RESILIENCE TESTS OF AUTOMOBILE TIRES UNDER COMMERCIAL CONDITIONS OF OPERATION

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Resilience Tests of Automobile Tires Under Commercial Conditions of Operation

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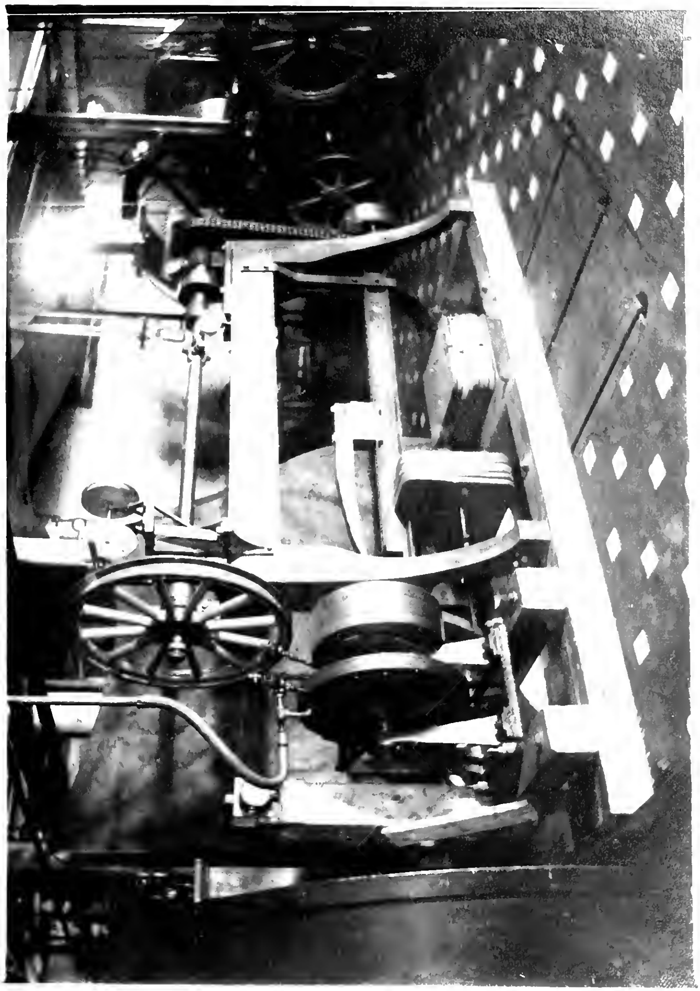

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Preface

Respecting the field of the theme, attention is called to the universally acknowledged fact that nearly all recent progress i the engineering art is due to experimental investigation and research.

The automobile tire-testing machine was devised and constructed for the purpose of finding such coefficients, in advance of actual trial, as might be employed with confidence in tire construction to produce definite results. Very little experimental work has been done in this field and very little data is obtainable, therefore experimental research and tests are valuable in discriminating between correct and false theories in regard to automobile tires.

We are much indebted to Mr. Adolph Fors for the use of his tire pressure gauge and to the instructions of the shops who so kindly gave their assistance in the process of construction of the apparatus.

Object

The object was to construct the tire-testing apparatus which is owned by the Armour Institute of Technology and to run some tests on a plain 36" x 3 1/2" Republic automobile tire.

The construction of the machine, which will be described later, was accomplished, and having made the preliminary calibration observations, it was decided to make the runs by keeping the load on the tire constant, and vary the pressure in the tire, and the tractive effort.

From these observations it is possible to calculate the slip of the tire, and the power loss due to the resilient action of the tire.

Running the tires on a plain cast iron pulley will give data by which a comparison of different makes of tires may be made and it will give also a means of obtaining the load, pressure and tractive effort for the point of highest efficiency of running the tire.

Description of Apparatus.

The work of constructing the machine was begun by outlining the work by means of drawings and a bill of material. These drawings were followed almost exactly as they were made.

The base of the machine was made of 6"x6" wooden timbers framed together and bolted. This wooden base was bolted to the bed plate which is located in the engine room of the main building. The machine was then bolted securely to the wooden base, this gave a good substantial foundation for the whole apparatus which when running was free from vibrations.

The machine proper is made of cast iron and is similar in construction to the bed of a lathe. The drive pulley, which is placed at one end, drives up to the main shaft by means of a "Maximum" silent chain and cut toothed wheels. The characteristics of this chain are such that it runs quietly at high speeds, and either forward or backward. It is not affected by heat, cold, or dampness, thus making it superior to a belt.

The main shaft is mounted in two ball bearings at the drive end between the bearings a Kenerson Dynamometer is coupled and stayed. The readings of

the dynamometer give the power input to the tire. All bearings are ball bearings thus inducing the friction load to the smallest obtainable quantity and also requiring no oil for lubrication. In the main shaft there is arranged a knuckle joint which permits the rise and fall of the tire when passing over bumps. This may be seen by referring to the accompanying photograph of the entire machine. At the tire end the main shaft is mounted in a bearing which is so constructed that it is allowed to move up and down in a ball slide arrangement as the tire passes over bumps.

The wheel was fitted to the drive axle and attached so that it would be driven pisitively by the main shaft. This arrangement requires a special axle for each make of wheel. The wheel axle is secured to the drive shaft by means of key and keyway with a set screw for further security.

The tire runs on a heavy cast iron pulley which is mounted to the axle of an absorption dynamometer, the power of which is calculated from its moment arm and load on the scales. The cast iron pulley has a diameter of eighteen inches. The power obtained from the absorption dynamometer is the power

transmitted by the tire. The tractive effort is applied to the tire by varying the water pressure in the absorption dynameter. The load on this dynamometer is very hard to maintain constant owing to the fluctuation of pressure in the water main. It is therefore suggested that some arrangement be made by which the pressure of the water will be adjustable and thereby remain constant. The whole test hinges on this one point of maintaining the tractive load constant.

The loadings on the tire are obtained by applying weights to the I-beam which is slung under the bed of the machine with a fulcrum at the drive end and fastened to the bearing at the wheel end by a steel rod having a knuckle joint inserted. This is attached to a leaf spring which is rigidly bolted to the I-beam.

The revolution of the main shaft and of the absorption dynamometer were recorded by two integrating revolution counters which were connected to the shafts by flexible spring shaftings. These are very fine instruments and were made by Mr. Falk, the school mechanician.

The rebounding of the tire on the cast iron pulley was recorded by means of levers on to a re-

volving disc to which a paper was attached. This method seems to work satisfactorily so drawings are submitted in the accompanying thesis for a revised bracket and perfected levers and pedestals for same. The paper recording apparatus is to be made by the school mechanician and will be attached to the cast iron bracket which will be placed where, by looking at the accompanying photograph, is seen the device which was used during the runs. The paper on which the records are made should be arranged to travel at a known speed for which 2" per minute would be about right.

The machine was driven by a 10 horse power variable speed motor. This allows a travel of from ten to sixty miles an hour for a thirty-six inch tire.

The whole apparatus ran without any heating of the bearings which shows that as far as running it was in good condition.

Preliminary Observations

The calibration of the Kenerson Dynamometer was made by mounting the dynamometer in the jaws of the torsion machine by means of two short pieces of shafts having keys and keyways.

H.P. from dynamometer equals the reading times revolutions per minute divided by 100.

Thus

$$H.P. = R \times H \div 100$$

The H.P. from the formula is

$$H.P. = \frac{2 \pi r NF}{33,000}$$

Let R equal one, then

$$33,000\ N = 100 \times 2 \pi r NF$$

$$\therefore rF = \frac{33,000\ N}{100 \times 2 \pi N}$$

$$\therefore rF = 52.55 \text{ ft. lbs.}$$

$\therefore$ Reading 1 = 52.55 ft. lbs.

Following are tables of figures found in the calibration of the Kenerson Dynamometer in the torsion machine.

These results have been represented in the calibration curve accompanying the thesis.

Preliminary Observations.

The preliminary observations were made to obtain the calibration curve for the Kenerson transmission dynamometer at varying loads and speeds, which incidently gave the speeds for the notches on the starting rheostat of the variable speed motor.

The absorption dynamometer was blocked up with wooden blocks so as to couple it to the main drive shaft of the machine. Then it was decided to run the apparatus with varying loads and speeds. The readings of the Kenuson dynamometer were taken and also the load on the scales and the N.p.m. of the main shaft.

The notches on the rheostat were numbered so that #1 indicates the lowest speed and as the numbers increase the speed increases.

Following are tables of figures obtained in the calibration of the Kenerson Dynamometer in actual running conditions.

Dead Load on Scales = 11.9#

Length of moment arm = 22 1/4"

For No. Load

Notch No.	R.P.M.	Load Ken.Dyn. Divs.	Load Scales lbs.	Ken Dyn H.P.	Brake H.P.
1	167	.04	15.1	#.067	#.189
	167	.04	15.1	.067	.189
3	188	.05	15.1	.094	.213
	189	.05	15.1	.095	.213
5	208	.05	15.2	.104	.243
	210	.05	15.2	.105	.244
8	258	.07	15.5	.181	.329
	258	.07	15.5	.181	.329
11	326	.085	15.9	.298	.462
	326	.085	15.9	.278	.462
14	408	.100	16.5	.408	.665
	414	.100	16.5	.414	.675
17	493	.125	17.1	.616	.910
	503	.130	17.3	.654	.965
20	622	.190	19.1	1.180	1.590

H.P. = 167 x .04 ÷ 100 ≑ .067

H.P. = $\frac{2\pi rnP}{33,000} = \frac{2\pi \times 22\ 1/4 \times (15.1-11.9) \times 167}{33,000 \times 12}$

= .189

Run for 40 miles per Hour 13th Notch.

R.P.M.	Load Ken.Dyn.	Load Scales	H.P. Ken.Dyn.	H.P. Abs.Dyn.
378	.02	15.3	#.076	#.454
386	.185	20	0.715	1.107
376	.36	25	1.353	1.741
380	.51	30	1.940	2.433
370	.65	35	2.420	3.190
376	.78	40	2.935	3.750
375	.935	45	3.510	4.390
369	1.05	50	3.878	4.980
375	1.205	55	4.520	5.720
371	1.43	60	5.315	6.320
373	1.49	65	5.560	7.000
373	1.635	70	6.100	7.650
371	1.79	75	6.640	8.320
370	1.94	80	7.180	8.900
357	2.00	85	7.140	9.860
345	2.16	90	7.449	10.180
330	2.25	95	7.425	10.300
322	2.40	100	7.730	10.580

$$H.P. = 378 \times .02 \div 100 = .076$$

$$H.P. = \frac{2\pi nrP}{33,000} = \frac{2\pi \times 378 \times 22\ 1/4 \times (15.3-11.9)}{33,000 \times 12}$$

$$= .454$$

For 15 miles per hour

R.P.M.	Load Ken. Dyn.	Load Scales	H.P. Ken. Dyn.	H.P. Abs. Dyn.
142	0	12.9	0.000	.050
141	.21	20	.296	.403
139	.34	25	.473	.646
133	.50	30	.661	.844
143	.64	35	.916	1.168
140	.81	40	1.135	1.390
142	.93	45	1.320	1.665
142	1.05	50	1.491	1.915
144	1.18	55	1.700	2.090
140	1.26	60	1.765	2.380
142	1.46	65	2.076	2.680

For 20 Miles per hour. 3rd Notch 187 R.P.M.

R.P.M.	Load K. Dyn.	Load Scales	H.P. Kn.Dyn.	H.P. Abs.Dyn.
186	.25	20	# .465	#.534
186	.39	25	.725	.864
189	.55	30	1.040	1.205
186	.70	35	1.302	1.520
185	.85	40	1.572	1.840
182	1.00	45	1.820	2.130
182	1.11	50	2.020	2.780
185	1.28	55	2.370	3.150
185	1.45	60	2.685	3.480
184	1.63	65	3.000	3.780
180	1.79	70	3.222	4.020
182	1.85	75	3.365	4.060
180	1.98	80	3.565	4.340
174	2.09	85	3.635	4.500
176	2.25	90	3.960	4.870
172	2.40	95	4.135	5.060
171	2.50	100	4.270	5.370

H.P. = 186 x .25 ÷ 100 = .465

$$H.P. = \frac{2\pi rPN}{33{,}000} = \frac{2\pi \times 22\ 1/4 \times (20-11.9) \times 186}{33{,}000 \times 12}$$

$$= .534$$

Run for Varying R.P.M. Constant Loads

R.P.M.	Load Ken. Dyn	Load Scales	H.P. Ken.Dyn.	H.P. Abs.Dyn.
164	.51	28.7	.84	.87
194			.990	1.15
240			1.220	1.43
300			1.53	1.78
380			1.94	2.26
460			2.35	2.73
560			2.86	3.33
162	1.00	45.5	1.62	1.93
184			1.84	2.19
234			2.34	2.78
295			2.95	3.51
380			3.80	4.52
465			4.65	5.53
161	1.50	61.0	2.42	2.80
192			2.88	3.34
235			3.53	4.08
300			4.50	5.22
374			5.62	6.50
456			6.85	7.92
152	2.00	81.5	3.04	3.74
192			3.84	4.73
234			4.68	5.76
297			5.94	7.32
360			7.20	8.86
420			8.40	10.35
154	2.50	100.0	3.85	4.81
186			4.65	5.80
234			5.85	7.30
290			7.26	9.05
348			8.71	10.85
396			9.90	12.36

Run for 30 miles per Hour. 9th Notch.

R.P.M.	Load Kin.Dyn.	Load Scales	H.P. Kin. Dyn.	H.P. Abs.Dyn.	Eff.
288	0.0	12.9	0.000	.102	
282	0.24	20	.677	.808	
282	0.35	25	.986	1.310	
281	0.505	30	1.420	1.800	
281	0.64	35	1.800	2.300	
282	0.73	40	2.060	2.800	
282	0.91	45	2.565	3.300	
280	1.06	50	2.970	3.790	
281	1.18	55	3.310	4.30	
284	1.30	60	3.690	4.810	

The scales were placed under the tire and the weights numbered and hung on the I-beam one by one and the following readings were taken

Lead Wt. on Scales		=	11 1/2#
" " " " + Wheel and Tire		=	196
" " " " + " " +	Wt. #1	=	229.0#
	" #2	=	259.5
	" #3	=	293.5
	" #4	=	326.5
	" #5	=	360.0
	" #6	=	398.0
	" #7	=	433.5
	" #8	=	470.0
	" #9	=	505.5
	" #10	=	541.5

The above figures give the actual load which is on the tire when running. There are enough weights to apply a load of 1500 pounds to the tire.

Stresses and Strain in Tires.#

The duty that the pneumatic tire has to perform is, very complex. So complex is it that no one has yet been able to completely analyze it; at any rate, not sufficiently in order to be able to reconstruct an integral synthesis from the resultant analysis so as to evolve the elastic wheel.

As soon as some one has discovered the exact manner in which the pneumatic cushions of an automobile wheel works then the problem of the elastic or resilient wheel will be mostly solved.

It is proposed to show the nature of the efforts supported by the tires, their approximate direction in the order of sizes.

It is proposed to classify the efforts to which the tire is submitted in static efforts (these are the efforts that act upon the tire when the car is standing still), and dynamic efforts, that is to say, efforts that are caused by the diverse movements of the car.

Static Efforts.

It is assumed that a tire presents geometrically the exact form of a tore. This hypothesis is as

The dimensions of tires are given in metric numbers because these figures were obtainable from the Auto, Sept.14,1911.

near the truth as it is possible to go and in every case the errors that may be made in adopting it are much less than approximation that we hope to attain.

It will be remembered that R is the mean radius of the tore, r the radius of the meridian circle. The dimensions by which tires are usually denoted are expressed by

$2(R+r)$ (diameter of the parallel equator)

and

$2r$ (diameter of the meridian)

supposing p to represent the difference in pressures (expressed in lbs. per square inch) between the air enclosed in the inner tube and the atmospheric air.

The figure p will be the reading on a pressure gauge applied to the valve.

po will denote the initial pressure to which the tire was inflated, or to be more exact we will call po the value that p will take when the tire is not opposed to any exterior effort, the temperature of the air inside being the same as the exterior air at the moment of inflation.

po will therefore be the theoretical pressure indicated by the makers, which are given in table I as a guide for inflating tires.

Finally we will admit for the calculations of tensions supported by the canvas, that

1. That the tire is perfectly souple.

2. That the canvas does the work, the rubber of the inner tube and outer cover not supporting any effort.

3. That the canvas known as straight grain included in the arc are not affected by the effort due to the internal pressure.

Superficial Tension.

One knows that an elastic membrane separating two gaseous masses, the pressures of which are different, supports an effort of traction which is a component of the differences in pressures and of the curvature of the membrane.

If the radii of the principal curvatures are designated by r' and R' at any point of the inflated tire, the surface tension will have a value at this point

$$A = \frac{P}{\frac{1}{R} + \frac{1}{r}}$$

It is interesting to note the variations of the principal curvature of the tore at the different points of the surface.

The minimum radius R' is evidently equal to the constant value of the meridian circle.

$$R' = r$$

The radius R maximum will vary according to

the different points of a given meridian.

It will be as well to give it a positive (in the same manner as r') when the curvature will have its concavity turned toward the interior. Taking Fig. 1 as an example denoting a meridian section of the tore.

At the point A we have

$$R' = R + r$$

Considering the displacement from A to B the curvature diminishes until it becomes nil at B. R' will grow indefinitely from A to B while remaining positive.

In displacing from B to C the curvature becomes negative and augments the absolute value. The radius of the curvature varies from O to -(R-r).

The surface tension A varies therefore between the two values.

$$= \frac{p}{\frac{1}{r} - \frac{1}{R-r}}$$

and

$$+ \frac{p}{\frac{1}{r} + \frac{1}{R+r}}$$

It is easy to see that the maximum will be at the point C. In fact the denominator is maximum when R' is negative and equal to R-N.

The maximum surface tension is therefore

$$Am = \frac{p}{\frac{1}{r} - \frac{1}{R-N}}$$

$$= p \frac{r(R-N)}{R-2N}$$

It will be interesting to see how this compares with different sizes of tires. First of all it should be noted that R is always much greater than r. We have therefore for the current dimensions of tires of cars the following:

(700x90	R = 30.5 cm.	r = 4.5	$\frac{R}{N}$	= about 7
(790x90	R = 38.5 cm.	r = 4.5	$\frac{R}{N}$	= " 7.5
(790x90	R = 41 cm.	r = 4.5	$\frac{R}{N}$	= " 9
(820x120	R = 35 "	r = 6	$\frac{R}{N}$	= " 6
(920x120	R = 40 "	r = 6	"	= " 6.8
(895x135	R = 38 "	r = 6.8	"	= " 5.5
(935x135	R = 40 "	r = 6.8	"	= " 6

The pressure p to which tires should be inflated varies, as everyone knows, with the diameter of the tire. That is why tires of 90 millimeters section should be inflated to 5 kilograms, 120 m.m. section to 6 kilograms, and 135 mm. sections to 7 kilograms.

It is easy to see how for the same section and also for the same pressure the maximum surface tension will vary.

It is expressed by

$$Am = pr \frac{R - r}{R - 2N}$$

$$Am = pr \frac{\frac{R}{N} - 1}{\frac{R}{r} - 2}$$

For the same section the product pr is constant. The fraction

$$\frac{\frac{R}{r} - 1}{\frac{R}{r} - 2}$$

is greater than unity, and will decrease when $\frac{R}{r}$ increases. From which it is possible to draw the following conclusions:

The surface tension is proportionately smaller for a given section of the tire as the diameter of the wheel increases.

If we consider the various sections of casings we can find out that the surface tension is proportionately greater as the tire increases in size.

In fact, in the product

$$A = pr \frac{\frac{R}{N} - 1}{\frac{R}{N} - 2}$$

the time p will increase when r increases.

This table will show that $\frac{R}{N}$ diminishes when N

increases.

The three factors p, r, $\frac{\frac{R}{N} - 1}{\frac{R}{N} - 2}$ will increase with r.

That is why a 700 x 90 tire will have a superficial maximum tension:

$$Am = 5 \times 4.5 \frac{7 - 1}{7 - 2} = 27 \text{ kilograms.}$$

A_N 875 x 135

$$A_N = 7 \times 6.9 \frac{5.5 - 1}{5.5 - 2} = \text{ kilograms.}$$

It is for this reason that tire makers manufacture the tires with a proportionately greater number of layers of canvas as the diameter increases.

90 m.m. section tires usually have 4 layers of canvas, while 135 m.m. sections have 7 layers of canvas.

The proportion indicated by the calculation does not seem to have been followed. This is accounted for by the fact that in all times efforts independent of the diameters must be taken into consideration, which will be explained later. So that if the number of layers of canvas to be used is denoted by **n** and a the tension to support each one of them, n must be calculated from the formula

$$n = \frac{A}{a'}$$

which is rational if the surface tension were not taken into consideration, but it must be calculated from the following:

$$n = no + \frac{A}{a} .$$

The warp and the woof threads in pneumatic tires are placed at an angle of approximately 45 degrees in the principal plane of the surface. As the resistance of the canvas is none other than that of the warp and the woof it is interesting to look for the resistances imposed on the threads.

In articles that have appeared on the manufacture of tires, we find that the angle of the threads, which is about 90 degrees at the brad, comes down to 70 degrees at the center portion of the tire.

It is proposed to first of all calculate the tensions following the principal planes at the points A and c in Fig. 1.

Supposing the tire cut in a meridian plane. The layers will have to withstand a resistance as follows in order to remain stuck together:

$$\frac{p \pi r^2}{2 \pi r}$$

which equals $\frac{pr}{2}$.

This is the tension in the equatorial plane which can be designated by T_E.

If we now cut the tire in the equatorial plane the force which will tend to s the two halves will be equal to

$$p(\pi (R+r)^2 - \pi(R-r)^2)$$

that is to say

$$4 \pi Rrp.$$

Let these meridian tensions be called Tm.Min., and Tm. Max.

Near the beads the threads of the canvas are at an angle of 45 degrees to the direction of meridian and equatorial tensions.

The tension t following these threads will be (see Fig.4):

$$t = \frac{\sqrt{2}}{2} (T_E + Tm.Max.)$$

that is,

$$t = \frac{\sqrt{2}}{2} pr \left(\frac{1}{2} + \frac{R}{R-N}\right)$$

$$= \frac{pr}{2\sqrt{2}} \frac{3R - r}{Rr} .$$

At a point of the great equatorial circle where the threads form between them an angle α ($\alpha < 90^\circ$) the tension of these threads will be according to Fig.5.

$$T = \frac{1}{2} \left(\frac{Tm}{\cos\frac{\alpha}{2}} \quad \frac{T_E}{\sin\frac{\alpha}{2}} \right)$$

that is

$$T = \frac{1}{2} pr \left(\frac{R}{R+N} \; \frac{1}{\cos \frac{\alpha}{2}} \qquad \frac{1}{2 \sin \frac{\alpha}{2}} \right)$$

Let us apply these formulas to some standard sizes of covers.

1^{o} 760 x 90 R = 33.5 N = 4.5

Tension at the Bead of the cover

$$t = \frac{5 \times 4.5}{2\sqrt{2}} \cdot \frac{33.5 \times 3 - 4.5}{29}$$

$$= 26.5 \text{ kilograms}$$

The tension at the running tread (angle of the threads α = about 80^{o})

$$t = \frac{5 \times 4.5}{2} \left(\frac{33.5}{38 \cos .40^{o}} + \frac{1}{2 \sin 40^{o}} \right)$$

$$= \text{about 21 kilograms}$$

The tension is appreciably less at the thread, as can be seen.

This explains why when a tire bursts (unless the burst is due to a cut) the tear generally takes place at the side wall. Near the point of attachment where the tension is greatest, the tire is reinforced by the two small layers.   ually the tire bursts just below these layers.

The tensions that have been calculated shows what is supported by the general body of canvas.

Near the rim the two layers must be taken into consideration as well and the total tension divided by six

$$\frac{26.5}{6} = 4.5 \text{ kilograms}$$

Canvas of good quality should not break unless submitted to an effort of 56 kilos. per square centimeter. The coefficient of secutiry is therefore 12.

Another interesting point is at what part of a tire the work of each layer of canvas is greatest, granted that their number is variable.

Near the point B in Fig. 1, it can be seen that the tensions in the main planes are respectively

Tension in the perpendicular plane at the meridian:

$$t = T_E$$
$$= p\frac{r}{2}$$

Tension in the meridian plane:

$$Tm = \frac{p.\ 2\pi Rx2r}{2\ x\ 2\pi R}$$

$$= pr.$$

The angle that the threads make being α at this point, the forces that will act upon them can be expressed by (Fig.5)

$$T = \frac{1}{2}\left\{\frac{T_m}{\cos\frac{\alpha}{2}} + \frac{T_E}{\sin\frac{\alpha}{2}}\right\}$$

continuing to call T_E the tension in the main plane perpendicular to the meridian plane.

But in replacing Tm and T_E by their values

$$T = \frac{1}{2}\,pr\left(\frac{1}{\cos\frac{\alpha}{2}} \quad \frac{1}{2\sin\frac{\alpha}{2}}\right)$$

The angle of the threads for the 760 x 90 tire that we have chosen is, for example, about 85 degrees.

From which the value of T:

$$T = \frac{1}{2} \times 5 \times 4.5\left(\frac{0.737}{1} \quad \frac{1}{2\times0.676}\right)$$

$=$ about 22.5 kilograms.

This tension is much greater than that which exists at the rolling tread.

At the point B (in Fig.1) the number of layers of canvas is only 4. The tension of each thread of the canvas has a value

$$\frac{22.5}{4} = 5.5 \text{ kilograms.}$$

More, therefore than the tension of the bead.

The tension increasing when a displacement is made from B to C, it can easily be seen that the tension of each strand or thread will be a maximum fol-

lowing along the border of the bead strip.

This is borne out by practice. When a tire bursts prematurely it generally takes place at this point.

11^{o} 820 x 120 tire R = 35 N = 6

$$\frac{R}{N} = \text{about } 6$$

In applying the formula we have:

1. Tension at the bead for the entire canvas structure (p = kilogs.)

$$t = \frac{pr}{2\sqrt{2}} \cdot \frac{3R - N}{R - N}$$

$$= 44 \text{ kilogs.}$$

which for each layer equals:

$$\frac{44}{8} = \text{ kilogs.}$$

taking the side strip into consideration.

2. Tension at the running tread ($\alpha = 70^{o}$)

$$t = \frac{1}{2} pr \left(\frac{R}{R + N} \frac{1}{\cos \frac{\alpha}{2}} 2 \frac{1}{\sin \frac{\alpha}{2}} \right)$$

with $\cos \frac{\alpha}{2} = 0.819$

$\sin \frac{\alpha}{2} = 0.574$

$t = 34.5$ kilogs.

3. Tension at the walls ($\alpha = 80^{o}$)

$$T = \frac{1}{2} pr \left\{ \frac{1}{\cos \frac{\alpha}{2}} 2 \frac{1}{\sin \frac{\alpha}{2}} \right\}$$

with

$$\cos\frac{\alpha}{2} = 0.766$$
$$\sin\frac{\alpha}{2} = 0.643$$
$$T = 38 \text{ kilogs.}$$

Which is equivalent for each thread:

$$\frac{38}{6} = 6.3 \text{ kilogs.}$$

III. 935 x 135 tire

$$R = 40 \quad r = 6.8 \quad \frac{R}{r} = 6$$

1. Tension at the bead (p = kilogs.)

$$t = \frac{pr}{2\sqrt{2}} \quad \frac{3R - r}{R - r}$$

$$= 57 \text{ kilogs.}$$

which is equivalent for each strand

$$\frac{57}{9} = 6.33 \text{ kilogs.}$$

2. Tension at the running tread ($\alpha = 70^{\circ}$)

$$t = \frac{1}{2} pr \left\{ \frac{R}{R + r} \quad \frac{1}{\cos\frac{\alpha}{2}} + \frac{1}{2\sin\frac{\alpha}{2}} \right\}$$

with

$$\cos\frac{\alpha}{2} = 0.819$$
$$\sin\frac{\alpha}{2} = 0.574$$
$$t = 4.55 \text{ kilogs.}$$

3. Tension at the walls

$$t = \frac{1}{2} pr \left(\frac{1}{\cos\frac{\alpha}{2}} + \frac{1}{2\sin\frac{\alpha}{2}} \right)$$

with

$$\cos\frac{\alpha}{2} = 0.766$$
$$\sin\frac{\alpha}{2} = 0.643$$
$$t = 50.25 \text{ kilogs.}$$

which for each thread equals

$$\frac{50.25}{7} = 7.2 \text{ kilogs.}$$

It will be seen from the foregoing that the tension for each thread proportionately increases with the increase in diameter of the tire. But in all cases the coefficient of security remains superior to 8.

This high coefficient of security shows that a tire cannot burst under normal conditions through an additional excess of pressure.

The tensions of the canvas being always proportional to the internal pressure, it can be seen even in the most unfavorable case, viz: that a 135 m.m. tire, that it would be necessary to raise the internal pressure to 56 kilos. to arrive at a tearing point of the canvas. In practice the tire will probably burst before this limit is reached, owing largely to the inevitable imperfections of manufacture due to the unequal tension of the canvas.

But the fact remains, however, that practical tests that have been carried out by the simple means of increasing the internal pressure in order to burst a tire have been without result; in nearly all cases the rims become deformed, allowing the beads of the tire

to fly out before the tire shows signs of weakness.

If a tire is old and the canvas has been subjected to the action of the humidity to a point of becoming rotten (which is a state that exists more often than one would think, for although the tire looks to be in good condition) a burst can very easily take place.

Action of the Temperature.

It is interesting to note the influence of the temperature on the internal pressures in tires. Suppose a tire to be inflated at 0^o to a regular pressure of 10 kilogs. During the course of the day, under the simultaneous action of the sun and especially the speed and weight of the car, the imprisoned air can attain a temperature of 80^o Centigrade, consequently producing an increase of pressure.

The pressure p attained at this moment will equal

$$p = p^o\ (1 + \alpha t)$$

that is to say $p = p^o\ (1 + \frac{80}{273})$

$$= p^o \times 1.3 \text{ about}$$

The pressure will only rise in the third of the primary value. The proportional increase of the tension and the canvas for a tire in good condition is

more or less a negligible quantity.

Further, when one talks of the causes of the deterioration of tires it will be seen that the action of the heat on the rubber is more important than on the internal pressure.

Action of Weight on Tension of Canvas.

All that has previously been stated refers to tires simply inflated and not carrying any weight.

There is nothing to be modified in the conclusions drawn is one only passes to a practical case where the tire rests upon the ground and carries a weight P (It will be remembered that we are only interested at the moment in static efforts - that is to say, the case where the tire is stationary.

Under influence of the charge the tire will flatten out until the force exerted by the internal pressure on the surface of contact equilibrates the weight supported.

Allowing for the stiffness of the canvass it can be seen that we will have the equation

$$ps = P$$

calling s the surface of contact of the tread with the ground and measured in square centimeters.

This contact area is not in the form of a

well-defined geometrical form. It can be likened to an ellipse, the greater axis of which lies in the lateral plane of the wheel. This ellipse will be proportionately lengthened according to the narrowness of the tire and the increase in diameter of the wheel.

It can be seen that the work necessary for the propulsion of the car is dependent on the form of this surface, and is greater according to the relation of the large and smaller axis being smaller.

The flattening of the tire produces a depression on the interior of the casing and the volume thereof diminishes slightly, due to this flattening. The increase in pressure is quite insignificant and need not be considered. The point which must be borne in mind, however, is the change in the form of the meridian section of the tire at the point of contact with the ground. Fig. 7 shows in an exaggerated form what takes place.

If the tire were very narrow or, on the other hand, formed of a single layer of canvass this deformation would not be of great importance. But as the various layers of canvass present a considerable thickness, it follows that to pass from the normal form to the form represented in Fig. 7, the layers of can-

vaswill slide on one another. This displacement is possible owing to the layer of rubber compound interposed between each layer; the rubber stretches at the points extended and contracts at the others, permitting a small relative displacement.

It is clear that this sliding should be as small as possible; the tensions that are developed between the layers of canvas and their coating of rubber develop values proportionately greater as the displacement increases, tensions which could in time cause the rubber to become detached from the canvas.

On the other hand, on account of the hystersis that accompanies all physical phenomena, in the present case the deformations of the rubber, during the movements of the revolutions of wheel successive deformations of the diverse sections are accompanied with a considerable production of heat.

In a large measure it is due to this that a tire that is insufficiently inflated bursts more than the same tire submitted to the same change, but inflated to a greater degree. Another cause of heating lies in the friction of the tire with the ground.

Method of Attachment.

The tire is held in position in the rim by the pressure of the air on the beads.

It is interesting to form an idea of the greatness of the force that holds the tire in position. The tire in the vicinity of the sides of the bead is submitted to the action of two forces: the one ϕ (superficial tension) tends to draw the bead outward, the other F (arising from the internal pressure) has on the contrary action of forcing the bead into the base of the rim (Fig.6).

On account of the form of this latter, it is possible for the bead to turn toward the point A (allowing for the resistance of the canvas). Then the force ϕ is applied at the middle of the thickness e of the tire at this point. Its moment in relation to the fixed point A is equivalent to

$$\frac{\phi \times e}{2}.$$

The force F is applied at the middle of the interior width of the bead. It is normally at the surface. Its moment in relation to A is

$$\frac{Fl}{2}$$

In order that the bead should be maintained in position, one must have

$$Fl > \phi e$$

For the unity of the length of the tire the force F is equal to: pxl.

The force ϕ is the maximum meridian section tension of the tire. It is expressed by

$$Tm = \frac{Rr}{R - r}$$

From which

$$pl^2 > pe\frac{Rr}{R-R}$$

The resultant couple, which we will call the couple of security, will be equal to the difference of the components.

$$C = \frac{p}{2}\left\{ l^2 - e\frac{Rr}{R - r}\right\}$$

It should be positive and have as large a value as possible.

Let us calculate this value for current dimensions of tires (90,120,135)

The value of C can be written

$$C = \frac{p}{2}\left(l^2 - e\frac{R}{\frac{R}{r} - 1}\right)$$

From the foregoing it becomes at once apparent that C will be proportionally smaller as $\frac{R}{r}$ decreases in size.

The values of $\frac{R}{r}$ are given in the table earlier in the writing.

The minimum values are:

7	for	tires	700 x 90
6	"	"	820 x 120
5.5	"	"	895 x 135

It will be remembered that for each section

$\frac{R}{r}$ is proportionately smaller as the size of the wheel is smaller.

The corresponding value of $\frac{R}{\frac{R}{r}-1}$ are respectively 3.5 6.3 8.5.

The thickness e is approximately equal to 1 m.m. per layer of canvas as:

6 m.m. for a tire of 90 m.m. section.

8 " " " " " 120 " "

9 " " " " " 135 " "

But for a 90 m.m. section tire the width of the bead is about 23 m.m.

From which for C

$$C = \frac{p}{2}\left\{ 2.3^2 - 0.6 \times 3.5 \right\}$$

$$= p \times 1.6$$

8 kilo-centimeter per centimeter.

It is necessary, therefore, that the width of the beads increase with the tire width.

To obtain a like value for C with the tire 895 x 135 (taking into consideration the internal pressure) it is necessary to make the beads 33 m.m. wide.

Effect of Speed on Tire Wear.

The destructive effect on tires increases rapidly with the speed, because of the increased shock, slipping and braking streeses at high speed.

The Power Consumption of Tires.

In considering the power consumption of automobile tires, the electric automobile has entered so largely into the tests and researches on the subject.

The weather conditions have a considerable effect on power consumption of tires. On a warm day when the asphalt is hot and dry, pneumatic tires, especially if they are not inflated very hard, seem to cling to the road's surface, and certainly cause more power to be consumed. If the surface is wet the power consumption immediately becomes less. If the surface is not only wet but oily or greasy, it is smaller yet. The reason for this is that there is considerable motion between the tire and the road surface, not so much a direct rotary motion, which is of course, slippage, but a crosswise motion, due to the flattening of the tire as the wheel rotates and the load comes upon it. When the road surface is wet or greasy the frictional surfaces are lubricated, and, of course, the motion takes place with less friction and power loss. The surface which a tire presents to the ground when it is not loaded is shown in Fig.1. Fig. 2 shows the surface the tire presents when it is sustaining the weight of the vehicle and load, and is

properly inflated. These contours can be obtained by painting a portion of the tread of the tire and while the paint is still fresh turning the wheel until its full weight rests on a sheet of paper suitable for recording the impression.

Rubber tires are popularly supposed to be used on automobiles for three purposes:

First, for providing a resilient cushion supplementary to the springs between the ground and the car to relieve the passengers and the mechanism of jar and vibration, and to reduce noise.

Second, to prevent the wheels from skidding and slipping on the road surface.

Third, to reduce road friction and make the car run easier.

Method Procedure.

The following data is the result of four two hour runs which were made on a 36" x 3 1/2" Republic Plain Automobile Tire. At the end of the first reading of the fifth run the tire burst and as no other tires were available, it was decided to stop with the small amount of data which had been obtained.

It is therefore impossible to draw any conclusion from the results obtained.

A few bumps were allowed to pass between the pulley and the tire. This, however, was not done for any experimental purpose as this was beyond the scope of our thesis. As a matter of interest, however, we include two diagrams which were recorded as an inch block of pine was allowed to pass through.

Conclusion.

From the summary log it can be seen that the horse power loss through resilience is very great compared with the horse power input. These losses are respectively: 63%, 39.5%, 39%, 62.5%, showing that for heavy loads the percentage loss is smaller than for lighter loads. These losses are probably somewhat high, in our case, as it was very difficult to maintain constant conditions at the absorption brake due to water-hammer in the line.

The slippage, as might be expected, increases with the load, although the result of the second run looks very doubtful.

The tire which was a Republican 36" x 3 1/2" did not stand up well. This is probably due to the fact that it has been allowed to stand in the engine room, for a year, or more, where a temperature of from 100° to 120° is maintained almost all the time. The tire gave way without any warning and although it heated up somewhat during the run it did not reach a dangerous temperature.

RUNNING LOG
FOR
CALIBRATION
KENERSON TRANSMISSION DYNAMO

Load on Scales		Load on Gauge	
Up	Down	Up	Down
30.8	675.0	0.0	10.0
73.4	561.0	0.5	9.4
122.2	507.0	1.0	8.9
163.9	482.8	1.5	8.5
203.8	442.4	2.0	7.99
249.7	401.0	2.5	7.45
292.8	379.5	3.0	7.0
327.6	346.0	3.5	6.5
361.8	316.9	4.0	6.0
400.0	293.0	4.5	5.43
430.0	270.8	5.0	4.98
443.0	240.0	5.5	4.4
504.0	223.8	6.08	4.0
542.0	200.0	6.5	3.5
580.0	171.0	7.0	2.98
611.2	139.6	7.5	2.5
641.2	117.2	8.0	2.0
675.2	85.8	8.5	1.5
705.0	58.0	9.0	1.0
731.0	28.0	9.59	.5
750.8	21.0	10.0	0.0

Run # 3.

RUNNING LOG
FOR
CALIBRATION
KENERSON TRANSMISSION DYNAMO.

Load on Scales		Load on Gauge.	
Up	Down	Up	Down
34.0	631.0	0.0	10.0
76.5	543.0	.5	9.37
114.5	590.0	1.0	8.97
153.0	462.0	1.5	8.5
193.0	420.0	2.0	7.91
230.0	396.0	2.5	7.50
273.0	358.5	3.0	6.86
320.0	331.0	3.6	6.50
358.0	305.0	4.0	6.0
390.0	282.0	4.5	5.5
425.0	258.2	5.0	5.0
458.0	231.7	5.5	4.47
503.0	201.0	6.0	4.0
541.5	188.0	6.5	3.49
587.5	160.0	7.0	2.96
607.0	134.0	7.5	2.55
650.0	108.0	8.0	2.04
686.5	79.0	8.5	1.50
719.0	48.0	9.0	0.99
752.2	29.0	9.5	0.54
777.0	20.0	10.0	0.0

Run #2.

RUNNING LOG
FOR
CALIBRATION
KENERSON TRANSMISSION DYNOMO.

Load on Scales		Load on Gauge	
Up	Down	Up	Down
33.0	662.0	0.0	9.95
69.8	568.5	0.5	9.45
114.8	515.6	1.0	8.95
164.0	471.2	1.52	8.5
200.0	431.5	2.0	7.9
232.0	400.0	2.5	7.45
283.6	382.5	3.0	7.05
316.2	341.6	3.57	6.45
356.2	319.1	4.0	6.0
390.8	295.0	4.55	5.5
427.0	268.0	5.05	4.95
462.8	241.8	5.55	4.5
501.3	219.8	6.0	4.0
542.0	190.0	6.5	3.4
580.8	168.0	7.0	2.95
613.0	140.5	7.55	2.55
646.0	111.7	8.0	2.05
681.0	80.0	8.55	1.5
713.8	52.5	9.0	1.01
745.0	25.0	9.5	0.52
780.1	12.0	10.0	0.0

Run #1.

SUMMARY LOG

FOR

CALIBRATION

KENERSON TRANSMISSION DYNAMO

Load on Dyn. Divisions.		Load on Scale in lbs.		Load on Scales Corrected.	
Up	Down	Up	Down	Up	Down
0.0	10.0	32.6	[illegible]	.52	12.46
0.5	9.4	73.2	[illegible]	.84	[illegible]
1.0	8.94	117.2	[illegible]	2.26	10.20
1.51	8.5	160.3	[illegible]	2.56	9.55
2.0	7.93	198.9	421.3	3.22	8.20
2.5	7.45	237.1	399.0	4.5	7.56
3.0	6.97	286.4	376.3	5.44	[illegible]
3.56	6.48	321.8	339.4	6.1	[illegible]
4.0	6.0	358.7	[illegible]	6.88	5.96
4.52	5.49	393.6	[illegible]	7.4	5.52
5.02	4.99	427.0	[illegible]	8.12	5.05
5.52	4.46	464.6	[illegible]	[illegible]	4.56
6.03	4.0	502.8	[illegible]	[illegible]	[illegible]
6.5	3.47	541.8	193.6	[illegible]	[illegible]
7.0	2.97	582.8	165.3	[illegible]	3.17
7.52	2.54	610.4	138.9	11.60	2.62
8.0	2.03	645.7	112.3	12.28	2.14
8.52	1.5	680.9	81.6	13.18	1.55
9.0	1.0	712.6	52.8	13.56	1.00
9.53	0.52	742.7	27.3	14.07	.52
10.0	0.0	772.6	14.3	14.70	.27

AUTOMOBILE TIRE TESTING MACHINE

RUNNING LOG. SIZE OF TIRE 36" × 3½" RUN NO. 1

Time.	R.P.M. Main Shaft	Reading Dyna. Input	I. Revolution Counter	II. Revolution Counter	Load on Scales	R.P.M. Dynamo Shaft	H.P. Input to Tire	H.P. Tractive Load
7:35 P.M.	314	1.00	96780	98341	20.4	327		
:50	321	0.94	94200	94480	"	330		
8:05	324	0.94	91770	[illegible]	"	327		
:20	319	0.94	89215	93590	"	[illegible]		
:35	320	0.91	86880	[illegible]	"	329		
:50	329	0.90	84750	84461	"	330		
9:06	329	0.90	[illegible]	78580	"	329		
:20	329	0.89	79200	68545	"	327		
:35	329	0.89	76760	68697		329	2.95	1.08
55 #/□" Pressure in Tire at Start — 60 #/□" at Stop								

AUTOMOBILE TIRE TESTING MACHINE.

RUNNING LOG. SIZE OF TIRE. 36"×3½" RUN No. 2.

Time.	R.P.M. Main Shaft	Reading Dyno. Input	I. Revolution Counter.	II. Revolution Counter	Load on Scales.	R.P.M. Dynamo Shaft.	H.P. Input to Tire	H.P. Tractive Load.
1:05 P.M.	305	1.60	73580	62300	35#	320		
:20	305	1.60	71250	47690	"	320		
:35	306	1.58	69140	43339	"	320		
:50	307	1.55	66520	38580	"	321		
2:05	306	1.53	64115	33705	"	322		
:20	308	1.50	61600	28815	"	323		
:35	305	1.48	59360	24235	"	320		
:50	306	1.45	56960	19490	"	321		
3:05	308	1.46	54450	14548	"	322	4.50	2.73
55 #/□" Pressure in Tire at Start - 58 #/□" at Finish.								

AUTOMOBILE TIRE TESTING MACHINE.

RUNNING LOG. SIZE OF TIRE. 36" x 3½" RUN No. 3

Time.	R.P.M. Main Shaft.	Reading Dyno. Input	I. Revolution Counter	II. Revolution Counter	Load on Scales.	R.P.M. Dynamo Shaft.	H.P. Input to Tire	H.P. Tractive Load.
3:05 P.M.	306	2.42	54450	914548	50	320		
:20	305	2.40	51870	909401	"	321		
:35	305	2.38	49960	905790	"	320		
:50	306	2.38	47485	900960	"	322		
4:05	306	2.38	45050	896110	"	321		
:20	307	2.38	42595	891430	"	320		
:35	308	2.40	40190	886700	"	321		
:50	306	2.40	37750	881970	"	322		
5:06	307	2.40	35209	877170	"	318	7.26	4.42

58 #/□" Pressure in Tire at Start— 60 #/□" at Finish.

AUTOMOBILE TIRE TESTING MACHINE.

RUNNING LOG. SIZE OF TIRE. $36'' \times 3\frac{1}{2}''$ RUN NO. 4

Time	R.P.M. Main Shaft	Reading Dyna. Input	I. Revolution Counter	II. Revolution Counter	Load on Scales	R.P.M. Dynamo Shaft	H.P. Input to Tire	H.P. Tractive Load
6:15 P.M.	327	0.79	34420	75326	204	320		
:30	327	0.81	31710	71200	"	320		
:45	326	0.81	29270	65130	"	319		
7:00	328	0.81	26750	60000	"	321		
:15	327	0.81	24240	54165		321		
:30	327	0.81	21610	50000	"	321		
:45	326	0.81	19170	44800	"	320		
8:00	327	0.80	16660	39890		320		
:15	328	0.79	14145	34870	"	321	2.85	1.07
60#/□″ Pressure in Tire at Start – 63#/□″ at Finish.								

AUTOMOB[illegible]

TESTIN[illegible]

INFLATION TABLE SHOWING AIR PRESSURE RECOMMENDED BY TIRE MANUFACTURERS

SIZE OF TIRE	AJAX-GRIEB RUBBER CO.	DIAMOND RUBBER COMPANY	EMPIRE TIRE COMPANY		FIRESTONE TIRE AND RUBBER CO.	FISK RUBBER COMPANY	B. F. GOODRICH COMPANY	GOODYEAR TIRE RUBBER CO.	LEE TIRE AND RUBBER CO.	MICHELIN TIRE COMPANY	PENNSYLVANIA RUBBER CO.	PORTAGE RUBBER COMPANY	RACINE RUBBER COMPANY	REPUBLIC RUBBER CO.	SWINEHART TIRE & RUBBER CO.		U. S. TIRE CO.
	LBS.		F	R											F	R	
$2\frac{1}{2}$ in. Tires.		45	46	60			55	50			50		50		40	45	50
3 in. Tires.	60	54	50	60	50	60-65	65	60	60	50-60	60	60	60	50	50	55	60
$3\frac{1}{2}$ in. Tires.	70	63	60	70	60	60-75	70	70	70	60-70	70	70	70	60	60	70	70
4 in. Tires.	80	72	65	75	75	65-80	75	80	75	60-75	80	80	80	70	70	80	80
$4\frac{1}{2}$ in. Tires.	90	81	75	90	85	70-85	80	90	80	70-80	90	90	90	80	80	90	90
5 in. Tires.	100	90	80	100	90	75-85	85	100	90	70-85	100	100	100	85	90	95	100
$5\frac{1}{2}$ in. Tires.	110	99				80-90	90	110	95		100	110	110	90			110
6 in. Tires.		108				85-95		120						100			

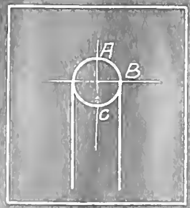

Fig. 1 - Diagram Denoting the Meridian Section of a Tore.

Fig. 2.

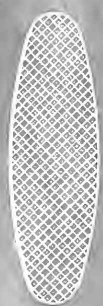

Fig. 3.

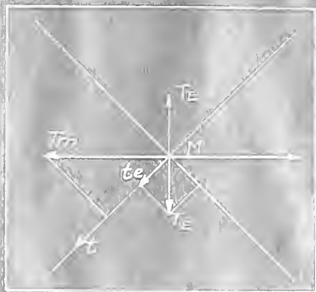

Fig. 4—Diagram Showing the Tension of the threads at a 45° Angle.

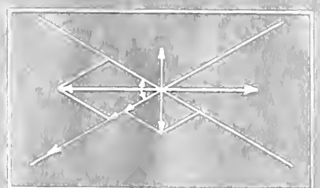

Fig. 5—Diagram Showing the Tension of the threads at a 45° Angle.

Fig. 6 - Showing Forces Acting at Bead of Tire.

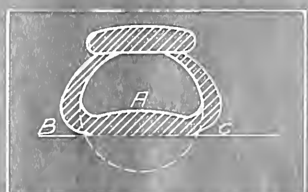

Fig. 7 - Showing Change in Form of Meridion Section of Insufficiently Inflated Tire.

RECORDING [illegible]