national accelerator laboratory

TM-234
0491

COMPLETION OF PROTOMAIN MILESTONE

J. F. Schivell

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In June 1969 it was decided to establish a milestone goal for the Main-Ring Section consisting of building a complete operating accelerator cell in the protomain tunnel and service building. The date set for this milestone was March 20, 1970. The various aspects were actually achieved ahead of schedule:

Magnet installation complete: 6 p.m. March 8

100-BeV excitation: 12 a.m. March 9

200-BeV excitation: 11:50 a.m. March 10

Vacuum: 12:25 a.m. March 13

Controls and Auxiliary Magnets: 5:00 p.m. March 14

Many important lessons were learned from this work. It is the purpose of this report to summarize information gained from the milestone.

I. MAGNETS

A. Cores

A summary of the number of manhours required to stack each core is given in Appendix I. The average number of manhours per core for these first cores was 17-1/2. One lesson learned was that there was

some problem with pressing the stacked core so that the end plates were square. This has been taken care of in the design of the new stacking fixture which is now in use. A small but important point is that it was found that cores, that is half magnets, can be stacked four high without damage. This fact will allow more efficient storage of half cores.

B. Coils

Appendix II is a summary of average manhours for making a magnet inner coil. It was found that the clean-up time for a mold was rather long but the mold must be absolutely clean and free of all bits of resin in order to maintain the dimensional tolerances on the inner conductors. The clean-up time will hopefully be shortened by modifications to the mold. We have also learned that bolt modifications are necessary so that the mold squeezes down properly at all parts of the coil to maintain dimensional accuracy. Potting time will be reduced to an average of 2-1/2 manhours per coil by potting four at one time.

C. Vacuum Chamber

The average time required to weld the vacuum chamber together between two magnets was 4 manhours per weld. This long time was caused largely by offsets between successive vacuum chambers which in turn was caused by the fact that the vacuum chambers had been spliced up from short pieces and tended to be undersized. In the future, chambers will be built from single pieces of tubing and will be built more accurately.

Also, we will have an alignment fixture for magnet feet so that neighboring magnets will line up better. These improvements will make it possible to use our automatic welding machine.

D. Magnet Assembly

This turned out to be easier than we had expected. For one thing, the coils turned out to be very sturdy and could be handled without damaging them simply by picking them up in the middle or by the ends. Appendix III summarizes the manhours for assembling each magnet. A large part of this time was spent in sanding coils to make them fit. When the mold improvements mentioned above are made magnet assembly time will be reduced considerably.

Another problem discovered was difficulty in turning over cores. A special fixture is now being made which will allow this to be done quickly and safely. The design of the magnets requires that bedding resin be used not only inside but also on the ends. We have found that a mold box which fits over the ends will be very useful. We have also found that it might be desirable to put on the coil connection manifolds before curing the magnet.

In working on the quadrupole manifolds two conclusions were reached. One is that making the manifolds of round pipe is much easier and better than making them from square copper conductor. The other is that we decided to change the quadrupole to two parallel water circuits instead of four, thereby, simplifying the end connections a great deal.

E. Magnet Structural Measurements

The vertical deviations from straightness were measured for the eight magnets assembled. While vertical deflection in the magnet core is not in itself critical--it affects only the aperture--a difference in deflection from side to side, resulting in a twist, is serious. The tolerance on twist, or average magnet rotation, for proper accelerator operation is an rms value to 10^{-4} radians. The results of the measurements are given in Appendix IV where the net rotation angle for each magnet is given at the bottom of the graph. From these data it is seen that the mean rotation for the eight magnets is -0.39×10^{-4} radians, while the rms rotation from level is 1.8×10^{-4} radians.

F. Magnet Measurements

Measurement of the gradients in the first few B2 magnets showed very good agreement with calculated gradients at 9 kG and 18 kG. At 400 G (injection field) the measurement was difficult but it appears that the gradient is less than or equal to the estimated gradient. In the first three magnets some unusual effects were noticed in the field shape at low excitation. In the first two it was found that iron contamination in the filling in the bedding epoxy seriously affected the low field quality. In the third it was found that the abnormal permeability in the welded seam of the 304 stainless-steel vacuum chamber also affected the low field quality.

Data on the measured versus calculated ampfactors for a B1 and a B2 magnet is given in Appendix VI. It is seen that even up to the highest field rather good agreement is obtained with the calculations.

Correlations of excitation data (the integral of $Bd\ell$) versus magnet construction for the first four B1 magnets are shown in Fig. 1. In the top chart variation in the core weight is shown plotted against variation in the ampfactor for 18 kG and 22.5 kG. In the lower chart variation in the excitation current at 9 kG is shown with variations in the average air gap.

II. MAGNET INSTALLATION

Nine magnets were installed with the magnet handling vehicle. It took an average of four manhours to install one magnet. In general, the vehicle performed better than expected. Modifications found necessary:

1. Some sort of line-up device to aid in parking the vehicle at the right position
2. Some capacity for lateral movement of magnets for fine positioning of about ± 1 in.
3. Improvement in the lifting cylinders to eliminate downward drift of the magnets during operation
4. Improved magnet grippers for a more secure hold on the magnet. Also grippers designed for handling the quadrupoles.

One more thing learned from the installation was that the wedge jacks need to be modified so that they cannot tip with only one magnet on them.

III. MAGNET POWER AND WATER SUPPLY SYSTEM

At the time of writing, the cell had been pulsed successfully for one hour at 2500 amperes. There are no electrical faults in the magnets or bus system.

A summary of the manhours necessary for installing the power and water distribution system is given in Appendix V. The amount of time was rather large but this was due to a great extent to the fact that this system was a custom-fitted job including parts of the tunnel of different cross sections. It did become clear that this job needs to be well organized and to have as much of the system as possible pre-fabricated. Certain bent pieces in the entrance ways could be made by an outside contractor and the sections of pipe for the tunnel itself need to be cut square and beveled ahead of time. On the other hand, pre-assembled or pre-cut pieces which are too long are hard to handle in the tunnel.

It was also found that it is important to use deoxidized phosphorous or oxygen-free copper pipe. In the part of the tunnel where such copper was used there were no leaks in the weld joints, while in the part where common water-pipe was used numerous leaks were caused by the porosity of the welds. The automatic welding of the 6-in. aluminum water pipes was a success. There was only one leak found and that was in an end plate. Experience with the cable trays has shown that the trays are quite useful in the tunnel during the installation of other

equipment. They are handy for such things as running extension cords and storing copper pipe temporarily. On the other hand, the trays tend to be in the way in the entrance areas, and in fact in the protomain some of the trays in the entrance ways had to be removed in order to install the other piping.

IV. CONTROL SYSTEM

The MAC-16 control computer has now successfully run the following:

1. The main magnet power supply control system
2. Five of the auxiliary magnets
3. The vacuum monitoring system.

The MAC-16 has also successfully run in the mode in which it checks the status of each of the devices it is controlling to see if they are running as intended. It retransmits their commands if their status is not correct.

A main-ring clock system master controller has been operating in the prototype service building to provide clock signals for the main-magnet power supply.

APPENDIX I.

Core No.	Assembly Date	Assembly Man-Hours
(B2)		
1	1-21-70	14
2	1-16-70	15
3	1-28-70	23
4	1-27-70	22
5	1-29-70	20
6	2-3-70	24
7	2-6-70	15
8	2-9-70	16-1/2
(B1)		
1	2-16-70	22-1/2
2	2-17-70	22-1/2
3	2-17-70	20-1/2
4	2-18-70	19-1/2
5	2-18-70	19
6	2-19-70	19
7	2-20-70	20-1/2
8	2-21-70	26-1/2
(Quad)		
1	2-19-70	8-1/2
2	2-20-70	8
3	2-20-70	7
4	2-21-70	7

Average Assembly Man-Hours for Bending Magnets - 20

Average Assembly Man-Hours for Quadrupoles - 7-1/2

APPENDIX II.

COILS - BENDING MAGNET INNER

Measuring and cleaning of bars	8 m-h*
Sandblasting of bars	1-1/2 m-h
Taping (complete set)	1 m-h
Taping hairpin ends	1 m-h
Brazing (complete coil)	10 m-h
Ground wrapping	8 m-h
Shorted turn test	1/2 m-h
Encapsulation	8 m-h
Potting (mixing, pumping, curing, bringing up to air)	8 m-h
Demolding	4 m-h
Clean-up time	1 m-h
Clean up of mold	20 m-h
Testing	2 m-h
	73 m-h

* m-h = man-hours

APPENDIX III.

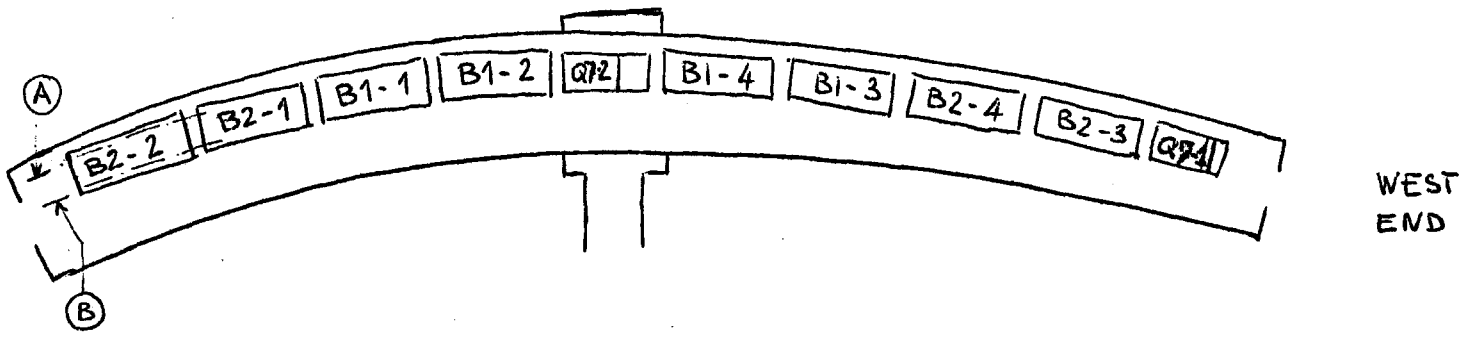
MAGNET NO.	ASSEMBLY DATE	ASSEMBLY MAN HOURS	DATE INSTALLED
B2-1	1-23-70	50	2-14-70
B2-2	1-29-70	35	2-14-70
B2-3	2-5-70	30	2-17-70
B2-4	2-11-70	16	2-21-70
B1-1	2-17-70	24	2-24-70
B1-2	2-22-70	24	2-26-70
B1-3	2-27-70	18	3-3-70
B1-4	3-6-70	15	3-7-70
Quad-1	3-7-70	18	3-7-70
Quad-2	3-7-70	24	3-8-70
		254	

Average Assembly Man-Hours - 25

PROTOMAIN MAGNETS DEFLECTION AND TWIST

* ROW "A" REFERS TO THE OUTER ROW
* ROW "B" REFERS TO THE INNER ROW
* DEFLECTION AND TWIST ARE GIVEN IN MILS (0.001")
* VALUES TABULATED AND PLOTTED REFER TO MAGNETS WITH FOUR FEET LEVELLED, AND FOR AN AVERAGE TEMPERATURE OF 75 °F
* TWIST ANGLE ESTIMATED AS FOLLOWS :

$$\theta = \frac{1}{9} \times \frac{1}{19000} \times \sum_{i=1}^{9} \left(\delta_{Ai} - \delta_{Bi} \right) \quad , [\text{rad}]$$

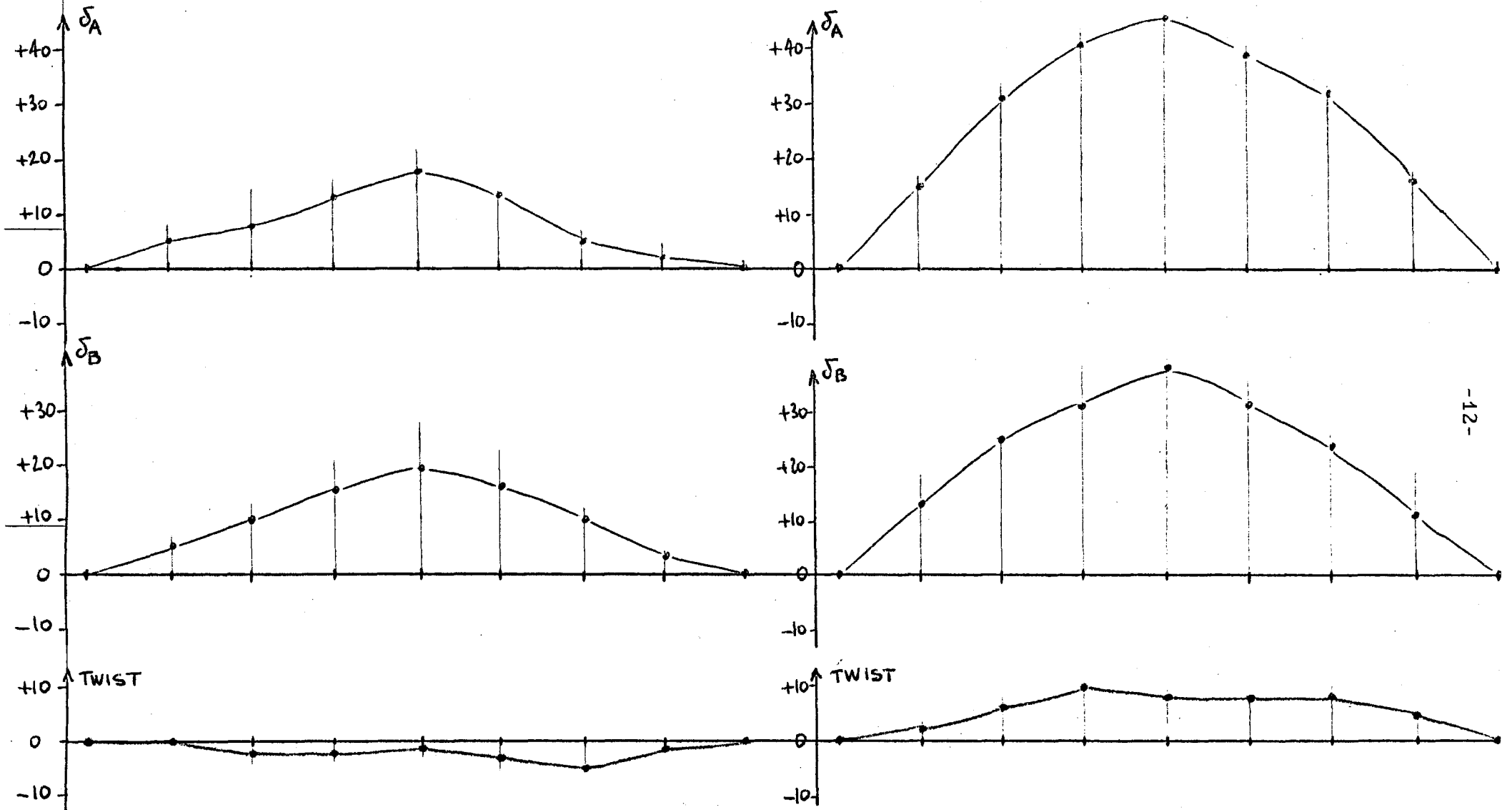


B2 - 2

A	0	+5	+8	+13	+18	+13	+5	+2	0
B	0	+5	+10	+15	+19	+16	+10	+3	0

B2 - 1

0	+15	+31	+41	+46	+39	+32	+16	0
0	+13	+25	+31	+38	+31	+24	+11	0

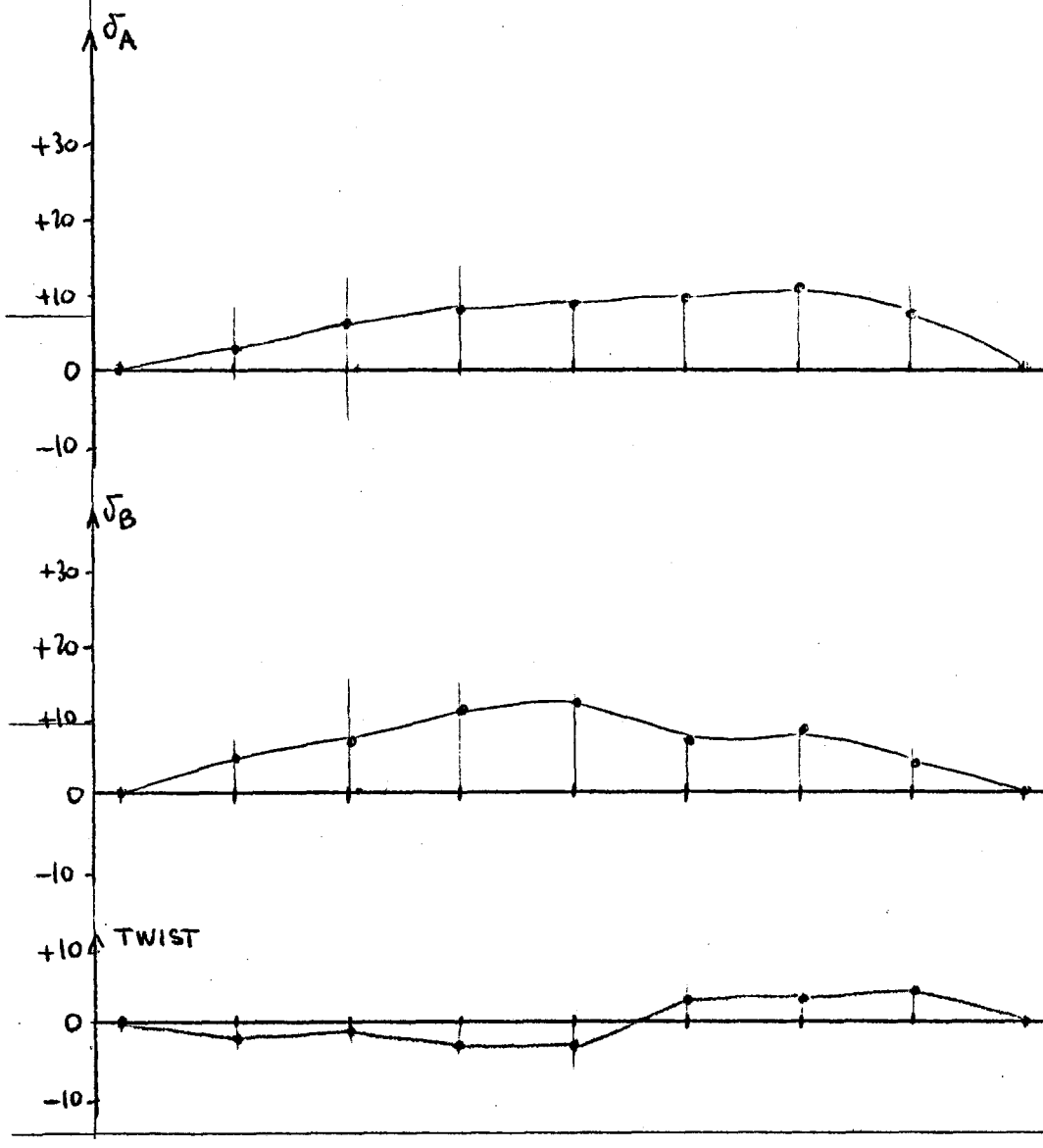


TWIST ANGLE : -0.82×10^{-4} (rad)

TWIST ANGLE : 2.75×10^{-4} (rad)

B1 - 1

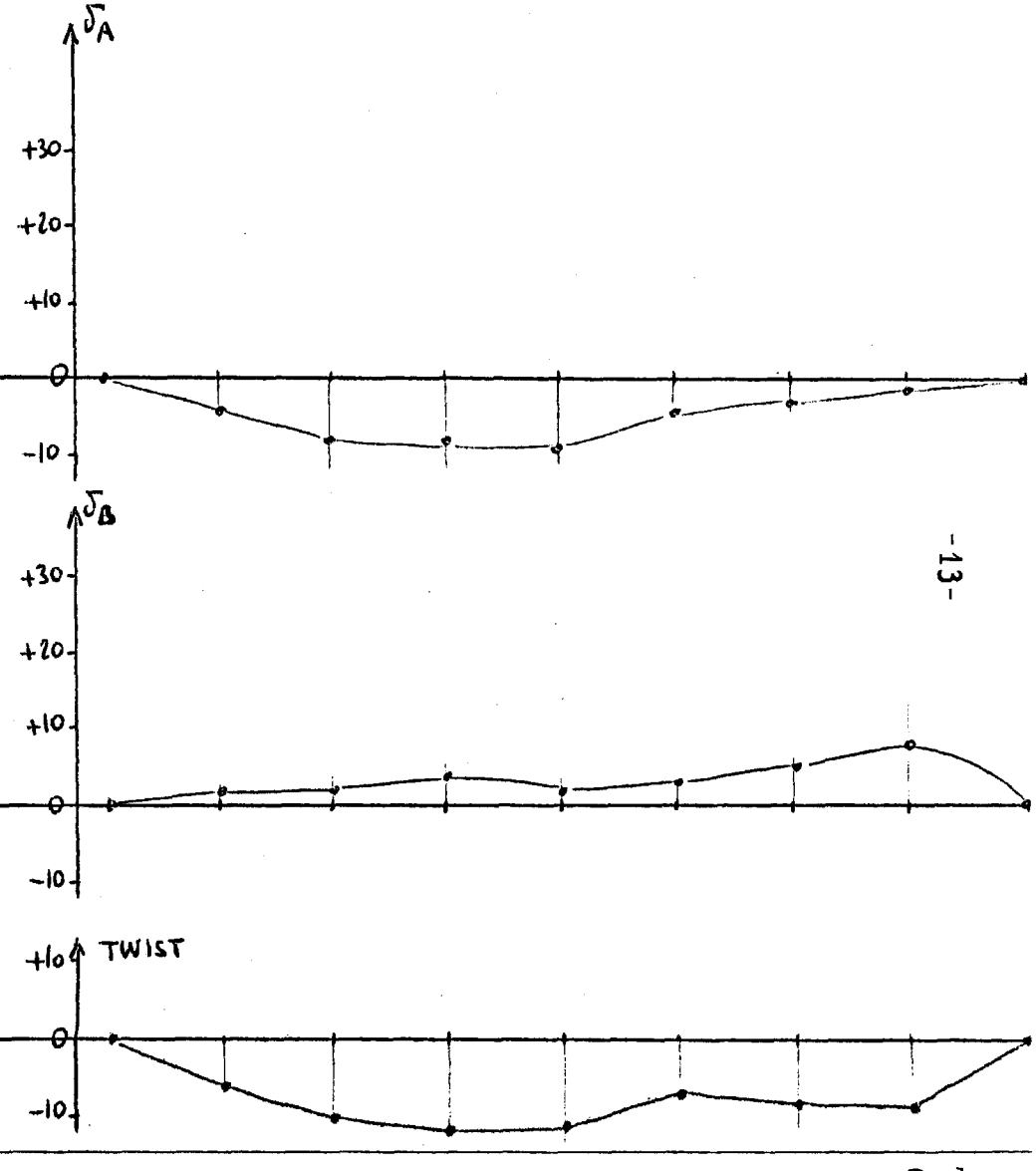
A	0	+3	+6	+8	+9	+10	+11	+8	0
B	0	+5	+7	+11	+12	+7	+8	+4	0



TWIST ANGLE : 0.06×10^{-4} (rad)

B1 - 2

A	0	-4	-8	-8	-9	-4	-3	-1	0
B	0	+2	+2	+4	+2	+3	+5	+8	0



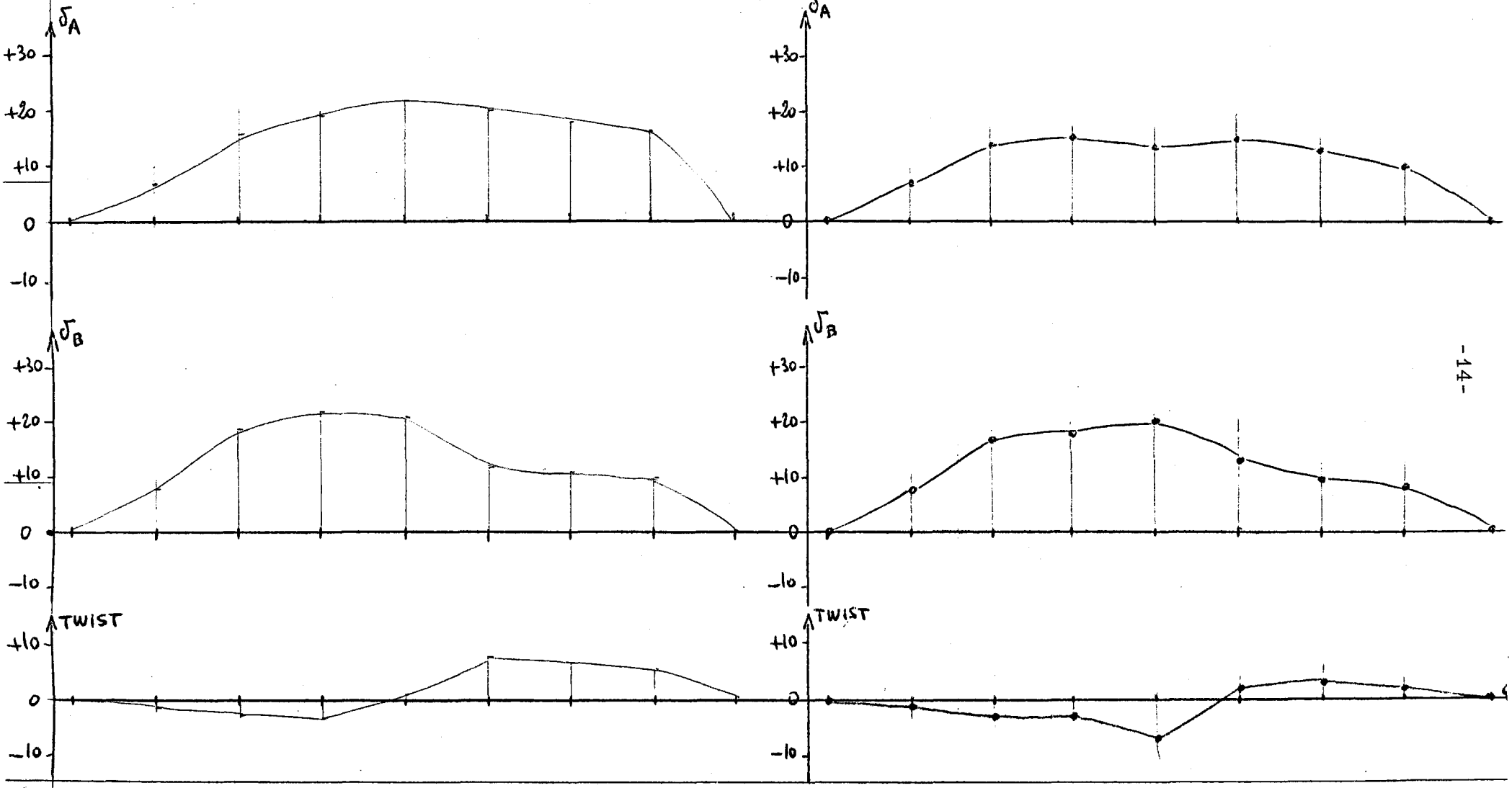
TWIST ANGLE : -3.68×10^{-4} (rad)

B1- 4

A	0	+7	+16	+19	+22	+20	+18	+16	0
B	0	+8	+19	+22	+21	+12	+11	+10	0

B1-3

0	+7	+14	+15	+13	+15	+13	+10	0
0	+8	+17	+18	+20	+13	+10	+8	0



TWIST ANGLE : 0.88×10^{-4} rad

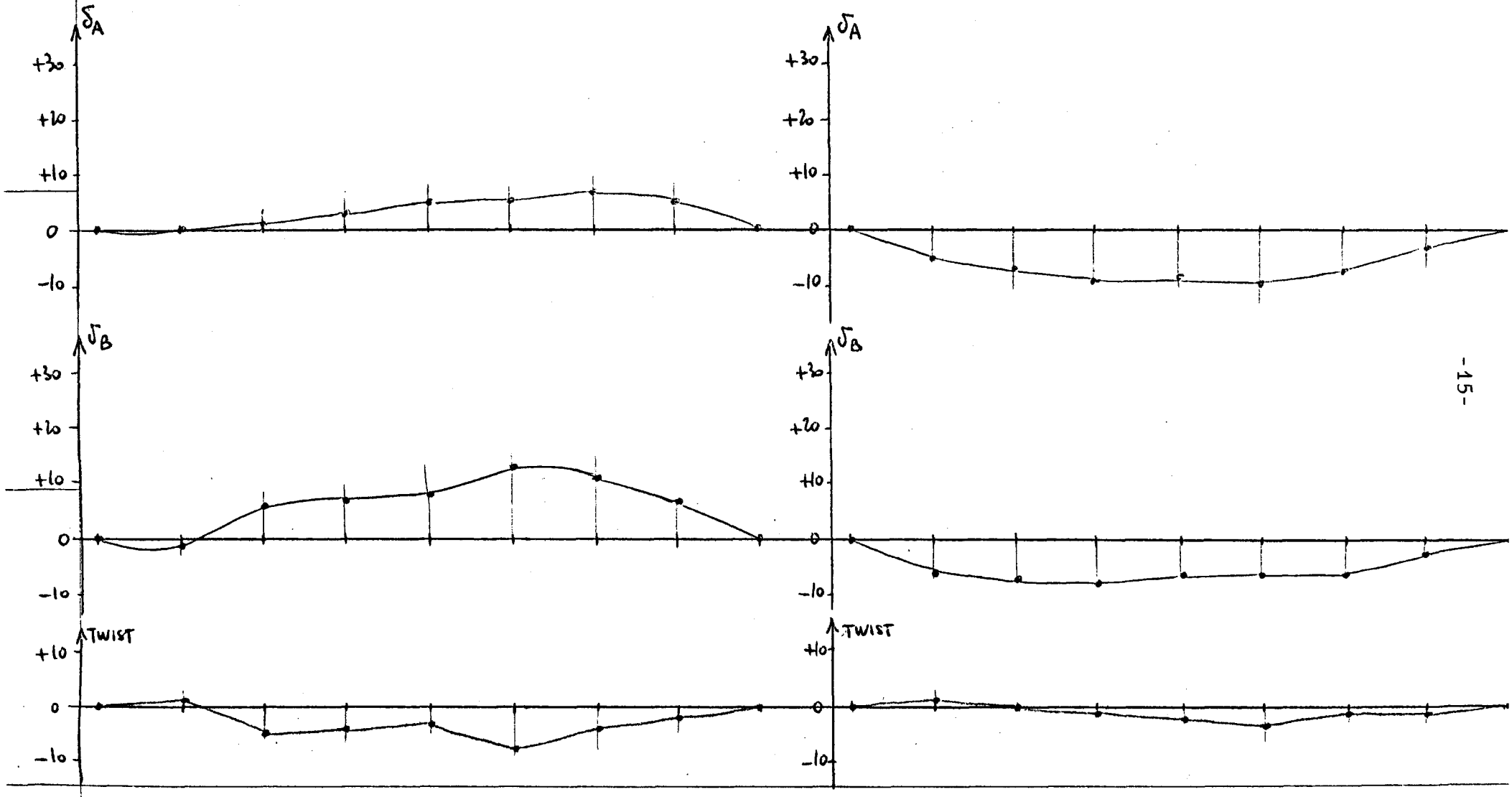
TWIST ANGLE -0.41×10^{-4} (rad)

B2-4

A	0	0	+1	+3	+5	+5	+7	+5	0
B	0	-1	+6	+7	+8	+13	+11	+7	0

B2-3

0	-5	-7	-9	-8	-9	-7	-3	0
0	-6	-7	-8	-6	-6	-6	-2	0



TWIST ANGLE : -1.46×10^{-4} (rad)

TWIST ANGLE : -0.41×10^{-4} (rad)

APPENDIX V.

Installation Times - Power & Water Distribution

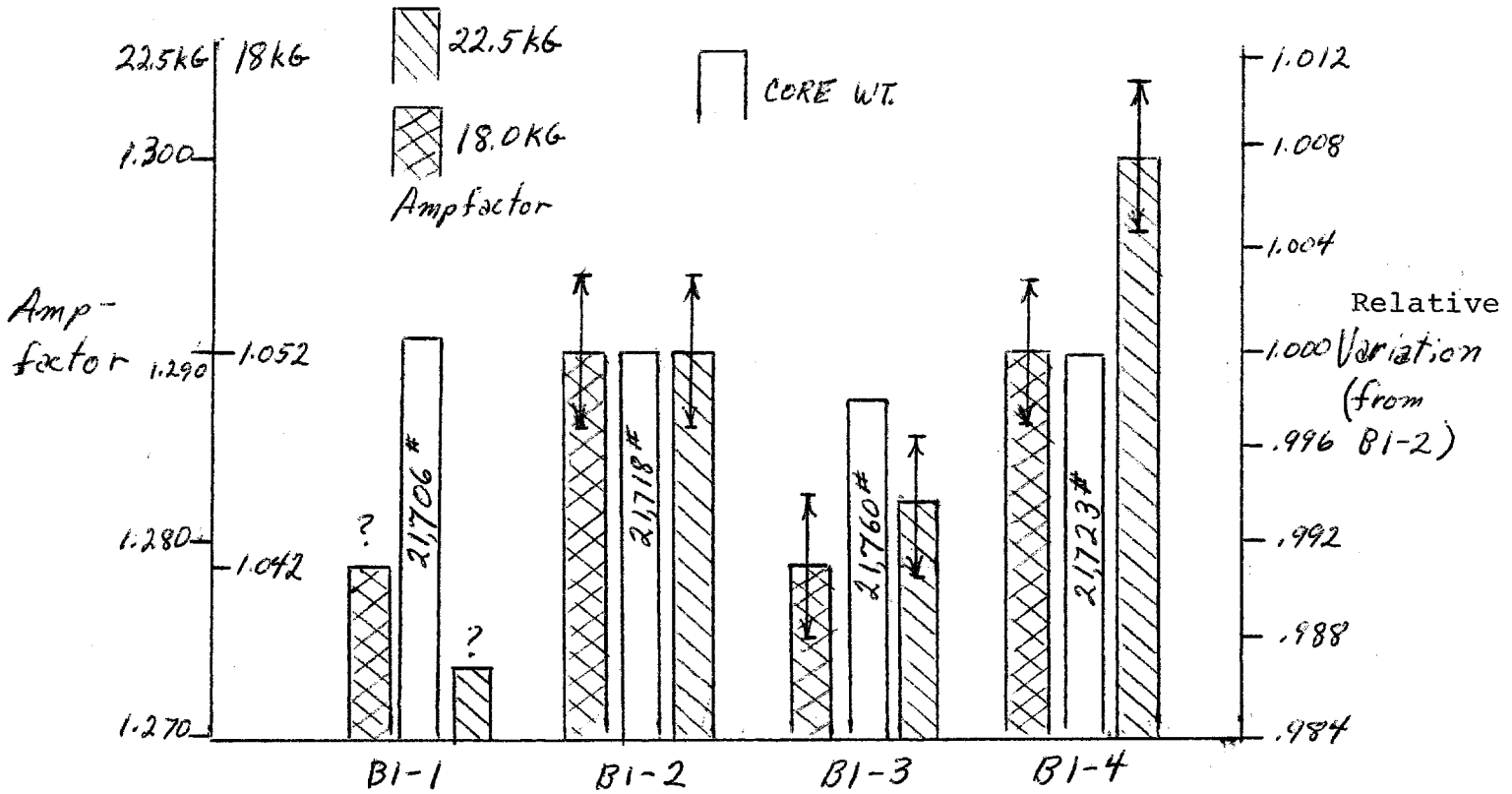
Cable Trays	48 m-h*
Entrance (additional unistrut brackets, etc.)	16 m-n
Pipe supports (including insulators)	100 m-h
Pipe welding	294 m-h
Copper brazing	140 m-h
Aluminum welding	40 m-h
Coil manifolds (BM & Quads)	80 m-h
	718 m-h

* m-h = man-hours

APPENDIX VI.

AMPFACTOR

Field (kG)	B1 calc.	B1 (1001)	B2 calc.	B2 (2004)
9.	1.0021	.997 ±.003	1.0016	.999 ± .002
18.	1.0482	1.050	1.0463	1.046
21.	1.1394	1.165	1.1256	1.138
22.5	1.2494	1.278	1.2417	1.230



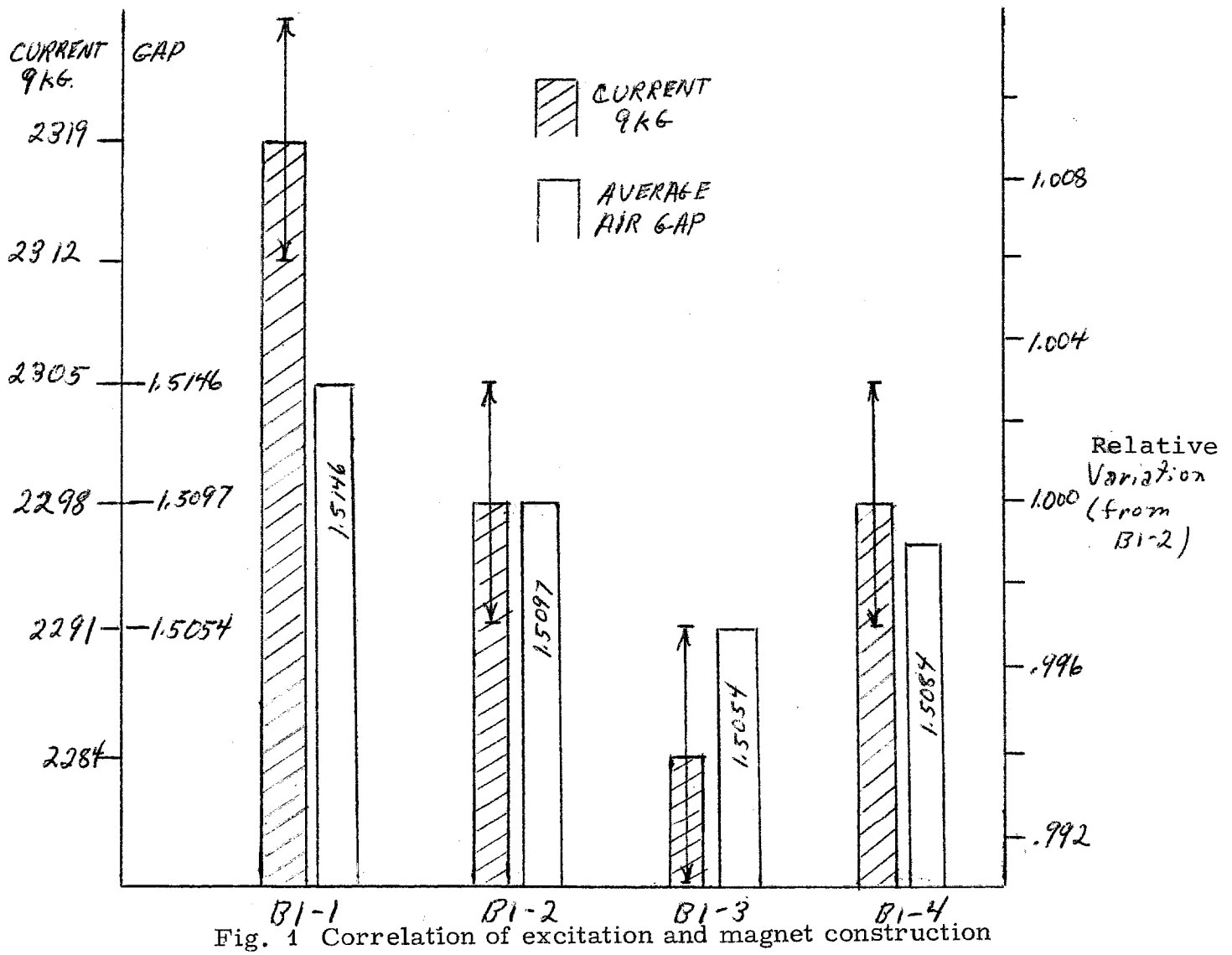


Fig. 1 Correlation of excitation and magnet construction