C.G.T.M. #5
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Layout is a program which facilitates the handling of numbers required to place magnets and other equipment in a beam transport system. The usual input is the TRANSPORT deck used to compute the beam optics, for the system, plus other cards defining point of interest such as vertices, etc. The origin is defined at the point (0, 0, 0) with unit vectors:

$$\vec{1}_x = (1, 0, 0)$$
$$\vec{1}_y = (0, 1, 0)$$
$$\vec{1}_z = (0, 0, 1)$$

The name of this origin is <u>REF</u>. All points are computed and stored with respect to this origin.

Unless otherwise specified (by a <u>TILTSY</u> card, see below) the beam central trajectory is assumed to initially coincide with $\vec{1}_z$ and the horizontal beam plane is the plane defined by $\vec{1}_x$ and $\vec{1}_z$. The starting position of the system is (0, 0, 0).

The positions of "flagged" points along the central trajectory are stored with a set of three mutually perpendicular unit vectors associated with the beam at that point:

$\vec{1}_z$ = the beam direction, i.e., the direction of an electron on the central trajectory passing through the point.

$\vec{1}_y$ = the beam vertical direction, $\vec{1}_z$ and $\vec{1}_y$ form the beam vertical plane used in the optics calculations.

$\vec{1}_x$ = the beam horizontal direction, $\vec{1}_z$ and $\vec{1}_x$ form the beam horizontal plane used in the optics calculations.

Flagging a point along the central trajectory is done by inserting

a card into the TRANSPORT data deck at the desired point:

```
15.     7.     'XXX'     0.
```

The character inside the quotes is the name given to the point. These cards will be ignored by the TRANSPORT program, but when the same data deck is given to the LAYOUT program, a point-axis, along with its name, is stored for each such card.

Example:

```
.
.
.
3.     78.5
5.     1.     -1.661     4.
15.    7.     'Q10'      4.
5.     1.     -1.661     4.
3.     2.
.
.
.
```

The point Q10 is defined to be at the center of the two meter quadrupole. (See TRANSPORT manual for details on the format of the other cards.)

Other point-axes may be defined in terms of these flagged ones by means of the interpreted instructions given below. It is hoped that most of the numbers needed to describe the various surveying procedures may be generated by proper sequences of interpreted instructions.

Once points are defined, they are identified by their names. A list of such names on a PRINT card (see below) will cause the co-ordinates (and other data) of the points whose names are on the list to be printed. These may be printed with respect to any other defined point-axis as origin; if no such point is specified the internal origin REF is used. The units of distance may be specified by the user by a UNIT card; if non are specified meters are used.

Any collection of defined points may be identified by use of the SET card. This is sometimes convenient in organizing the printout.

Interpreted Instructions

TRANS reads cards 3 thru to sentinal of any transport deck. points on beam line where a 15. 7. 'XXX' 0. card occurs are flagged and stored. XXX may be any 3 alphanumeric characters except spaces. The 1_z axis given to such a point is the beam line - i.e. the direction of an electron central trajectory at that point. 1_x and 1_y are beam horizontal and beam vertical and the 3 form a right hand system of coordinates.

TILTSY N_1 N_2 N_3 A

Computer recomputes all points read in by preceding TRANS as follows. The initial beam line (original $\vec{1}_z$) is tilted downward by N_1 radians and the beam line at point A is perpendicular to local gravity vector located at (x,z) = (N_2N_3) is the horizontal plane. The equations which define the tilted plane are given in Appendix II.

VERTEX A_0 A_1 C_1 A_2 C_2

computes and stores the point A_0 defined by intersection of lines (A_1C_1) and (A_2C_2). If they do not come closer than 10^{-6} meters, this fact is printed. The axes of A_0 are those of A_1. C_1 and C_2 are axis numbers. Axis numbers of 1., 2., 3. refer to axes x, y, z respectively.

MARK A_0 A_1 C_1 N

computes and stores the point A_0 defined by marking of N meters (+ or -) along the vector (A_1C_1) from A_1. The axes of A_0 are those of A_1.

MOVE A_0 A_1 N_1 N_2 N_3

computes and stores point A_0 defined by translating point A_1 by $N_1N_2N_3$ along $1_x1_y1_z$ axes respectively. The axes of A_0 are those of A_1.

SET A_0 L ;

collects all the points in list L in a single set for printing. L is a list of points and/or other sets.

UNIT A N

converts meters to units whose name is A. The conversion factor is: $\frac{\text{no. of 'A' units}}{\text{meter}}$

example: UNIT IN 0.0254

converts all distance output to inches, and assumes all distances input in inches.

APPENDIX I

Reserved words

SENTINEL
TRANS
PRINT
TILTSY
VERTEX
MOVE
MARK
SET
REF
WRT
IN:
ONTOP
ALL
;

These words have special meaning to the program. In general, giving a point-axis any of the above words as names will lead to an error.

SYNTAX: for the interpreter

TRANS	⟨transport deck minus 'title' and 'zero' cards⟩ SENTINEL
TILTSY	⟨number⟩ ⟨number⟩ ⟨number⟩ ⟨name⟩
VERTEX	⟨name⟩ ⟨name⟩ ⟨axis no.⟩ ⟨name⟩ ⟨axis no.⟩
MARK	⟨name⟩ ⟨name⟩ ⟨axis no.⟩ ⟨number⟩
MOVE	⟨name⟩ ⟨name⟩ ⟨number⟩ ⟨number⟩ ⟨number⟩
MOVE	⟨name⟩ ⟨name⟩ ⟨name⟩
SET	⟨name⟩ ⟨name list⟩
PRINT	⟨format spec⟩ ⟨origin spec⟩ ⟨name list⟩
PRINT	⟨format spec⟩ ⟨origin spec⟩ ALL
UNIT	⟨name⟩ ⟨number⟩

⟨format spec⟩ : = ONTOP
or (empty)

⟨origin spec⟩ : = WRT ⟨name⟩
or (empty)

⟨name list⟩ : = ⟨name⟩ ⟨name⟩ ⟨name⟩ ..... ⟨name⟩ ;

⟨name⟩ : = any six or less typed characters the first of which is not a digit and none of which is a space.

⟨number⟩ : = any number <u>with</u> a decimal point, with or without sign.

⟨transport deck minus 'title' card and 'zero' card⟩ : = any deck which can be input to computer program TRANSPORT minus the first two cards.

⟨axis no.⟩: = 1. 2. 3.

APPENDIX II

Mathematical Equations for the Tilted Plane of the Switchyard

In the beam transport system the central trajectory bends through an angle θ ($\theta = 24.5^{\circ}$ for the A beam) all in a single plane called the beam plane. If an origin is given in this plane the beam transport parameters $d_1\ \theta_1\ \rho_1\ d_2\ \theta_2\ \rho_2 \ldots$ are sufficient to compute the co-ordinates of vertices $p_1\ p_2 \ldots$, which define the beam line (see figure 3). In vector notation this means that the position vector of each point is a linear combination of two unit vectors $\vec{u}_1\ \vec{u}_3$ which define the beam plane:

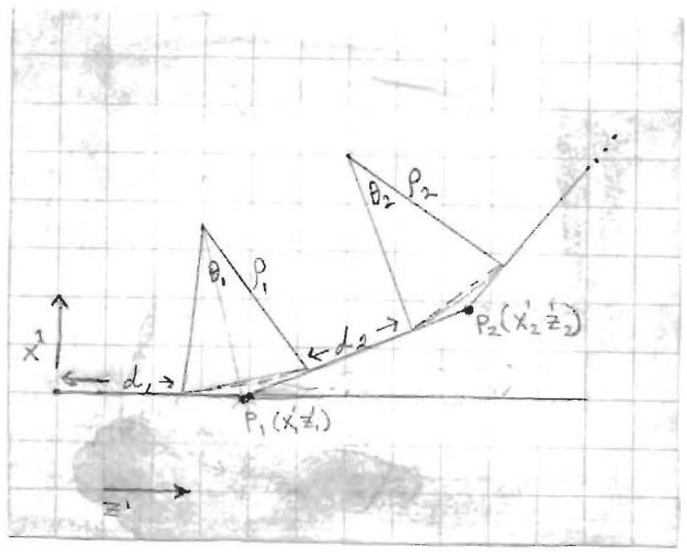

Figure 3 - In Beam Plane

$$\vec{p}_i = x_i^{\,1}\,\vec{u}_3 + z_i^{\,1}\,\vec{u}_1 \tag{1}$$

This beam plane must be "placed" so that the entrance line into the transport system is coincident with the downhill sloping accelerator line and the exit line to the end station is horizontal. Further, the vertices p_i must be related to a co-ordinate system convenient for tunnel construction and equipment layout. The co-ordinate system chosen has as its y axis the unit vector $\vec{1}_y$, straight up at station 105 + 08.* (i.e., coincident except for sign to local gravity at this station). The z axis $\vec{1}_z$ is the projection of the accelerator line upon the horizontal plane (defined at 105 + 08). The x axis $\vec{1}_x$ is perpendicular to these two vectors. The vectors

* This is the position of the accelerator alignment monument.

$\vec{1}_x$ $\vec{1}_y$ $\vec{1}_z$ are assumed to be unit vectors in the derivation below. The position of the origin is (arbitrarily) set at the beginning of the transport systems, station 101 + 75. This point is near the entrance face of the first of the pulsed magnets.

In figure 4 the vectors $\vec{u}_1$ $\vec{u}_2$ $\vec{u}_3$ are unit vectors in the beam plane. $\vec{u}_2$ is along the beam transport exit line. They are related by:

$$\vec{u}_1 \cdot \vec{u}_3 = 0$$

$$\vec{u}_2 \cdot \vec{u}_3 = \sin\theta$$

$$\vec{u}_1 \cdot \vec{u}_2 = \cos\theta$$

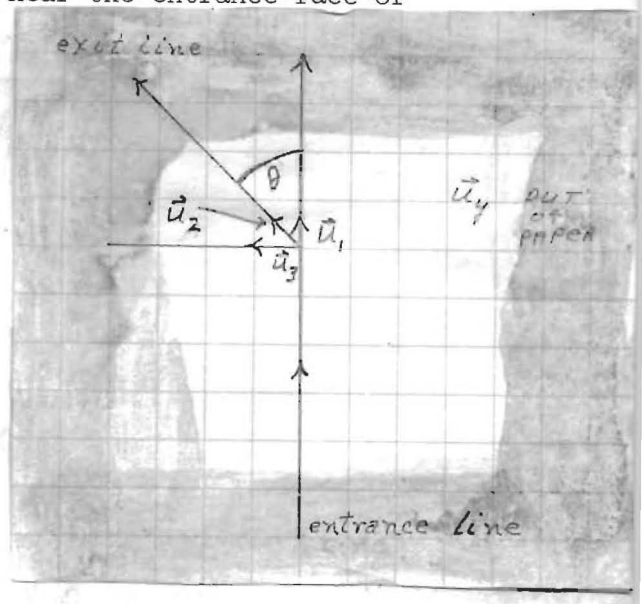

Figure 4 - In Beam Plane

For the exit line to be horizontal,

$$\vec{u}_2 \cdot \vec{1}_y = 0 \qquad (2)$$

If φ is the accelerator grade angle at station 105 + 08,* then the entrance line is expressed by,

$$\vec{u}_1 = 0 \cdot \vec{1}_x - \sin\varphi \cdot \vec{1}_y + \cos\varphi \cdot \vec{1}_z$$

These conditions plus the fact that all vectors are of unit length are sufficient to get $\vec{u}_2$ in the desired co-ordinates:

$$\vec{u}_2 = \left(1 - \frac{\cos^2\theta}{\cos^2\varphi}\right)^{\frac{1}{2}} \vec{1}_x + 0 \cdot \vec{1}_y + \frac{\cos\theta}{\cos\varphi} \vec{1}_z \qquad (3)$$

Finally, $\vec{u}_3$ is expressed as a linear combination of $\vec{u}_1$ and $\vec{u}_2$:

* The accelerator grade angle at station 105 + 08 was measured to be:

$\varphi = .00474$ radians.

$$\vec{u}_3 = \frac{1}{\sin\theta} \cdot \vec{u}_2 - \cot\theta \cdot \vec{u}_1 \tag{4}$$

So that the last 3 equations substituted into eq (1) will give each point in the desired co-ordinates:

$$\vec{p_i} = x\ \vec{1_x} + y\ \vec{1_y} + z\ \vec{1_z}$$

where

$$\left\{\begin{aligned} x &= \frac{x^1}{\sin\theta}\left(1 - \frac{\cos^2\theta}{\cos^2\varphi}\right)^{\frac{1}{2}} = x^1\left(1 - \frac{\tan^2\varphi}{\tan^2\theta}\right)^{\frac{1}{2}} \\ y &= \frac{x^1}{\sin\theta} \cdot \cos\theta\ \sin\varphi - z^1\ \sin\varphi = x^1\left(\cos\varphi \cdot \frac{\tan\varphi}{\tan\theta}\right) - z^1 \cdot \sin\varphi \\ z &= \frac{x^1}{\sin\theta}\left(\frac{\cos\theta}{\cos\varphi} - \cos\theta\ \cos\varphi\right) + z^1\ \cos\varphi = x^1\left(\cos\varphi\ \frac{\tan^2\varphi}{\tan\theta}\right) + z^1\ \cos\varphi \end{aligned}\right\} \tag{5}$$

<u>Correction for spherical earth</u>: In the above calculations it is assumed that $\vec{1}_y$ is "vertical" at all points of the switchyard, neglecting the fact that the earth is round. The beam exit line really should be normal to <u>local gravity</u> at some point E in the end station rather than to $\vec{1}_y$.

This means that eq (2) should be replaced by

$$\vec{u}_2 \cdot \vec{1}_{g(E)} = 0 \tag{6}$$

where $\vec{1}_{g(E)}$ is the local gravity vector at some (arbitrary) point E in the end station. In the monument co-ordinate system defined on the first page, $\vec{1}_{g(E)}$ is:

$$\vec{1}_{g(E)} = (\sin\Psi \cdot \sin\bar{\theta})\ \vec{1}_x + (\cos\Psi)\ \vec{1}_y + (\sin\Psi \cdot \cos\bar{\theta})\ \vec{1}_z$$

where:

$$\Psi = 1.511 \cdot 10^{-7} \cdot d$$

$$\bar{\theta} = \arctan \frac{x}{z}$$

$$d = \left[(z - 101.4984)^2 + x^2\right]^{\frac{1}{2}} \text{ meters}$$

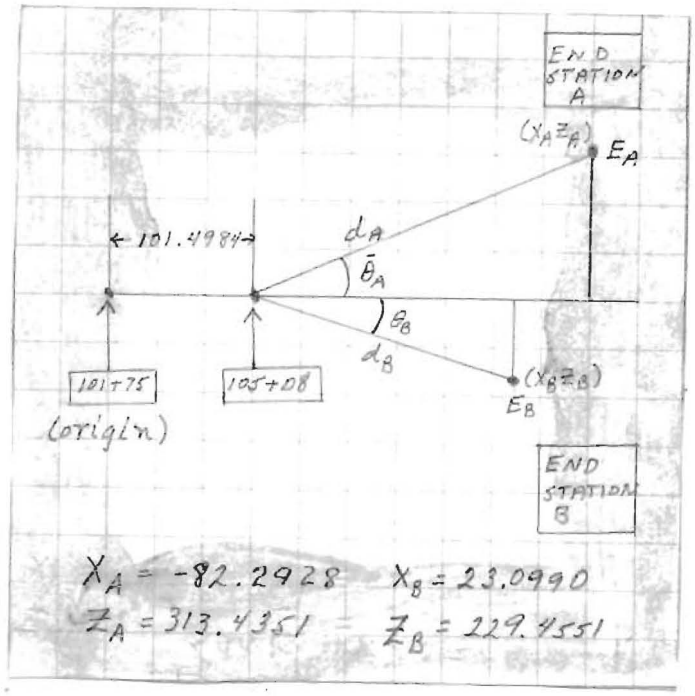

Figure 5

The values for (x,z) for both end stations A and B are given in the table at right, figure 5. The number 1.511 at 10^{-7} radians/meter is the curvature for a spherical earth. 101.4894 is the distance in meters between station 101 + 75 and 105 + 08.

Using eq (5) instead of (2), the vector $\vec{u}_2$ is modified slightly from its value in eq (3):

$$\vec{u}_2 = \left[\left(1 - \frac{\cos^2\theta}{\cos^2\varphi}\right)^{\frac{1}{2}} - \sin\Psi \cdot \frac{\cos\theta\sin\varphi}{\cos^2\varphi}\left\{\sin\bar{\theta} + \frac{\cos\bar{\theta}\cos\theta}{\cos\theta}\left(1 - \frac{\cos^2\theta}{\cos^2\varphi}\right)^{\frac{1}{2}}\right\}\right] \cdot \vec{1}_x$$

$$+ \left[0 - \sin\Psi \cdot \left\{\left(1 - \frac{\cos^2\theta}{\cos^2\varphi}\right)^{\frac{1}{2}} \sin\bar{\theta} + \frac{\cos\bar{\theta}\cos\theta}{\cos\varphi}\right\}\right] \cdot \vec{1}_y$$

$$+ \left[\frac{\cos\theta}{\cos\varphi} - \sin\Psi \cdot \left\{\left(1 - \frac{\cos^2\theta}{\cos^2\varphi}\right)^{\frac{1}{2}} \sin\bar{\theta} + \frac{\cos\bar{\theta}\cos\theta}{\cos\varphi}\right\}\frac{\sin\varphi}{\cos\varphi}\right] \cdot \vec{1}_z$$

+ Terms quadratic or higher in $\sin\Psi$, which may be neglected.

This expression for $\vec{u}_2$ together with the vectors $\vec{u}_1$ and $\vec{u}_3$ of the previous section enable one to compute points in the beam plane in the desired co-ordinates from eq (1). The values for x, y, z, are those given in eq (5) plus correction terms involving $\sin\Psi$.