PROCEEDINGS OF THE INTERNATIONAL RUBBER CONFERENCE

1972

PROCEEDINGS OF RUBBERCON 72

International Rubber Conference, Brighton, May 1972

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TYRE DEVELOPMENTS – THE CHANGING REQUIREMENTS

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INTRODUCTION

Service return information indicates that the reliability of the pneumatic tyre has improved considerably during the last 15 years. Taking this new level of reliability as a basis and adding to it the more scientific approach which the industry is now adopting, it should be possible to exploit the other dynamic properties of the tyre to meet the more sophisticated requirements of the vehicle industry.

When discussing tyre developments, it is customary to divide the detail into groups which correspond to the main vehicle groupings, but in the space available it is suggested that the concentration be on three main categories. The first being earthmover in view of the interesting technical developments and the high capital expenditure required for the manufacture of these products. The other two categories being car and truck because of the importance by volume to the tyre industry. Perhaps we may review each in turn and attempt to determine any major tyre changes which could be required.

EARTHMOVER

The enormous growth of the earthmoving industry, particularly in the mining areas during the last few years has resulted in the continual development of larger and more efficient earthmoving vehicles. In addition these operations are normally so large and variable in character that they can call for the development of a special tyre to suit the particular operational requirement. The tyre can vary in dimensions, tread compound or casing construction, in other words a "tailor-made" product.

There are two main types of earthmover vehicle, the first associated with the lifting of the material and the second concerned with transportation. The first category is often referred to as the working machine or the loader (Fig. 1). Fortunately the average speed of operation is normally of the order of 5 mile/h but loads are increasing and apart from the normal tyre problems associated with this extra load there are also problems of instability.

To improve the position, developments are proceeding with low section height tyres (65% aspect ratio) and in some cases stability is still further improved by the addition of steel breakers. Although steel breakers may be used this tyre is not normally of radial construction and, therefore, we believe that for the future this section of the earthmoving industry will require tyres incorporating: (i) high load capacity (50 tons); (ii) increased resistance to concussion failure; (iii) cut resistant tread compounds; (iv) low aspect ratio.

The tyre industry is fortunate that in spite of these increased requirements, it should be possible to make this type of tyre with existing equipment.

By using current tyres and size extensions of the same type, it is also possible to deal with the shorter term requirements of the second category of earthmover equipment which is concerned with transport (Fig. 2).

The manufacturers of these machines, however, are developing units which can carry 300 tons for distances up to 20 miles at speeds up to 50 mile/h, so that in addition to the load carrying capacity, concussion and fatigue resistance, etc., we also have the problem of severe heat generation. There is no doubt that in the future this type of tyre will require a radial construction and the tyre industry, therefore, must be prepared to invest considerable sums to provide special production equipment.

Several companies are now responding to this challenge, but an indication of the magnitude of their task can be seen by examining this photograph of only one stage of the manufacturing process (Fig. 3).

For the earthmoving industry to continue with the development of these larger units, it is essential for them to receive supplies of extra large radial earthmover tyres in 1974 and, therefore, the work must be accelerated to meet this most important changing requirement.

TRUCK TYRES

The constant requirement of the trucking industry is that of reduced cost per mile and the tyre industry can help in several ways. Here are four examples: (i) an increase of 20% in tread life can affect the total truck operating margin by 1%; (ii) a reduction of 20% in tyre and wheel assembly weight by permitting an equivalent extra pay load can also improve the operating margins by 1%; (iii) a reduction of tyre rolling resistance of 20% and, therefore, a fuel saving of 5 to 8% can affect the operating margin by ½% but (iv) all of the above advantages can be lost if tyre failure results in the vehicle being off the road for two days in any one year.

There have been changes to tyre constructions, tread compounds, patterns and profiles which have improved tread life during the last 5 years by a greater margin than the 20% quoted above and these developments are still proceeding. The radial ply tyre in its own right effects a considerable improvement in normal operational mileage and this type of construction is gaining in favour, particularly since we can also record a fuel saving of approximately 5% when compared with trucks operating on standard cross ply tyres. Reduced heat generation can also permit higher cruising speeds and the trucker with a normal over-the-road type of operation can effect considerable savings by using a well designed radial ply tyre.

It is fortunate that the radial ply tyre is also well suited to the 15° tubeless type construction which, by elimination of the multi piece wheel, tube and flap, permits an assembly weight saving of 10 to 12% in addition to providing improved brake ventilation.

The latest developments in radial ply truck tyres are concerned with the height to width ratio and it is possible to effect even further weight saving, lower fuel consumption, improved tread life and vehicle stability by using low profile tyres.

The European Council of Ministers in Brussels have called for standardization of European axle loadings which at present fall into two main categories. Some countries, particularly France and Spain, have a maximum axle loading of 13 tons, whilst the U.K., Germany, etc., have a maximum of 10 tons. The compromise maximum axle loading could be of the order of 11 to 11.5 tons and from this and from the points discussed above, it should be possible to determine the most popular tyre size for the future total European community.

We believe this size will be 12/70-R-22.5: 12 in section to carry the standard load; 70% height to width ratio (perhaps 65) to give the benefits of low profile; R for radial and 22.5 in wheels for the weight saving of the tubeless tyre.

With improved road conditions and higher rates of pay for truck drivers, the transport industry is looking for higher speeds of operation and, therefore, engine horsepowers are increasing rapidly. This extra power must be transmitted through the driving wheels to the road and during the next few years this could call for the development of special tyres with the ability to transmit high torque and yet offer increased resistance to tractional wear. It is unfortunate that the type of tyre required for these driving wheels is normally unsuitable for the front axle and, therefore, special patterns must be developed to meet the varying requirements of the axles on any truck or truck/trailer combination. Freedom from irregular wear will obviously be of paramount importance, since it will be difficult to interchange tyres between axles to reduce this tendency.

Retreading of truck tyres is an important part of the overall economics and, therefore, improved casing durability must be a target and perhaps the most logical axle position for the remoulded casing is that of the freely rolling axle on the trailer unit.

To summarize the truck position, the changing requirements indicate the following features: (i) greater standardization of tyre sizes and load ratings; (ii) low profile; (iii) tubeless construction on 15° Drop Centre Wheels; (iv) radial ply tyres with high remould potential and tread patterns suited to particular axle positions.

CAR

Market surveys together with discussions with motoring organizations and vehicle manufacturers have resulted in a list of requirements for the motorist of the 70's. These requirements fall under four main headings – safety, economy, comfort and convenience.

Safety

A vital part of tyre safety concerns grip, not only when the road surface is dry but also when wet. Tyre development has been directed towards improving this grip in both the lateral and longitudinal direction and also aimed at reducing the difference between the wet and dry condition.

As a result of the advances made during the last 15 years it is now becoming extremely difficult to gain further improvements in cornering grip by changes in tyre technology, but since vehicle controllability is dependent upon the grip between tyre and the road, the tyre engineers are now turning to the examination of road surfaces. During the last two years they have developed, patented and even arranged for the construction of new types of road. Fig. 4 shows the difference between a normal polished road surface and one developed to extract the maximum from modern tyre technology.

To meet the changing requirements of the car tyre user, we expect to see intensive cooperation between the road and tyre engineer and by closer cooperation, it should be possible not only to improve tyre safety but also to improve tyre life and vehicle ride.

Economics

To the tyre user this means a combination of initial price and tread life. In this world of discounts, etc., the initial price is not always a technical subject but tread life certainly is. The accurate measurement of tread life is a precise art and must involve very accurate control of testing which normally means tests in convoy and the statistical analysis of many field results. The issue is further complicated by the constant drive by car manufacturers to enhance vehicle performance, but in the U.K. there is at least one vehicle where the basic model has remained virtually unchanged during the last 12 years. Fig. 5 indicates first of all the performance of the standard cross ply original equipment over this period and you will observe the gradual lift which is believed to be due to improved road conditions and, it is hoped, to improvements in tyre technology. On this particular model there is a further 80% improvement by fitting a radial tyre, and a still further improvement by changing to a 70 series low profile radial. It should be noted that this particular set of figures are based on the use of radial ply tyres with a similar outside diameter and although the mileage improvement will be reduced if the full load carrying capacity of the radial is used, there is no doubt the improvement will still be significant.

We have already mentioned the anticipated move to low profile tyres for trucks and this change will be even more marked in the car industry. The selection of the low profile tyre not only improves mileage but also improves stability and can permit the use of a wheel with a larger internal diameter, thereby permitting larger brakes. It is believed that this trend is inevitable since apart from the engineering advantages, the car stylist prefers the appearance of the low wide tyre which enhances the overall appearance of the modern car.

This requirement by the vehicle industry for the low profile tyre and the more extensive use of motorways will change the wear pattern in the contact patch.

In the past many papers have been presented, indicating that tyre wear is proportional to a power lying between 4 and 9 of the cornering speed and technologists have been concentrating on improving the resistance to cornering wear. The gradual changes expected during the 1970's, however, will result in a different type of uneven tread wear and the tyre technologists must now pay more attention to movement in the longitudinal direction. Another changing requirement.

Comfort
Completely new comfort standards are being called for by the vehicle designer and he is looking for further improvements in ride and tyre uniformity.

The ride of any given vehicle is normally the result of technical cooperation between the vehicle and tyre designers, and with the use of the sophisticated facilities including rolling rigs and electronic analytical techniques, it is possible to bring about individual improvements.

It is the question of tyre uniformity which is proving to be the more difficult and vast sums of money are being spent by the tyre industry, not only to improve the general level but where necessary to measure and correct the tyre. Different companies are measuring different characteristics, some listen for tyre thump, others measure eccentricity, some measure conicity, but the majority have decided to measure force variation, particularly those subjected to pressure from the vehicle manufacturers. The machines for measuring and correcting are extremely expensive (Fig. 6) and there is a belief amongst the tyre company executives that the money should be directed towards improving the standard of the product during manufacture.

This statement is very logical, the only problem being that even with expensive quality control and in-process inspection it is difficult to manufacture consistently uniform products with many separate components being assembled on a circular drum. Useful improvements have, however, been recorded following the application of such analytical techniques as the study of moment probability and Fig. 7 indicates the production improvement during the last 18 months for a 165-13 radial ply tyre.

The demand by the vehicle engineer for improved tyre uniformity is a paramount requirement, and it would be useful if we could eliminate the need for these internal tyre components. Whilst the next paper indicates the progress of the fabricless tyre, work in this country has indicated that the uniformity of fabricless tyres is excellent. There are, however, several other dynamic problems which have still to be resolved.

Convenience
Although the tyre industry can be proud of the improvements made, particularly during the last 15 years, the pneumatic tyre when deflated is a most unsatisfactory device. Even if the motorist can bring the vehicle to rest without an accident, he is then completely immobile. Improvements in tyre design and material technology have reduced the number of stoppages due to structural failure, but we are still left with tyres which can suffer damage from external objects. The frequency of such punctures is decreasing but can still be highly inconvenient.

Table of basic puncture statistics in U.K.

Average interval between punctures	2 years 4 months (16 800 miles)
High mileage motorists (15 000+ miles per year)	puncture each 17 months

Over 50% said a puncture was a "major nuisance".

Since the spare wheel is difficult to house in the modern low car, the vehicle designer has been pressing for at least a modification to this unit and, therefore, the tyre industry have been developing certain "get you home" devices which have consisted of a very compact system which can be used in place of the failed tyre and wheel for a limited mileage. There is still the problem, however, of storing the damaged unit and the even greater problem of changing the wheel.

Several surveys produced the following conclusions: 40% of punctures are noticed when the car is in motion; 35% of punctures occur in the hours of darkness; more than 75% of women drivers cannot change a wheel; most punctures are caused by nails (pressure at the end of a nail can be several thousand lb/in^2); more than 25% of spare wheels are unsafe or unserviceable. These conclusions have resulted in a change of direction in the spare wheel development and it was decided to include the "get you home" principle in the four existing tyres and wheels. A principle has been developed which not only permits the driver to reach a service centre but considerably reduces the danger associated with sudden deflation and also avoids the necessity of changing the wheel which can be a dangerous procedure on a modern highway.

For the time being this unit is called the Total Mobility tyre and here is a comparison of the main features with those of a normal tyre and wheel unit:

Detailed performance of tyres

	Current Tyre	New "Total Mobility" Tyre
Distance	1 - 1.5 miles	Up to 100 miles
Speed	5 miles/h	Up to 50 miles/h
Driving	Very difficult Tyre destroyed	Driving safe and easy Tyres normally re-usable.

This new concept is centred on a low profile 60 series tyre and wheel and when inflated the properties are very similar to those of the normal unit. When deflated, however, the vehicle can maintain mobility for a limited distance with a high degree of controllability.

When a normal tyre deflates the beads drop into the rim well, this not only permits any residual air to escape but also produces instability and sometimes the separation of the tyre and wheel since the tyre can now be pulled over the flange. With the Total Mobility tyre, there are two types of wheel under consideration: in one the well has been eliminated and in the other, there are mechanical devices to prevent the bead moving into the well.

For simplicity let us examine the tyre and wheel unit where the well has been eliminated. The dimensions of the tread, sectional height and rim width have been adjusted to ensure that the system automatically adjusts so that the rim remains central to the contact patch (Fig. 8).

The rim profile has also been modified to provide a support for the load which is now carried by two columns composed of the breaker edge, filler region and rim flange. Under these conditions it is possible for the vehicle to continue running except that there would be considerable friction generated in the contact area between the tread and filler regions. To reduce this friction and also to provide some cooling a lubricant has been included (Fig. 9). This lubricant also incorporates a sealant which is effective for penetrating objects not exceeding 0.25 in in diameter (it is believed that 95% of penetrations fall into this category) and when sealed the lubricant also generates a slight re-inflation pressure of approximately 4 lb/in^2 which considerably reduces the tyre stresses.

Even when the tyre has suffered major damage such as the removal of a large section of the sidewall, it is possible to continue for some 10 to 20 miles, furthermore since the tyre beads cannot fall into the well, the tendency towards a violent change of direction which is sometimes caused by rapid deflation is considerably reduced.

The ability to retain some control even at zero pressure can be explained by examining Fig. 10 which shows the cornering force for the Total Mobility tyre at varying pressures. Only below 5 lb/in^2 is the cornering power seriously affected and whilst the cornering power at very low slip angles at zero pressure is reduced, it is still possible to provide some 40% of the normal when operating between 6 and 10°.

During the last 4 years many hundreds of tyres have been tested and it has been possible to run with a deflated tyre for 100 miles at 50 miles/h.

The work continues and it is expected that certain vehicles will be using this type of tyre and wheel, since many vehicle engineers consider this to be a major contribution towards greater safety and customer convenience.

SUMMARY AND ACKNOWLEDGMENT

An attempt has been made to indicate how the tyre industry will try to meet the requirements of the customer in at least three categories of tyre – earthmover, truck and car, and in order to meet these requirements there have been many surveys, technical discussions and much crystal ball gazing. It is encouraging to find that even after these comprehensive analyses it is concluded that the pneumatic tyre will be required for at least the next two decades. So far no other device has been envisaged which can combine the properties of a load carrying member which can also give a degree of comfort, stability and grip.

It is also encouraging to see that the tyre industry is responding to these requirements and is now adopting a more scientific approach to its problems.

I would like to thank my colleagues who are contributing to this greater understanding and whose work I have been reporting.

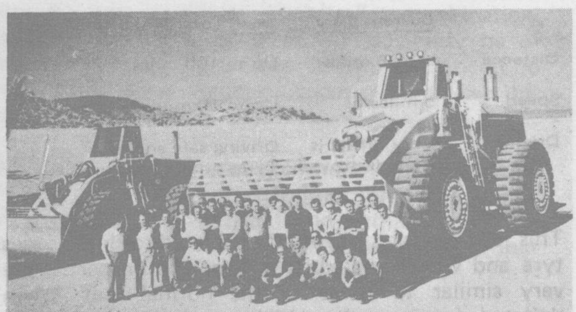

Fig. 1. Earthmoving machine – shovel loader.

Fig. 2. Earthmoving machine – rear dump truck.

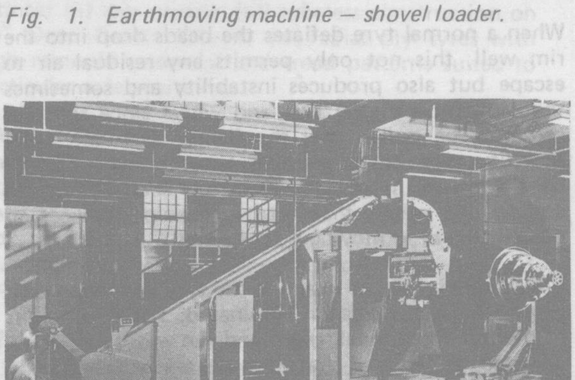

Fig. 3.

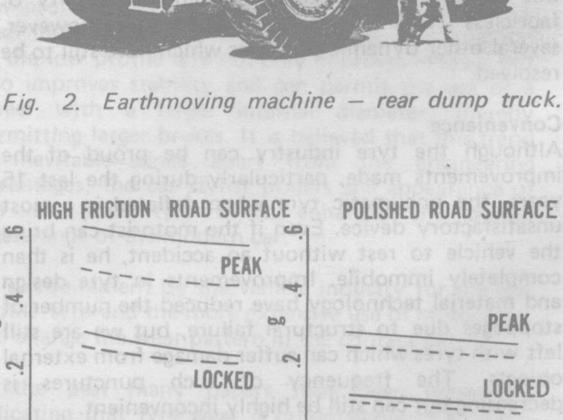

Fig. 4. Influence of road surface on wet grip.

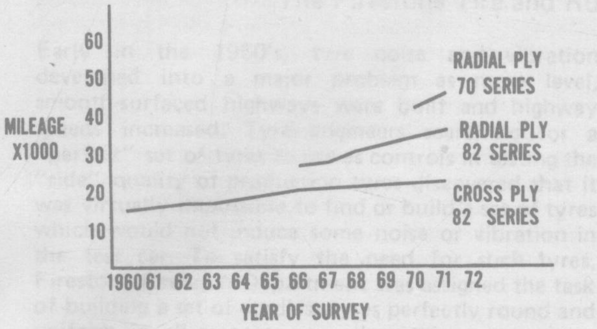

Fig. 5. Tyre tread life — U.K. national averages.

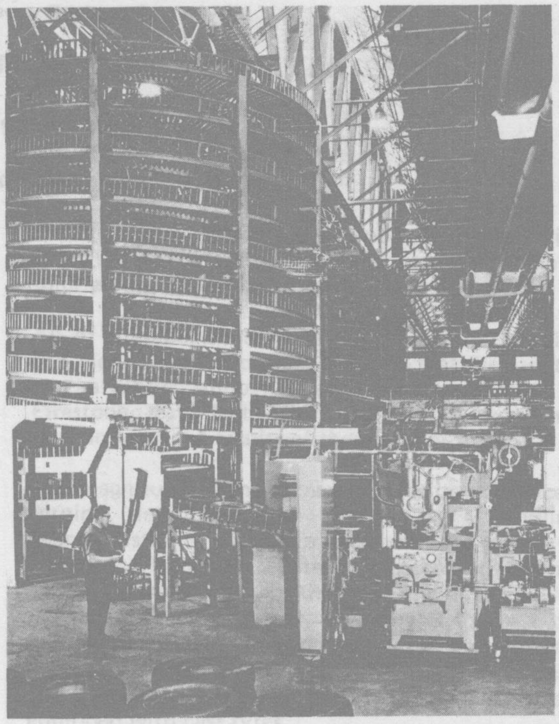

Fig. 6.

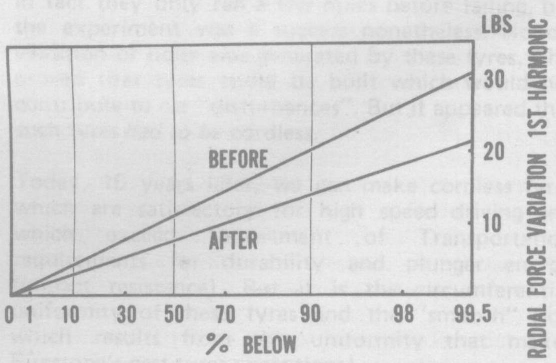

Fig. 7. Improved moment probability distribution.

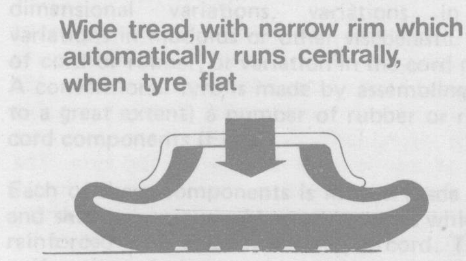

Fig. 8.

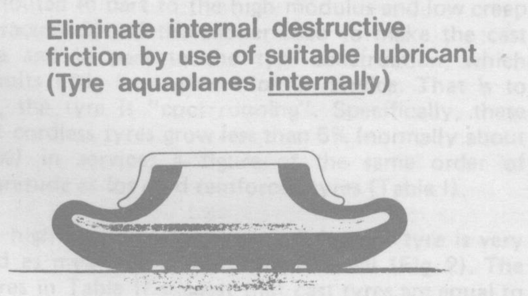

Fig. 9.

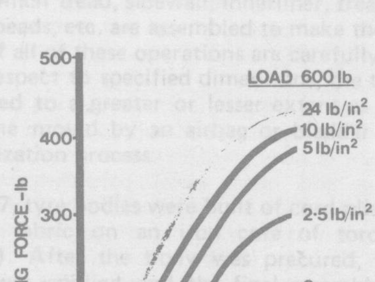

Fig. 10. Total mobility tyre 185/60-13.

THE CORDLESS TYRE – ITS PERFORMANCE AND MARKET POTENTIAL

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Early in the 1950's, tyre noise and vibration developed into a major problem as more level, smooth-surfaced highways were built and highway speeds increased. Tyre engineers searching for a "perfect" set of tyres to use as controls in testing the "ride" quality of production tyres discovered that it was virtually impossible to find or build a set of tyres which would not induce some noise or vibration in the test car. To satisfy the need for such tyres, Firestone Research Department was assigned the task of building a set of cordless tyres perfectly round and uniform in all respects as well as strong enough to hold their shape during a ride test. This was about 15 years ago.

First attempts at building a cordless tyre involved the careful filling of a mould with a liquid rubber and heating to cure it. The first tyres so made were defective because of trapped air, but eventually four tyres free from defects of any kind were successfully cast and tested on a car. They were not very durable, in fact they only ran a few miles before failing, but the experiment was a success nonetheless. No car vibration or noise was generated by these tyres. This proved that tyres could be built which would not contribute to car "disturbances". But it appeared that such tyres *had to be* cordless.

Today, 15 years later, we can make cordless tyres which are satisfactory for high speed driving and which exceed Department of Transportation requirements for durability and plunger energy (impact resistance). But it is the circumferential uniformity of these tyres and the "smooth" ride which results from this uniformity that makes Firestone's cast tyres exceptional.

The Firestone cast tyre is conventional in shape and appearance. Cast tyres deflect somewhat less than conventional tyres under a given load (Fig. 1); therefore, inflation pressures can be reduced to obtain equal deflection, if desired. Inflation or service growth of the cast tyre is small considering its cordless construction. The low growth may be attributed in part to the high modulus and low creep characteristics of the rubber used to make the cast tyre and in part to the tyre construction, which permits little heat generation in service. That is to say, the tyre is "cool running". Specifically, these cast cordless tyres grow less than 5% (normally about 3-4%) in service, a figure of the same order of magnitude as for cord reinforced tyres (Table I).

The high speed performance of the cast tyre is very good as measured on an indoor wheel (Fig. 2). The figures in Table II suggest that cast tyres are equal to bias cord tyres for high speed performance and are perhaps better than most radial tyres in this respect.

The durability of cast tyres is excellent and exceeds Department of Transportation requirements by a considerable margin (Tables III and IV). The plunger energy (a measure of a tyre's ability to resist the impact of running over sharp objects or projections from the road's surface) of cast tyres is excellent in spite of the absence of cord reinforcement (Table V).

All of the above indoor tests of strength, durability and high speed performance suggest that the cast tyre is a safe tyre. Almost two million tyre miles on the Firestone test fleet at Ft Stockton, Texas, have substantiated the results of these indoor tests.

The magnitude of the cornering force or resistance to turning determines the steering or "handling" characteristics of a car. Up to a point the greater the cornering force the better. Also,cornering force should increase evenly as the cornering or slip angle is increased. As can be seen from Fig. 3 the cast tyre compares well in this respect with conventional, cord-reinforced tyres. Numerous ride tests have confirmed the "handling" and steering quality of cars equipped with cast tyres.

The "ride" quality of tyres is difficult to define. It is desirable that a tyre should not induce vibrations in the car. Any irregularity in the tyre will induce such vibrations. Irregularities may be the result of dimensional variations, variations in density, variations in modulus or other viscoelastic properties of cord or rubber, or variation in the cord placement. A conventional tyre is made by assembling (by hand to a great extent) a number of rubber or rubber and cord components (Fig. 4).

Each of these components is in turn made by mixing and shaping various rubber compounds which may be reinforced with steel wire or tyre cord. The overall uniformity of the tyre depends upon the precision with which the dimensions of these various components are controlled. It also depends upon the precision of cord placement in the calendered body and tread plies. Finally, it depends upon the precision with which tread, sidewall, innerliner, tread and body plies, beads, etc. are assembled to make the final tyre. Even if all of these operations are carefully controlled with respect to specified dimensions, the tyre may be distorted to a greater or lesser extent as it is forced into the mould by an airbag or bladder during the vulcanization process.

In 1917, tyre bodies were built of cord plies or square woven fabric on an iron core of toroidal shape (Fig. 5). After the body was precured, a precured tread was applied and the final assembly then was wrapped with fabric and cured in an autoclave. In the 1920's and 1930's tyres were built on drums (Fig. 6) and shaped first on airbags having a toroidal shape and then in moulds which were then heated in vertical autoclaves called "pot heaters" to complete the shaping and to vulcanize the tyres (Fig. 7). Later automatic curing presses were introduced which shape and cure the tyre in one operation (Fig. 8).

It is evident that modern tyres have a very complex construction whether of bias construction (Fig. 9), bias belted (Fig. 10) or radial (Fig. 11).

Compared with these conventional constructions, the cast tyre is extremely simple. We have built and tested tyres of various shapes and designs (Fig. 12). As the colour suggests, the rubber used in these tyres need not be reinforced with black although it can be if extra strength, stiffness or abrasion resistance is required.

It has been obvious to tyre industry scientists and technologists for years that if one could make a cordless tyre by converting a liquid into a solid rubber product of the desired shape, such a process would eliminate most of the fabrication problems mentioned above and result in a homogeneous product having the precise shape it was designed to have. A tyre so made would be uniform, rounder and, therefore, generate fewer vibrations in the car.

There are many ways of measuring tyre uniformity. Radial runout measures how far the tyre departs from perfect roundness. Balance measurements indicate whether there is a uniform distribution of weight throughout the tyre. Perhaps the most used uniformity parameter is radial or lateral force variation measured by so called tyre uniformity grading (TUG) machines. The TUG values for cast tyres are much lower than the minimum values currently required by major automobile manufacturers (Table VI), which suggests the advantage of cast tyres over today's cord reinforced tyre with respect to uniformity.

The greater uniformity of the cast tyre is illustrated most dramatically by Figs 13 and 14. These pictures are holograms. That of the bias-belted tyre (Fig. 13) has wavy irregular circumferential lines of variable width. The irregularity of these lines indicates variability of one kind or another in the tyre. The variability may be dimensional or it may reflect a variation in dynamic stiffness about the tyre. In any case the variation is attributable in the main directly or indirectly to the cord body and/or to the fact that any conventional tyre is built by putting together various components, in part by hand.

The hologram of the cast tyre is made up of evenly-spaced circumferential lines and the overall appearance is one of roundness and a minimum of irregularity (Fig. 14).

The real payoff, of course, is the actual ride test. The "ride" quality of tyres is difficult to define because the evaluation is purely subjective and sensitivity to car vibration and noise varies considerably from person to person. Tyre and automobile engineers have ears carefully tuned to noises generated by tyres and their bodies can pick up the slightest bit of "shake" or "roughness" (to use two of the several terms which automotive engineers employ for tyre-induced disturbances in a moving car).

"Shake" is a vibration which can be felt or heard and which is most objectionable at certain critical speeds, generally at about 60-65 miles/hour. A more general type of tyre-induced vibration just gets steadily worse as the speed of the car increases. Both phenomena are referred to by the tyre or autotive engineer as "roughness" or "roughness of ride". Almost any set of cord reinforced tyres will cause some roughness as pointed out earlier in this article, although for good quality cord tyres roughness will be at a minimum.

The average person may not be as sensitive to noise and vibration as the tyre engineer but anyone driving long distances will be affected consciously or unconsciously. In our society noise and vibration of various mechanical devices disturb us, cause nervousness and fatigue, and add greatly to the discomfort of modern life. The cordless tyre has a real contribution to make in reducing discomfort on the highway.

Another factor in ride is the ability of the tyre to cushion the car and rider from the shock of driving over rough pavement or such irregularities as pavement joints. In this respect the cast tyre resembles a radial tyre more than one of bias construction in that the maximum spindle acceleration occurs at lower frequencies than in the case of a tyre having a bias cord construction (Fig. 15). Again ride tests confirm this.

As a witness to what such tyres can do here are quotes from several unbiased observers, members of the working press, men not easily impressed:

"No cord plies, no cuts, no splices! This tire gives great ride and strong side bite. I found the ride similar to that of radial ply tires, except for noticeably softer taking of bumps at slow speeds – they do not act as harsh as most radials." This is a quotation from an article in *Popular Science* by Jim Dunne, Editor, who took a ride on our cast tyres

"The most phenomenal aspect of the Firestone cast tire – is its inherent uniformity. Twenty-two miles at Turnpike speeds above 80 miles/h and not a squiggle or a shake. History in the making." wrote Stephen LeFerre, Managing Editor, *Modern Tire Dealer* who also had ridden cast tyres, as had Joseph M. Callahan, Editor of *Automotive Industries* who said, "Possibly the most important tire development in the tire industry's history – the cordless tire".

It would be premature to predict when the cast tyre will be put on the market. But the need of an answer to the problem of tyre uniformity in the tyre industry dictates the necessity of developing it into a commercial product. The most critical technical problems of designing a cast tyre have been overcome but much remains to be done. Wear and traction must be improved. Automation of the production of the cast tyre must be accomplished in order to achieve the economy and process control necessary to turn out a quality product at a price which the customer will find attractive.