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A Bubble Chamber Track-Centering Device with Digitized Output*

Frederick Ayer, Eric Pickup, Edwin F. Rappe, and Gaylord Wall

Brookhaven National Laboratory, Upton, New York

ABSTRACT

A means for automatically determining the coordinates of a point at the center of a bubble chamber track is described. A coarse setting of operator-controlled cross-hairs, supported by a toolmaker's stage, is made and the distance between the cross-hairs and the track center is found by means of a system based on a vibrating slit which scans a portion of the track. The distance is reduced to digital form and printed out on tape along with the coordinates of the coarse stage setting. A computer routine then determines the true position of the point on the track.

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Introduction

Early forms of bubble chamber track measuring devices relied on the ability of an operator to set cross hairs accurately on the center of the photographic image of a track, the viewing being done either by means of a microscope or a projection system. Two such devices, based on Gaertner toolmaker's stages, one manually and the other motor driven, have been built. In each, the lead screw motion was digitized and the measurement carried out with the help of Bausch and Lomb stereomicroscopes. Measurement error was 35μ in the chamber, corresponding to 3.5μ on the ¹ film. However, the system, while basically accurate, has the disadvantage that the operator quickly becomes fatigued, with a consequent slowing down of production and a loss of setting accuracy.

In order to increase accuracy by removing human bias and fatigue, and (hopefully) to increase the rate at which events could be measured, a device has been designed whereby the operator makes a crude setting, and the final, vernier measurement is left to the track centering device and electronic computation. It eliminates the necessity for complex track following systems, such as were installed originally on the sophisticated Franchenstein developed at UCRL Berkeley, the Shutt machines at ORNL, the Plano machines at the Naval Laboratory of Columbia University and the Russian device at Moscow. These systems have since been incorporated in the commercial film-measuring machines made by Harman Electronics and the Gilliland Instrument Company, to mention only a few. The underlying principles are well known and have been used, in a modified form, for astral tracking in the Schwarzschild Stratoscope and the automatic navigational systems of Kollsman Instruments, among others. The concept of combining rough measurements and accurate settings is the basis of the

Hough-Powell rapid measuring system, in which the former are used to
(2)
indicate the area in which the measuring engine must operate.

The device operates in the following manner: If a vibrating slit scans across the image of a track, the intensity of the light which passes through the slit will be varied by the track shadow twice in each cycle. If the track is so placed that it is over the equilibrium point of the slit, a photomultiplier sensing the transmitted light will generate a succession of equally spaced pulses. However, as described in greater detail below, when the track image is displaced from the mid-point of the slit vibration, an error signal is generated. This error signal causes a dc bias to be superimposed on the ac voltage which drives the slit, and the bias displaces the equilibrium point of the slit until it coincides with the track image. The amount of bias is determined by the rotation of a potentiometer driven by a servo motor at the command of the error signal; the magnitude of the rotation is digitized and expressed as a linear displacement of the slit. Hence, the operator need only place a point on the track within the limits of the displacement of the slit; the digitizers attached to the lead-screws of the stage will then give the stage coordinates while the motion of the slit, reported by its separate digitizer, serves as a vernier. A routine in the computer program resolves the slit motion into increments along the coordinate axes, and the true coordinates of the point on the track are the sum of the lead screw digitizer readings and these increments.

The operator is guided in making the setting by means of an illuminated reticle which is accurately lined up with the equilibrium point of the slit and projected on the track image. The axes of the slit

and reticle are interlocked so that the operator may simultaneously make both reticle and slit parallel to the track by simply turning a hand wheel. Fig. 1 is a photograph of the device, the lens and mirror on the left serving to project the image onto a screen; it is shown schematically in Fig. 2.

The dc movement of the slit is limited to about 30μ on each side of the equilibrium point. The reticle consists of two parallel lines crossed at their midpoint by a single line. The line separation is the equivalent of about 80μ in order to make it relatively easy for the operator to place a 30μ track between them and within reach of the slit. Since the latter will move only 30μ on either side of its equilibrium point, there remains a band about 10μ wide between each outside line of the reticle and the greatest motion of the slit. The circuitry has been designed to make this a "guard band" to prevent the printing out of digitizer information when a setting has been made on a track lying outside of the travel of the slit.

While the sensitivity of the instrument will decrease if the slit is not parallel to the track, this setting is not at all critical and the slit may make as much as a 10° angle with the track before the electrical response of the device is impaired. However, if the slit is not parallel to the track the center of the slit will not move over to the center of the track unless it sees bubbles along its entire length, and the operator should be cautioned about this.

The amplitude of the slit vibration must not exceed the required dc movement, in order that images of closely neighboring tracks shall not compete with that of the principal track. In the present instrument, the

dc excursion of the slit is limited to $\pm 30\mu$ in order to minimize the accidental measurement of the wrong track in a region where many are crowded together. The optics of the reticle system are determined by considerations similar to those of the slit. If the width of the reticle is chosen to be equivalent to 80μ on the film, then the virtual image at B' must be 80μ . The actual reticle size at A, as well as the magnification of its lens system, will depend on the engraving or photographic facilities at hand.

This device is subject to the same limitations as the conventional track centering and following systems as regards the problems of measuring event vertices, fiducial mark images and the position of the last bubble on an ending track.

Optical Arrangement

From Fig. 2 it may be seen that a portion of the track image on the film passes through a partially silvered aperture in a fully silvered mirror, and a short segment is focussed by a system of lenses on the plane of the vibrating slit. The balance of the film image is reflected out through a projecting lens onto a screen.

The reticle is illuminated in a conventional manner and its image is partly projected through the aperture in the mirror at C and partly reflected toward the slit. It is important that the center point of the reticle coincide with both the axis of rotation of its housing and the optical axis of its lens system. Similarly, the rotational and optical axes of the slit must also coincide with each other as well as with the optical axis of the reticle system, i.e. the image axis BCD must coincide with the CD segment of the reticle axis ABCD. The vibrating slit will

then "see" the center of the reticle at F and be guided to the vicinity of a point on the track image near E, the coordinates of which are desired. The virtual image of the reticle is formed at the point E' where $EC=E'C$.

Both vibrating slit and reticle systems are carried in barrels which are geared together to maintain parallelism in rotation and rigidly mounted in four ball bearings. Provision is made for the centering of the slit and reticle on their respective axes, and for inclination of the mirror at C about two axes.

The width of the slit must be about equal to that of the image of a track at the slit. The width of an average track on the film is about 30μ and as a 300μ slit can readily be made, the associated lens system should have a magnification of 0.1x. Under these conditions the slit should have a length of about 4mm. This is sufficient to span 400μ , or eight bubble diameters, on the film, and, on the average, three bubbles of a minimum ionizing track. No attempt has been made to increase the resolution of the device by defocussing the image.

Circuitry:

The electrical circuits are shown in Fig. 3. The slit is cut in a thin light metal plate attached to two loudspeaker voice coils arranged so that their amplitudes of vibration are additive. The slit vibration is produced by 60 cycle ac derived from a filament transformer and controlled by a variable resistor; the slit translation is obtained from the dc bias provided by the bridge A (Fig. 3).

The feedback control system that centers the slit over the track image depends on a phase-sensitive amplifier and servo-motor.

When the equilibrium point of the vibrating slit coincides with the center of the track, the axes of slit and track being parallel, a Dumont 6467 photomultiplier, sensing the light through the slit, produces a 120 cps signal which is amplified and applied to the control winding of the servo motor. The reference winding is excited by a 60 cycle supply, and under these conditions no torque is developed in the motor.

However, when the center of the track image does not coincide with the equilibrium point, a 60 cycle component appears in the photomultiplier signal which either leads or lags the reference signal depending on which side of the slit the track lies, and a torque in one direction or the other is developed in the servo motor. This torque is transmitted through a reducing gear train to the potentiometer B, which controls the direction and magnitude of the bias of the bridge A and thereby causes the slit to move toward the track center until they coincide, reducing the motor torque to zero. The shaft encoder indicates the direction and extent of the rotation and its information is delivered to a data processor along with that of the lead-screw digitizers.

The servo motor is kept at a zero position by means of the connections through a chopper P to the bridge potentiometers B and C, until the operator gives the command to find and record the data. At this point, relay D switches the photomultiplier output into the servo amplifier and the servo motor rotates until the slit is centered over the track. The duration of the recording cycle is less than 2 seconds; it begins as soon as the error signal, detected by B, falls to zero, as a precaution against premature delivery of data. In the event that a track lies more than 30 μ away from the equilibrium point of the slit, a cam on

The motor shaft operates a limit switch which prevents the starting of the recording cycle.

The two decade shaft encoder must rotate 3.6° , and the servo motor 108° , for each unit increment which corresponds to one micron of slit translation. Repeated trials have shown that very small stage translations result in motor rotations of considerably less than 108° indicating that even a small 60 cycle component develops more than the breakaway torque in the motor and that the system is capable of resolving translations of fractions of microns.⁷ However, no attempt has been made to determine the limit of resolution because measurements based on a least count of 1 micron are accurate enough at the present state of the art.

2

As stated elsewhere, the standard deviation in 95 settings made with the track centerer on a line about 40 μ wide was 1.5 μ . Using a manually controlled stage and cross hairs viewed through a stereomicroscope at 60x, 36 settings on the same line had a standard deviation of 1.6 μ . In the first case, no attempt was made to approach the line always from the same side to avoid backlash although this precaution was observed in the manual measurement. However, a test of the sensitivity of the slit to motions on each side of the equilibrium point was run. Denoting the directions as + and - the standard deviations showed that the slit favored neither side:

$$\sigma_+ = 1.5\mu \text{ in 25 trials}$$

$$\sigma_- = 1.2\mu \text{ in 16 trials}$$

The Computer Routine

Imagine that the operator has measured the stage coordinates ($x_{1,2,3}$, $y_{1,2,3}$) of points 1,2,3 near the track shown in Fig. 4(a) and that the vibrating slit digitizer has recorded the distances δ_1 , δ_2 , δ_3 normal to the tangents to the track at the points A, B and C. Then, if ($x_{1,2,3}$, $y_{1,2,3}$) are fitted to the curve

$$y = a + bx + cx^2 \quad (1)$$

by, let us say, the method of Least Squares, and the coefficients computed, the distances δ_1 can be resolved into their respective components δx_1 and δy_1 in the following manner:

$$-\frac{\Delta y_1}{\Delta x_1} = b + 2cx \quad (2)$$

$$T = (\Delta x_1^2 + \Delta y_1^2)^{1/2} \quad (3)$$

Therefore, at any measured point x_1

$$\cos \theta_1 = \frac{\Delta x_1}{(\Delta x_1^2 + \Delta y_1^2)^{1/2}} = \frac{1}{(1 + (b+2cx_1)^2)^{1/2}} \quad (4)$$

$$\sin \theta_1 = \frac{\Delta y_1}{(\Delta x_1^2 + \Delta y_1^2)^{1/2}} = \frac{b + 2cx_1}{(1 + (b+2cx_1)^2)^{1/2}}$$

and

$$\begin{aligned} \delta x_1 &= \delta_1 \cos (\theta_1 - \theta_1) = \delta_1 \sin \theta_1 \\ \delta y_1 &= \delta_1 \cos \theta_1 \end{aligned} \quad (5)$$

giving for the true coordinates of the points A, B and C on the track

$$x_i = (x_1 + \delta x_1); \quad y_i = (y_1 + \delta y_1) \quad i = A, B, C, \dots$$

These coordinates are then fitted to any curve considered to be representative of a charged particle trajectory.

In general, the curve fitted to the points (x_1, y_1) will not have the same curvature as the track, and the tangent to the track at A in Fig. 4(b) will make an angle α with the line which is tangent to the fitted curve at, say A'. The resolution of δ results in $(x + \delta x, y + \delta y)$ being the coordinates of the point A'' and not A. However, the error is negligible, for, if we suppose that in a particular case, $\delta = 30\mu$, and the fitted curve passes through A' and a second point B, 5mm distant on the film (this being a representative length of a track image)

$$\tan \alpha \sim 0.006; \quad \alpha \sim 20'$$

The point A'' will lie a radial distance ϵ and a distance β parallel to the tangent, away from A where ϵ for this value of ϵ

$$\epsilon \sim 10\lambda^3 \quad \beta \sim 0.2\lambda$$

Even if the track is a very short one, say 1μ long on the film, and $\delta = 3Q\lambda$

$$\delta \sim 2^\circ \quad \epsilon \sim 0.04\lambda \quad \beta \sim 1.0\lambda$$

In the worst possible case, where A'' and C'' lie on the same side of the track, while B'' lies on the opposite side, the sagitta of the final curve through A'', B'' and C'' will differ from the true sagitta of the track by very much less than the 1λ which is the limit of resolution of the whole instrument. The interaction angles of an event are measured from points such as A'', B'' and therefore are not directly affected by the magnitude of δ .

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FIGURE CAPTIONS

Fig. 1 The track-centering device. (a) steering device and gearing, (b) reticle tube and illumination, (c) vibrating slit housing, (d) projection lens, (e) film aperture plate, (f) photomultiplier.

Fig. 2 Schematic drawing of the track-centering device.

Fig. 3 Semi-block diagram of the vibrating slit circuit.

Fig. 4 (a) Fitting the curve $y = a \cdot \ln x + c x^2$ to the stage coordinates, (b) the negligible errors in the coordinates of point A.

FIG. 1

Run about 2 hours

FIG. 2

BNC Neg. No. 2-424-62

FIG. 3

FIG. 4a

BNC REP No 2-26-62

FIG. 4b

ANV Ver. No 2-437-62

END