SLAC TN-65-70
August 1965
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ALIGNMENT OF 8 BEV SPECTROMETER

Introduction

The 8 BeV spectrometer presently being designed at SLAC for end station "A" is approximately 70 feet long rising at an angle to 30 feet above ground level. Sitting on the main superstructure are five relatively large magnets, three quadrupoles weighing approximately 20 tons each and two 14.8 bending magnets weighing approximately 100 tons each. Table 1 lists the tolerances to be held on these magnets and one can readily understand why a fairly sophisticated alignment system will be required in order to check the magnet positions under running conditions.

Reference throughout this technical note will be made to TN-65-29 (Luke Mo and C. Peck) from which tolerances to be held on the 8 BeV Spectrometer have been obtained.

It is obvious that the data accumulated at the detector will only be worthwhile if the conditions under which it is obtained are precisely known. Some of these conditions are beam intensity, beam energy, field strength of the bending and quadrupole magnets and the position of the complete set of magnets Q1, Q2, B1, B2, Q3 with respect to the target and the detector.

When we refer to position we are naturally referring to the magnetic (position) rather than the geometric position of the magnet itself. The magnetic measurements group will work in cooperation with Group A in determining, the magnetic centers and putting bench marks on the magnets to provide external reference points. Once these points have been established it will be the responsibility of Group A to place the magnets within the 8 BeV spectrometer according to the tolerance listed in Table 1, Page 3.

The initial alignment of the magnets will be conducted using optical techniques employing theodolites and jig transits, to determine their position relative to the target which will act as the reference point or origin.

Once aligned, a system has been proposed (refer to section on other systems) to determine relative movements of the magnets with respect to one another and with respect to detector and target. This system consists of two taut wires strung from the target to the detector.

The following represent some of the characteristics and properties of the wire presently in use.

Ultimate tensile stress = 575,000 psi

Diameter of wire = .005"

Density of wire = 0.2829 lbs/cub ins.

Using a permissible stress of 400,000 lbs/sq in the free hanging weight required will be given by:

$$W = \text{Stress} \times \text{Area}$$

$$= 4.0 \times 10^5 \times (.005)^2 \times \pi/4 \text{ lbs}$$

$$\text{Weight} = \underline{\underline{7.854 \text{ lbs.}}}$$

Under this tension the vertical deflection at mid span is given by:

$$\text{Deflection} = y = \frac{\ell^2 W}{8 \times T} \quad \ldots\ldots\ldots (1)$$

ℓ = Length in inches

T = 7.854 lbs

W = Weight/unit length (lbs/ins).

TABLE 1 TOLERANCES OF THE 8-BeV/c SPECTROMETER

Component	X-Position of center		Y-Position of center		Z-Position of center		Angle About Axis Through Center Parallel to x		Angle About Axis Through Center Parallel to y		Angle About Axis Through Center Parallel to z		$\frac{\Delta B_o}{B_o}$		$\frac{B_y}{B_x}$	Remarks
	Due x	Due y	Due x	Due y	Due x	Due y	Due x	Due y	Due x	Due y	Due x	Due y	Due x	Due y	Due x	
Q1	±0.007"	---	---	±0.021"	±0.26"	±0.27"	---	±14 mr	±15.3mr	---	±0.71mr	±2.0mr	±0.14%	±0.6%	---	1. Due x (y) means due to limit in the x (y) direction.
Q2	±0.0085"	---	---	±0.0074"	±0.39"	±0.15"	---	±10mr	±8.25mr	---	±0.61mr	±0.5mr	±0.59%	±0.1%	---	2. The tighter one is binding.
B1	±0.165"	---	---	Loose	±1.22"	±0.99"	---	±47mr	±14.7mr	±7.9mr	±0.32mr	±20mr	±2.1%	±0.02%	±0.032%	
B2	±0.26"	---	---	Loose	±1.17"	±0.96"	---	±47mr	±11.5mr	±8.8mr	±0.51mr	±21mr	±3.3%	±0.021%	±0.051%	
Q3	±0.067"	---	---	±0.012"	±2.26"	±0.36"	---	±44mr	±43mr	---	±4.6mr	±0.84mr	±0.92%	±0.17%	---	
Q1+Q2	±0.051"	---	---	±0.014"	±0.73"	±0.51"	---	±0.13mr	±0.092mr	---	±4.7mr	±0.64mr	±0.18%	±0.12%	---	

$$y = \frac{(70 \times 12)^2 \times \rho \times \pi D^2}{8 \times 7.854 \times 4}$$

$$\text{Deflection} = \underline{\underline{0.0625''}}$$

The natural frequency of the wire may be obtained from the expression:

$$v = \left(\frac{g\ T}{D}\right)^{\frac{1}{2}}$$

where v = velocity of propagation

g = acceleration of gravity

D = weight per foot.

$$v = \left(\frac{32.2 \times 7.854}{5.55 \times 12 \times 10^{-6}}\right)^{\frac{1}{2}}$$

$$= \underline{\underline{1948.5 \text{ ft/sec.}}}$$

Full span length is 70 feet. For the fundamental frequency this will be a half wave length.

$$\text{resonant time} = \frac{35 \times 2 \times 2}{1948.5}$$

$$\text{Time} = 0.07185 \text{ secs.}$$

$$\text{Frequency} = \frac{1}{T}$$

$$= \underline{\underline{13.918}} \text{ cycles per sec.}$$

FRICTION AT SUPPORT BEARINGS

Typical coefficients of friction for a roller race of 1/2" o.d. and static (radial) loading of 48 lbs is 0.001.

In this instance radial loading with weight hanging vertical and assuming wire horizontal (not strictly true due to design of spectrometer framework).

$$\text{Radial load} = (2)^{\frac{1}{2}} \times 7.584 \text{ lbs.}$$

$$= \underline{\underline{11.1055 \text{ lbs}}}$$

Tangential force at 1/4 ins radius to overcome friction =

$\mu \times N$ where μ = coefficient of friction

N = Radial load.

$$= \pm\, 0.001 \times 11.1055 \times 16 \text{ ozs.}$$

$$= \pm\, \underline{\underline{0.1777}} \text{ ozs.}$$

Assume the wheel diameter over which wire passes is 2 inches then the tangential force will be:

$$= \pm\, 0.1777 \times 1/4$$

$$= \pm\, 0.04444 \text{ ozs.}$$

change in tension as a percentage will be given by:

$$= \frac{\pm\, 0.0444 \times 100}{7.854 \times 16} \%$$

$$= \pm\, 0.0353 \%$$

Referring to formula (1) : The deflection is inversely proportional to the tension, hence, change in y is given by:

$$\text{change} = \frac{\pm .0353 \times .0625 \times 1}{100}$$

$$= \pm 0.022 \times 10^{-3} \text{ inches}$$

$$= \underline{\underline{\pm 2.2 \times 10^{-5} \text{ inches}}} \text{ (Negligible)}$$

Influence of a magnetic field on the wire has not yet been precisely determined, however, experience at Mark III (Hansen Labs) would indicate that it may be ignored* if the magnets are close to the supports. Calculations and experiments are in hand to determine the affect with the wires hanging in free air and in a degaussing cylinder. The proposed system consists of two wires running parallel to one another in both x and y directions. In practice providing the skewness of the planes are known or the angle which they form with respect to one another is known most any configuration of the pair will be acceptable, in determing the magnet alignment.

Skewness may be determined by three levels (comparators). One level placed at the detector, another at the bogies and a third at the detector. (see Fig. 1.)

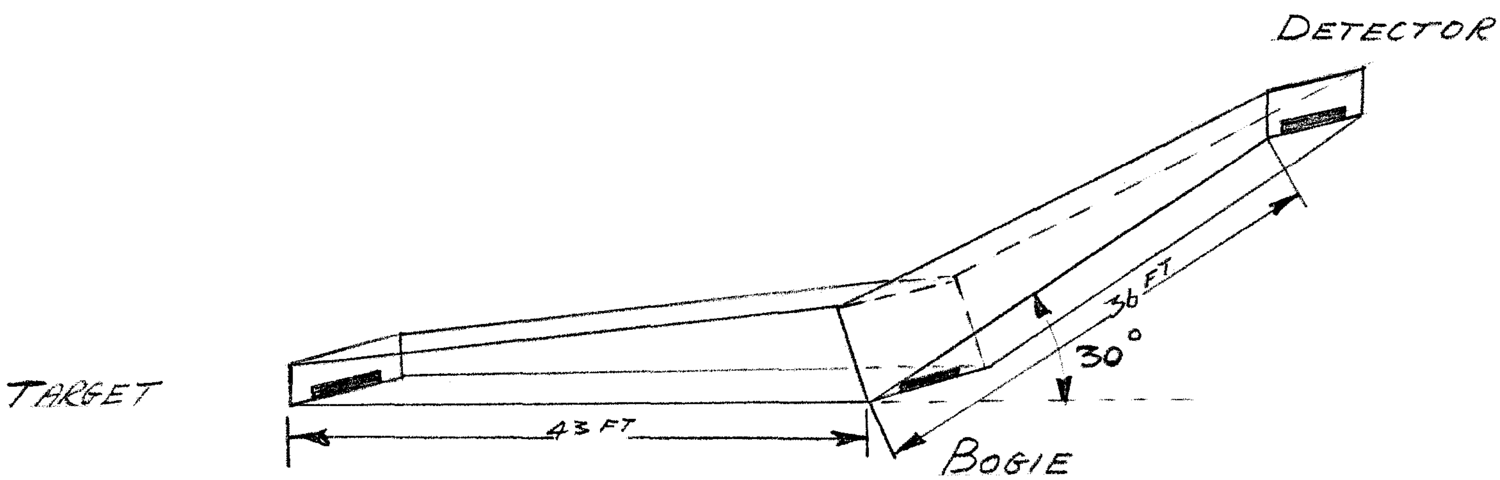


Figure 1

* A non-magnetic wire is under consideration and is being evaluated.

The two levels at the target and detector determine the skewness in the wires from one end to the other. The level at the bogie section serves two purposes. The first purpose is to answer the case demonstrated in Fig. 2, whereby two planes may appear parallel as indicated by levels but in actual fact have a skew angle of "any" value.

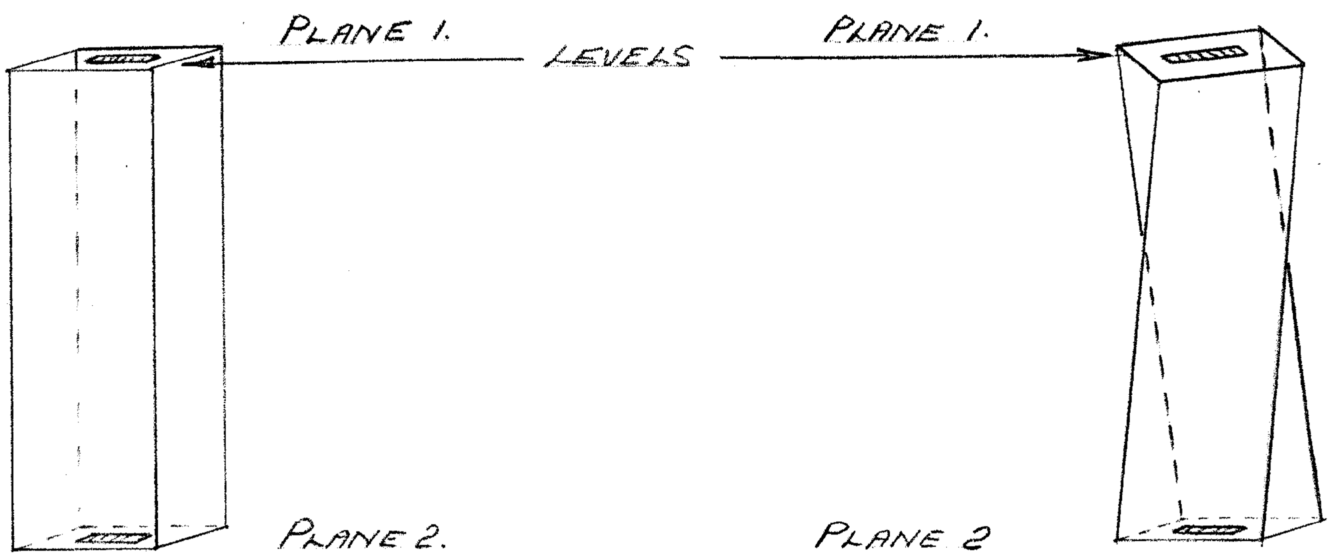


Figure 2

Plane (1) is parallel to plane (2) and lines are parallel.

Plane (1) is parallel to plane (2) and lines are not parallel.

Figure 1 shows the cantilevered section of the structure rising at an angle of 30° to the horizontal.

Now consider the following mathematical treatment to determine skewness of planes which could occur due to thermal expansion of one side-member of the spectrometer relative to the other.

Definition of "x" "y" "z" Pitch, yaw and roll.

x is transverse (horizontally) to the beam line

y is transverse (vertically) to the beam line

z is along (parallel) to the beam line.

Pitch assumes rotation about "x" axis

Yaw assumes rotation about "y" axis

Roll assumes rotation about "z" axis.

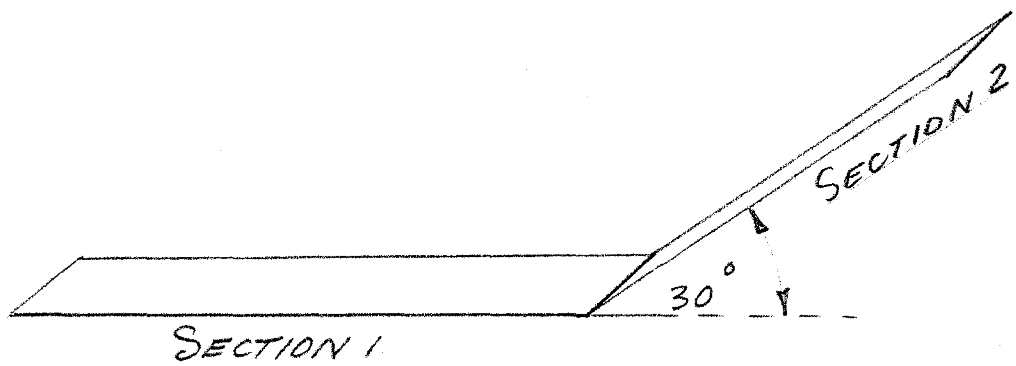


Figure 3

Let

$$W = \text{width of structure}$$

$$Ext_1 = \text{Extension of section (1)}$$

$$Ext_2 = \text{Extension of section (2)}$$

then, yaw for section (1) $= \frac{Ext_1}{W}$ mrads (units consistent)

roll for section (2) = zero

This is premised on the fact that there is no change in the temperature between upper and lower portions of the extending member and vertical growth of the member is ignored.

Now at the detector we have the following in general terms,

$$\text{Roll} = \frac{\text{Ext}_1}{w} \times \text{Sin } 30^\circ + 0$$

$$\text{Yaw} = \frac{\text{Ext}_1}{w} \times \cos 30^\circ + \frac{\text{Ext}_2}{w}$$

Assume,

Coefficient of thermal expansion $= 6.5 \times 10^{-6}$ in/in/°F

Temperature change $= 50^\circ\text{F}$

Referring to Figure 1:

Distance from target to bogie rail = 43 ft.

Distance from Bogie Rail to Detector = 36 ft.

Expansion for 43 ft length $= 43 \times 12 \times 6.5 \times 10^{-6} \times 50$

$= \underline{\underline{0.1677''}} = \text{Ext}_1$

Expansion for 36 ft length $= 36 \times 12 \times 6.5 \times 10^{-6} \times 50$

$= \underline{\underline{0.140''}} = \text{Ext}_2$

Distance between side members, i.e., w = 78"

Then roll at detector is given by:

$$\frac{0.1677}{78} \times \sin 30^\circ = 1.075 \text{ mrads}$$

and yaw at detector is given by:

$$\frac{0.1677}{78} \times \cos 30^{\circ} + \frac{0.140}{78} = 3.651 \text{ mrads}$$

In practice if expansion of the structure has taken place and not been observed then corrections could be applied to the magnets when, in point of fact, none were required. This indicates that skewness of the wires can occur and yet not be detected by a level placed at the detector. From this we infer apparent roll of a magnet could occur and a correction applied which would actually induce an error into the magnetic optics (as pointed out in the numerical example.

In the numerical example a temperature difference of 50° was chosen; it is not the author's intent to exaggerate the problems of the skewness of the two planes, however, it is worthwhile noting that the table on page 3 allows a roll angle of ± 4.6 mrads for Q3. A 50°F difference will produce ± 1.075 mrads which is approximately one-quarter of the working tolerance and could lead us, to correct the magnetic optics when they were yet within tolerance. Conversely a correction might not be applied, when in practice one should be, depending on the algebraic summation of the two values.

The second purpose for having a level across the bogie section is to enable us to determine the angle θ.

Presently the angle θ (defined as being the angle in the "x" plane made by the magnetic axis of the spectrometer and the main beam line) is to be determined by measuring the position of the center of the bogie system running on the 43 foot radius rail. At first glance this would appear to be satisfactory. In practice however, θ has to be repeatable and known within ± 1/5 × .15 mrads* where 0.15 mrads represents a bin width at

* See TN-65-29

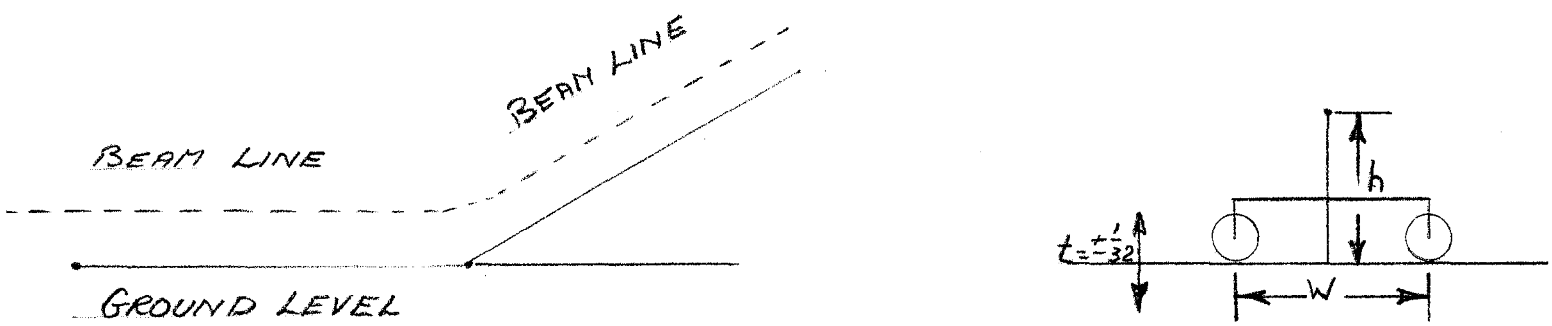
the detector and we wish to resolve to 1/5th of this. Or resolution required is equal to ± .03 mrads.

At a 43 foot radius this represents a peripheral distance of p where p is given by:

$$p = R\theta$$

$$p = \pm 43 \times 12 \times .03 \times 10^{-3} \text{ inches}$$

$$p = \underline{\underline{\pm 0.0155 \text{ inches}}}$$



Side Elevation

End View

Figure 4

The tolerances to be held on the rail according to ABA, the contractors, is ± 1/32". The deformation of the wheels and rail under the loadings contemplated will lie between 1/16" and 1/8", (and maybe an additional factor).

Assuming (as we must) that "t" the ± 1/32" error can occur within the span of the bogies then the lateral movement of the beam line which can occur at the 43 foot radius rail is given by

$$\text{Lateral movement} = \pm x$$

where $$x = \frac{h \times t}{W}$$

$$x = \frac{82 \times 0.030}{72}$$

$$= \underline{\underline{\pm 0.034''}}$$

Converting this to an angular tolerance in θ we have:

$$\underline{\underline{\Delta\theta = \pm 0.066 \text{ mrads}}}$$

as can be seen this is a factor of 2.2 times the allowable angular tolerance.

Providing the roll introduced by the uneveness of the track: (which is $\frac{2t}{W}$ rads

$$= \frac{0.060}{72} \text{ rads}$$

$$= \underline{\underline{0.833 \text{ mrads}}}$$

or $\underline{2.86 \text{ minutes of angle}}$:)

is a known quantity at any given time. A correction can be applied to the θ as observed on the direct measuring device to compensate for the error and provide us with a value of θ within $\pm$ 0.03 mrads. It is worth noting that a standard machine level will give an accuracy of 0.04125 mrads, or 1 division on the scale = 0.0005"/foot, or 10 seconds of arc. This is a factor of 17 times less than the values anticipated and will be perfectly satisfactory.

Plain machine levels would be inconvenient to read and an "electronic remote readout" level has been located. At present a unit has not been available for inspection, however, minimum graduations are one, five and twenty seconds of arc respectively and would appear to be the answer to "a line readout" of the spectrometers attitude.

Magnet Positioning

Reference to Table 1 shows the limiting tolerances are x, y and roll furthermore, calculations performed knowing the lengths of the magnets involved indicate that holding the x and y tolerances within the permitted limits automatically holds the other tolerances within their limits by at least an order of magnitude.

Consider the following typical calculation performed on Q1

length of magnet = 40"

permissible x tolerance = ± .007"

permissible y tolerance = ± .021"

Refer to section on jacking.

Assume the magnet rotates about its center then maximum YAW angle (without exceeding "x" tolerance = $\pm \frac{.007}{20}$

$$= \underline{\underline{\pm 0.35 \text{ mrads}}}$$

In the table we see allowable YAW angle to be ± 15.3 mrads.

Thus x tolerance is the controlling tolerance for "yaw" as well as "x". Similarly maximum pitch angle without exceeding "y" tolerance

$$= \pm \frac{.021}{20}$$

$$= \pm 1.05 \text{ mrads}$$

From table 1, we see the allowable pitch angle to be ± 14.03 mrads.

Hence, the "y" tolerance is the controlling tolerance for "pitch" as well as "y". Additional calculations may be performed on the other magnets and similar results discovered.

At this point it would be well to consider the manner in which the magnets are supported.

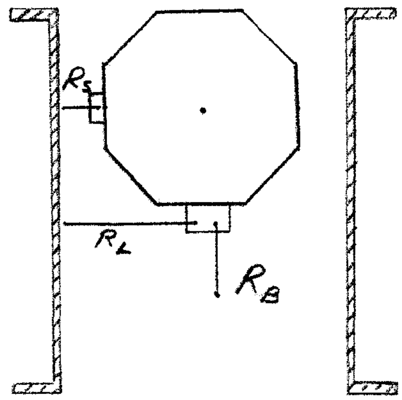


Figure 5

Principles of Adjustment and Locus of Centre Due to Adjustment

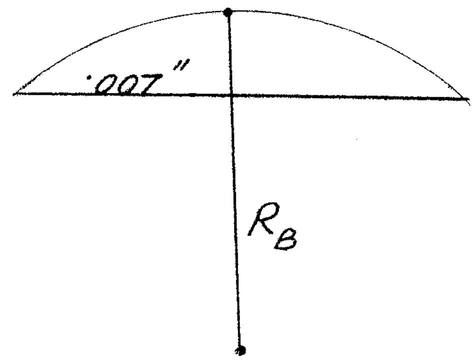
To move magnet in the x direction, 3 jacks are operated (refer to Fig. 5) R_S and two R_L. In moving through "x" the magnet will be carried over R_B and a vertical error will be introduced; for Q1 the lengths are:

$$R_S = 16''$$

$$R_L = 39''$$

$$R_B = 9''$$

$$\text{Total "x" movement} = \pm .007''$$



Vertical error i.e., in y direction. $= \dfrac{(.007)^2}{2 \times 9}$

y movement $=$ $\underline{-2.72 \times 10^{-6} \text{ inches}}$ (negligible)

In making an "x" correction by operating R_S only and leaving R_L unaltered, we introduce a roll error which would be

$$= \pm\frac{0.007}{20}$$

$= \underline{\pm\ 0.35 \text{ mrads}}$ (for maximum tolerance),

if 20" is distance from magnet center to support. Compare Roll permitted in Q1 this is a factor of only two smaller. In general it would be dangerous to accomodate "x" movement by operating R_S only. In moving through "y" the magnet will be raised by vertical jacks R_B and in moving vertically two errors will be introduced, roll and some "x" translation.

Total "y" movement is $\pm$ 0.021".

The "x" error or translation is given by $x = \dfrac{-(.021)^2}{2 \times 16}$

$= \underline{-13.78 \times 10^{-6} \text{ inches}}$ (negligible)

Roll is given by the following

$$\text{"x" movement at base of magnet} = \frac{-(.021)^2}{2 \times 39}$$

$$\text{"x"} = \underline{-5.65 \times 10^{-6} \text{ inches}}$$

$$\text{Roll} = \frac{(13.78 - 5.65)}{20} \times 10^{-6} \text{ rads}$$

$$\underline{\text{Roll} = 0.4 \times 10^{-3} \text{ mrads}} \text{ (negligible)}$$

In summary in applying a "y" correction an "x" error is introduced and in applying a "y" correction an "x" error and "roll" error is introduced. This presents us with a picture of the center of the magnet not truly "rotating" about its center but rotating and travelling on a locus. However, reference to the numeric examples indicate that the errors are negligible.

Corrections in "y" will, therefore, be accomplished by extending or shortening (two) R_B's.

Corrections in "x" will be accomplished by extending or shortening R_S and/or (two) R_L's depending on the error.

YAW will be introduced or corrected by applying equal and opposite length changes to the jacks labelled R_L. Pitch will be introduced or corrected by applying equal and opposite length changes to the jacks labelled R_B.

"True" rotation of any magnet may be accomplished if the additional complications in logic and readout design are felt to be worthwhile.

Structural Support

At this point it would be well to consider the construction of the structure in which the magnets are supported. For obvious reasons the vertical moment of inertia of the structure needs to be high to provide a rigid structure in the vertical plane, since this is the direction in which the weight forces are acting. However, differences in temperature which may exist between the upper and lower sections will cause the structure to deflect as shown.

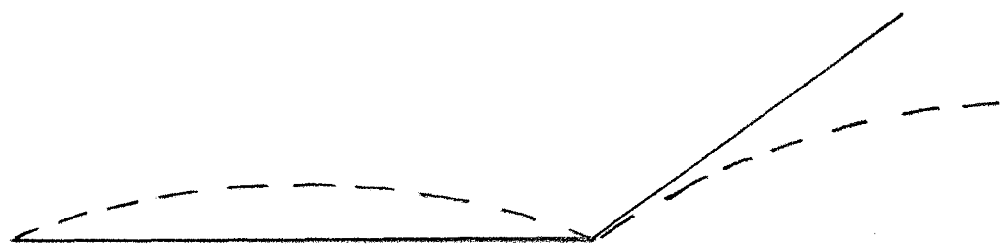


Figure 6

This assumes the upper member hotter than the lower. The deflections caused will be compensated for by adjusting the "y" motions on the jacking systems.

Calculations (Notebook 563) indicate an angular rotation θ_B at bogies of 0.3057×10^{-1} mrads/$^{\circ}$F which gives a deflection S where

$$S = R\,d\theta$$

$$= 20 \times 12 \times .3057 \times 10^{-1}$$

$$= \underline{\underline{.0074''/^{\circ}F}}$$

Furthermore, the cantilevered section due to the "bimetallic" strip effect will deflect (calculation Notebook 563).

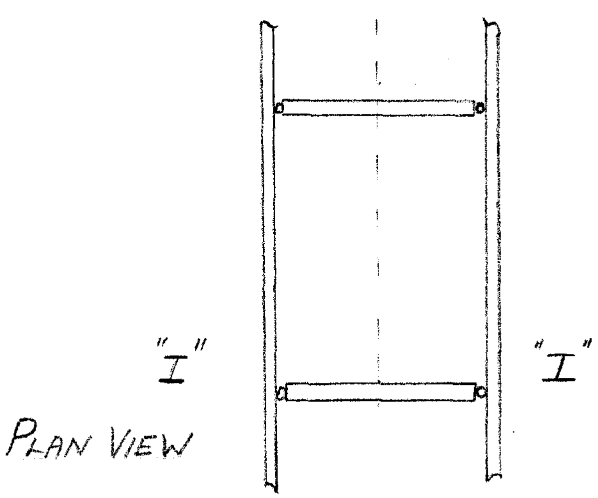
approximately $\underline{\underline{0.004''/^{\circ}F}}$

The total deflection at the detector per $^{\circ}F$ is the sum of 0.0074" and 0.0041"

$$= \underline{\underline{0.0115''/^{\circ}F}}$$

The author feels that one of the most satisfactory methods of preventing this large movement is to provide hydraulic rams, capable of carrying load into the shield carriage. Extension of these rams, providing predetermined loading would effectively return the detector to its original position applying a bending moment in the structure of opposite sign to that produced by the thermal stresses. In this manner a minimum amount of magnet adjustment would be required to maintain alignment.

In the "x" direction the structure should be designed in such a manner that the lateral moment of inertia of the structure is provided by the lateral stiffness of the side members. Without recourse to increasing "I" by introducing shear carrying members which will increase the effective h of the formula $\frac{bh^3}{12}$ where h is the width between side members.



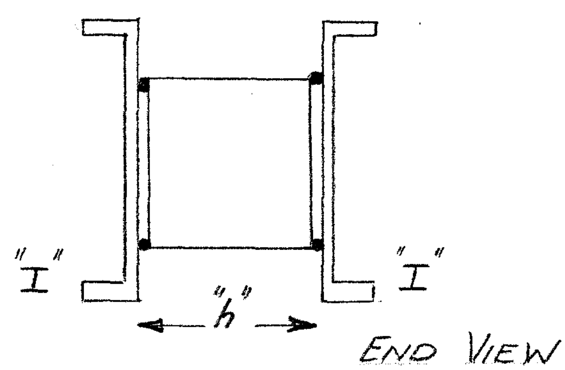


Figure 7

Let each side member have lateral moment of inertia "I" then TOTAL "I" as a pin jointed frame in Fig. 7 is 2"I"

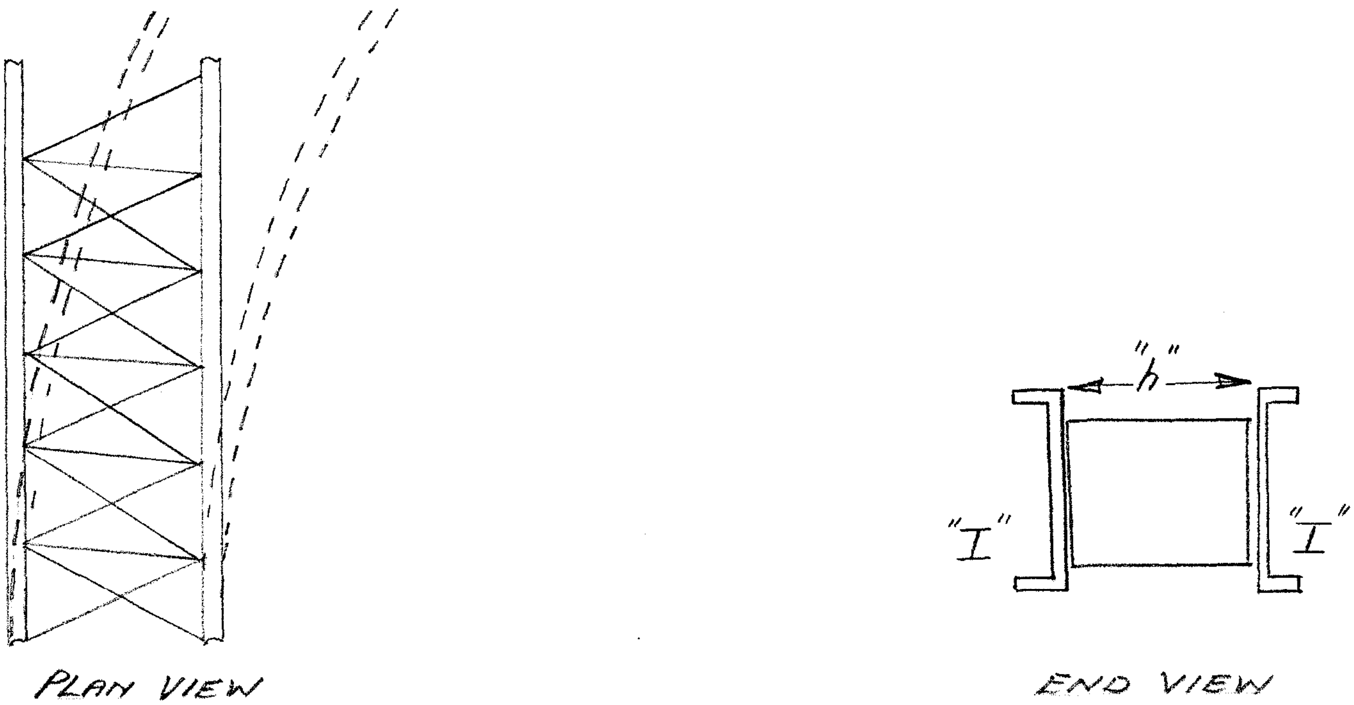


Figure 8

In figure 8 the total inertia is 2"I" plus a factor dependent on h^3 and to what degree the shear carrying cross braces are capable of carrying shear. Figure 7 is a preferable configuration since any temperature difference which may occur or exist between side members will merely cause the side members to move relative to one another. The neutral axis will remain in its original position due to symmetry; although the side members will be pointing towards a point in space at which they would intersect the neutral axis. In this instance no lateral ("x") movement of the magnetic optics will occur and the magnets should require no realignment.

In figure 8 with shear carrying members any difference in temperature between side members will cause a "bimetallic"strip effect and curvature of the whole structure will occur, necessitating corrections to each of the magnets and under some conditions the actual position of the spectrometer on its rail as determined by θ (the angle of main beam and magnetic beam could be outside of tolerance).

Refer to calculation.

If the section were a true box and "h" were "78" then the curvature introduced due to a T °F difference in temperature would be:

$$R = \frac{h}{\alpha T}$$

h = depth

α = coefficient of linear expansion

T = Temperature difference.

The "x" displacement which would occur at mid span is given by

$$x = \frac{L^2}{8R}$$

where L = length of frame

R = radius of curvature

or

$$x = \frac{L^2}{8h} \times \alpha T$$

where T = 1 °F

$$x = \frac{(70 \times 12)^2 \times 6.5 \times 10^{-6} \times 1}{8 \times 78}$$

$$= \underline{\underline{0.00735'' \text{ per } ^\circ F}}$$

It is well worth noting that this is of the same order of magnitude as the permissible tolerance as shown in Table 1. Indicating "x" corrections would be required to the magnetic optics in the event small temperature differences (i.e., 1°F) existed between side members.

The 8 BeV structure has now been designed utilizing wheels with flanges and a bogie sub-assembly which is free to move in a radial direction with respect to the main structure. This eliminates any radial loading on the center pivot with consequent movement of the target. This design feature was felt necessary after the following calculations had been performed to determine the type of radial loadings which could occur, and the subsequent movement of the target.

In practice the center post is a gun barrel: - which has

An 18" internal bore

A 26" outside diameter at base

A 24" outside diameter at top

A cantilevered height or length of 15 ft.

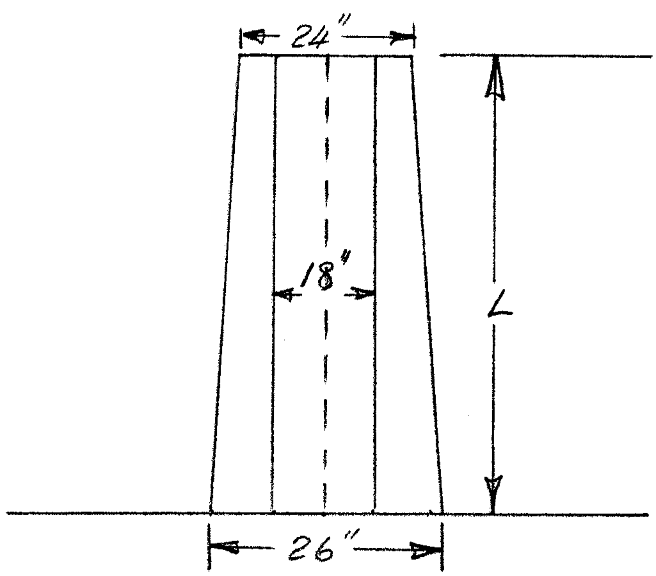


Figure 9

Then deflection of gun barrel treated as a cantilever

$$= \frac{P\ell^3}{3EI}$$

Where P = Side load

ℓ = Free length

E = Modulus of Elasticity

I = Moment of Inertia.

For 1000 lb side load and $L = 15$ ft and $E = 30 \times 10^6$ lbs/sq inch we have, (treating gun barrel as uniform with an outside diameter of 26")

$$\text{deflection} = \frac{1000 \times (1.8)^3 \times 10^6}{3 \times 30 \times 10^6 \times 17.281 \times 10^3}$$

$$= .00374 \text{ inches/1000 lbs.}$$

we have (treating gun barrel as uniform with an outside diameter of 24")

$$\text{deflection} = \frac{1000 \times (1.8)^3 \times 10^6}{3 \times 30 \times 10^6 \times 11.134 \times 10^3}$$

$$= .00582 \text{ inches/1000 lbs.}$$

we have (treating gun barrel as a cantilever of variable I)

I at section x is equal to $\pi/64 \left[\left(24 + \frac{2x}{\ell}\right)^4 - (18)^4 \right]$

and in the expression $\frac{P\ell^3}{3EI}$ we may integrate between the limits $0 - \ell$ and obtain

$$\text{deflection} = \int_0^{\ell} \frac{64P\ell^3}{3E\pi \left[\left(24 + \frac{2x}{\ell}\right)^4 - (18)^4 \right]}$$

$$= .0042''/1000 \text{ lbs.}$$

The weight of the spectrometer = 230 Tons

The coefficient of friction (static) shiny wheel on shiny rail = 0.25

Hence, maximum radial load which can be developed before slippage of the wheels occurs on the rail is = $0.25 \times 2000 \times 230$ lbs

= 115,000 lbs.

This load will produce: using stiffest section

deflection = $115 \times .00374$ inches

= 0.430 inches

or a deflection using weakest section

deflection = $115 \times .00582$

= 0.662 inches

or a deflection using variable "I" section

deflection = $115 \times .0042$

= 0.483 inches

This force and hence the deflection occurs using flat wheels without flanges on flat rails and is developed by the wheels scrubbing on the rails. This scrubbing can be caused in one of two manners:

a. The eccentricity of the rails which is presently anticipated in the design is ± 1/4". Thus the target could move by ± 1/4" developing a load at the pivot of

$$\pm \frac{.250 \times 1000}{0.0042}$$ (using variable "I" stiffness coefficient.)

= ± 59,525 lbs

b. The central pivot can move for an additional reason:

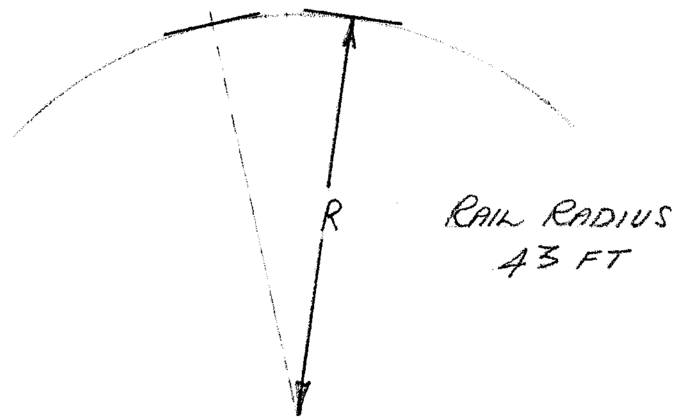
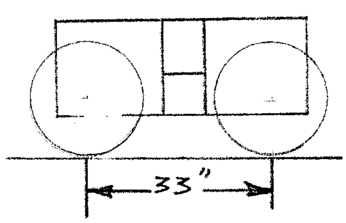
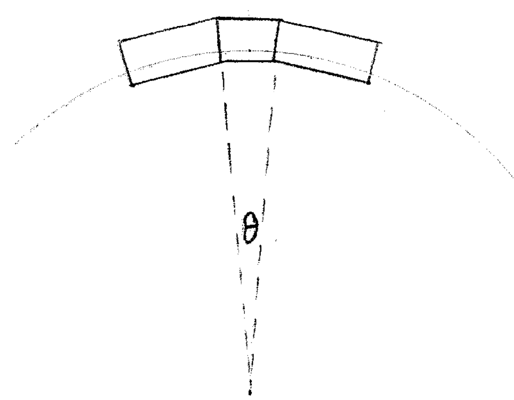


Figure 10

Distance between point contact of Bogie units is 33".



Side Elevation



Plan View

The bogies are to be fabricated in three pieces. The two webs and wheels, together with a wedge block to offset the wheels to run on the appropriate rail.

At a radius of 43 feet the angle θ which is subtended at the pivot by the point contacts of the wheels is equal to

$$\theta = \frac{S}{R}$$

$$= \frac{33}{12 \times 43}$$

$$= \underline{0.063954 \text{ Radians}}$$

Note: This is equal to 3.66426°.

It is reasonable to suppose a total error of arc in the fabrication and assembly. This represents 0.291 mrads.

subtracting from .063954 rads

gives .0636631 rads.

Substituting back into $S = R\theta$, we have

$$R = \frac{33}{.0636631}$$

$$= 43.196 \text{ ft.}$$

New radii are 43 ft ± 2.352 in.

A tendency will therefore exist for the bogies to run off the rails, they would run off until the reaction at the column was equal and opposite to the static friction developed at the bogies. This has a value of 115,000 lbs. Hence, pivot deflection before sliding of the wheels on the rail occurs, would be

$$\pm 115{,}000 \times .0042'' = \pm 0.483 \text{ inches (using variable "I" figure)}$$

The distance from the target to the pivot point of the bogie subassembly is 37 ft = L.. Change in temperature of spectrometer frame due to ambient and/or on/off conditions of power supplies = 40 °F.

Coefficient of Thermal expansion $= 6.5 \times 10^{-6}$ ins/ins/^{o}F

Then expansion of structure $= L \times \alpha \times T$

$= 37 \times 12 \times 6.5 \times 10^{-6} \times 40$

$= \underline{\underline{0.1155''}}$

This is the target movement due to thermal affects assuming the bogies do not stick (which is the case) and the center post deflects. The foregoing deflections would be acceptable if one could assume they always occured in the "z" direction. In part this is the case, however, the 20 BeV spectrometer utilizes the same target and serious interaction problems occur if the two spectrometers are separated by a relatively large θ angle. Since what is a "z" direction for the 8 BeV is a component in "x" for the 20 BeV.

i.e., "x" movement for 20 BeV $= z \times \text{sine}\ \theta$.

When θ is small the problem disappears, when θ is large it is unacceptable, thus laying the foundation stone for the present design utilizing a separate bogie subassembly from the main frame.

Mounting Sensors on Magnets

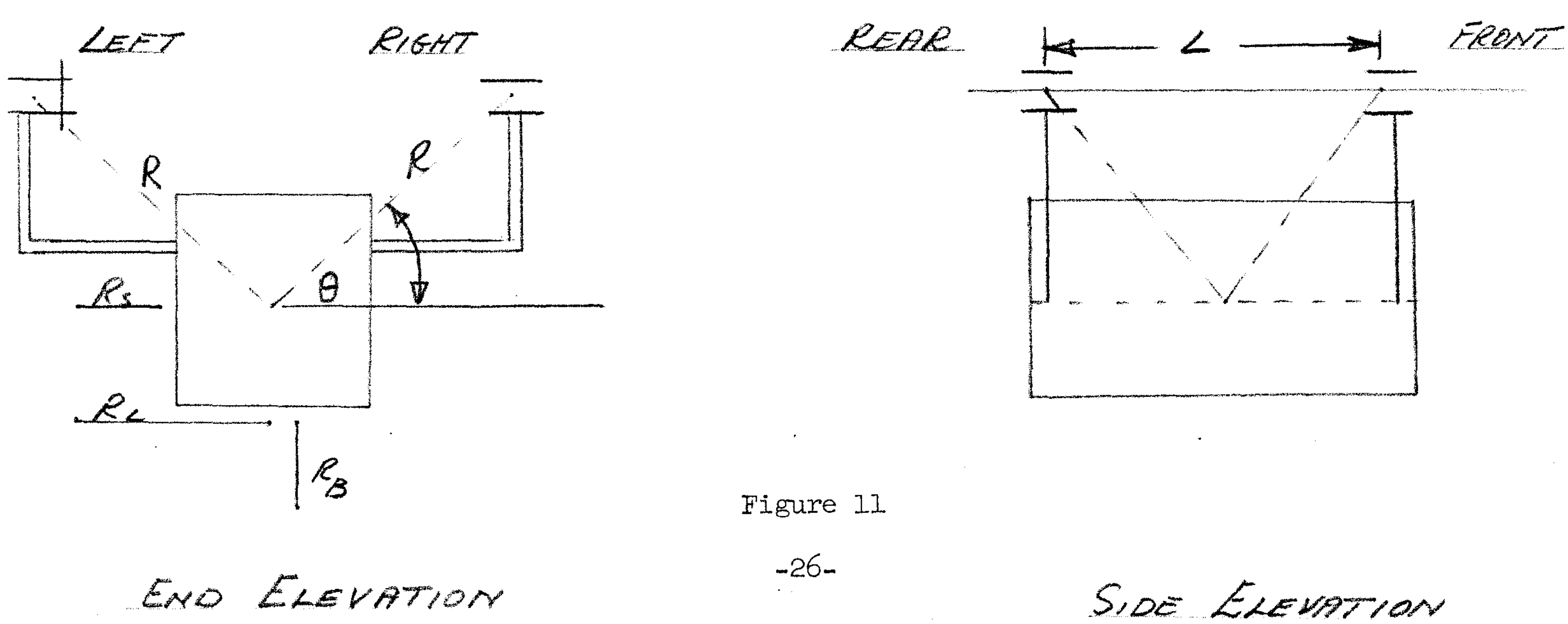


Figure 11

Referring to Fig. 11 above each magnet will have a minimum of six sensors. Three sensors at each end, one either side will indicate the "y" displacement of the magnet and one sensor will indicate the "x" displacement. We may designate these six sensors by the following:

Left Vertical Front	LVF
Right Vertical Front	RVF
Side Horizontal Front	SHF
Left Vertical Rear	LVR
Right Vertical Rear	RVR
Side Horizontal Rear	SHR

The readings obtained from the sensors will then give the appropriate magnet movements according to the following formulae:

$$YF = 1/2\,(LVF + RVF)$$ YF is actual front "y" movement

$$YR = 1/2\,(LVR + RVR)$$ YR is actual rear "y" movement

$$ROLL = \frac{(LVR - RVR)}{2 \times R \times \cos\theta}$$

$$XF = SHF - ROLL \times R \times \sin\theta$$ XF is actual front "x" movement

$$XR = SHR - ROLL \times R \times \sin\theta$$ XR is actual rear "x" movement

$$PITCH = \frac{YF - YR}{2 \times L}$$

$$YAW = \frac{XF - XR}{2 \times L}$$

Providing the following sign convention is adhered to:

Positive "y"	upwards
Negative "y"	downwards
Positive "x"	to the right
Negative "x"	to the left

Positive Pitch	Up	Front End
Negative Pitch	Down	
Positive Yaw	To the right	Front End
Negative Yaw	To the Left	

Directions determined looking down beam line from target to detector.

A computer program is available for calculating the above, printing the results and indicating an adjust signal whenever the absolute values exceed the allowable tolerance.

Alignment Systems

So far the author has only analyzed and described a taut wire system and has not mentioned "how" the wire displacement will be determined. Presently, a 25 milliamp 10 KC signal is applied to the wire with the wire passing through a set of bucked coils arranged as shown in Fig. 12.

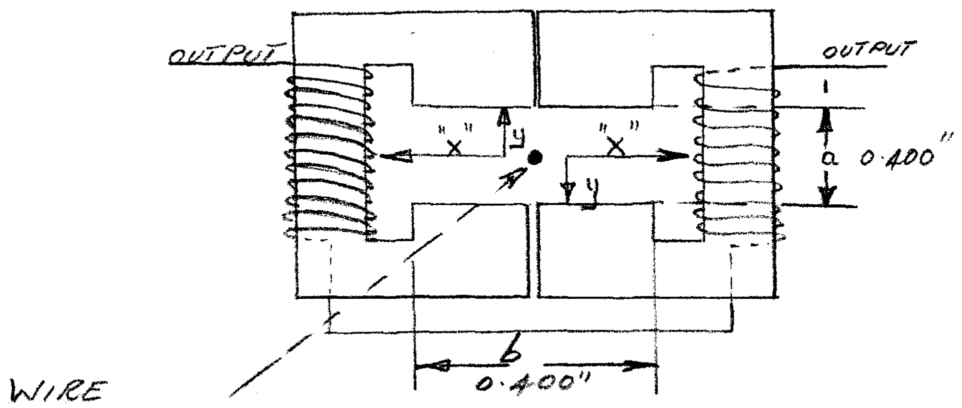


Fig. 12.

Providing the wire passes through the magnetic center of the sensor the output is zero. In the event a displacement takes place in the "x" direction more "coupling" occurs in one leg of the pickup than the other providing a resultant component of voltage. Amplification followed by demodulation provides a DC level as the signal output. Typically, 7 mv per ml is the scale factor and the unit is linear over a range of ±.040". The dimensions a and b are 0.400", chosen arbitrarily. Increasing these dimensions would increase the linear range but decrease the scale factor for the same "electronics package".

In the case of the 8 BeV spectrometer a linear range of ± 0.040" is completely adequate and yet movements as large as ± 0.200" can occur without the sensors interfering with the wire and causing interaction between sensors and/or magnets. A final system would probably have 10 mv per mil movement for convenience of readout. The unit it should be added, is insensitive in the "y" direction which is of paramount importance, since each sensor will be determining one set of coordinates at a time and any interrelation between the x and y coordinates would be unacceptable. Reference to Fig. 12 shows a .006" slit in the magnetic head; this is provided as a facility to help in the original set up to avoid the necessity to thread the "wire". An added advantage is gained since the slit enhances the sensitivity by a factor of approximately 5.

Other systems have been contemplated utilizing the taught wire and have been rejected for various reasons. See Fig. 13 and 14 for typical examples.

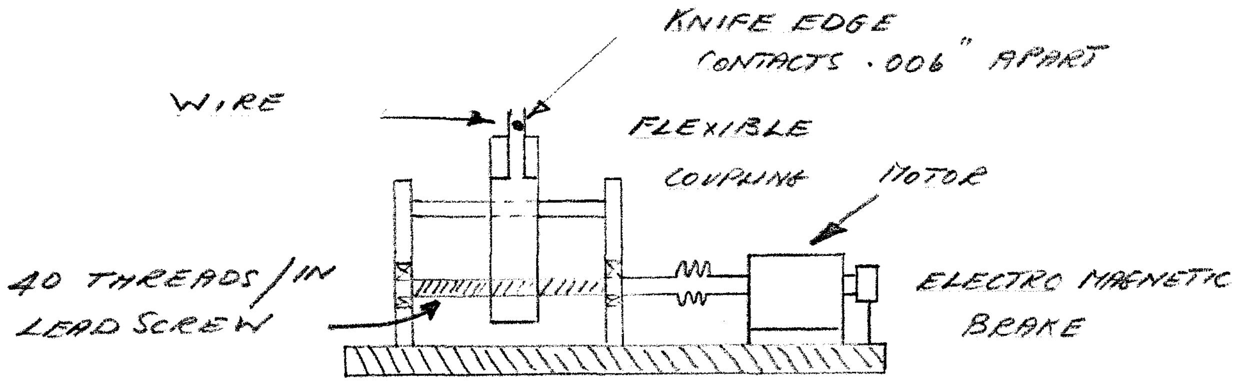


Fig. 13

1) A set of knife edged contacts set on either side of the wire sensing the position of the wire and driving themselves to a "null" point. The distance from the datum point to the null is a measure of the displacement. The disadvantages of the system are several,

a) Contact is made with the wire which displaces the wire.

b) Any film on the wire could cause failure of the sensors to trigger the drive unit.

c) Interaction between units is possible and "hunting" could occur in a large structure.

d) Failure of any "one" sensor to track the wire would displace the wire, indicating an error in all other subsequent sensors with corrections being applied when unnecessary, to the magnets.

e) Digitizing the error and displaying the information is an expensive process.

f) The sensors with mechanical drive units are fairly large. Refer to Fig. 13.

2) Photoelectric Sensing.

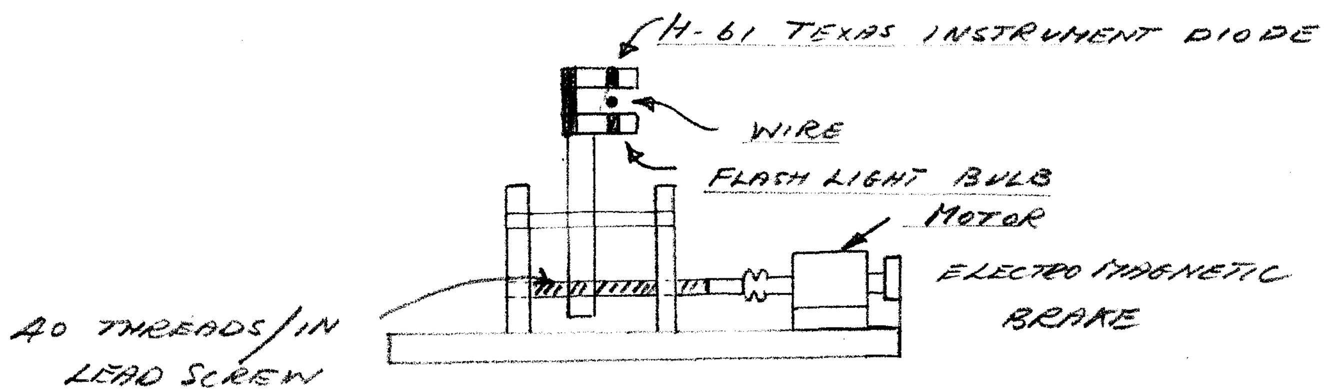


Fig. 14.

A device such as that shown in Fig. 14 has been examined and proved to resolve within .001"; the main disadvantages are:

a) A mechanical drive is required to drive the photo electric dėvice in searching for the wire.

b) The cost of the unit installed would be fairly high.

c) Packaging of sensor and mechanical drive makes the unit fairly large (Refer to Fig. 14) which complicates installation of the unit within the shielding around the spectrometers.

d) Digitizing the error and displaying the error is just as difficult as in case 1.

Many other systems have been contemplated and rejected for a variety of reasons. It is not the object of this TN to analyze each and every system, suffice it to say that optical techniques, x-rays, lasers, etc., have been discussed and to the present have disadvantages, mainly readout, which are unacceptable, since the system must be remote and on-line while high radiation fields are present.