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DESIGN STUDY OF THE TEV I PULSED SEPTUM MAGNET

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Introduction

Magnetic field calculations have been performed using the POISSON code to assist in the design of a pulsed septum magnet for beam manipulation in the TeV I antiproton accumulator/debuncher system. Magnet current distributions are obtained from eddy current considerations relative to a pulsed half-sine wave of 1200 Hz. Magnet end effects are not considered here.

Specifications[1]:

Maximum field	- 6 kG
Gap height	- 2x0.781 inches
Good field span	- 1.40 inches
Beam separation	- 0.80 inches (edge to edge)
Field uniformity	- ±1 part per 1000
Septum thickness	-
	.125 inch copper
	.180 inch stainless steel backing
	.180 inch magnetic shield and vacuum chamber
Current drive frequency	- 1200 Hertz
Yoke steel	- M22 silicon steel
Shield material	- M22 silicon steel

General Features

The overall design of the pulsed septum magnet is illustrated in Figure 1. The septum across which the beam is kicked consists of three components: (a) a copper conductor carrying the pulsed current (20000 amps); (2) a stainless steel back to stiffen the copper septum against deflection from the magnetic forces; and finally (c) a magnetic shield to shunt out the leakage flux going to the adjoining circulating beam channel when the magnet is pulsed on. The four piece copper segmentation was used only to model eddy current density variation. Actual construction will be in one piece.

The modelling study described here focussed on the following aspects of the pulsed magnet design:

1. the influence of the non-uniform current distribution caused by the eddy current diffusion on the internal field uniformity;
2. the influence of current sharing in the stainless septum backing on the internal field and useful corrective measures;
3. design of the inner conductor keeper slot and its effect on the good field boundary;
4. modelling two insulation thickness options for the inner conductor, which carries the inductive voltage swing, using lamination shimming near this conductor;
5. estimating the leakage flux entering the adjoining circulating beam channel, with and without the magnetic shield in place, at the design excitation.

Eddy Current Modelling

The "POISSON" magnet code has been used to model the resulting magnetic fields, calculated to exist at the peak of the half sine-wave drive current. The calculated current distributions are those resulting from a transient solution of the eddy current diffusion[2], under the assumption that the flux density goes to zero at the copper-stainless steel interface. This is a simplifying approximation that allows an approximate transient distribution to be estimated. The actual modelled distribution is shown in Figure 2.

Current Sharing

The copper septum is backed by a stainless steel insert to provide sufficient strength to counter the pulsed magnetic forces.

Because the stainless steel backing is part of the drive circuit the total current is shared between the copper septum and its backing. Under dc conditions this would be determined by the resistivity ratio, typically 50/1 for stainless/copper. However, in the transient condition flux linkage as well as ohm's law determines the current sharing. The calculated distribution[2] for an ideal geometry is shown in Figure 2. For a 0.125 inch copper septum at 1200 Hertz, the current carried by the stainless steel is estimated to be 2-4% of the drive current. Thicker copper septa would reduce this sharing. For a 1/4 inch thick septum current sharing would be negligible at 1200 Hertz.

Current Distribution

Estimates of the eddy current effects at this frequency (1200 Hertz) were made by comparing the internal field qualities resulting from a uniform current distribution vs as estimated transient distribution within the copper septum, assuming all the current was carried by the copper. No significant differences were predicted by the modelling code at the design operating frequency (1200 Hertz). However, when the stainless steel septum backing is allowed to be in the drive circuit, then the resulting 2-4% sharing of the drive current introduces a 1/2 to 1% field droop near the septum. Compensation for this predicted field droop has been modelled by introducing a slot in the upper portion of the copper septum, with a similar slot in the mirrored lower half. For 4% of the drive current in the backing, the predicted compensating correction is a .025x.032 inch slot at the top and bottom edges of the copper septum, as shown in Figure 3.

Figure 4 shows the typical field qualities for the various conditions. The field perturbation near the inner conductor is caused by the pole tip notch introduced for a mechanical insert. Actual field shaping can be accomplished by shimming either the copper, or the silicon steel lamination near the notch area. Figure 5 shows the effect of reducing the current conductor height within the field gap. This effect was studied to determine the change in field uniformity if a thicker insulation option for the inner conductor was deemed necessary; such a requirement would shorten the inner conductor height. The field perturbation introduced by the lamination notch at the inner conductor can be adjusted by use of a shimmed pole.

Pole Shimming

Two pole shims (trims A and B) were modelled to indicate useful ranges of the tip shimming (Figures 6 and 7). Trim A is optimized for a inner conductor geometry that assumes a .015 inch insulation wrap. Trim B is the corresponding pole shim, when a .030 inch insulation wrap geometry is assumed. Note that trim B produces a satisfactory good field region for both inner conductor geometry options.

Fringing Field

The modelled leakage field that exists in the adjoining storage ring aperture is shown in Figure 8 with no shield in place. This fringing field assumes the magnetic shunt to be laminated, such that there are negligible eddy currents in the shielding. Figure 9 shows the flux distribution in the gap with the shield removed (2-10 gauss). When the shield is in place the flux picked up yields 200-400 gauss in the clamp. Dividing this by the permeability (say 5000) yields fringe fields outside the gap of less than 0.08 gauss. Residual magnetization effects are not estimated.

Modelling Code Consistency Checks

The finite elements modelling code used for this study was the updated bimodal "POISSON" code installed on the CDC cybers[3]. The consistency checks were performed to ascertain the significance of predicted field uniformities down to 1-2 parts per 10,000. The following tests were carried out:

A. Complete problem solutions were obtained for 3000 and 5000 mesh mode formulations. No significant variations were observed in the predicted field uniformities.

B. The bimodal POISSON solver used here allows two different numerical methods for solving the POISSON equation (direct and relaxation mode). Both methods yielded the same results when convergence thresholds were held to the 10^{-7} level.

C. Mesh mode resolution was doubled near the good field boundaries by using the "FERMESH" preprocessor[4] for the mode density manipulation. No change in field uniformity was observed when the resolution went from .06 inch to .03 inch in the good field region.

Conclusions

1. Field uniformity of ±1 part per 1000 in the working region (1.4 inches) can be achieved by slotting the copper septum to compensate for current diffusion into the septum backing plate.

2. Field uniformity is not skin effect dependent at this operating frequency (1200 Hertz).

3. Shimming the pole near the inner conductor can compensate for both the keeper slot and extra insulation (.030 inch) required for this conductor (Figure 10).

4. Leakage flux densities in the adjoining circulating beam aperture should be less than 1 gauss at 6 kG gap field for the geometries given.

References

1. Fred Mills (Private communication).

2. Steve Holmes, "Esimated Transient Current Distribution in a Pulsed Septum", (Private communication, October 1983).

3. CHR. Iselin - CERN publication T604 (January 1982), "Solution of POISSON'S Equation in Two-Dimensional Regions".

4. L.W. Oleksiuk, "FERMESH, An Intelligent Mesh Generator for FEM Methods", (in preparation).

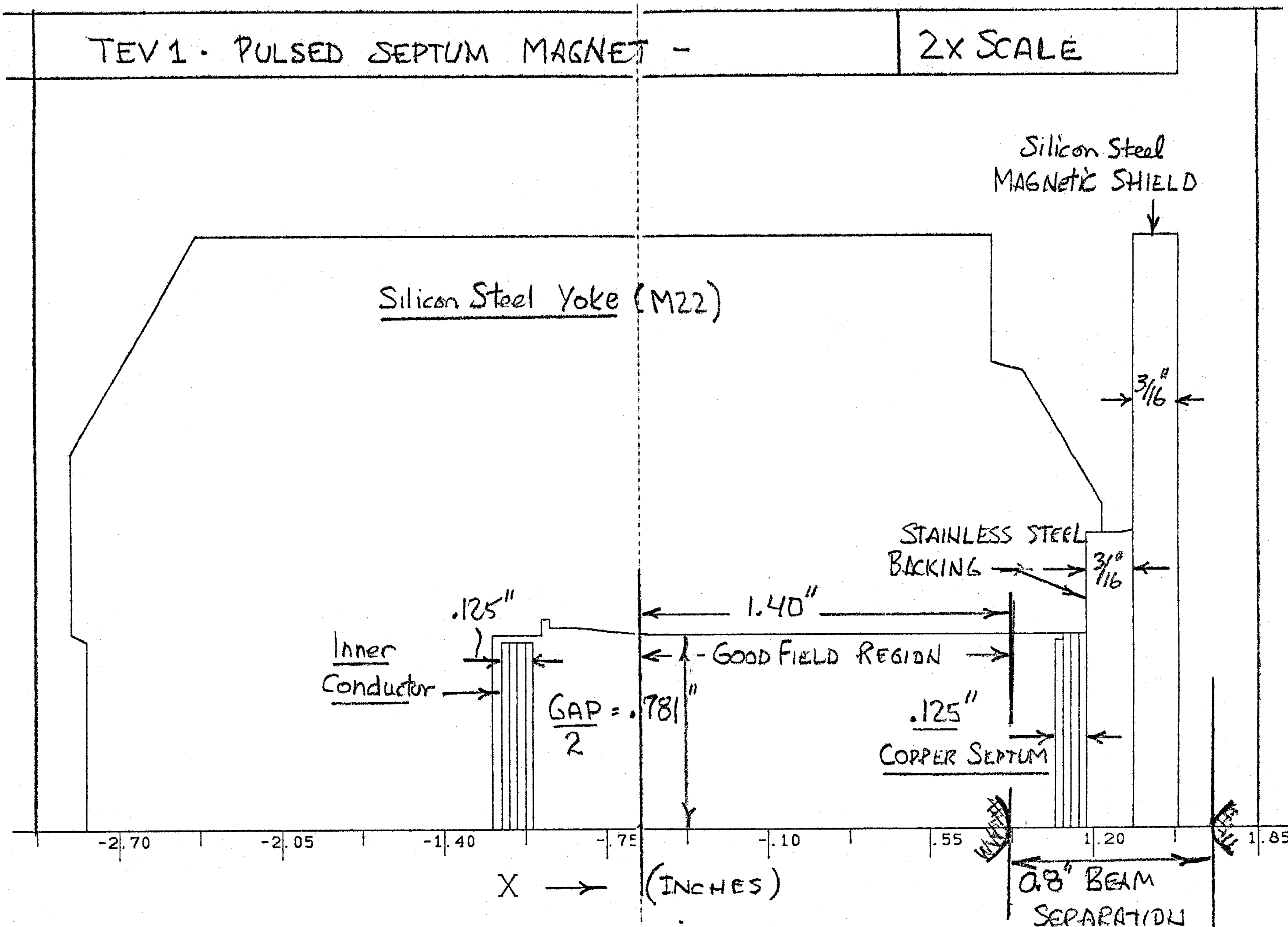


FIGURE 1 - PULSED SEPTUM MAGNET

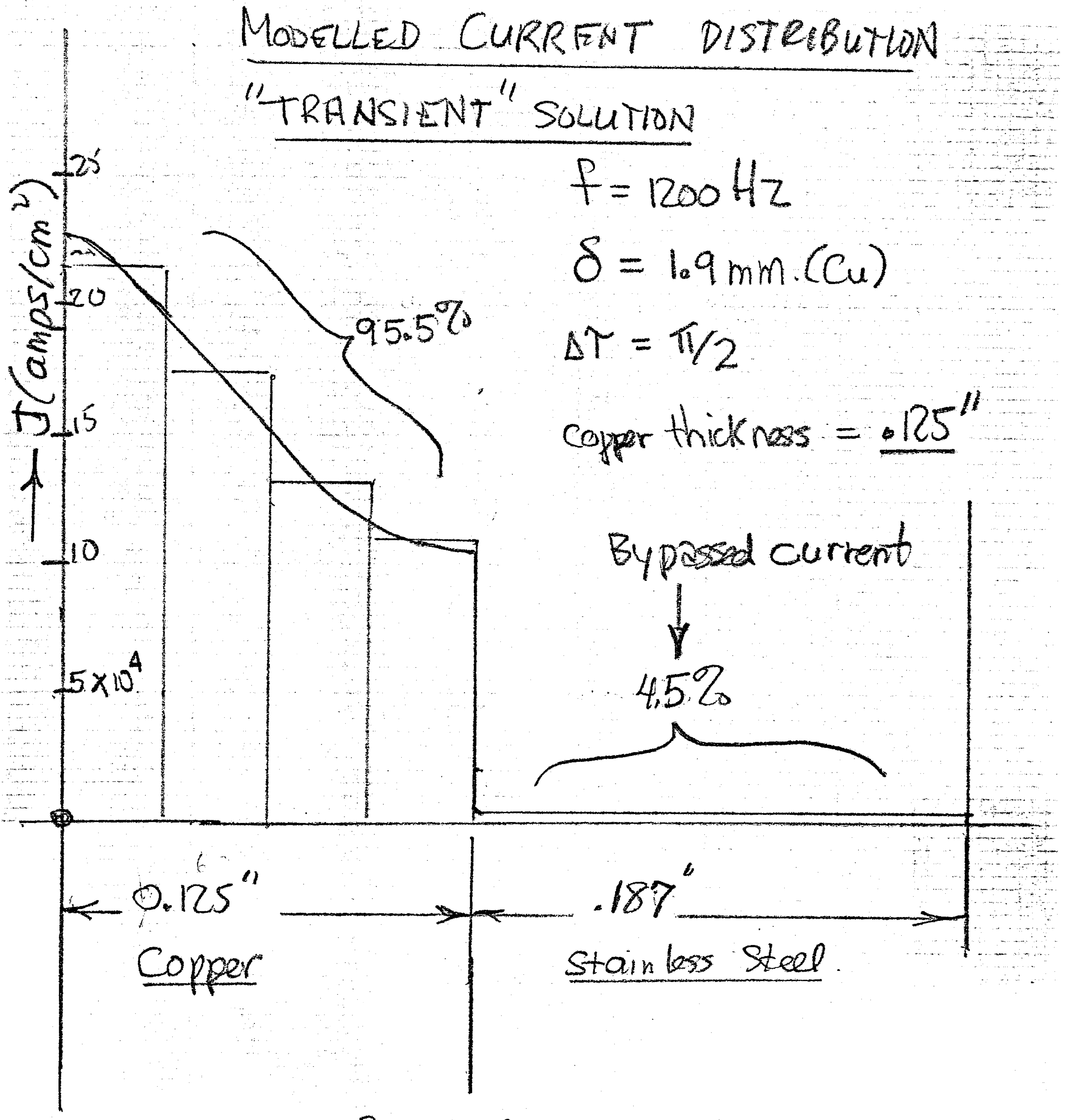

MODELLED CURRENT DISTRIBUTION
"TRANSIENT" SOLUTION
f = 1200 Hz
δ = 1.9 mm. (Cu)
ΔT = π/2
copper thickness = .125"
J (amps/cm²)
25
20
15
10
5 x 10⁴
95.5%
Bypassed current
4.5%
0.125"
Copper
.187"
Stainless Steel

figure 2.

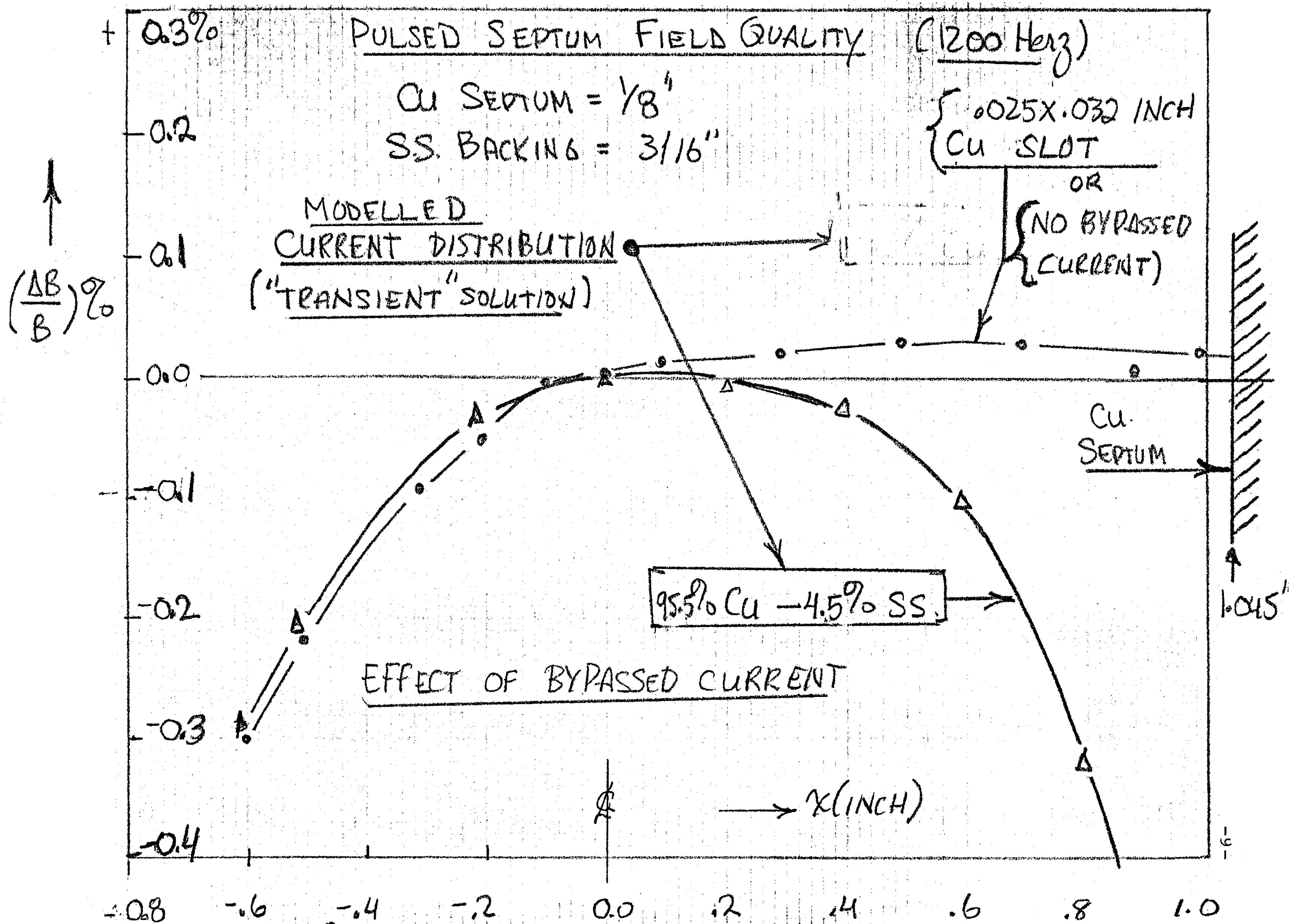


figure 3 – EFFECT OF BYPASSED CURRENT.

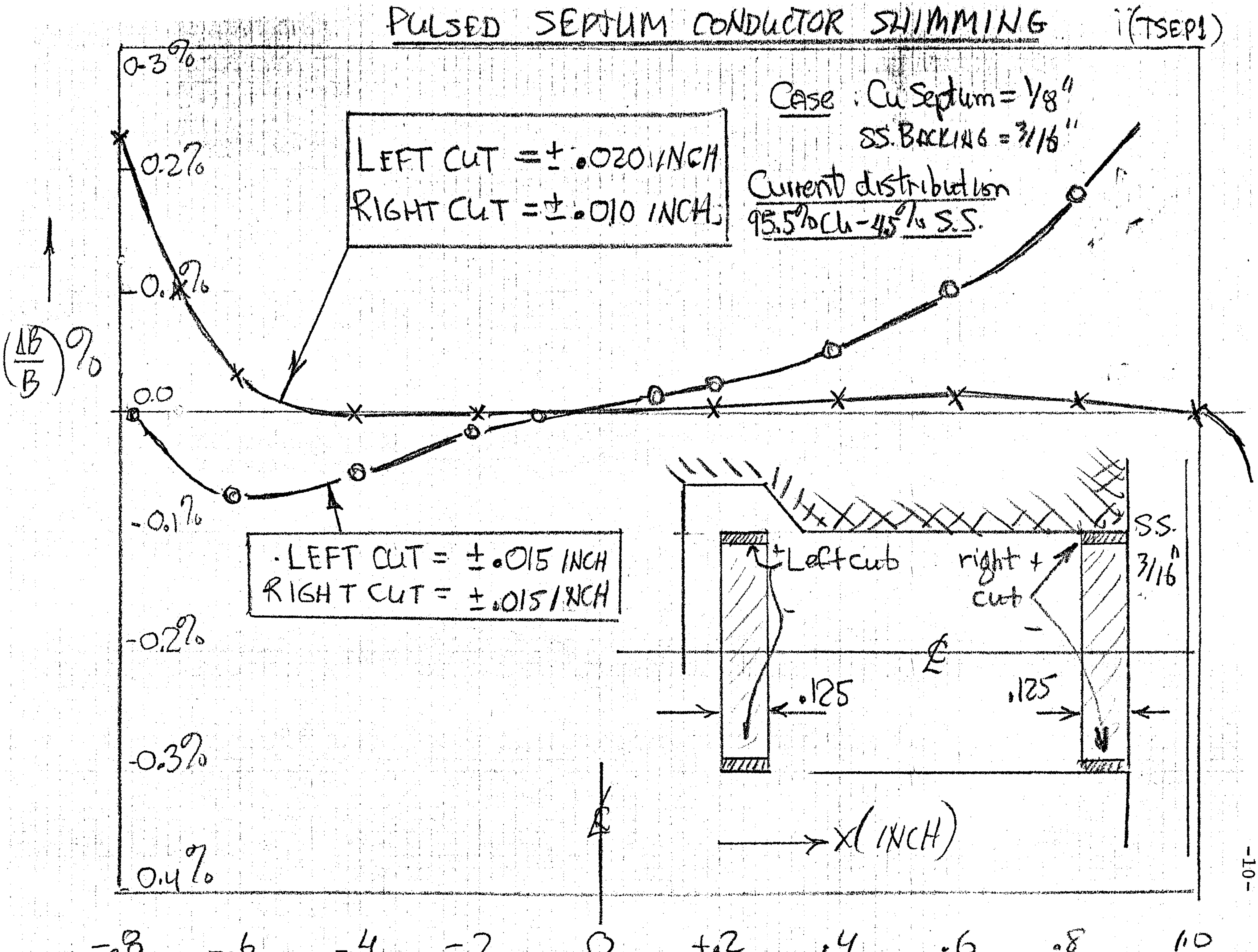

PULSED SEPTUM CONDUCTOR SHIMMING
i(TSEP1)
Case : Cu Septum = 1/8"
SS. BACKING = 3/16"
Current distribution
95.5% Cu - 4.5% S.S.
LEFT CUT = ±.020 INCH
RIGHT CUT = ±.010 INCH
LEFT CUT = ±.015 INCH
RIGHT CUT = ±.015 INCH
(ΔB/B)%
0.3%
0.2%
0.1%
0.0
-0.1%
-0.2%
-0.3%
0.4%
Left cut
right cut
S.S.
3/16"
.125
.125
℄
X (INCH)
-.8
-.6
-.4
-.2
0
+.2
.4
.6
.8
1.0

figure 4.

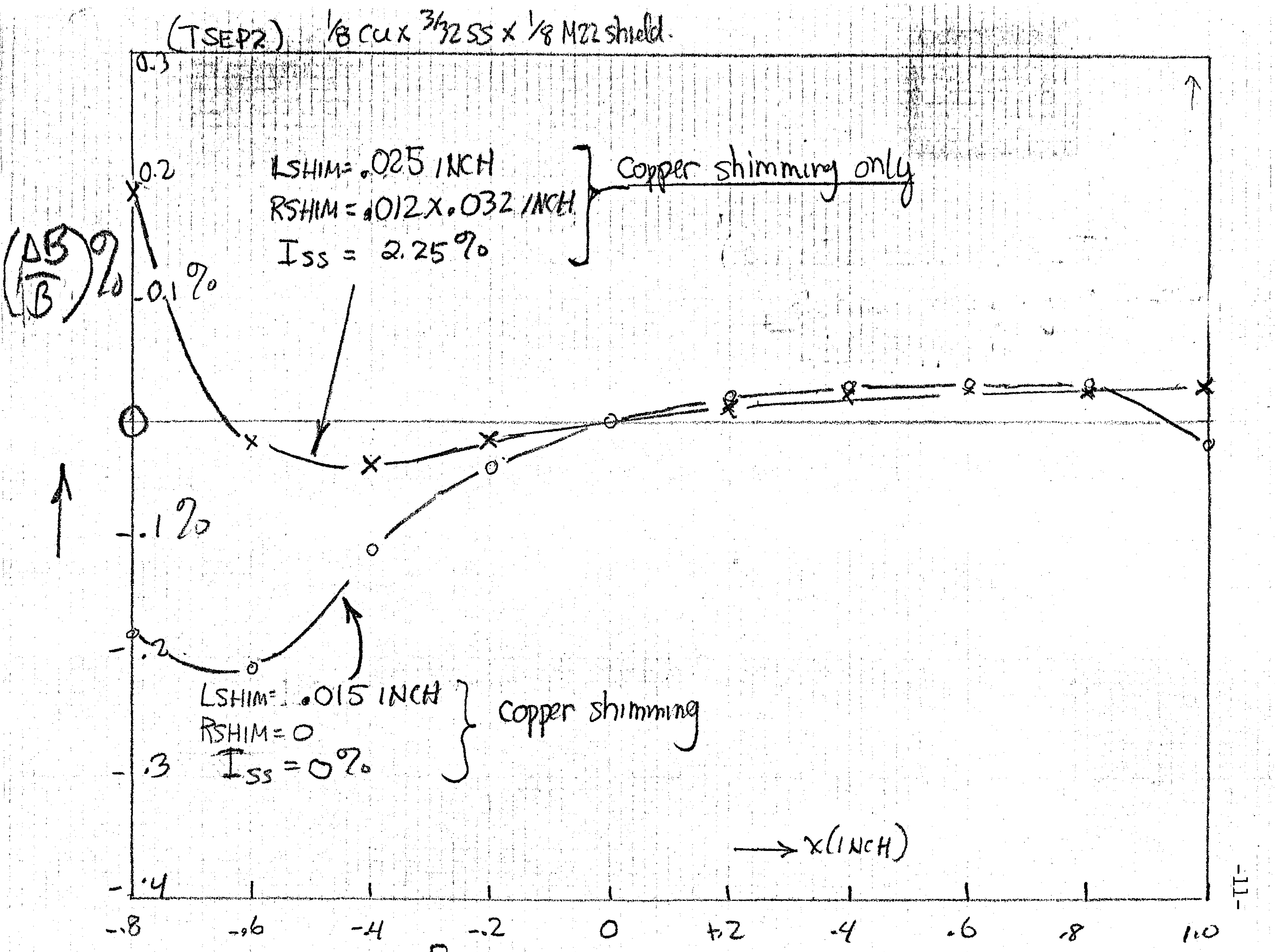
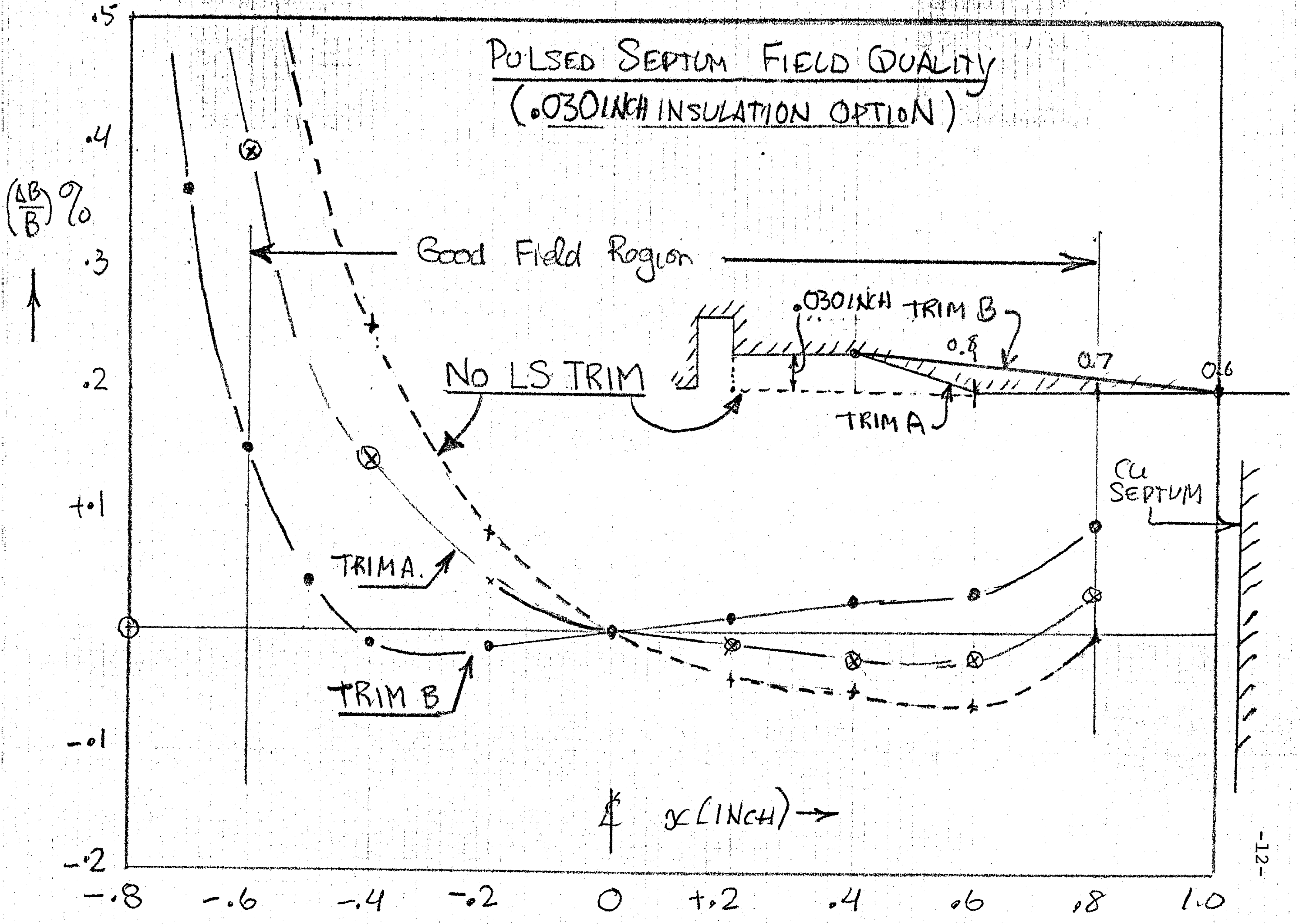

(TSEP2) 1/8 CU x 3/32 SS x 1/8 M22 shield.
LSHIM = .025 INCH
RSHIM = .012 x .032 INCH
Iss = 2.25 %
copper shimming only
LSHIM = .015 INCH
RSHIM = 0
Iss = 0 %
copper shimming
(ΔB/B) %
0.3
0.2
0.1 %
0
.1 %
.2
.3
.4
x (INCH)
-.8
-.6
-.4
-.2
0
+.2
.4
.6
.8
1.0

figure 5.



PULSED SEPTUM FIELD QUALITY
(.030 INCH INSULATION OPTION)
(ΔB/B) %
.5
.4
.3
.2
+.1
-.1
-.2
Good Field Region
.030 INCH
TRIM B
0.8
0.7
0.6
NO LS TRIM
TRIM A
CU SEPTUM
TRIM A.
TRIM B
℄
x (INCH) →
-.8
-.6
-.4
-.2
0
+.2
.4
.6
.8
1.0

FHF

FIGURE 6

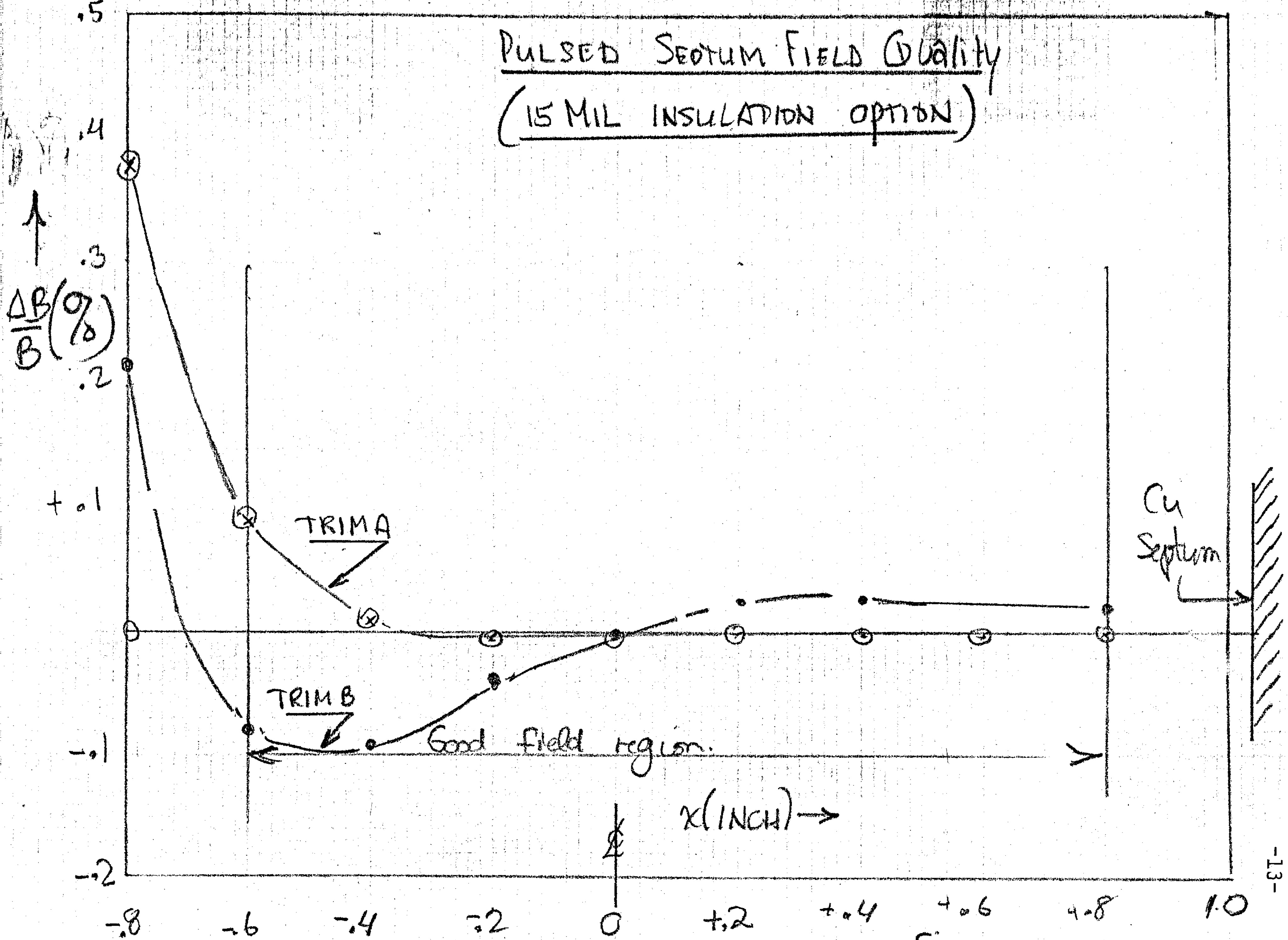

PULSED SEPTUM FIELD QUALITY
(15 MIL INSULATION OPTION)
ΔB/B (%)
.5
.4
.3
.2
+.1
-.1
-.2
TRIM A
TRIM B
Good field region.
Cu Septum
x(INCH) →
-.8
-.6
-.4
-.2
0
+.2
+.4
+.6
+.8
1.0

FIGURE 7.

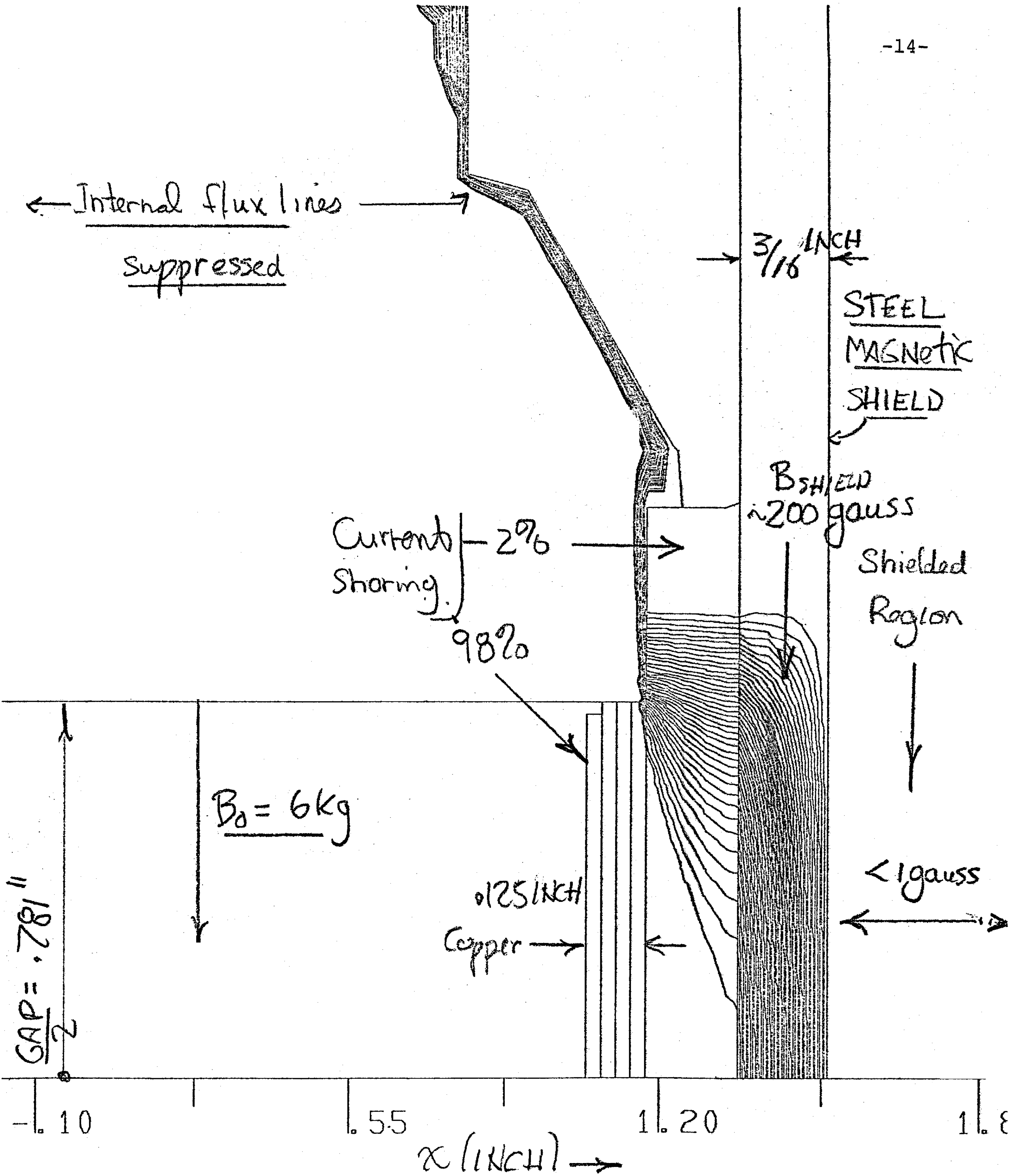


figure 8 – Modelled leakage flux due to current sharing.

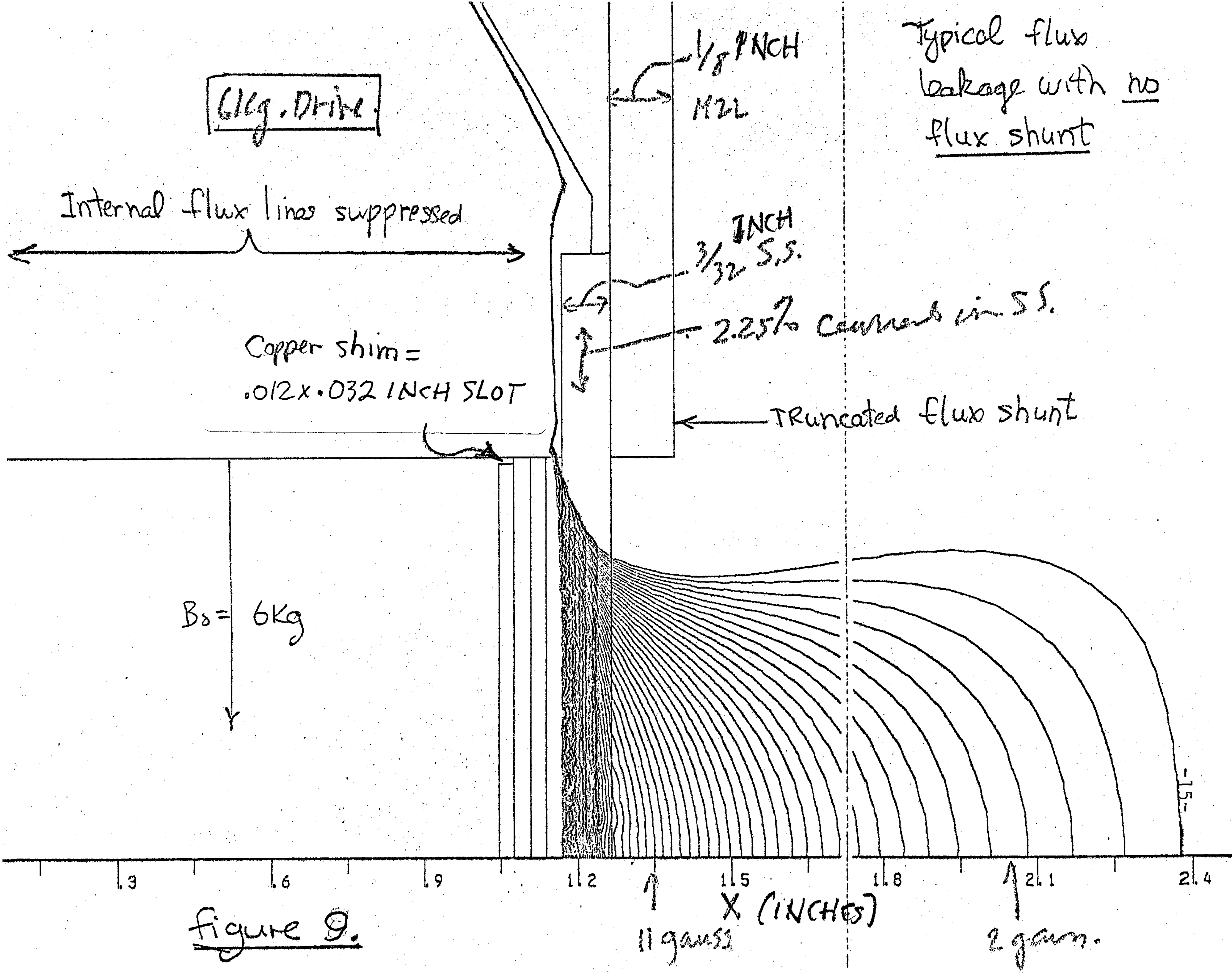

6Kg. Drive
Internal flux lines suppressed
Copper shim =
.012 x .032 INCH SLOT
B_0 = 6Kg
1/8 INCH
M2L
INCH
3/32 S.S.
2.25% Carbon in S.S.
TRuncated flux shunt
Typical flux
leakage with no
flux shunt
.3
.6
.9
1.2
1.5
1.8
2.1
2.4
X (INCHES)
11 gauss
2 gauss.

figure 9.

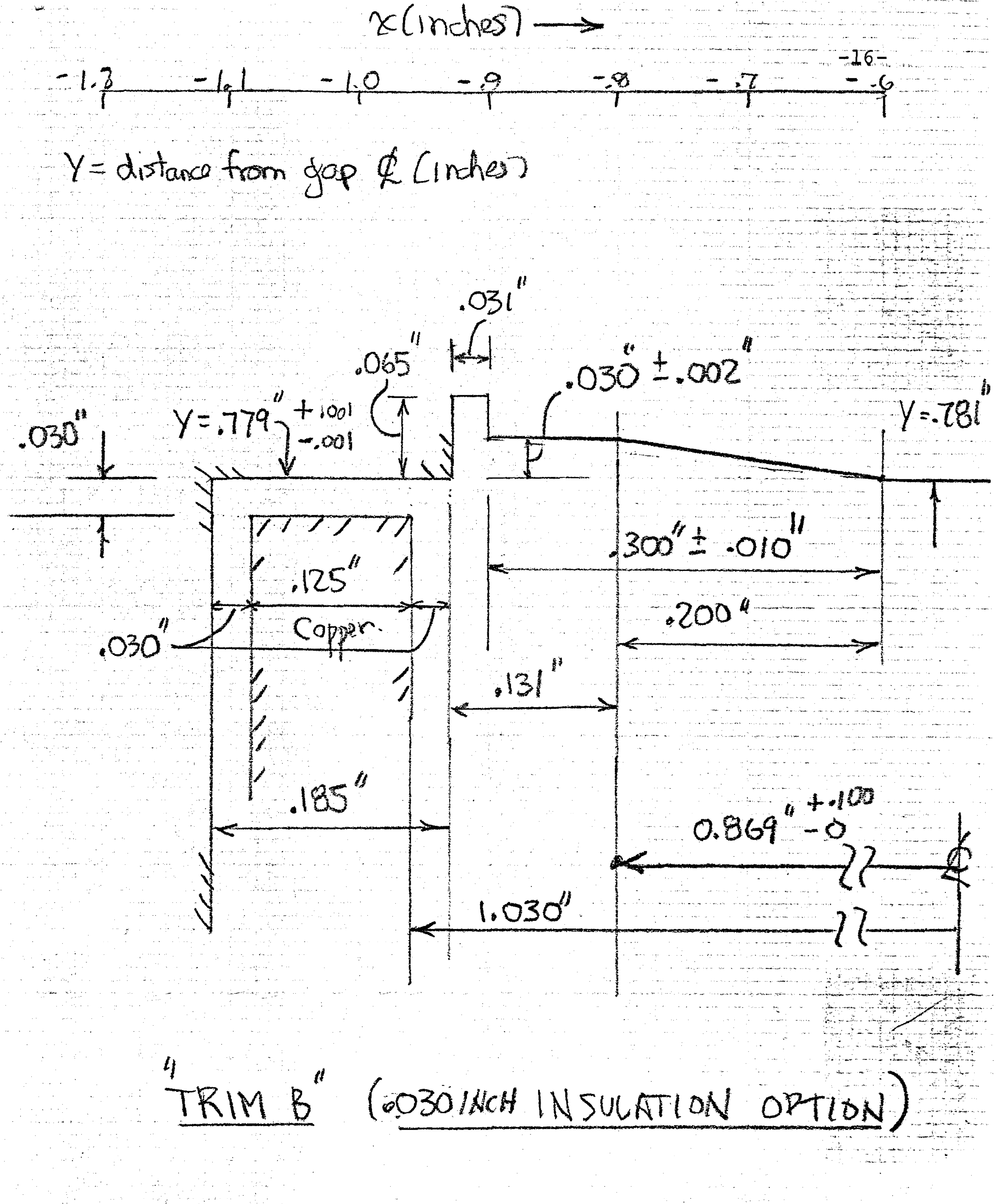


Figure 10. Pulsed Septum Inner Conductor Detail