Fermilab

$\bar{p}$ Note #291

Tev I Gradient Search Coils: (With Micron Accuracies)

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P-note # 291

TEV 1 GRADIENT SEARCH COILS:
(WITH MICRON ACCURACIES)*

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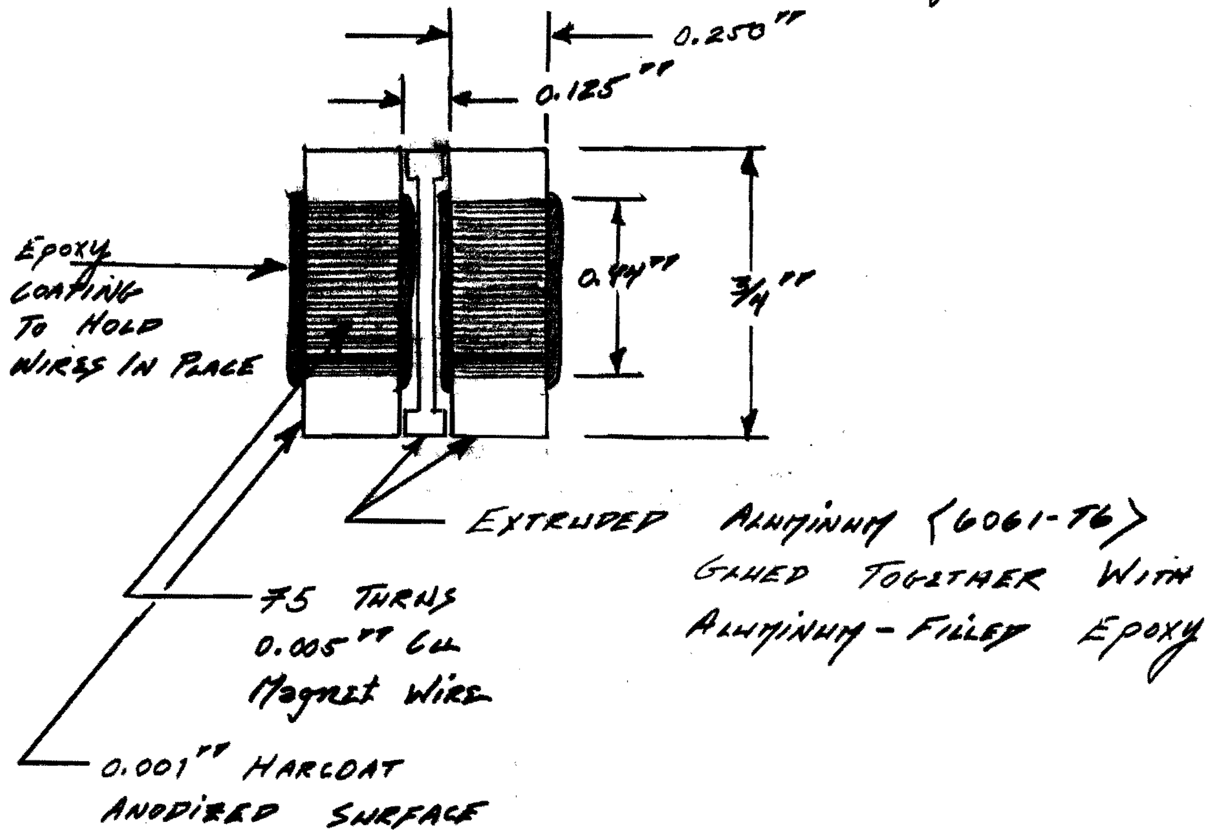
INTRO: THIS NOTE SUMMARIZES THE DESIGN & CONSTRUCTION TECHNIQUES USED FOR THE GRADIENT SEARCH COILS.

SMALL APPERTURE QUAD COILS:

FIGURES 1 and 2 show the two types of COILS MADE FOR MEASURING THE SMALL APPERTURE QUADS. ALL COILS ARE 7 FEET IN LENGTH.

* NO BRAG, JUST FACT

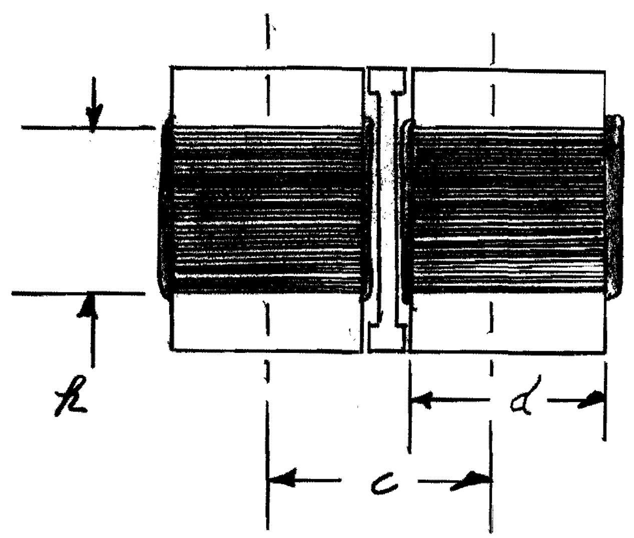
Fig 1: (2X Scale) Skinny Coil



$R_{coil\ pair} = 870\ \Omega$

Fig 2: Fat Coil (2X Scale)

Same as Figure one, But coils are 1/2" Wide



CONSTRUCTION TECHNIQUE:

ABOUT 3X THE NEEDED ALUMINUM STOCK NEEDED IS OBTAINED AND HARDCOAT ANODIZED TO PREVENT GROUND FAULTS.

THE ANODIZED STOCK IS THEN MEASURED WITH 1×10^{-4} INCH PRECISION.

MATCHED SETS < WITH WIDTHS DIFFERING BY AN AVERAGE OF LESS THAN 1×10^{-4} INCHES (2.54 μm) > ARE CHOSEN.

THE SETS ARE THEN WOUND WITH 75 TURNS OF 0.005" WIRE.

THE WOUND COILS ARE THEN BENT INTO A BOW SHAPE TO MAKE THE WIRES LIE FLAT. THEY ARE THEN GLUED INTO PLACE.

THE TWO COILS ARE GLUED TOGETHER USING ALUMINUM-FILLED EPOXY.

THE COILS ARE WIRED WITH A SWITCH THAT ALLOWS THE COILS TO BE SWITCHED FROM THE AIDING TO BUCKING MODE.

MECHANICAL PRECISION:

THUS FAR WE HAVE BEEN ABLE TO MAKE COIL PAIRS WITH AREA DIFFERENCES OF 50×10^{-6} INCHES, OR 1.3 μm WITH THIS TECHNIQUE!

THE AREA DIFFERENCES ARE MEASURED

By measuring the response of the coil in a cooling ring dipole, with the coils in both the summing and bucking modes:

$$\frac{\Delta A}{A} = 2 * \frac{V_{BUCKING}}{V_{SUMMING}}\bigg|_{G_{INT}}$$

Coil Response:

The skinny S.A.Q. search coils was designed to have no octopole response:

$$h^2 = c^2 + d^2$$

The response of the coil to quadrapole field is:

$$V_0 = G_{INT} * \int B' dl * c * d * N_T$$

G_{INT} ~ Integrator gain
N_T ~ # turns
$\int B' dl$ ~ 5T for shortest small app. quad

The response of the coil to a part in 10^4 gradient change is then

$$V_0 = G_{INT} * 2.3\,\mu V\text{-sec}$$

Hz (skinny coil, shortest quad)

The measured integrator noise over 70 seconds after computer correction of linear

AND QUADRATIC DRIFT IS

$$V_0 = G_{INT} \times 0.43\,M\text{-}SEC$$

↳ UNITS: 1/SEC

THE SIGNAL TO NOISE RATIO IS 5.7 WITH THE SKINNY COIL & 21.2 WITH THE FAT COIL FOR THE SHORTEST QUAD — REGARDLESS OF INTEGRATOR GAIN.

DIPOLE RESPONSE OF COIL:

SINCE THE COILS HAVE SLIGHTLY DIFFERENT AREAS, THE REAL COILS RESPOND AS A PERFECT GRADIENT COIL IN SERIES WITH A SMALL DIPOLE COIL: THE OUTPUT VOLTAGE OF THE INTEGRATOR WILL BE LINEAR WITH POSITION IF THE COIL WERE MOVED ACROSS A PERFECT QUADROPOLE.

THE RATIO OF THE DIPOLE RESPONSE AS THE COIL MOVES 6 INCHES <APPERTURE> IN THE SMALL APPERTURE QUAD TO THE RESPONSE DUE TO A PART IN 10^4 GRADIENT CHANGE IS:

$$\frac{V_{DIPOLE}}{\frac{V_{PART}}{10^4}\ \text{GRADIENT}} = \frac{\Delta d * \int B''\,dl * x * G_{INT}}{10^{-4} * c * d * G_{INT} * \int B''\,dl}$$

$$= \frac{\Delta d * x}{c\,d \times 10^{-4}}$$

x : DISTANCE MOVED

FOR A RATIO OF 1:

$$\Delta d = \frac{10^{-4} c d}{x}$$

$= 1.5 \times 10^{-6}$ INCHES ⟨0.04 μm⟩ FOR SKINNY COIL

$= 3 \times 10^{-6}$ INCHES ⟨0.08 μm⟩ FOR FAT COIL

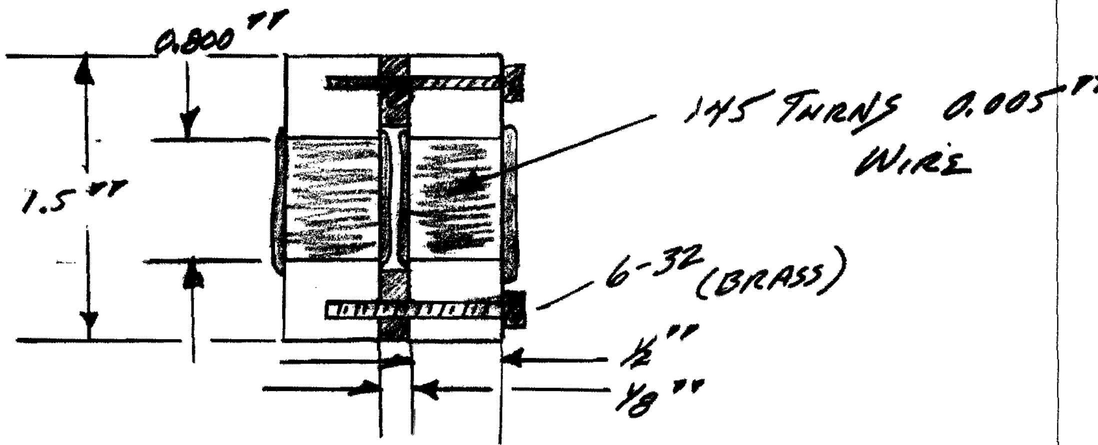
THE BEST Δd WE HAVE ACHIEVED IS 1.3 μm ⟨50×10^{-6} INCHES, 0.05 MIL⟩ AND WE DON'T THINK WE HAVE MUCH ROOM FOR IMPROVEMENT.

THE DIPOLE RESPONSE CAN BE REMOVED BY EITHER FITTING THE DATA TO A STRAIGHT LINE ⟨FIELD SHOULD BE AN EVEN FUNCTION⟩, OR BY TAKING

TWO MEASUREMENTS ~~-~~ ONE WITH THE PROBE IN ONE ORIENTATION, AND ANOTHER WITH THE COIL ROTATED 180° ON THE Z-AXIS. IF THIS DATA IS AVERAGED, THE DIPOLE RESPONSE CAN BE REMOVED FROM THE DATA.

FIGURE 3 SHOWS THE LARGE APPERTURE QUAD CONSTRUCTION. IT WILL HAVE A S/N RATIO OF 24 FOR THE WEAKEST LAQ. IN ALL OTHER RESPECTS IT IS THE SAME AS THE SAQ PROBES.

FIGURE 3: LARGE APPERTURE QUAD SEARCH COIL
(1" = 1")



LENGTH : 5 FEET
$R_{coil\ pair} = 1.2\ k\Omega$

INTEGRATOR GAIN & CALIBRATION:

FOR A BUCKING MEASUREMENT FOR THE SMALL APPERTURE QUAD, THE INPUT RESISTANCE WILL BE $2 * R_{coil\ pair} = 1740\ \Omega$, AND $2.4\ k\Omega$ FOR THE LARGE APPERTURE QUAD. THIS WILL LIMIT INTEGRATOR GAIN $\{C = 1.0\mu F\}$ TO 575 HZ AND 417 HZ RESPECTIVELY. THESE ARE REASONABLE GAINS TO USE. IF THE INPUT RESISTORS ARE REMOVED FROM THE INTEGRATORS, AND THE INTEGRATORS

ARE CALIBRATED WITH THE COILS ON THE INPUT, THERE WILL NEVER BE ANY QUESTION ABOUT INTEGRATOR TIME CONSTANTS WHEN REVIEWING THE DATA. {REMINDER – SIGNAL TO NOISE RATIO IS INDEPENDENT OF INTEGRATOR GAIN}.

TEMPERATURE EFFECTS:

THE TEMPERATURE COEFFICIENT FOR THE PROBES IS $1.2 \times 10^{-5}/°F$. SINCE BOTH COILS IN A PAIR SHOULD EXPAND THE SAME, THERE SHOULD BE NO EFFECT WHEN MEASURING GRADIENT AS A FUNCTION OF POSITION. DIFFERENTIAL EXPANSION, IF IT DID OCCUR, WOULD MERELY CHANGE THE $\frac{\Delta d}{d}$ OF THE COIL PAIR. {EITHER REDUCE IT OR ENLARGE IT}.

MEASUREMENT OF $\int B' dl$ WILL, HOWEVER, VARY AS $1.2 \times 10^{-5}/°F$.