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A Flywheel Impact Test for Measuring Physical Properties of Tire Cords

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INTRODUCTION

The interest with which industry is viewing impact testing of materials is apparent from the increasing number of published papers on this subject. Textile groups, particularly, have recently become more concerned in dynamic behavior of end products made from the many natural and synthetic fibers. This concern has been brought about by the general realization that the physical properties of yarns and cords are rate sensitive[1-4] and that this effect of the loading rate on their stress-strain properties casts some doubt on the value of using conventional test data to predict the behavior of yarns during high speed operations.

Recognition of the need for studying the dynamic physical properties of textile materials has led to the development of several types of instruments designed to fill special requirements. Rotary and pendulum impact testers with velocities of 1 and 38 m./sec., respectively, were developed by Meredith[5] and Lyons and Prettyman.[6] Schiefer's group,[7-10] working in ballistic ranges (upward of 65 m./sec.) with the aid of high speed photography, extended Von Karmen's[11] studies in stress-strain wave propagation relationships to impacted yarns.

However, the contributions of these and other workers notwithstanding, it was felt that there was a need for a relatively low cost instrument that could be used routinely for the testing of twisted cords under conditions more nearly simulating their end use; specifically, cords in tires subjected to impacts at 20–60 m.p.h. driving speeds. Obviously, simplicity of operation and data reduction must be a primary consideration.

Toward this end the development of the flywheel impact tester was undertaken. This was designed to break cords transversely at selected impact velocities between 10 and 80 ft./sec., a range lying between the pendulum and the ballistic types of testers.

APPARATUS

The apparatus described in this paper is designed to measure: (*1*) the total energy absorbed in the cord sample during its breaking process, (*2*) the load elongation characteristics during the course of the test break, and (*3*) the time required to carry the cord from the point of impact to its break point.

The apparatus consists of the flywheel impacting assembly, drive motor and clutching system, transducers and their exciters, and energy load-elongation detecting and recording devices (Figs. 1 and 2).

The tester (Fig. 3) is simply a flywheel similar in many respects to the apparatus described by Villars[12] in his studies on the dynamic properties of various rubbers. The wheel, an 8-in. aluminum disc, rotates freely on ball bearings, and is driven through a clutch by a variable-speed $^1/_4$ h.p. motor.

This cord sample is mounted parallel to the axis of the wheel and is held away from it by movable fingers. After the motor is adjusted to the desired speed with the aid of a Strobotac, the flywheel is engaged by means of a dual purpose clutch. In order to overcome the flywheel inertia it is first brought approximately to the desired speed by a friction clutch, and then, by means of a locking clutch, it is fixed rigidly to the motor drive shaft. After the flywheel has been adjusted to the operating speed, the clutch is disengaged, and the cord is lowered into the path of the impact pin located on the periphery of the flywheel. The breaking energy, load-elongation characteristics, and the time required to carry out the breaking operation are detected with appropriate transducers and recorded. During the course of the break, made by transverse load application, the sample experiences distortion rates which are similar to those of a cord in a tire.

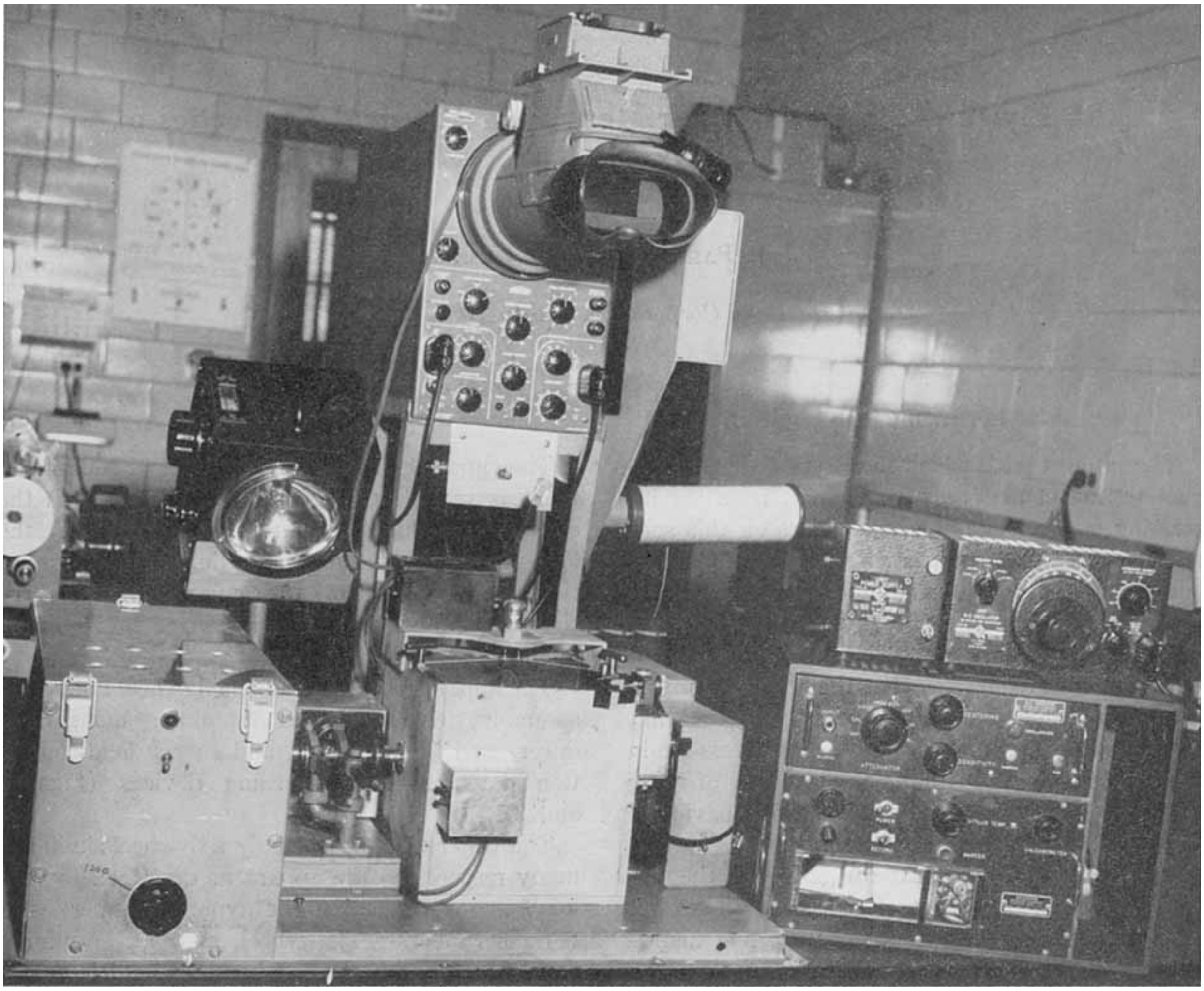

Fig. 1. Flywheel impact tester and accessory instrumentation.

Energy Detection

It is assumed that the energy absorbed in the cord break is equal to that lost by the rotating system, and it will be shown that this is essentially proportional to the decrease in speed of rotation. This loss is measured by the optical system shown in Figure 4. Light from the source passes through two Polaroid discs mounted on the collinear but separate shafts of the drive motor and the flywheel, and onto a photocell. At the start of a test, when the two shafts are locked together, there is no relative motion between the Polaroid discs and there is consequently no variation in the light intensity. (Actually a small variation due to minor imperfections does occur and is useful in checking the operating speed.) However, when the shafts are disconnected and a break is made, the resulting drop in flywheel speed causes relative rotation between the discs and produces strong variations in the transmitted light intensity at a frequency just twice the change in frequency experienced by the flywheel. The resulting signal from the photocell is fed to a strip chart recorder.

Load Detection

The means by which the load developed in the cord is determined is shown in Figure 3. One of the cord clamps is mounted on a cantilever beam designed to move only in the direction of the initial cord position, i.e., parallel to the flywheel axis. The amount of deflection of this cantilever, when it is subjected to any force, is then essentially proportional to the component of that force in this direction. Since the displacement of the cord is precisely known at any moment during the break, the load developed in the cord may be derived from the cantilever deflection and the position of the flywheel.

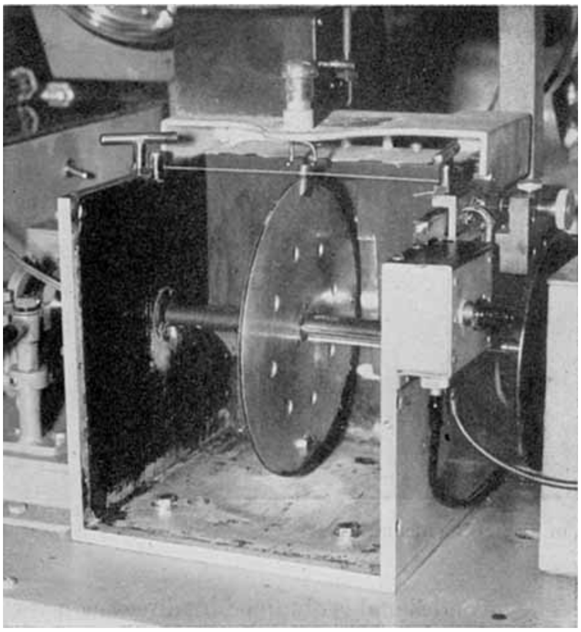

Fig. 2. Close-up of flywheel.

The deflection of the cantilever is easily measured by means of a linear variable differential transformer (LVDT) excited by a 20-kc. 6-v. signal. The output is fed directly to the vertical axis of an oscilloscope and provides a time base as well as information on the load applied to the cord sample being tested.

Elongation Detection

While it is not convenient to measure the elongation directly, it is quite simple to determine the position of the wheel at all times during the breaking process. The elongation itself can then be derived as is shown later. In order to determine the angular position of the flywheel the apparatus shown in Figure 5 is used. A light aluminum disc, attached to the end of the flywheel shaft, has a slit cut near its outside edge. The slit is designed so that the amount of light passing through and onto the photocell increases linearly with angular displacement of the flywheel. Since the leading edge of the slit enters the light beam just as the striking pin makes contact with the sample, the electrical voltage from the photocell is proportional to the angular movement of the pin from this point. This signal is then fed directly to the horizontal amplifier of the oscilloscope.

Displacement Calibration Markers

One additional feature, while not a part of the measuring system, serves as a convenient check on the elongation measurements and should be mentioned. To avoid the effects of 60-cycles/sec. signals, batteries are used to supply the light sources. Some method of checking on the absolute intensity is then required since it gradually decreases as batteries age. This is accomplished by providing a

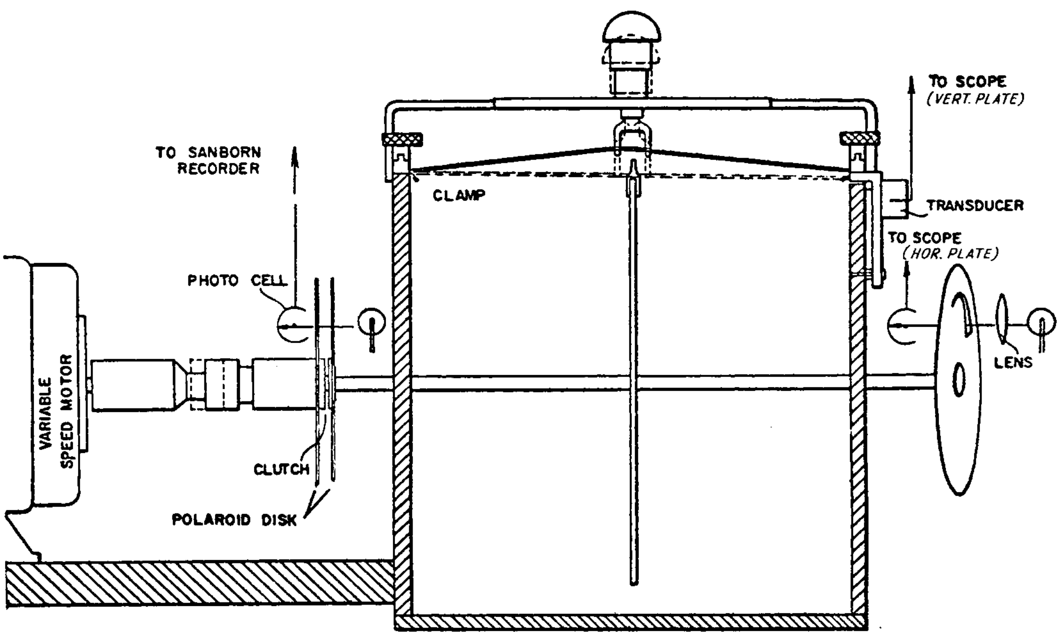

Fig. 3. Schematic diagram of flywheel impact tester and transducer system.

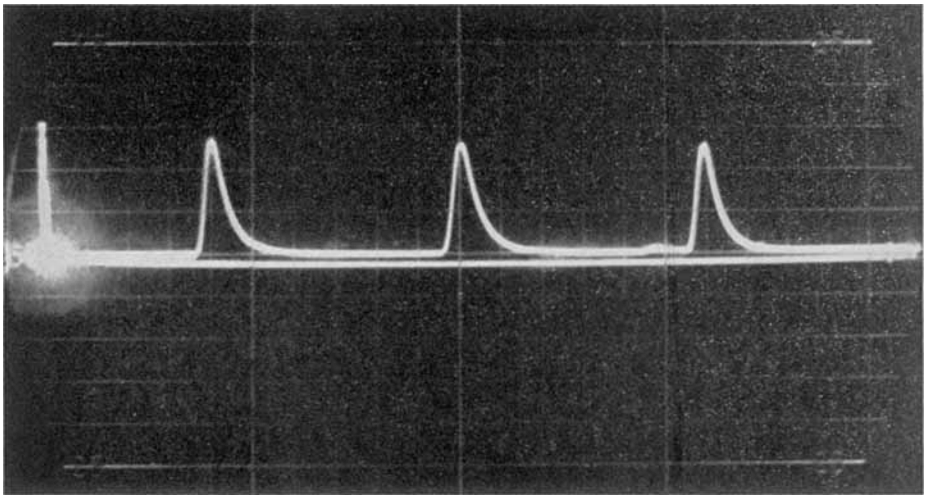

Fig. 6. Oscillographic photograph of displacement markers.

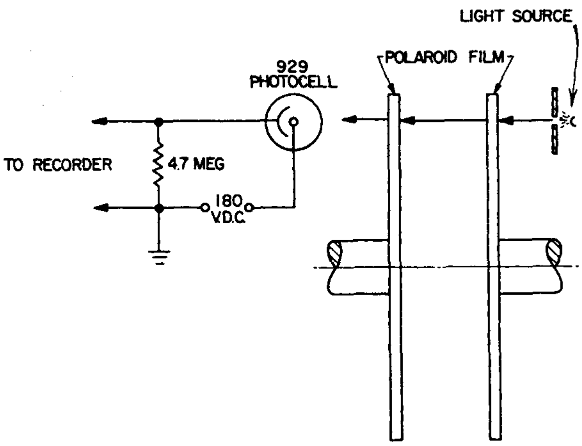

Fig. 4. Schematic diagram of energy-detecting system.

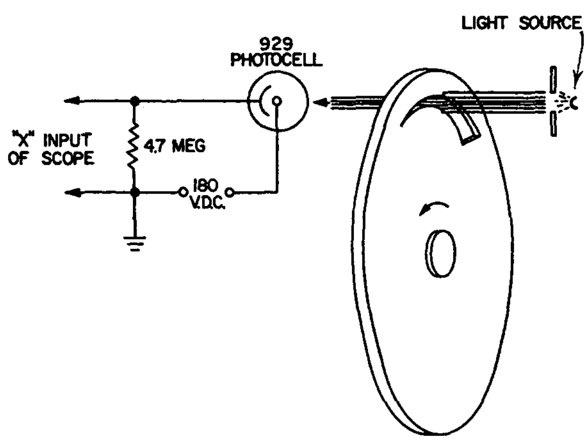

Fig. 5. Schematic diagram of angular displacement detection.

second signal which is dependent only on the angular position of the flywheel and comparing it with that obtained from the elongation detector.

The second signal is obtained by directing a very fine beam of light at the edge of the flywheel itself. As the pin reaches the point of impact with the sample, a small hole drilled in the flywheel allows this beam to fall on a photocell on the other side of the wheel. Additional holes are drilled at 12°, 30°, and 48°. Now if the output from this photocell is fed to the vertical axis of the oscilloscope, and the signal from the wedge-shaped slit system to the horizontal axis, we get the picture shown in Figure 6. Here the vertical pulses are the calibration markers which provide a convenient and reliable check on the elongation system.

MEASUREMENTS

Breaking Energy

When the cord sample is moved into the path of the small pin mounted on the periphery of the freely rotating flywheel, it is picked up and carried to break. The energy absorbed during the action results in a sudden decrease of the wheel's angular velocity. From conservation of energy principles, this reduction in speed is a measure of the total energy required to break the cord sample.

For a flywheel system having a moment of inertia I about its axis of rotation, the kinetic energy is

$$E = (1/2)I\omega^2 \tag{1}$$

The energy absorbed during a cord break is then given by

$$\begin{aligned} \Delta E &= E_0 - E = (1/2 I(\omega_0^2 - \omega^2) && (2) \\ &= 2\pi^2 I(f_0^2 - f^2) \\ &= 2\pi^2 I(f_0 + f)(f_0 - f) \\ \Delta E &= 2\pi^2 I(2f_0 - \Delta f)\Delta f && (3) \end{aligned}$$

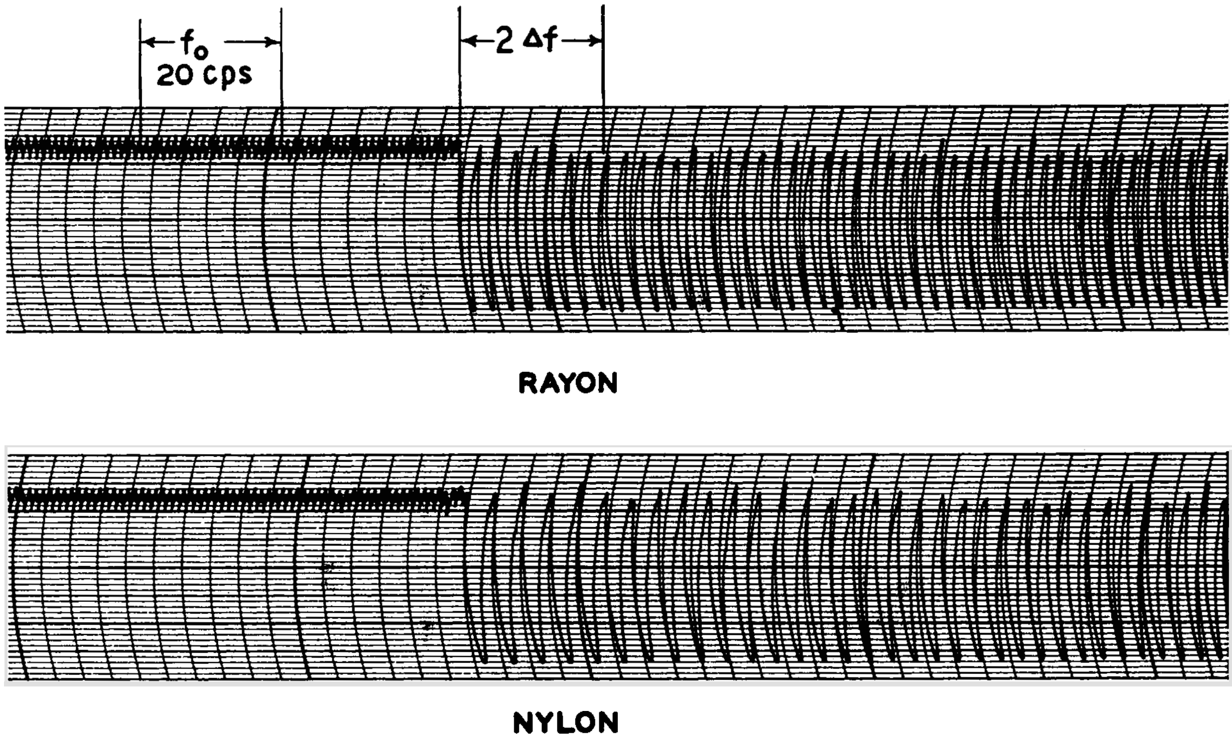

Fig. 7. Recorder traces for determining breaking energy data (chart speed = 25 mm./sec.).

where f_0 is the initial frequency of rotation, f the resulting frequency of rotation after break, and Δf is $f_0 - f$.

The last expression in eq. (3) shows that the energy in question can be measured with approximately the same accuracy used in determining the change in speed undergone during the break. The change in speed Δf is readily obtained with the Polaroid system previously described.

Before the flywheel is disengaged for tests, a constant level of light intensity passes through the Polaroid discs to the phototube detector because of their constant relative phase displacements with respect to each other. However, as mentioned above, due to imperfections in the Polaroids, there are slight fluctuations of intensity which are related to the initial angular velocity of the flywheel.

The instant the cord is broken, the angular velocity of the flywheel is sharply reduced and this is immediately indicated in the recorder trace. The initial flywheel frequency f_0 and the change in the wheel frequency Δf are obtained directly from the trace (Fig. 7).

Load Elongation

The load detecting transducer senses only the lateral component of the stress applied to the cord, i.e., that which is parallel to the axis of the flywheel. The strain detecting transducer senses only the angular displacement of the pickup pin as it carries the cord to break. Referring to the geometries indicated in Figures 8*a* to 8*d:* let $2b$ be the initial length of cord sample, $2c$ the instantaneous length of cord sample, r the radius of point of impact on the flywheel, θ the angular displacement of striking pin from point of impact, ϵ the elongation in the cord, P the instantaneous stress on cord, and F the instantaneous lateral component of stress as sensed by the transducer. **Then from the geometry:**

Elongation

$$\epsilon = (2c - 2b)/2b = c/b - 1 \qquad (4)$$

$$c = (a^2 + b^2)^{1/2}$$

$$c = [(2r)^2 \sin^2 \theta/2 + b^2]^{1/2}$$

$$\epsilon = [(2r/b)^2 \sin^2 \theta/2 + 1]^{1/2} - 1$$

or

$$\epsilon = [1 + (2r/b)^2 \sin^2 \theta/2]^{1/2} - 1 \qquad (5)$$

By binomial expansion the angular displacement and breaking energy may be presented in a more usable form.

$$\epsilon = (1/2)(2r/b)^2 \sin^2 \theta/2 - (1/8)(2r/b)_4 \sin^4 \theta/2 + (1/16)(2r/b)^6 \sin^6 \theta/2 - \ldots \qquad (6)$$

Sufficient accuracy is acquired without carrying the expansion beyond the third term.

Load

Since

$$P = F(c/b) \qquad (7)$$

then from eq. (4):

$$P = F(\epsilon + 1) \qquad (8)$$

Equation (6) establishes the relationship between the elongation and the angular displacement and eq. (8) that between the load and elongation.

It should be understood that this geometric analysis holds only in impact velocity ranges where the cord maintains straight line configuration. At higher velocities, the effects of wave propagation and instrumental response manifest themselves and must be taken into consideration.[13]

In practice the lateral load component of the stress is indicated as a function of the angular displacement on the oscillograph (Fig. 9). Needless to say, carrying out the calculations required to obtain load-elongation data for each test would be prohibitive. However, these can be readily determined by graphic methods. The oscillograph is projected on graph paper, and either with the use of tables or templates which can be readily constructed from

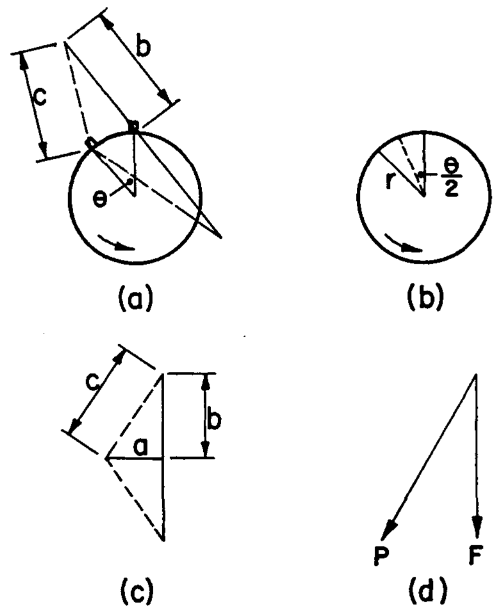

Fig. 8. Geometric configuration representing stress-strain application during test.

eq. (6), the angular displacement may be directly translated to elongation (Fig. 10). Likewise, with eq. (8) the lateral load P is translated to the resultant stress sensed by the cord. Although the entire load-elongation curve can be readily translated, one normally requires only the break point data.

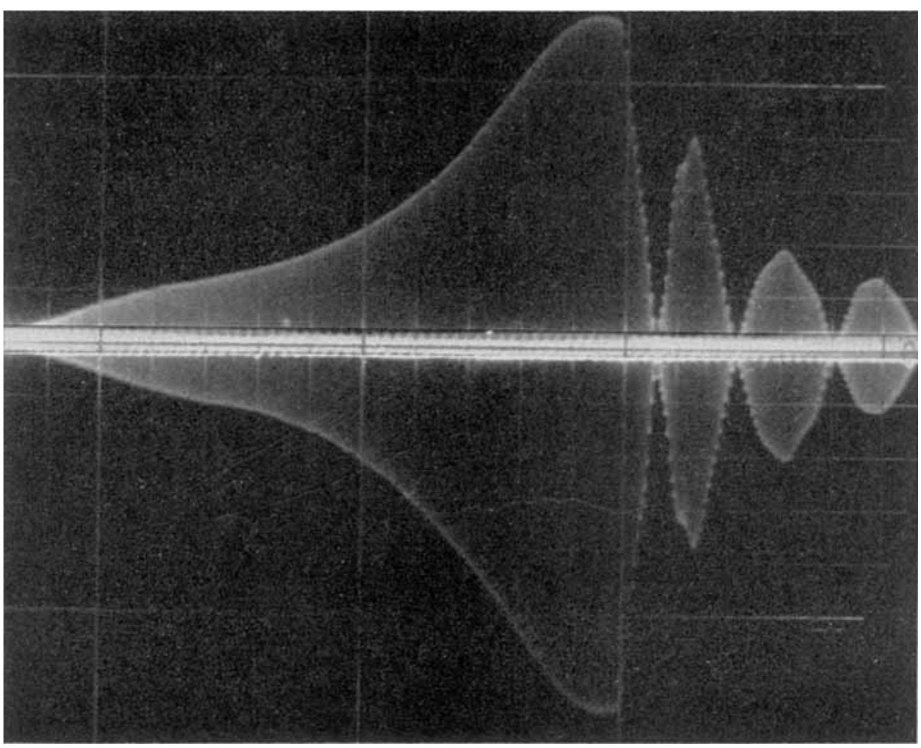

Fig. 9. Oscillographic representation of stress-strain curve obtained from test.

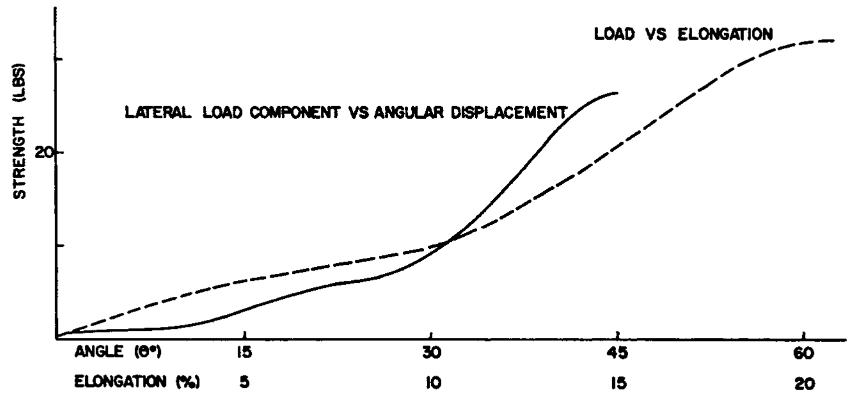

Fig. 10. An example of an oscillographic trace translated to load-elongation data.

Experimental Results and Discussion

Table I gives the samples tested at the indicated impact velocities. All tests were carried out on the flywheel impact tester except those at the lowest speed which were made on the Scott IP4 tester. For convenience, the IP4 data are plotted off the y axis on the following graphs. The cord samples tested were made from typical commercially produced yarns of compatible static strength levels designed for industrial end use. The four basic material types were selected to point out the distinctive behavior of each.

The data obtained from the tests are presented graphically as a function of the impact velocity at which the cords were broken. (The IP4 energy data were obtained from areas under load-elongation curves.)

The energy required to break the cords at the increasing impact velocities is shown in Figure 11. The behaviors of nylon 6 and 66 are similar. The energy absorbed during the course of the break first decreases, apparently passes through a minimum, and then shows a tendency to increase as the impact velocity increases. Polyester and viscose (rayon) absorb an increasing amount of energy as the impact velocity is increased. Polyester energies increase gradually but consistently throughout the range investigated. Those of the viscose show an initial rapid increase and then tend to level off at the higher impact velocities.

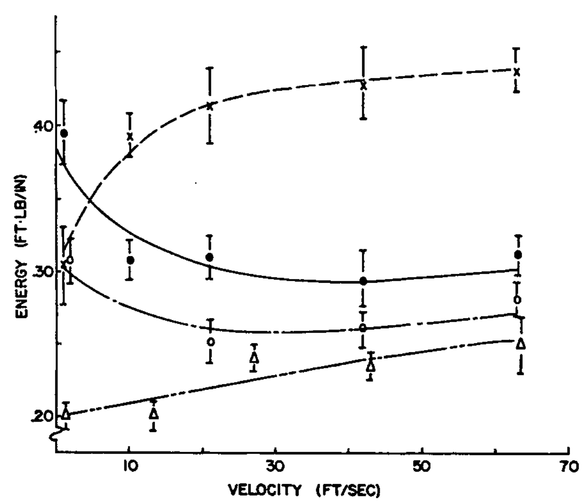

Fig. 11. The effect of impact velocity on the breaking energy found for the tire cords tested: (●) nylon 6, (×) viscose, (O) nylon 66, and (△) polyester.

TABLE I
Description of Tire Cords

Sample	Denier	Twist
Viscose	1650/2	12 × 12
Nylon 6	840/2	12 × 12
Nylon 66	840/2	12 × 12
Polyester	1100/2	12 × 12

The change in breaking energies found in viscose is attributed to the increasing resistance offered to the loading as impact velocity is increased. Those of the nylons and polyester are primarily attributed to the changing elongations found as the impact velocity is increased.

The strength level of the viscose increases significantly with impact velocity (Fig. 12). That of the nylon 6 appears to pass through a minimum resulting in higher strength levels being obtained at the high speeds. The somewhat different behavior observed between nylon 6 and 66 cords is possibly related to their initial structures as produced during processing, i.e., such as draw ratio.

Breaking elongations found at the different impact velocities are shown in Figure 13. Both nylon cords first show a sharp drop in elongation

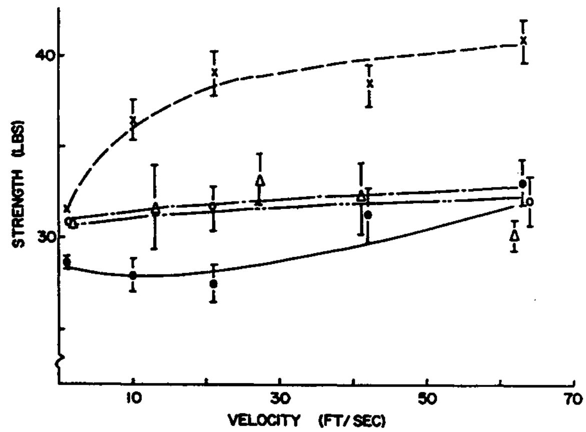

Fig. 12. The effect of impact velocity on the breaking strength found for the tire cords tested: (●) nylon 6, (×) viscose, (○) nylon 66, and (△) polyester.

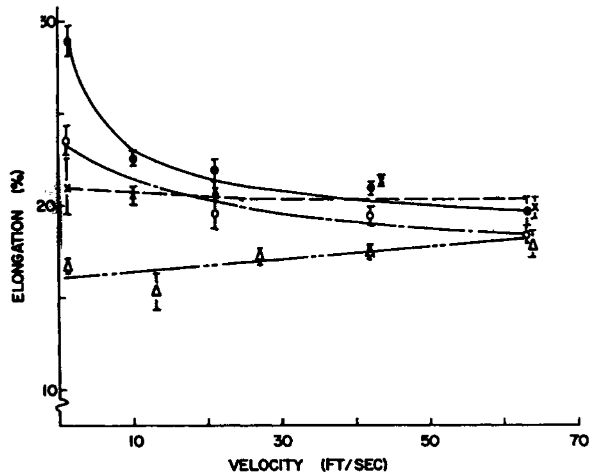

Fig. 13. The effect of impact velocity on the breaking elongation found in the tire cords tested: (●) nylon 6, (×) viscose, (○) nylon 66, and (△) polyester.

and then a tendency to level off as the impact velocity is increased. The breaking elongation of viscose cord is relatively constant throughout the velocity range; that of the polyester shows the same gradual but consistent tendency to increase with velocity that its breaking energy does.

CONCLUSIONS

An impact tester has been developed which provides a means of testing tire cords by transverse load application at impact velocities comparable to those found in tires. This apparatus has been found by experience to be relatively simple to operate and, along with subsequent calculations, can be used in routine laboratory testing by technicians.

The distinctive behavior found for the basically different tire cords supports the contention that static test data are insufficient for predicting the dynamic behavior of materials, thereby indicating the need for high speed testing.

References

1. Schiefer, H. F., W. D. Appel, J. F. Krasny, and G. G. Richey, *Textile Research J.*, **23**, 489 (1953).
2. Holden, G. J., *J. Textile Inst.*, **50**, T41 (1959).
3. Smith, J. C., P. J. Shouse, J. M. Blandford, and K. M. Towne, *Textile Research J.*, **31**, 721 (1961).
4. Chu, C. C., R. J. Coskren, and H. M. Morgan, WADD Tech. Rept., 60–511 Pt. 1, 1960.
5. Meridith, R., *J. Textile Inst.*, **45**, T30 (1954).
6. Lyons, W. J., and I. B. Prettyman, *Textile Research J.*, **23**, 917 (1953).
7. Stone, W. K., H. F. Schiefer, and G. Fox, *Textile Research J.*, **25**, 520 (1955).
8. McCracken, F. L., H. F. Schiefer, J. C. Smith, and W. K. Stone, *Textile Research J.*, **25**, 529 (1955).
9. Smith, J. C., F. L. McCracken, and H. F. Schiefer, *Textile Research J.*, **25**, 701 (1955).
10. Smith, J. C., F. K. McCracken, H. F. Schiefer, W. K. Stone, and K. M. Towne, *J. Research Natl. Bur. Standards*, **57**, 83 (1956).
11. Von Karman, T., and Pol Duwez, *J. Appl. Phy.*, **21**, 987 (1950).
12. Villars, *J. Appl. Phy.*, **20**, 565 (1950).
13. Ballou, J. W., and J. A. Roetling, *Textile Research J.*, **28**, 631 (1958).

Synopsis

The development and operation of a dynamic tire cord testing apparatus is described. The apparatus consists of a rotating wheel which applies a transverse load to a tire cord and carries it to break. It can be operated at speeds which impact tire cord at velocities of from 10 to 80 ft./sec. The techniques used for detecting, recording, and calculating energy load-elongation characteristics and time to break are described. Some data showing the effect of impact velocity on the physical properties of nylon, rayon, and polyester tire cords are presented.

Résumé

Le développement et la manipulation d'un appareil servant à l'exécution de tests dynamiques sur fils pour pneus sont décrits. L'appareil consiste en une roue appliquant une charge transversale à ces fils et provoquant leur rupture. Il peut être utilisé de façon à ce que l'impact des fils se fasse à des vitesses de 10 à 80 pieds/sec. Les techniques utilisées pour détecter, enrégistrer et calculer l'énergie, les caractéristiques charge-élongation et le temps de rupture sont décrites. Quelques données montrant l'influence de la vitesse d'impact sur les propriétés physiques des fils pour pneus en nylon, en rayonne et en polyester sont présentées.

Zusammenfassung

Die Entwicklung und Funktion eines dynamischen Reifencord-Testgerätes wird beschrieben. Das Gerät besteht aus einem rotierenden Rad das auf den Reifencord eine transversale Belastung ausübt und ihn zum Reissen bringt. Es kann mit Geschwindigkeiten betrieben werden, welche zu einer Schlaggeschwindigkeit am Reifencord von 10 bis 80 ft/sec führen. Die Verfahren zur Bestimmung, Registrierung und Berechnung von Energie, Belastungs-Dehnungscharakteristik und Reissdauer werden beschrieben. Einige Ergebnisse bezüglich des Einflusses der Schlaggeschwindigkeit auf die physikalischen Eigenschaften von Nylon, Rayon- und Polyesterreifencord werden mitgeteilt.

Discussion

Question: What is the effect of pre-tension on the cord?

Answer (Mr. Kemic): I don't know, but in following established testing laboratory procedure, it was felt that a constant level of pre-tension is necessary. Although it was somewhat arbitrary, we selected a one-pound pre-tension out of practical consideration of our load-sensing device, but maintaining what we felt was a reasonable level.

Question: In your test condition you always went to rupture. Could you modify your equipment so that you could stop before rupture?

Answer (Mr. Kemic): It could be done. However, as our apparatus now stands, the sudden stop from the speeds we are using would cause considerable damage to the alignment and bearings. There are methods of limiting the extension of the sample to avoid rupture. One would be the replacement of our fixed pick-up pin with a pressure spring-loaded one, which could release the cord at some selected level of applied tension.

Question: Please explain why you pointed out that longitudinal loading was not as good as transverse loading.

Answer (Mr. Kemic): In discussing the design of our apparatus, it was felt that for our purposes we should use a transverse type of loading rather than a longitudinal because this would more closely simulate the conditions that a cord in a tire would feel if it were striking a rut or a six-inch curb. Actually, longitudinal stress application is present in the cord sample, although the loading is transverse. With transverse loading one can simulate the change in rate of loading present in tire impacts, whereas this could not be readily accomplished with a longitudinal type of loading.

Question: Do you consider the location of the break significant?

Answer (Mr. Kemic): Yes, this is an important consideration. In our earlier work we experienced considerable clamp and pin breaks, which we felt could give us misleading results. This can be overcome by such precautionary measures as maintaining clean and highly polished capstan and pin surfaces. One would like to see a good distribution of break points in testing significant numbers of samples.

Question: Does the cord wrap around the capstan?

Answer (Mr. Kemic): No. The cord does not *wrap* around the capstan, although it is passed around it to the clamp. Because of this, one may consider that our method is not precise, since it does not take into consideration the distribution of incremental extensions along that portion of cord length which is in contact with and beyond the capstan. However, with some calculations and measurements we approximated an effective sample length for test purposes.

Question: Specifically, what fraction of the initial kinetic energy of the flywheel is removed in the breaking of the specimen?

Answer (Mr. Kemic): The wheel loses essentially that amount of kinetic energy which is absorbed by the cord during the process of breaking, about 0.23 ft.-lbs./in. for some typical samples. The frequency of the flywheel will change, depending on the energy absorbed by the sample. Typical frequency drops observed during the course of the break are in the order of 5 to 6 cycles/sec.