Fermi National Accelerator Laboratory

FERMILAB-TM-1893

A Preliminary Power Consumption Estimate For A Toroid Spoiler Magnet Proposed For The PWest Upgrade

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Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

TM # 1893
Cat. 9204.000

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June 28, 1994.

A preliminary Power Consumption estimate for a toroid spoiler magnet proposed for the PWest Upgrade.

The estimate is based on the preliminary magnet design provided by B.Lundberg and shown in the Fig. 1. The main approach to the magnetic field calculation was drawn from [1].The required magnetic field induction in the winding carrying toroid leg is specified as a initial condition. Based on the cross section areas of the toroid legs the induction in all four toroid legs can be calculated. A particular type of steel which will be used to build the magnet is unknown at the moment, so we can use the curve on Fig. 2 for the most wide spread steels to obtain a field strength in the steel. For every value of B the curve yielding the highest value of H was chosen from the curves family in Fig. 2. The number of steel plates and accordingly the resulting technological air gap are unknown, therefore the calculations for two different gaps .25 mm and 2.5 mm were performed.

In general we can write:

$$\oint H_i \cdot dl = N \cdot I = H_1 \cdot l_1 + H_2 \cdot l_2 + H_3 \cdot l_3 + H_4 \cdot l_4 + H_{AIR} \cdot l_{AIR}, \qquad (1)$$

where l_1 = 1.5 m - mean magnetic path length in the leg 1,
l_2 = 2.25 m - in the leg 2,
l_3 = 1.5 m - in the leg 3,
l_4 = 2.25 m - in the leg 4,
l_{AIR} - the combined length of the air gaps between the steel plates.

The conservative approach is to calculate the field strength in the air gaps based on the maximum field induction B_1:

$$H_{AIR} = \frac{B_1}{\mu_0}, \qquad (2)$$

where $\mu_0 = 4\pi \cdot 10^{-7}$.

Knowing $N \cdot I$ it is possible to calculate the magnet power consumption W without finalizing the coil design. For now it is enough to know that it will be made out of copper and to choose the maximum allowable current density.

The coil resistance R_c can be found as follows:

$$R_c = \frac{\rho \cdot l_{turn}}{S_{turn}} \cdot N \ , \qquad (3)$$

where ρ - specific resistance of the coil material at specified temperature, Ω·m;
N - number of turns,
l_{turn} - mean turn length, m;
S_{turn} - turn's cross section area, m^2.

The expression for the power dissipation in the coil is:

$$W = I^2 \cdot R = \frac{\rho \cdot l_{turn} \cdot j_{max} \cdot S_{turn}}{S_{turn}} (N \cdot I) = (N \cdot I) \cdot \rho \cdot j_{max} \cdot l_{turn} , \qquad (4)$$

where j_{max} - maximum allowable current density in the coil, A/m^2.

Table 1 shows the results of the power consumption calculations for the proposed toroid spoiler magnet for different magnetic field induction values and two different technological air gaps. It is interesting to compare operating cost of running the magnet with different magnetic field. The present cost of electricity is $.043 per kWh. The cost of daily magnet operation is calculated based on 24 Hours operating mode. One has to keep in mind, that by the time the experiment starts the electricity cost may go up substantially due to the ComEd rebate expiration.

Table 1.

B max	Air gap, mm					
	0.25			2.5		
Tesla	(N·I), A·turns	W, kW	Cost, $	(N·I), A·turns	W, kW	Cost, $
1.8	18,984	22.04	22.74	22,206	25.78	26.6
1.9	29,045	33.68	34.76	32,438	37.67	38.87
2.0	40,107	46.56	48.05	43,690	50.67	52.29

It might be possible to run the magnet from one or two 55 kW LINK power supplies. LINK power supply has either 100 ADC @ 550 VDC or 200 ADC @ 275 VDC settings. This has to be considered as one of the design parameters for the spoiler toroid magnet coil design.

REFERENCES

1. A. T. Visser, A short approach to the electrical design of a muon spoiler magnet, TM - 978, June, 1980

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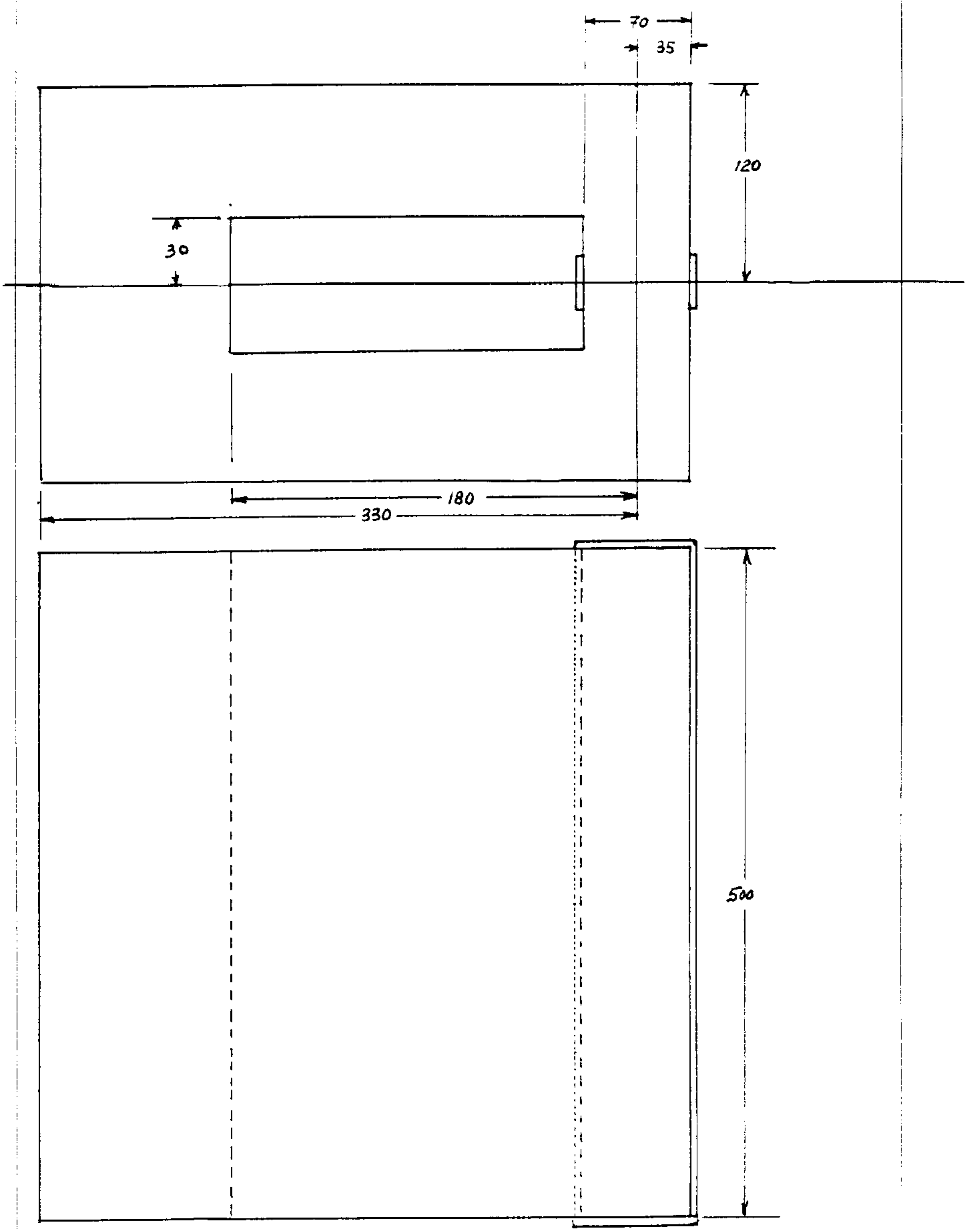
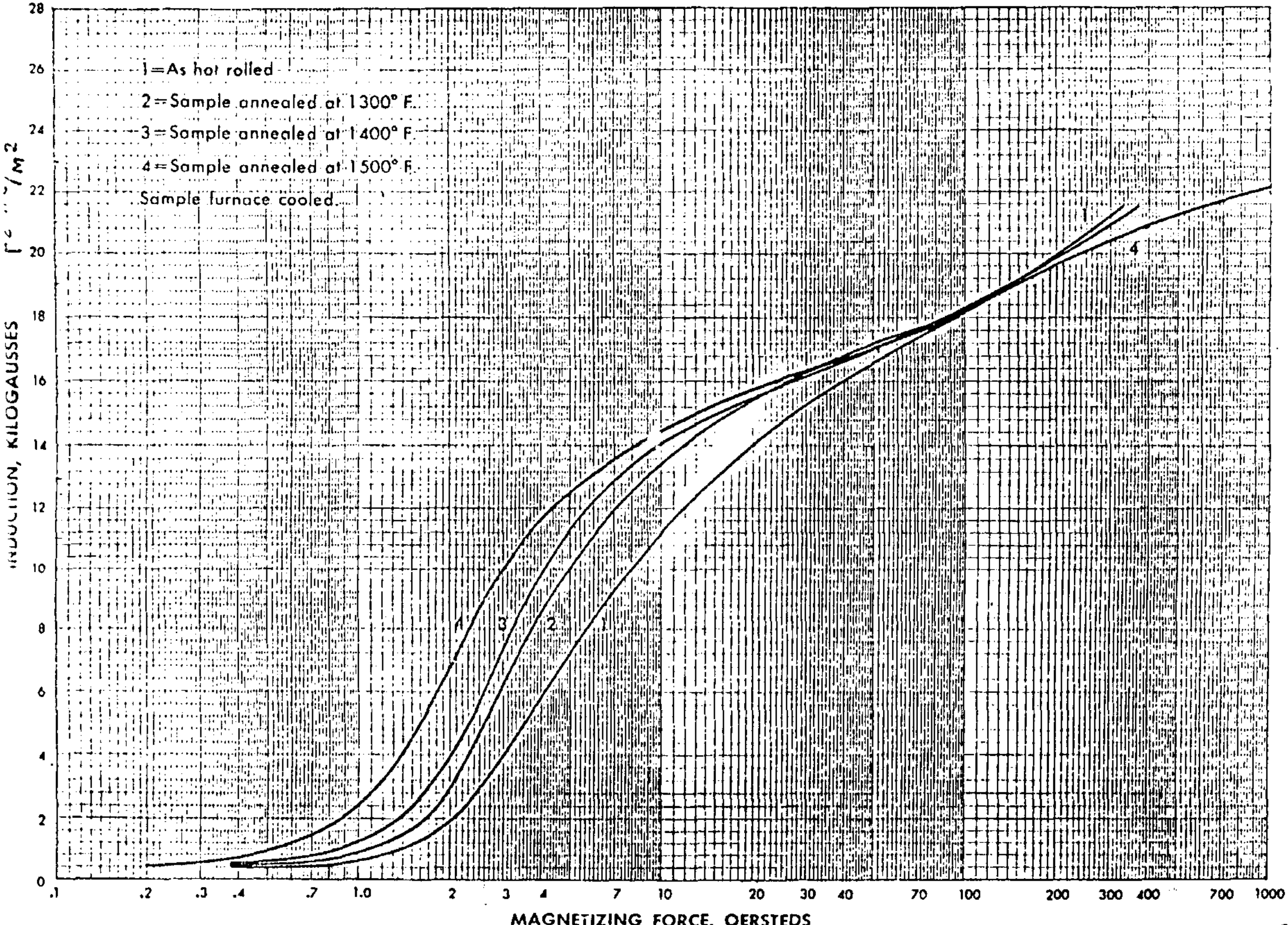


Fig. 1

USS HOT ROLLED LOW CARBON STEEL PLATES
C1010 — OVER .250 INCHES
DC MAGNETIZATION



Test Conditions: Lengthwise samples tested in Fahy Permeameter.

FIG. 2

1 OERSTED = 2.0213 AMP. TURNS/INCH

= 79.577 AMP. TURNS/