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AN ANALYSIS OF SCANLAN'S DATA ON RESISTANCE OF COPPER PLATING FOR APPLICATION TO BORE TUBE STRUCTURAL CONSIDERATIONS

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INTRODUCTION

In order to design the bore tube from a structural point of view we need to know the resistivity of the copper plating as a function of field. A low resistivity gives large eddy-current forces. The most applicable data on plated copper appears to be that recently measured by Scanlan [1] (Appendix 1).

Scanlan's data have been plotted on a Kohler diagram, and it agrees with previously published data for bulk copper (not platings) [2].

For the structural analysis of the bore tube it will be handy to have a simple formula for the resistivity as a function of magnetic field, one that gives resistivities conservatively lower than Scanlan's lowest values; such a formula is developed in this report.

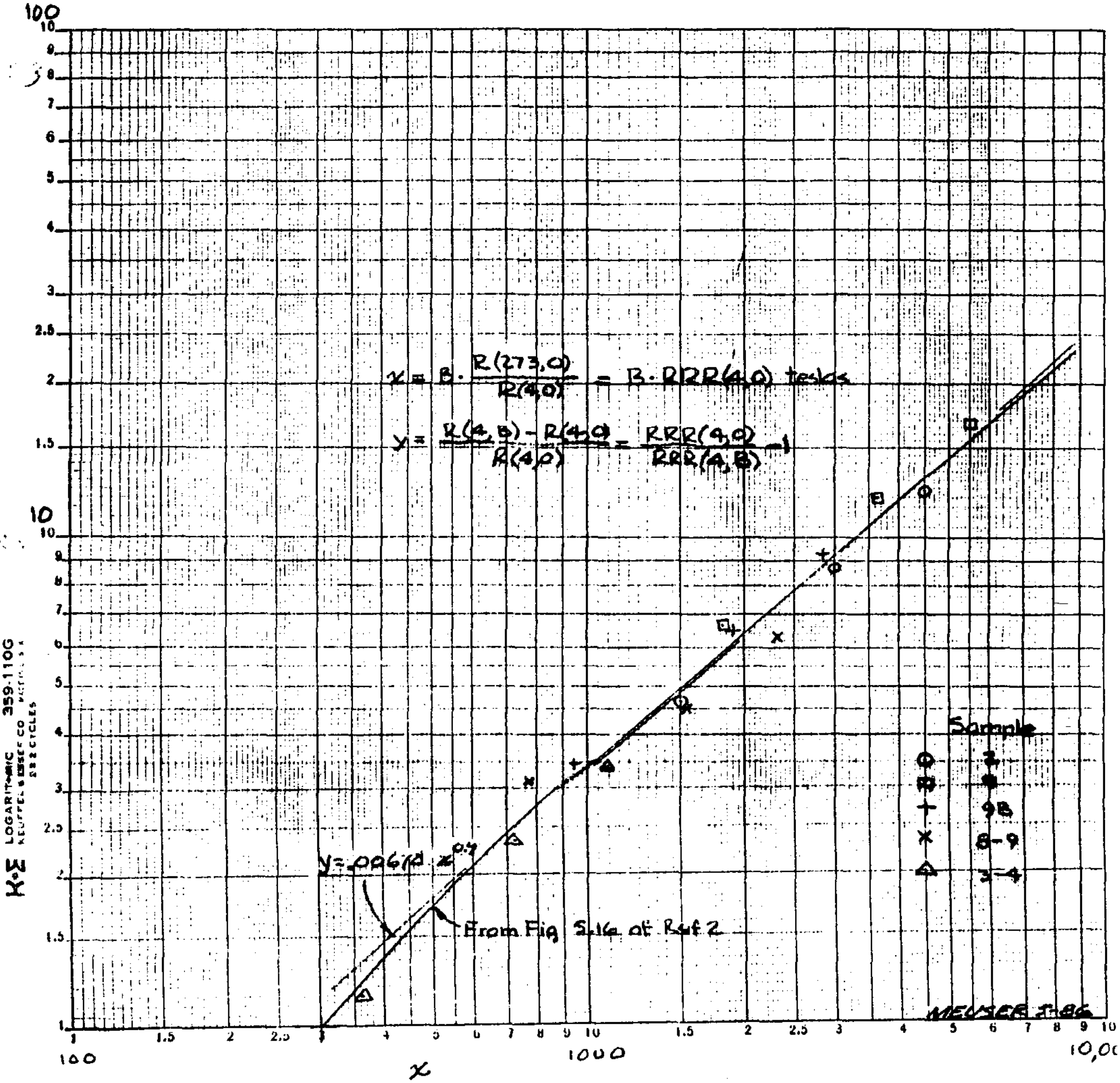
DISCUSSION

Scanlan's data, which give resistance ratios rather than absolute resistances, are shown in Table 1. Also shown in Table 1 are his data extrapolated to 6.6 T (the design field) and 7.5 T (the maximum expected field at quench). (The extrapolation is done from the 6-T value using Kohler-diagram variables, and the relationship $y=0.00678\ x^{.90}$.) The values of RR at 6.6 T are all comfortably higher than the value of 30 used in beam-loss estimates presented in the Conceptual Design Report (SSC-SR-2020).

TABLE 1
RESISTIVITY RATIOS FOR PLATED COPPER

Sample	Resistance ratio for B =					
	0 T	2 T	4 T	6 T	6.6 T	7.5 T
	Scanlan's data [1]				Extrapolated	
2	747	132	77	56	52	46
9	908	119	70	51	47	42
9B	474	106	63	46	42	38
8-9	387	94	70	53	49	44
3-4	181	84	54	41	38	35

The data of Table 1 have been plotted on a Kohler diagram (Appendix 1), Figure 1. Also shown on Figure 1 is a curve representing a lot of copper data [2], together with a straight-line approximation to the curve.



x = B · R(273,0)/R(4,0) = B · RRR(4,0) teslas
y = (R(4,B) − R(4,0))/R(4,0) = RRR(4,0)/RRR(4,B) − 1
y = .00614 x^0.9
From Fig 5.16 of Ref 2
Sample
3B
8-9
3-4
K+E LOGARITHMIC 359-110G
100
10
1000
10,00
x

Since the data are sparse, and inasmuch as there are as yet no data on the properties of the plating deposited by whatever process will be used for the SSC, it seems prudent to use design values of RRR that are somewhat higher than Scanlan's highest data, particularly in the high-field range.

CONCLUSION

The following working formula (Appendix 1) seems to turn the trick, giving a margin of 15 to 18% on RR over Scanlan's data in the range of 2 to 7.5 teslas (but only 10% at zero field, where it doesn't matter anyhow).

$$\rho(4,B) = 1.71 \times 10^{-11} [0.00678(1000 \cdot B)^{0.88} + 1]/RRR \ \Omega\text{-m}$$

for B in teslas.

REFERENCES

1 Ron Scanlan, private communication.

2 Materials at Low Temperature, edited by R. P. Reed and A. F. Clark, National Bureau of Standards, American Society for Metals, 1983.

3 Standards Handbook 1973, Copper Development Association, Inc., New York.

APPENDIX 1

The conventional Kohler diagram presents

$$(y = \Delta\rho/\rho_o) \text{ vs. } (x = B\cdot RR(T))$$

where $\rho(T,B)$ = resistivity at temperature T, magnetic field B

$$\Delta\rho = \rho(T,B) - \rho(T,0)$$

$$\rho_o = \rho(T,0)$$

$$RR(T) = \rho(273,0)/\rho(T,0)$$

Then

$$x = B\cdot RRR$$

$$y = [RRR/RR(4,B)]-1$$

where

$$RRR = RR(4,0)$$

Usually (and as is the case with Scanlan's data) resistances are measured rather than resistivities, but since only ratios are involved it amounts to the same thing.

An eyeballed best straight-line fit gives

$$y = .00678\ x^{0.90}$$

Upon making the appropriate substitutions we obtain

$$\rho(4,B) = \rho(273,0)\ [0.00678(B\cdot RRR)^{0.90} + 1]/RRR$$

To obtain a relationship that a margin on RR(4,B) that is some 15 to 18% above Scanlan's highest values above 2 teslas we use an exponent of 0.88 rather than 0.90, and an RRR of 1000. Lacking data for the resistivity at 273 K specific to platings, we use a value of 1.71×10^{-11} (from the CDA Standards Handbook [3] for oxygen-free copper).

The final working formula is, then

$$\rho(4,B) = 1.71 \times 10^{-11} [0.00678(1000\ B)^{0.88} + 1]/RRR$$

for ρ in Ω-m, B in teslas.

Scanlan's highest values for RR compared with those corresponding to the above formula are shown in Table 2.

TABLE 2
COMPARISON OF SCANLAN'S HIGHEST RESISTIVITY COMPARED WITH THOSE CORRESPONDING TO WORKING FORMULA

	Resistance ratio for B = 0 T	2 T	4 T	6 T
Scanlan's data	747	132	77	56
Formula	1000	155	91	65