U. S. Department of Commerce
National Bureau of Standards

Research Paper RP1907
Volume 41, August 1948

Part of the Journal of Research of the National Bureau of Standards

Strain Tester for Rubber[1]

By William L. Holt, Ellis O. Knox, and Frank L. Roth

A tester for measuring the strain of rubber vulcanizates when subjected to a predetermined stress is described. The operation of the tester and a description of the apparatus for cutting and measuring the test specimens are presented. With this equipment, routine determinations of a point on the stress-strain curve can be made with greater accuracy and precision than has hitherto been possible with the usual stress-strain equipment. This strain test also requires less labor than the customary stress tests.

I. Introduction

The strain tester described herein was designed to measure the strain at a definite time after the application of a predetermined stress. In the usual testing procedure, stress is measured at a specified strain during the extension of the specimen at a relatively rapid rate. Interest in the development of the strain tester resulted from previous investigations [2], which showed that the replicate measurements of strain at a predetermined stress have a variance of approximately one-tenth the variance of the usual measurements of stress at a specified strain.

The apparatus was designed to permit routine measurements of strain at any selected stress below rupture to be made with the degree of precision found by Roth in the earlier investigation. In designing the strain tester, accuracy of measurement, as well as precision, was considered. The design features that are responsible for the improved precision and accuracy of measurements in the strain test are (1) Observation of bench marks when they are essentially at rest, (2) use of freely suspended weights to attain the desired stresses without friction effects, and (3) increase in distance between bench marks of from two to four times that possible with usual dumbbell-shaped specimens.

This test is not intended to measure stress-strain properties near or at rupture. For control testing, however, and for many research tests, a knowledge of the properties below the region of failure is sufficient. The improved precision of the strain test warrants a separate determination of the properties at failure in those cases where they are necessary.

II. Details of Construction

Three accessory instruments are required to prepare specimens for measurements in the strain tester. These are (1) a die to cut specimens from a sheet of rubber, (2) a device for placing bench marks on the specimen, and (3) a device for determining the average thickness of the specimen. The construction of each of these instruments and of the strain tester is described in turn.

1. Die for Cutting Specimens

The construction of the die used to cut specimens from a sheet of rubber is shown in figure 1. The cutting blades of the die consist of six strips of razor blade steel sharpened on one edge. Each strip is 6 in. long, ¾ in. wide, and 0.009 in. thick.[3] They are clamped between metal spacers 6 in. long, ⅝ in. wide, and 0.245 in. thick, so that the cutting edges project ⅛ in. The die is used in an arbor press or "clicking" machine.

With this device, five strips 0.254 in. in width are cut simultaneously. This width was chosen for its convenience in determining the load to be applied to the specimen to obtain the desired

[1] The tester was designed and constructed at the request of the Subcommittee on Test Methods of the Committee on Specifications for Synthetic Rubbers and was financed in part by funds transferred from the Office of Rubber Reserve, Reconstruction Finance Corp.

[2] Frank L. Roth and Robert D. Stiehler, J. Research NBS 41, 87 (1948) RP1906.

[3] These blades were supplied through the courtesy of the Gillette Safety Razor Co., 125 Granite Street, Boston, Mass.

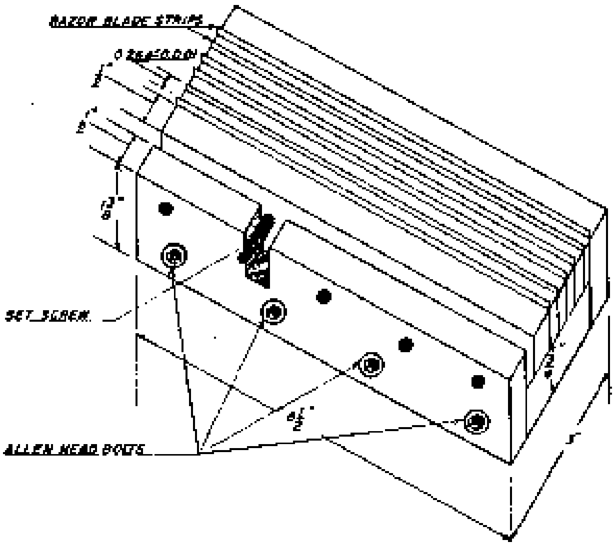

FIGURE 1. *Die for cutting fine test specimens.*

stress based on the cross sectional area of the unstrained specimen. The width is one one-hundredth the numerical factor by which the thickness in millimeters must be divided in order to convert it to inches. Consequently the load, expressed in pounds, is equal to the numerical value of the thickness of the specimen measured in millimeters, multiplied by the numerical value of the desired stress expressed in "hundredweights" per square inch. For example, to obtain a stress of 400 lb/in.^{2}, the load to be applied to a specimen 2.03 mm in thickness and 0.254 in. in width would be $2.03 \times 400/100 = 8.12$ lb.

2. Bench Marker

Bench marks are placed 10 cm apart upon each specimen. This distance makes it convenient to measure elongation (strain) directly by means of a scale graduated in millimeters. The device used is essentially a metal bar with razor blades fastened on each end, as shown in figure 2. In order to prevent cutting of the specimen by the blade the edges are ground, as shown in the detailed section. With this marker, distinct lines not over 0.010 in. wide are easily made.

3. Thickness Gage

The thickness of specimens is measured with the gage shown in figure 3. This gage has a dial indicator graduated in hundredths of a millimeter. One revolution of the pointer corres-

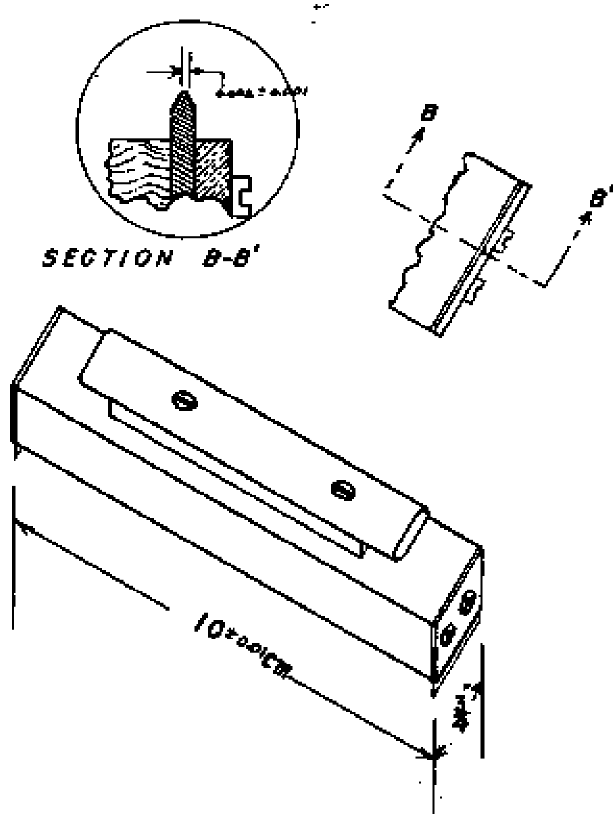

FIGURE 2. *Bench marker.*

sponds to 1.0 mm, and the total range of the indicator is 2.5 mm. The indicator is mounted above an especially constructed base shown in figure 4. An important feature of this base is the pressure-bar arrangement. This metal bar is 10 cm long and is pressed upon the surface of the specimen with a force of 4 lb by means of a spring. The bar is attached to a ball joint, which possesses sufficient freedom of movement to average the thickness of wedge-shaped specimens. The dial indicator is adjusted to read zero for specimens 1.50 mm in thickness, as specimens of this thickness require a load corresponding to the basic weight of the weight assembly described in section II, 4. Additional thickness beyond 1.50 mm is read in hundredths of a millimeter.

4. Strain Tester

The strain tester is designed to apply automatically the selected weights to a specimen to produce the desired stress, to provide means for measuring the elongation accurately and easily, to assure that measurement of elongation is made

FIGURE 3. *Gage for obtaining average thickness of the specimen.*

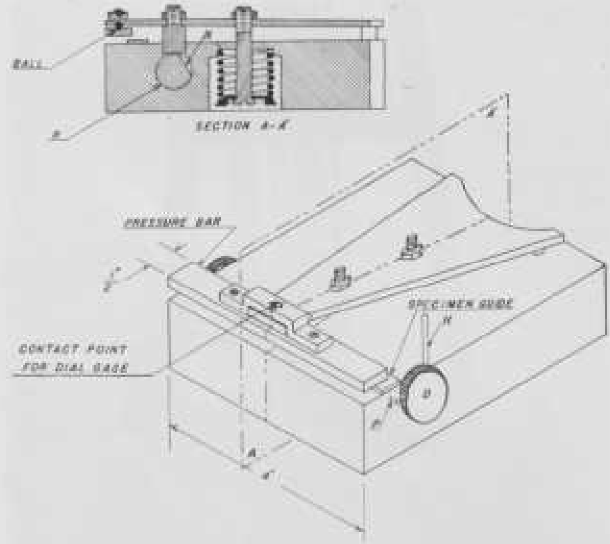

FIGURE 4. *Construction of the averaging mechanism of the thickness gage.*

The apparatus is shown with the pressure bar raised. The specimen is placed on the base under the bar and against the guide. When the knurled disk D is turned so that the handle H rests against the pin P, the notch N in the rod R is at the top, allowing the spring to pull the pressure bar down against the top side of the specimen.

at the proper time after application of the load, and to return automatically the specimen and tester to their starting positions after the measurement has been made. The design of the tester embodies mechanical and electrical features that are discussed separately.

(a) Mechanical Assembly

The strain tester is shown in figures 5 and 6. Essentially, the tester consists of two parts. The upper part comprises a vertical track, the driving mechanism for extending and suspending the specimen and the mechanism for measuring the elongation. The lower part consists of the weight assembly and mechanism for placing the proper load on the specimen.

The vertical track is constructed from five strips of cold-rolled steel 48 in. long. The basic steel strip is 2 in. in width and $\frac{3}{8}$ in. in thickness. To this strip, two strips, $\frac{3}{8}$ in. by $\frac{1}{8}$ in., and two strips,

FIGURE 5. *General view of rubber strain tester.*

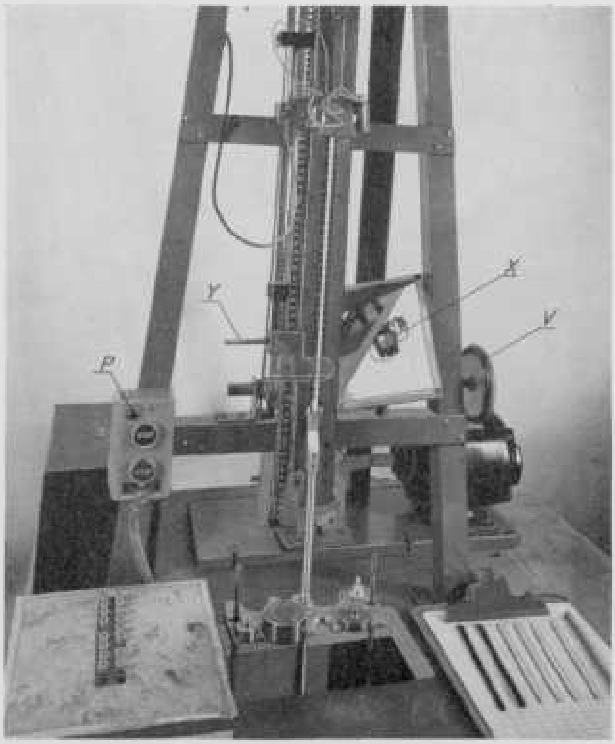

FIGURE 6. *Rubber strain tester from the perspective of the operator.*

P, Pilot in series with motor of time-cycle controller; *V*, hand wheel for alining upper positioner with upper bench mark; *X*, prism and specimen as seen in plane mirror; *Y*, handle for rotating positioners to the specimen and alining the lower positioner with the lower bench mark.

¾ in. by ⅛ in., are fastened to form a T-slot ¾ in. in width at the base and ½ in. at the throat. This slot serves as a guide for the grip, which stretches and supports the upper end of the specimen. The specimen grip also connects the two ends of a roller chain (Boston No. 35), which passes over sprockets at each end of the vertical track, and thence to a ⅙- or ¼-hp-ratio motor. The motor raises and lowers the specimen grip in the T-slot at a speed of 200 in./min. Two limit switches located fore and aft of the sprocket at the upper end of the track prevent the specimen grip from reaching the sprockets and damaging the tester.

A steel tape graduated in millimeters is used to measure the elongation. As the bench marks are placed on the specimen 10 cm apart, each millimeter of extension corresponds to an elongation of 1 percent. Two transparent plastic positioners with hair lines are used to locate the position of the bench marks on the millimeter tape. The end of the tape is fixed to the upper positioner, and the zero point on the tape is adjusted exactly 10 cm below the hair line on this positioner. Thus, when the positioners are placed on the bench marks, the elongation is read from the tape at the lower positioner directly in percentage. In order to permit the operator when seated at the tester to locate the hair line of the upper positioner on the upper bench mark arrangement, *X* in figure 6, is made to observe the hair line and the bench mark by means of a fixed plane mirror and a reflecting prism attached to the upper positioner. Lights attached to the prism illuminate the upper bench mark during the time an observation is to be made. The upper positioner, prism, and lights are moved up or down by means of a ladder chain and sprocket assembly. The assembly is driven by means of a hand wheel, *V* in figure 6, within easy reach of the seated operator. The lower positioner slides freely on a vertical square bar, which serves as a guide for both positioners and rotates them away from the specimen. A handle, *Y* in figure 6, on the lower positioner enables the operator to slide it and to rotate both positioners to the specimen in order to make observations without parallax.

The lower part of the apparatus, consisting of the weight-assembly and weight-loading mechanism, is centered around a plumb line from the upper grip. The weight assembly passes freely through a rectangular hole 4 in. by 8 in. cut in the table top that supports the upper and lower parts of the apparatus. The assembly consists of an aluminum rod (approximately 32 in. long), on which is fastened two weight holders, one at the lower end for the fixed weight and the other about 24 in. above for the additive weights. At the upper end of the rod is fastened the grip for the lower end of the specimen. The holder for the additive weights is constructed as shown in figure 7. Guide rods pass through the holes in the ends of the weight holder, and the additive weights are placed in the semicircular notches on the sides.

The combination of the weight assembly and weight loading mechanism is shown in figure 8. The eight additive weights are supported on arms that are normally inclined at an angle of about 8° from the vertical. When additive weights are needed, the arms supporting the selected weights are moved to a vertical position. The additive weights are then lifted from the ends of the arms by the upward movement of the weight holder at

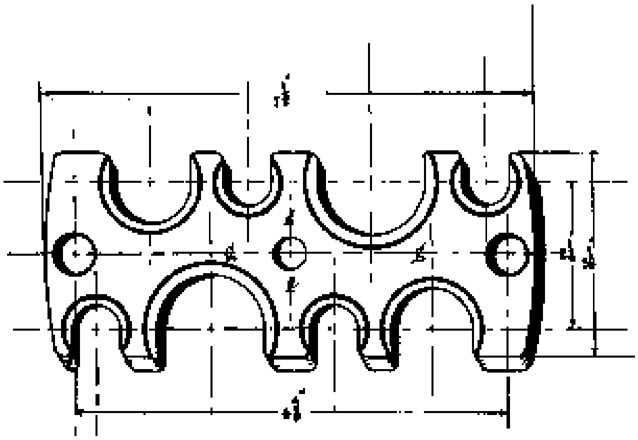

FIGURE 7. *Holder for additive weights.*

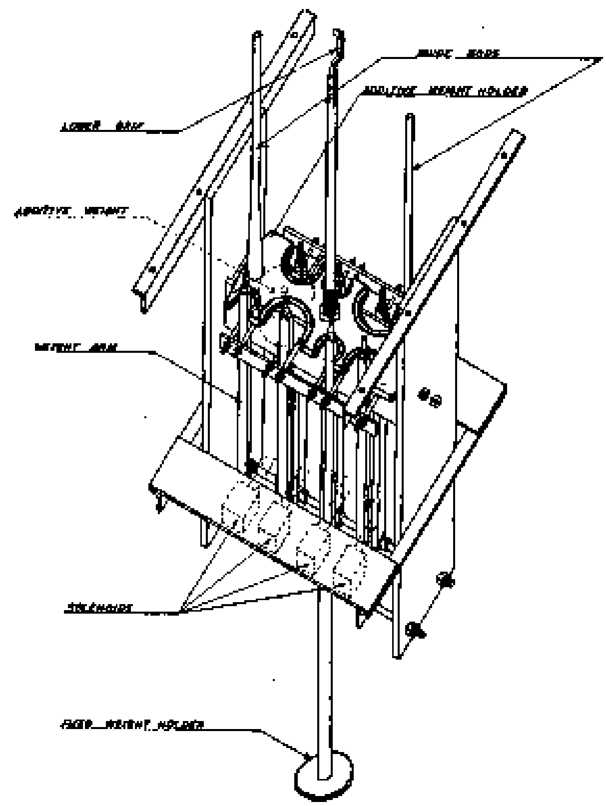

FIGURE 8. *Weight assembly and loading mechanism.*

The weight arms are shown in their vertical position. In operation there are never more than four arms in this position at one time. One of the additive weights is shown by dashed lines in position on the weight arm.

the time the specimen is elongated. The weights are returned to the arms during the retraction of the specimen.

The arms are moved to the vertical position by means of solenoids and returned to their normal position by the action of a coil spring after the circuit to the solenoid is broken. The mechanism for actuating the solenoids and the mechanism for indicating when the weight assembly is suspended freely are discussed in the section on the electrical circuit.

(b) Electrical Circuit

The mechanical operation of the tester is controlled by the electrical circuit shown in figure 9. The part of the circuit that controls the weight loading mechanism utilizes eight solenoids, *S*, (Guardian No. 12 AC) for moving the eight weight arms into their vertical positions and 18 normally open switches for selecting the proper solenoids to apply the desired load. The keys operating the switches are locked by means of an additional solenoid, *K*, while the weight assembly is suspended. During the time the switches are free to be changed for selection of the desired load, this part of the circuit is not excited.

Four of the solenoids are controlled by one decade of switches and the other four by a second decade. Four switches of each decade are single-pole, single-throw and control individual solenoids. The other five switches of each decade are either double-pole, single-throw, or split-contact single-throw (Micro-Switches BZ-3YLT were used) and control appropriate combinations of two solenoids. Thus with four weights, the selection of any additive load in a decade is obtained by closing one of nine switches. One decade can adjust the load to correspond to specimen thicknesses from 0.1 to 0.9 mm in steps of tenth-millimeters and the other decade from 0.01 to 0.09 mm in hundredth-millimeter steps. Thus the two decades can adjust the load for specimen thicknesses ranging from zero to 0.99 mm in hundredth-millimeter steps. To close these switches it is convenient to use two decades of keys and the keyboard mechanism from a Friden calculator. This assembly is arranged so that the closing of one switch in a decade opens the others. The keyboard mechanism also provides a convenient device for locking the keys while the tester is in operation.

The electrical circuit, which controls the weight loading mechanism, is excited when the main relay (4PST, 110 v AC, 6 amp) is closed. This relay is closed by pressing the start button at the start-stop station. Once closed the relay remains

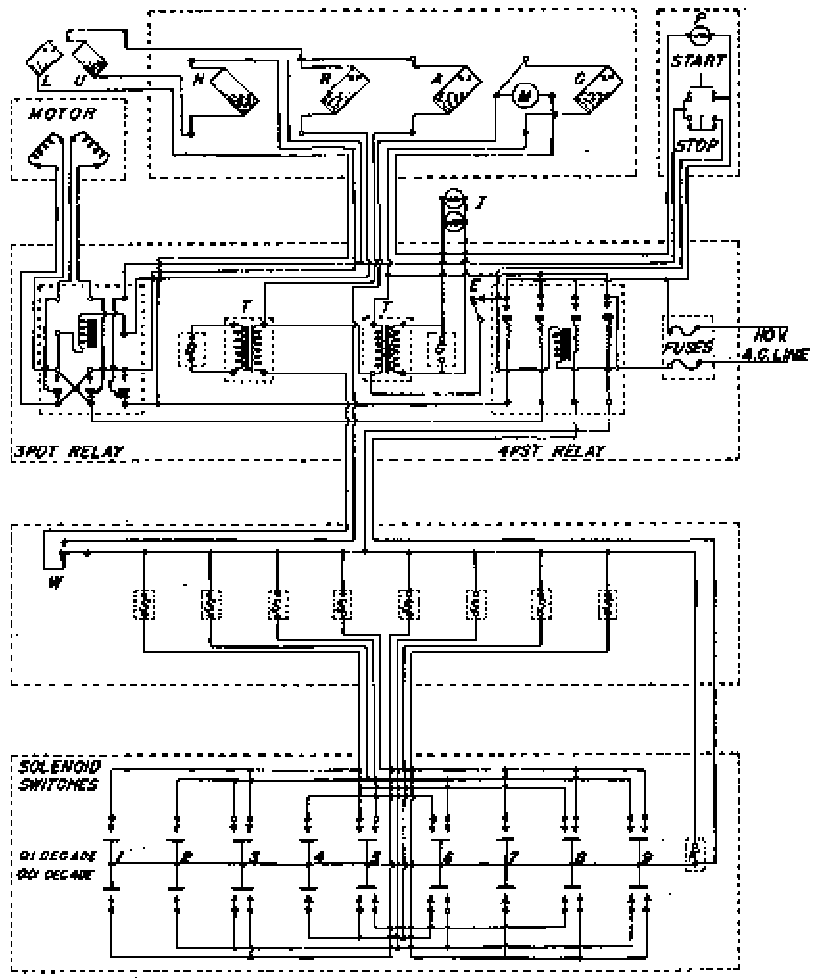

Figure 9. *Electrical circuit for the rubber strain tester.*

The positions of the switches and relays shown in the circuit are for the tester at rest. *A*, Switch for actuating single stroke bell or gong, *G*, and lamps, *I*; *B*, bell or buzzer; *C*, switch for stopping motor, *M*; *E*, switch for manual operation of lamps, *I*, when the tester is not in operation; *G*, single stroke bell or gong; *H*, switch for limiting the lift of the weight assembly after switch, *W*, is released; *I*, lamps for illuminating upper bench mark during the observation period; *K*, solenoid for locking the keyboard; *L*, switch for opening four PST relay when upper grip returns to starting position; *M*, time-cycle controller motor; *P*, pilot light for motor, *M*; *R*, switch operating 3 PDT relay to return upper specimen grip to rest position at end of test; *S*, solenoids for moving weight arms to their vertical position; *T*, bell transformers; *U*, switch for limiting upward travel of the upper grip; *W*, SPDT switch for starting motor, *M*, and when weight assembly is not freely suspended at time of measurement for ringing bell, *B*.

closed until the circuit to its exciting coil is broken either by the action of the limit switch, *L*, which opens when the upper grip returns to its starting position or by the pressing of the stop button by the operator. Besides exciting the circuit controlling the weight-loading mechanism, this relay starts the motor that lifts the upper grip and stretches the specimen.

When the weight assembly is freely suspended, a single-pole, double-throw precision snap switch, *W*, mounted on the weight loading mechanism starts the motor, *M*, on a time-cycle controller. The function of the other position of this double-throw switch is to actuate a signal that is described with the signaling devices.

The sequence of operations after the weight assembly is freely suspended is controlled by a time-cycle controller (Electric Switch Corp., model 602). This controller consists of four mercury switches that are opened and closed by the action of cams rotated by a synchronous clock motor, *M*. The functions of the mercury switches are as follows:

The height switch, *H*, limits the height to which the weight assembly may be raised (approximately 8 in.).

The signal switch, A, operates an alarm, which indicates the time the measurement of elongation is to be made.

The reversing switch, R, actuates a 3-pole double-throw relay, which reverses the motor at the end of a test, permitting the specimen to retract and the weight assembly to come to rest.

The cycle switch, C, stops the time-cycle controller at the end of the cycle. The four switches open and close at the following points in the revolution of the cams:

Switch	Opens	Closes
	Degrees	*Degrees*
Height	9	355
Signal	284	248
Reversing	355	293
Cycle	360	5

A rotation of 360° requires 80 sec. In order to indicate when the controller is in operation, a pilot lamp, P (6 v, 0.15 amp) is connected in series with the motor.

The signal switch of the controller closes the primary circuit of an 8-v transformer, T. Connected to the secondary of the transformer is a single-stroke bell or gong, G, which serves to indicate when the elongation of the specimen is to be observed. The lamps, I, which illuminate the upper bench mark, are connected to the same circuit. If the weight assembly is not freely suspended at the time the observation is to be made, the double-throw switch, W, attached to the weight-loading mechanism, connects a second transformer into the signal-switch circuit. Connected to the secondary of this transformer is a vibrating bell or buzzer, B. This signal warns the operator that the observation is in error.

One of the limit switches, U, on the vertical track is used to protect the tester in case a specimen has an elongation greater than the limit of the tester or breaks before the motor of the time-cycle controller starts. The other limit switch, L, breaks the circuit to the coil of the main relay at the end of each test when the upper grip returns to its starting position. This action breaks all of the circuits except the one to the motor of the time-cycle controller.

A switch, E, is provided for manual operation of the lamps, I, when illumination is desired for purposes other than the normal operation of the tester. For example, illumination is required when the zero position of the steel tape is being initially adjusted relative to the hair line on the upper positioners. This adjustment is conveniently accomplished by use of a separate millimeter scale held in the position of the specimen.

III. Method of Operation

Three steps are involved in the strain test procedure: namely, (1) the preparation of the test specimen from a rubber vulcanizate, (2) the measurement of the cross-sectional area of the specimen to determine the load to be applied, and (3) the measurement of the elongation of the specimen at a definite time after the load is applied.

1. Preparation of Specimen

From the usual test sheet of rubber vulcanizate, 6 in. square and about 0.075 in. in thickness, five specimens are cut by means of the die described in section II, 1. Using the marker described in section II, 2, bench marks 10 cm apart are placed upon each specimen. The marking compound should be of a contrasting color to that of the specimen; e. g., if the specimen is dark in color, red or white marks are convenient.

2. Determination of Load

If the die is properly constructed and in good condition, the width of each specimen will be 0.254 in. (6.45 mm) to within 0.001 in. Then only a measurement of the average thickness of each specimen by means of the gage described in section II, 3 is required to determine the cross-sectional area.

For measurements at a stress of 100 lb/in.^{2}, changes in thickness will require changes in load, in pounds, which are numerically equal to the thickness change in millimeters. Consequently, by setting the zero position of the dial gage to the numerical value of the fixed weight, one needs merely to make the additive weights equal to the dial reading obtained with the different specimens. To obtain the same convenient arrangement at 200 lb/in.^{2}, the fixed load and each additive weight must be doubled. This is accomplished by the substitution of a different weight assembly. Analogously, weight assemblies corresponding to any other desired stress can be used, if desired.

794450—48——2

The tester in our laboratory is equipped with three sets of weights for applying stresses of 100, 200, and 400 lb/in ^{2}. Alternatively, the fixed weight can be manually adjusted for each stress, and a table used to obtain the key board settings corresponding to different dial-gage readings.

3. Measurement of Strain

The specimen is placed in the grips of the tester by the operator with the bench marks facing him. After depressing the proper keys controlling the additive weights, he presses the start button. This action engages the appropriate additive weights and stretches the specimen. The pilot light indicates when the weights become freely suspended, and the time cycle begins. Fifty-five seconds later when the signal sounds, the operator holds the positioners against the specimen with his left hand and superimposes the hair line of the upper positioner on the upper bench mark by turning the hand wheel with his right hand. After this positioner is adjusted, he superimposes the hair line of the lower positioner on the lower bench mark by sliding the positioner with his left hand. Approximately 8 sec are allowed for these two operations. The operator observes the elongation in percentage directly from the position of the hair line of the lower positioner on the millimeter tape. There is ample time to observe and record the elongation while the upper grip and weight assembly return automatically to their starting position. A new specimen can be inserted and the keys changed while the controller completes its cycle. Thus each specimen requires about 1½ min of machine operation. The operator, however, has about 1 min of this time free during which he could either operate a second machine or prepare specimens for measurement.

IV. Comments on Performance

The strain tester constructed in this laboratory has operated very satisfactorily for more than a year. In the usual stress-strain measurements, the errors in testing have been found to be of the same order of magnitude as those arising in the preparation of the vulcanizate. On the other hand, it has been found that the errors of testing with the strain tester are negligible in comparison to those arising in the preparation of the vulcanizate. This improvement in precision and accuracy of testing has been useful in both control and research testing. Data showing the improvement of precision have been omitted from this paper, as they are a part of a separate paper (see footnote 2).

An advantage of this test, in addition to the improved testing, is the reduction in man-hour requirements. This reduction is due in large part to obtaining the data in tabular form at the time of test. At the same time, the ease and convenience of the test has improved the morale of the testing personnel. The operation of the tester from a sitting position, the ease of changing weights, and the elimination of following two moving bench marks simultaneously have been the prime factors in this respect.

WASHINGTON, October 24, 1947.