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MASTER

A Versatile Bubble-Chamber Track Measuring Stage*

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ABSTRACT

A measuring stage for bubble chamber film, having some interesting features in both its film transfer mechanism and its stage motor drive, is described. Power for the stage motion is supplied by pairs of motors geared to differentials, the speed of one motor being controllable. Lead screw speed is, therefore, continuously variable in both directions. Measurement of coordinates of points on a track with the assistance of a track centering device is outlined in principle; details are given elsewhere in this issue. The film transfer mechanism will accommodate four stereo-views on separate films on any width from 35mm to 70mm and any length from 100-foot spools to 1,000 foot, wound on cores, with the maximum ease of convertibility.

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1. Introduction

A bubble chamber track measuring stage designed for maximum versatility which has several novel features, has been built at Brookhaven National Laboratory.

When design was first started in March, 1960, measuring stages in various laboratories ranged in sophistication from machines with semi-automatic devices for following a track and collecting coordinate data "on the fly", as in the "Franckensteins" of the Radiation Laboratory at Berkeley, to the simpler arrangements where the stage was manually driven and the operator, with the aid of a low-power microscope, set a cross-hair as near the center of the track as possible.

Film transport mechanisms were equally varied because the methods used had to be tailored to the dimensions of the films which were to be measured. Generally, the photographs were taken on unsprocketed 35mm film in 100-foot lengths, although some projected bubble chamber designs called for 70mm film¹ in lengths greater than 400 feet, and one chamber already in operation was turning out 46mm film in 850-foot lengths. In addition, the design of the machine was strongly affected by the placement of the stereoscopic views, that is, whether two or more views were taken on the same film strip or on separate strips.²

In building a machine which could handle and measure any size of film with any stereoview arrangement likely to be encountered, it was inevitable that a number of complications would arise, particularly because of certain limiting philosophies having to do mostly with optics. The basic specifications for the instrument were as follows:

1. A maximum of four stereo views must be available to the operator.
2. All widths of film must be handled--from 35mm to 70mm--with minor equipment changes.

3. All lengths of film must be accommodated, between 100 feet and 1,000 feet, on spools or cores.
4. Stage motion is to be fully controllable over a continuous range of velocities in both the X and Y directions up to a maximum of between 0.5cm and 1.0cm per second.
5. The stage motor drive needs to be electrically simple and reliable.
6. The control of both motor drives should be incorporated in a single device which would require only one of the operator's hands.
7. In order that the control circuits be kept as simple as possible, stage motion has to be under full operator control, but final accurate positioning of the optical measuring axis must be automatic.

The limiting philosophies, which strongly influenced design, were two in number. The first of these was that the film must be viewed through a microscope, rather than by means of a projected image, because the operators who were going to use the instrument had been trained for a number of years in microscopic examination of nuclear emulsions. The second limitation arose from a demand that extreme care be taken not to scratch the film in any way in order to eliminate confusion and loss of time attendant in differentiating tracks from scratches.

Inasmuch as the microscope is stationary, the film must be moved with relation to the optical axis of the system. In practice this means that for the sake of compactness, all of the film transport mechanism has to be attached to the stage, and the entire structure translated by the stage drive motors.

The elimination of film scratching required that the film drive be communicated through a spindle to a spool (or core) since the film is unperforated; a capstan drive in which the film was driven by pinch-rollers on its outer edge

was thought to introduce undesirable risks of abrasion. As a result, an electrical constant-tension system had to be devised in order to overcome the change of torque as a function of film radius on the spools.

The demands of versatility and simplicity were solved in various ways. The availability to the operator of four stereo views among which a choice can be made, was realized by mounting each of the four views on one face of a rectangular structure, referred to as the "cube", which can be rotated about one axis perpendicular to the top of the stage, i.e. about the Z-axis of the measuring system taking the X and Y axes as being in the plane of the film (see Fig. 1). The optical system was placed beneath the film and out of the film loop to avoid having to displace the microscope when the cube was rotated.

Any film width can be accommodated by simply making and inserting a set of aperture plates for each width.

The length of film which can be reeled from one spindle to another depends on the range over which the film tensioning device will operate. For the longer lengths, inter-spindle distances may be minimized by winding from cores.

Stage motor velocity control was obtained simply by combining the outputs of a constant speed motor and a variable speed motor through a differential. One particularly important feature of this arrangement is that the null of the differential output occurs at a point midway in the velocity range of the variable speed motor and at the design speed of the constant speed motor. As a result, the electrical control system can be kept very simple, and consists of a pair of vacuum tube circuits, one for the X and one for the Y drive, each controlled by a high resistance, low-torque potentiometer in the grid circuits. These two pots are mounted in such a way that they are driven by the motions of the two axes of a gimbal, which is, in turn, moved by a rod held in the operator's hand. This assembly is referred to as the "Joy Stick".³

The automatic fine positioning feature, which can be seen in Fig. 1,⁴ is based on a vibrating slit which sweeps across the track image. When the track is near but not over the midpoint of the excursion of the slit, an error signal is generated, which causes a direct current to be superimposed on coils which vibrate the slit, displacing its equilibrium point until it lies over the track. The magnitude of the dc bias is a measure of the displacement and the polarity determines its direction; suitable digitizing allows this distance to be punched into paper tape along with the coordinates of the center of the slit before displacement. A computer program determines the correct coordinates from this information. In some other systems of automatic track centering and following, based on vibrating slits or rotating images, the error signal causes the stage to move the film to a position corresponding to the midpoint of the excursion of the slit, requiring that motion be controlled along both stage axes. In the method here described, which was developed after suggestions from Dr. E. Pickup and Dr. W. A. Higinbotham,⁵ the slit is moved in only one direction, that is along the radius of curvature of the track, and the distance is measured analogically.

2. Details of the Drive Mechanisms

The measuring stage proper is one of a series made by William Brower of Orinda, California. Motions in the two directions are transmitted from the lead screws through nuts to two platens which run with a minimum of friction on steel balls in V-grooves. Each lead screw is 9/16" in diameter and the two provide excursions of 125mm and 75mm. The long dimension is aligned with the film and will be referred to as the X-axis. The shorter, or Y, dimension is oriented across the film. Together, these stage travels are sufficient to

allow measurement on almost the entire chamber image of the UNL 80" hydrogen bubble chamber according to present designs, and more than enough to cover the 5" image of the 72" chamber at Berkeley.

The X lead screw is located in the base of the measuring stage and is therefore stationary; the Y screw is translated only in a direction normal to its axis, that is, in the X direction. As a result, while power can be transmitted to the X screw through a double O-ring belt drive, the Y screw must be driven by means of a spline and ball nut,⁶ and spiral miter gears. The arrangement of the motors and drives can be seen in Fig. 2.

Lead screw torques are moderate, of the order of 20 oz.-in., and were measured only very crudely merely to allow an estimate of motor power. At the time when the stage drive was designed, no information was available on the increase in torque which might be expected due to the static load of the film transfer mechanism, and therefore ample power was allowed. The constant speed is delivered by a 1/15 h.p. induction motor, and the variable power by a 1/15 h.p. series motor, rewired as a shunt. The complete motor unit consists of a single constant speed motor driving one end of two differentials; the other end of each differential is connected to one of the two variable speed motors. The output of each differential is transmitted to its leadscrew through an electromagnetic clutch.⁷ The two clutches in parallel form a "dead man's throttle" as they are connected to a microswitch in the normally off position located in a knob on the joystick. This knob must be lightly squeezed before the clutches will engage.

Control of each variable speed motor is effected by varying the excitation of the field windings of a 1/15 h.p. shunt-wound motor acting as a generator and driven by an induction motor; the output of the generator armature is led to the drive motor armature, the field of which has a constant 12V excitation. The

generator field is varied by means of the circuit in Fig. 3. The entire drive unit of three motors and two motor-generator sets is shown schematically in Fig. 4. Power for the screens, plates and filaments can be furnished by certain commercial power supplies.⁸ The motor field excitation of 12V is obtained from small power supplies made from a Stancor RT-204 transformer and 1N-1124 silicon rectifiers and are incorporated in the control chassis.

It will be seen in Fig. 5 that control of the grid potential of each circuit lies in a 100K low-torque potentiometer; one for each motion is incorporated in the joy stick as shown in Fig. 5. The stick is anchored in a gimbal, the two orthogonal axes of which end in large spur gears which engage pinions on the shafts of the two potentiometers.⁹ The gear ratio is such that a 30° to 35° motion of the stick results in an almost complete rotation of the potentiometer. Both axes can be rotated simultaneously resulting in motion of the stage in any direction.

Gear box design is straightforward but embodies one or two interesting features. Fig. 6 shows the differential drive in schematic form together with the gearing. It will be seen that the gear ratios between the two motors and the differential are different in order to minimize beats at the null which would be disturbing to the operator. Since the variable speed motor must have a range equal to at least twice the 1725 RPM of the constant speed motor, consideration of gearing sets the range at 0-3000 RPM. At the null, points A and B (Fig. 6) must run at the same speed which is determined from the mid-point of the variable speed motor:

$$A_{RPM} = B_{RPM} = 1/2 (3000 \times 56/96) = 1459$$

and the constant speed motor, geared down to B, must be geared up by the pulley

ratio

$$P_c = 1459 \left(\frac{110}{1725 \times 65} \right) = 1.43$$

Under these conditions, maximum RPM will be same in opposite directions and will be

$$R_{\text{MAX}} = \frac{1459}{2} = 730 \text{ RPM}$$

Thus, since the lead screws have a 1mm pitch, the stage will have a slewing speed of about 0.7 to 0.8cm per second. It is questionable whether it is desirable to increase the speed of translation of the film transport mechanism which, loaded with film, can weigh over 200 pounds, beyond this point. In addition, the two Coleman digitizers are geared up 10:1 and run therefore at about 8000 RPM. Although this is well below the 18,000 RPM allowed by the company, the gearing, both internal and external, howls unpleasantly at this speed.

The stage is prevented from travelling beyond safe limits by a device operated by four microswitches mounted on the stage. The closing of any microswitch by excessive travel of the stage causes the output of the appropriate differential to be reversed. In practice, the system will arrest and reverse the stage, moving at maximum speed, in less than 2mm or about 0.25 seconds.

The stage position is recorded on tape by means of a pair of 5-decade Coleman digitizers and associated equipment which state the position of the undisturbed equilibrium point of the vibrating slit, and one Airflyte 2-decade digitizer which states the supplementary slit movement. The details of the measuring system are given in reference 3.

Finally, provision is made, by means of idler gears, for the alteration of the orientation of the digitizer count with respect to the direction of the stage motion, in order to simplify and standardize computer programs.

3. Film Transport

A maximum of four stereoviews on separate rolls of film are available to the operator. 35mm rolls in lengths of 200 feet or less are disposed in pairs on two sides of the four sided structure seen in Fig. 1. 70mm and 35mm film in lengths over 500 feet is distributed, one view to a side, on cores, the film being held on by protective plates. 400 foot, 35mm film may be accommodated, one view to a side, on spools.

The film emulsion side toward the aperture plate, passes over Teflon rollers, relieved in the center to minimize scratching, and is held flat against the glass apertures on the under side of the stage by vacuum ports. Small supplementary rollers, which may be swung out of the way when threading, help lift the film to a position where evacuation can take place.

The aperture plates are quickly removable, allowing easy change-over from one film size to the other. These plates are of three general types:

1. two-view for 35mm film in less than 200 foot lengths
2. one-view for 35mm film in lengths greater than 400 feet
3. one-view for 70mm film of any length

Other plates can easily be made which will take such unusual widths as the 46mm film currently used by the 72-inch chamber at the Radiation Laboratory in Berkeley.

Film drive speed is divided into two ranges, each of which is provided by motors whose speed is variable by means of a Variac. The fast range, from about 20 RPM of the spindle to 250 RPM will reel off 100 feet of film in about 25 seconds. The slow range is from zero to 1/3 RPM and is used for the final positioning of the film. This low speed is obtained by clutching a 1/70 h.p.

shunt wound motor with a maximum output speed of 6 RPM, to the armature of the unexcited 250 RPM motor which is rated at 1/18 h.p. with a 20:1 reduction and is also shunt wound. For fast traverse, the clutch between the two motors is disengaged and the 250 RPM motor is energized.

The problem of maintaining a constant film tension regardless of the length or width of the film is a relatively complex one, involving varying a slipping force inversely as the radius of the amount of film wound on a spool. In some other machines, this has been accomplished by means of a roller riding lightly on the film in the reel and controlling either a mechanical or an electric brake. As this introduces the risk of scratching the film, in the present instance a potentiometer is geared to the spindle drive shaft to control the current flowing in a brake on that spool from which the film is being fed, the take-up spool being connected positively to the drive shaft by a clutch.

Each spindle assembly contains a brake and a clutch⁷ with one disc in common attached to the spool drive shaft. Figure 7 is a schematic drawing of a "35-70" (see below) spindle and drive. Appropriate switching by means of relays determines whether the brake or the clutch is energized and serves to reverse the direction in which the film travels without having to reverse either drive motor.

Twelve spindles are mounted on the four faces of the "cube" and they are of three types:

1. "35-70's" designed to accommodate any width from 35mm to 70mm and any length from 100 feet to 1000 feet.
2. "35 only's" designed to reel only 35mm film in lengths up to 200 feet
3. "70 only's" designed to handle only 70mm film in any length up to 1000 feet

The brake control potentiometers are limited to one turn and must be geared down from the film drive shafts. The number of turns of a core or reel to accommodate various footages of 0.0055" thick film are shown, together with other

pertinent information in Tables I and II. From these tables we see that any film shorter than 400 feet in length must be handled on spindles geared down to the pot 376:1 and film longer than 400 feet on spindles geared down 603:1. In actual practice, choices of gears and space considerations resulted in the two ratios 300:1 and 611:1. The "35-70" spindle in Fig. 7 is capable of handling all film lengths and widths, and is shown with the 1:1.48 drive ratio and the 300:1 potentiometer gear ratio engaged. A special mounting is provided which allows both gear ratios to be changed simultaneously. The "35 only" and "70 only" spindles contain only that gearing appropriate to their use.

In minimizing the dimensions of the cube faces, the film diameters of loaded spools or cores determined that 35mm film spools in lengths of 200 feet or less could be accommodated two to a face, while the greater lengths and widths would be limited to one view per face (the superfluous spindles being removed to eliminate interference). Although 35mm film in 400 foot lengths comes from the BNL 20" chamber on cores, it is handled on the stage on special split spools about 7.4 inches in diameter. The maximum interspindle separation necessary to accommodate 1000 feet of film on 3 inch cores occurs when the film is equally divided between the two spindles and amounts to 7.14 inches, which is slightly less than is needed to accommodate 400 feet on spools. Core-wound film is held in place behind non-rotating flanges fixed to the cube. Because 200 foot spools have the highest D/C ratio with 1000 foot cores the next highest, each of these lengths will require the entire resistance range of the potentiometers to control the brakes. However, the film diameters are quite different and suitable drive gearing must be provided so that the maximum peripheral speeds of each length will be approximately equal and not excessive. There was no well-established film speed limit to go by, but after consideration of the speeds designed into other machines, a top limit of 400 ft/min was struck. Table II

summarizes the basic design parameters of the film transport mechanisms, to conform to this limit.

The disposition of the twelve spindles on the four faces of the cube is set forth in Table III.

From Table I we see that the shortest to longest film length ratio is the same in each gear drive ratio grouping:

$$\frac{188}{293} \approx 0.625 \approx \frac{377}{603}$$

The greatest film length in each group causes the wiper to sweep over the entire potentiometer winding, the shortest, 5/8 of it. Taps are placed at $5/8 \times 360^\circ = 225^\circ$ for the proper tensioning current control of the shorter lengths; padding resistors are used to allow proper control over all film lengths. The potentiometers have 358° electrical rotation and no stops, and are equipped with a fly-back device which returns the wiper to its starting point on the windings when the coupling clutches are de-energized at the command of the operator.

The 6.1 RPM motor, which supplies the low-speed film drive power, is also used to rotate the cube. A selector switch operates relays which disengage this motor from the 250 RPM motor and connect it to a can which engages a Geneva gear. The can motion is limited by a microswitch to a single turn which produces a 90° rotation of the cube; each rotation is initiated by a push button. Motion of the cube in one direction is held to 270° by limit switches. When put to this use, the motor and therefore the direction of rotation, is reversible.

Many details have been eliminated from the description of the stage for the sake of brevity and, therefore, a summary of the controls which are provided

for film handling will be useful:

1. A motor selector switch with four poles:
 - a) turntable motor
 - b) off
 - c) film advance-slow
 - d) film advance-fast
2. A push-button to start the turntable rotation.
3. A reversing switch which controls all right-left motions of film travel as well as turntable motion. The "off" position declutches the spindles and opens the vacuum line to the aperture plates.
4. A Variac which controls the speeds of both slow and fast film advances.
5. The View Selector Switch allows the operator to advance and position any one separately or all of the four films together.
6. The Right-Left Placement Switch permits full spools of film to be placed on either spindle and serves to reverse the leads on the tension potentiometers.
7. The Film Size Selector Switch selects the proper taps on the potentiometers and connects supplementary resistances whenever necessary according to the film length being used.
8. A potentiometer is provided for controlling the film tension manually.

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REFERENCES

1. This refers to the 72-inch chamber of the Radiation Laboratory at Berkeley, California.
2. See for example: "A Film Handling Mechanism for Bubble Chamber Film Projectors" by R. Smits, UCRL RE774, March 29, 1961.
3. Almost identical in design to the one developed by Dr. R. Plano at the Nevis Cyclotron Laboratory of Columbia University.
4. Although the stage was originally designed to use a microscope, the decision was made to project the image when the machine was almost completely assembled. The projection lens and a mirror are seen on the left of the track-centering device, below the stage, in Fig. 1.
5. Private Communication. The device is also described in F. Ayer, B. Pickup, E. F. Rappe and G. Wall, Rev. Sci. Inst. (published in this issue.)
6. The spline and recirculating ball nut was made by the Saginaw Steering Gear Division of General Motors Corporation, Saginaw, Michigan.
7. Made by Warner Electric Brake and Clutch Co., Inc., Beloit, Wisconsin.
8. We use the Model A3's made by Oregon Electronics, Inc., Portland, Oregon.
9. Made by Link Aviation Division of General Precision Company, Binghamton, New York.
10. Coleman Electronics, Gardena, California.
11. Airflyte Electronics, Bayonne, New Jersey.

TABLE I

Diameter and number of turns for several lengths of film wound on cores of different diameters, together with other information.

Film Length, Feet	Core Diam., Inches C	Maximum Film Diam., Inches D	D/C	Number of Turns	Film width; Spools or Cores?	Spindle to Potentiometer Gear Reduction
100	1	3.07	3.07	188	35mm, spools	300:1
200	1	4.22	4.22	293	35mm, spools	300:1
400	2	6.13	3.07	376	35mm, spools	611:1
500	3	7.14	2.38	377	70mm, cores	611:1
1000	3	9.64	3.21	603	70mm, cores	611:1

TABLE II

Film drive gear ratios, spindle RPM and film speeds for the several film lengths, based on a maximum motor speed of 250 RPM (fast drive).

Film Length Feet	Maximum Film Diam. Inches	Drive Gear Ratio From Motor	Spindle RPM	Film Speed in ft/min	
				Max.	Min.
100	3.07	1:1.48	370	298	97
200	4.22	1:1.48	370	410	97
400	6.13	1:0.64	160	257	84
500	7.14	1:0.64	160	300	126
1,000	9.64	1:0.64	160	405	126

TABLE III

Placement of the three spindle types on the cube faces, and the relation of the view number to the face.

Face Number	Number of Spindles			View Numbers		
	"35-70"	"35 only"	"70 only"	100'-200' (35mm)	400' (35mm)	500'-1000' (70mm)
I	2	2		1,2	1	1
II	2	2		3,4	2	2
III			2		3	3
IV			2		4	4

FIGURE CAPTIONS

- Fig. 1 Face I of the Versatile Measuring Stage. (a) Automatic fine-positioning feature with projection optics, (B) the aperture plate below which the film runs, (C) stage motor drive, (D) spindles are removed when handling film in lengths greater than 400'.
- Fig. 2 A close-up of the stage motor drive showing the splined shaft (but not the recirculating ball nut) for the Y-axis drive, and the double O-ring X-axis drive.
- Fig.3 Variable stage motor control circuit.
- Fig. 4 A schematic drawing of the stage drive unit.
- Fig. 5 The Joystick with its cover removed showing the gearing and one potentiometer.
- Fig. 6 A schematic drawing of the three-motor stage drive and differential unit.
- Fig. 7 A schematic drawing of a "35-70" spindle coupled to the motor drive through the 1:1.48 gear train, and to the film tension potentiometer through the 300:1 reduction. In this arrangement the spindle will accomodate up to 200' of film on a spool.

FIG. 1

3NL REG No. 1-740-02

FIG. 2

BAL 109 No 1-741-62

FIG. 3

Full neg. to 250 ohms

FIG. 4

Rev. 10/7/64 1-2, 2, 3, 4

FIG. 5

EN 109. No 174. 60

FIG. 6

FIG. 7

BNL Neg. No. 1-739 62

END