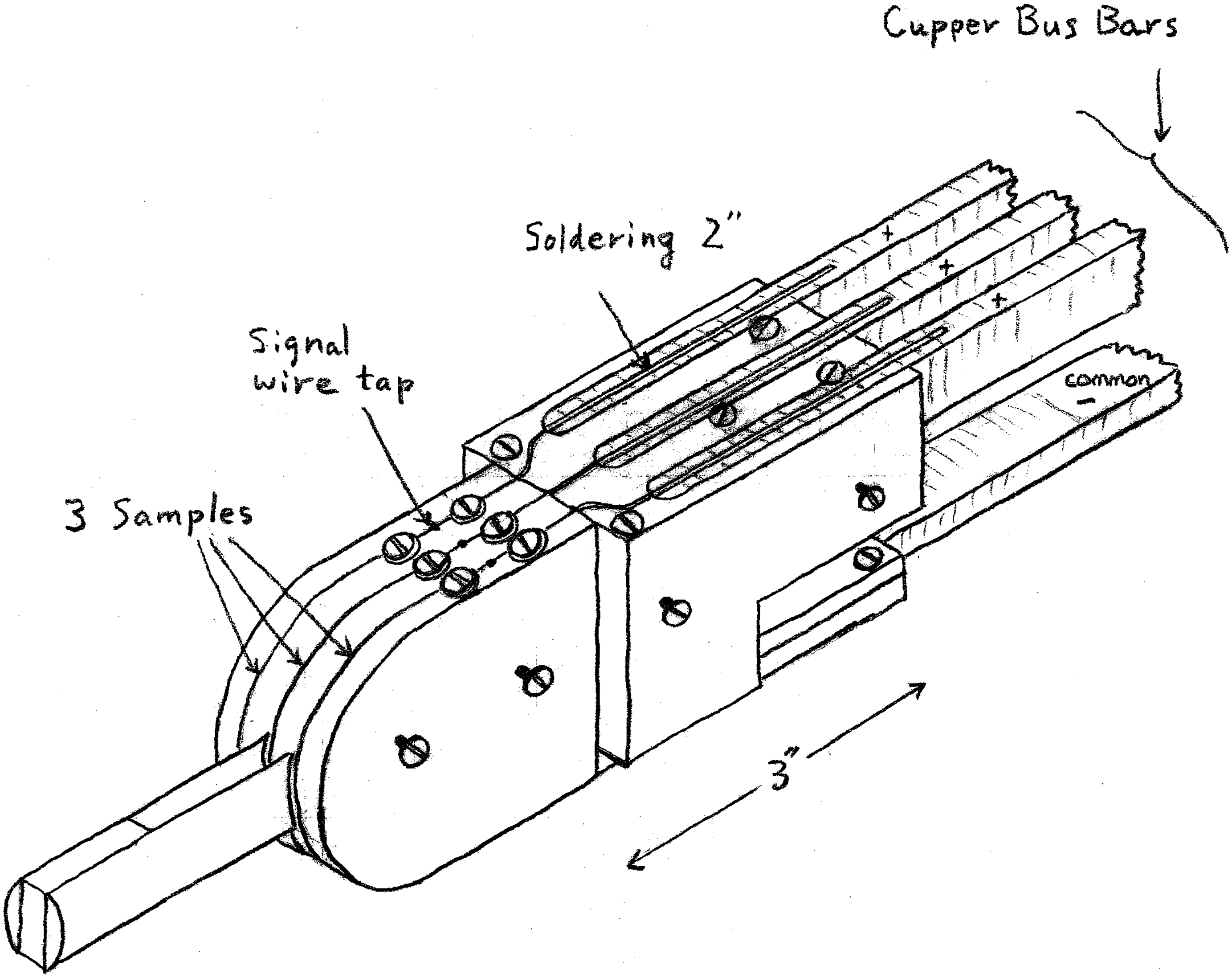
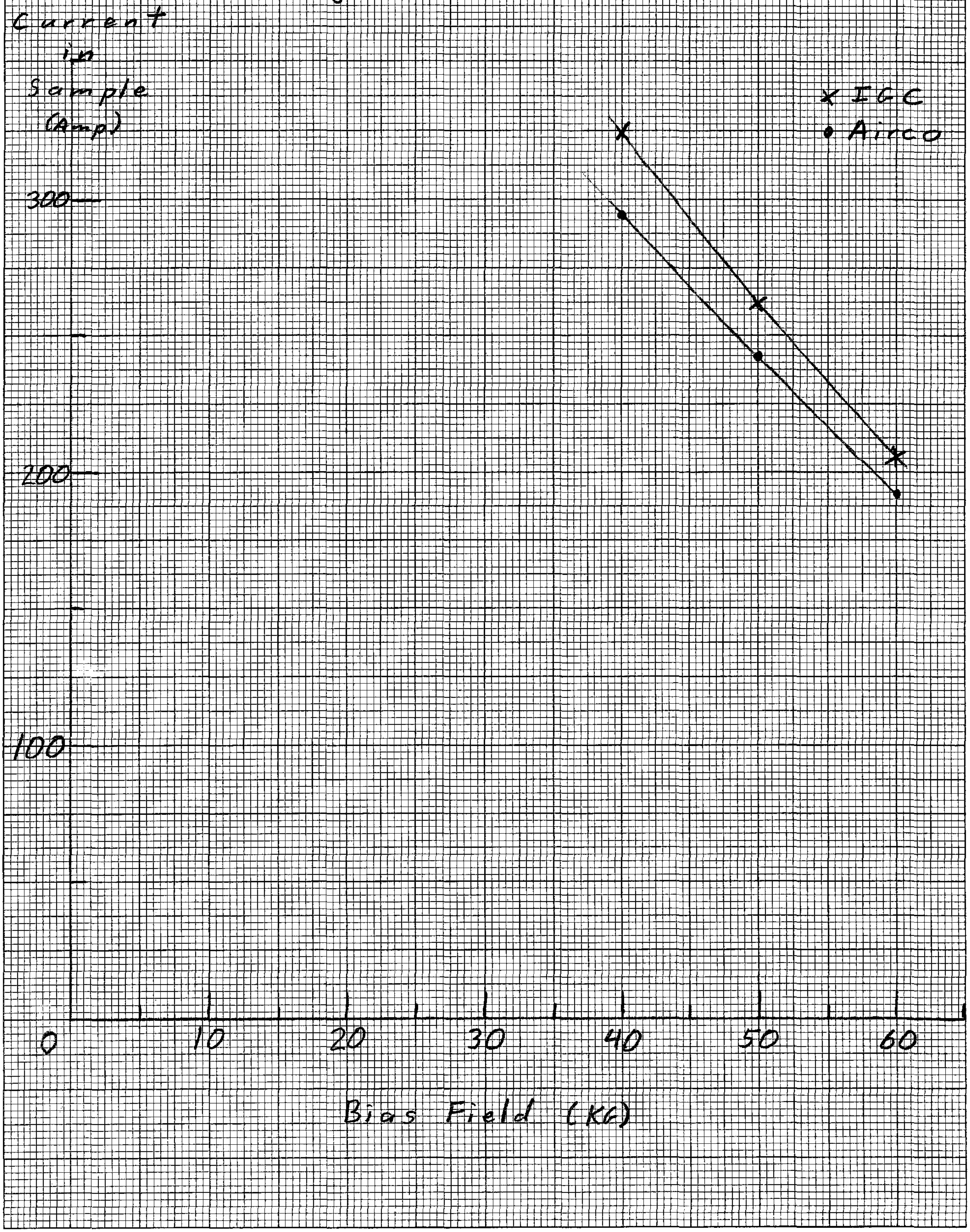


Fig 3 Short Sample Test Holder For Three Single Strand

Fig. 4 Short Sample Data of Single Strand Wire



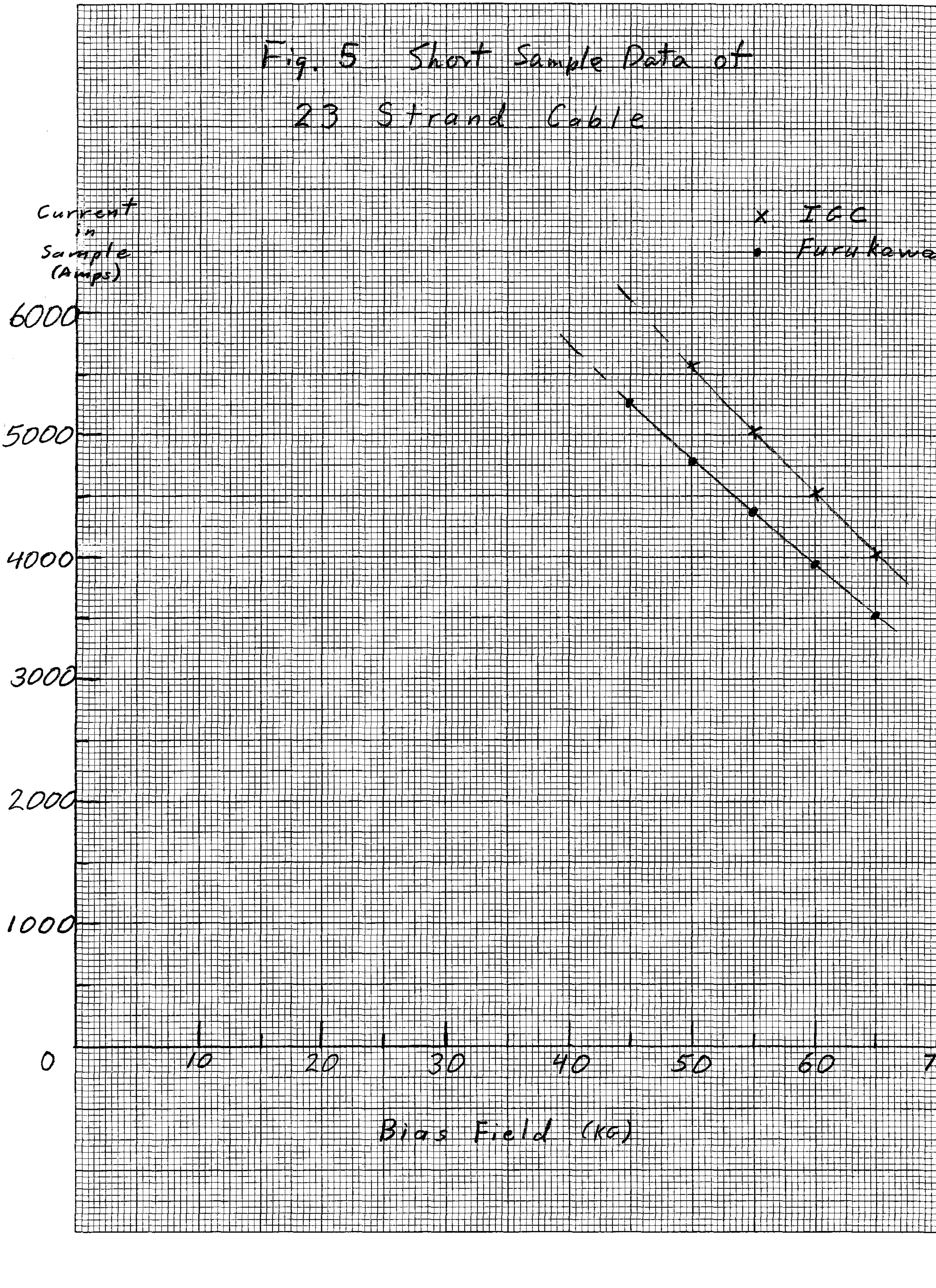


Fig. 5 Short Sample Data of
23 Strand Cable
Current in Sample (Amps)
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50
60
70
Bias Field (KG)
x IGC
• Furukawa

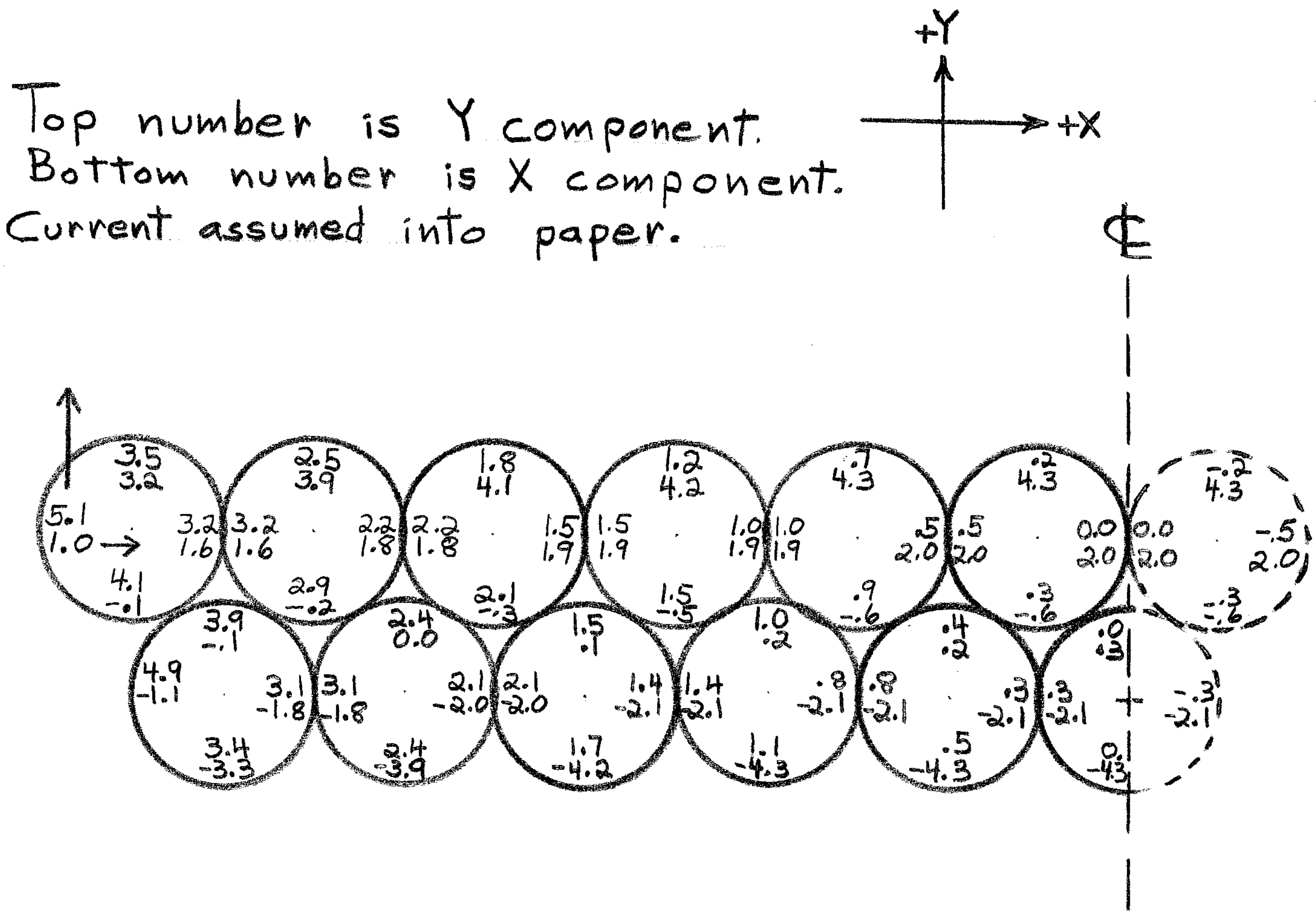


Fig. 6 Distribution of Self Field for 23 Strand Cable

Field strength at four points / strand is shown. It was calculated with a current of 240 A / strand for infinitely long cable. Unit of Field strength is kG.