FRICTION OF PNEUMATIC RUBBER TYRES ON SAND

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The paper describes an apparatus for determining the rolling friction of pneumatic rubber tyres on sandy surfaces at different loads for different inflation pressures. The coefficient of friction is dependent on the size and shape of the tyre. The results refer only to measurements at a very low speed. Tyres having a flat tread and low inflation pressure are preferred on sand.

Crossing of loose sandy terrains and dried up river beds[1] presents a major problem for wheeled vehicles. Bogging of an army vehicle in times of emergency is a source of great loss and an inconvenience. During Second World War, in Germany, about one hundred vehicles were bogged down at an instant. Casualties would have been halved and also this operation would have been shortened by three weeks if vehicles had been designed so as to meet this situation effectively. The disadvantages and grave consequences of nature were encountered on other occasions as well. This problem assumes special significance in our country owing to a vast sandy terrain. For designing vehicles suitable for traction on such ground, detailed study of rolling "friction" between pneumatic rubber tyres and sandy surfaces is very important. This data is scarce. McKibben and Davidson[2,3] have determined the rolling resistance of various types of rubber wheels for typical roads and field conditions but data do not cover the type of terrain encountered in desert areas. A knowledge of the coefficient of friction will be useful in estimating (*i*) the power required by a vehicle for traction on sandy surfaces, (*ii*) the life of the tyres and (*iii*) predicting roads/surfaces suitable for moving traffic in desert areas. This data can also be correlated with the field behaviour of rubber tyres of 'B' type vehicles at different seasons of the year. As this knowledge will be very useful for Defence purposes, research work under controlled conditions was carried out at Defence Laboratory, Jodhpur.

EXPERIMENTAL PROCEDURE

An apparatus for determining rolling resistance of pneumatic rubber tyres on sandy surfaces was designed and fabricated locally. The apparatus (Fig. 1) consists of a circular disc (dia. 3 ft. 8 in.) having a channel (8 in. inside and 6 in. deep) of M.S. plate ($\frac{1}{8}$ in. thick). Four rollers (1 in. dia. each) were attached to the bottom of the circular disc which was made to rest on an M.S. table. A shaft (3 ft. long and $2\frac{1}{4}$ in. dia.) passed vertically through the centre of the circular disc and rested on foot step ball bearing. A double wall ball bearing was fixed in the centre of the M.S. table through which the shaft passed. The circular disc was fixed with two nuts with the shaft. A triangular frame made of M.S. channels was attached to another M.S. channel which was fixed at one corner of the M.S. table. At the right angle side of the triangular frame, a fine threaded shaft ($1\frac{1}{2}$ in. dia. $1\frac{1}{2}$ ft. long) was attached to it. The centres of the lower shafts and the upper one were in the same vertical line. The upper shaft also contains a foot step ball bearing at the lower end and a thrust ball bearing at the top. A T-shaped arm 'L' was hinged with the upper shaft so that it could be raised or lowered during the experiment. The hinge was like a knuckle joint as there was provision to allow the arm to swing horizontally through a small angle. The wheel supported the arm at a point 18 in. from the centre of the hinge and a hook was provided 27 in. farther out on the arm for carrying a swing pan 'S_1'. Thus a 20 kg. weight on the pan 'S_1' produced a load of 50 kg. on the wheel. The weight of loading arm plus the weight of the pan 'S_1' and the weight put on the pan multiplied by $2\frac{1}{2}$ times was taken as the load 'W' on the wheel. The wheel could be loaded to various capacities by putting different weights in the pan 'S_1'. The level of the loading arm 'L' could be lowered or raised with the help of a handle 'H' rotating the shaft 'S'. The circular disc was rotated with the help of a 5 h.p. electric motor coupled with a reduction gear of ratio 10 : 1 which reduced the revolution to 96 per minute. The speed was further reduced by changing the ratio of the diameters of the pulleys 'P_1' and 'P_2'. Thus various speeds were obtained by simply changing the pulley 'P_2'. The frame 'F' and a chord 'C' were attached to the wheel. The other end of the chord was attached to another swing pan 'S_2'. The track was filled

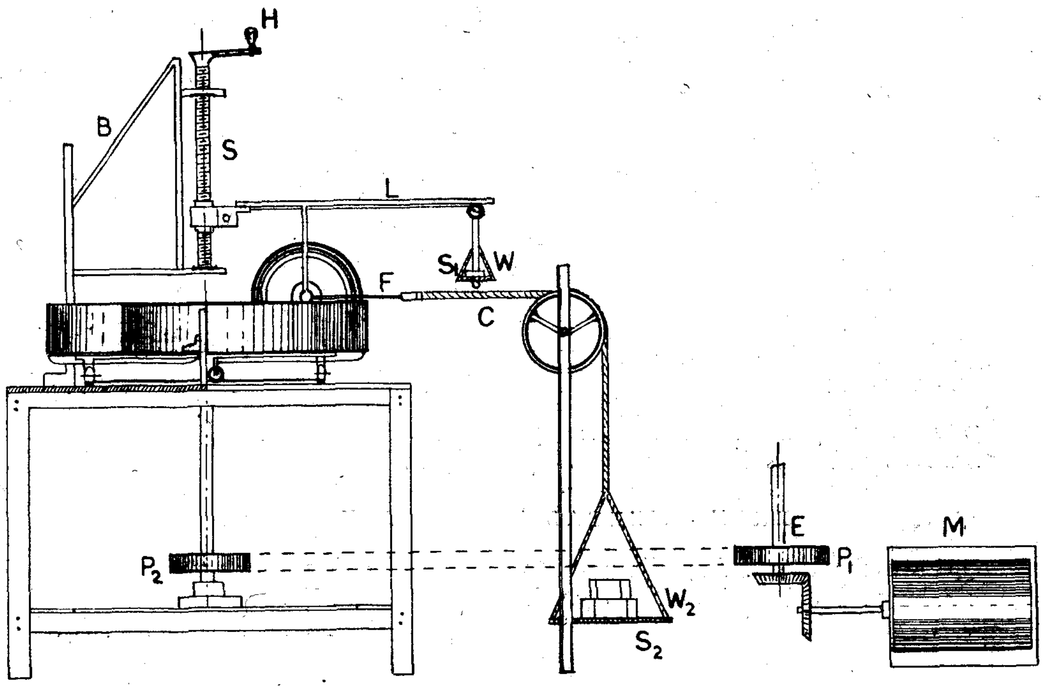

Fig. 1—Block diagram of friction apparatus for determining the rolling resistance of pneumatic rubber tyres on sand at various speeds.

with dry sand and was levelled. The mechanical analysis of the sand is given in Table 1. After adjusting the load which was to be put on the wheel, the chord was passed over the pulley and weights were put on the pan 'S_2' slowly. When the circular disc rotates, it tries to drag the wheel in its direction of motion, the weights were added to the pan 'S_2' till the wheel begins to rotate in the stationary position keeping the chord 'C' normal to the circular disc. The load in the pan 'S_2' required to keep the wheel rotating in its stationary position was taken as the value of the rolling resistance R for a particular load and inflation pressure of the tyre. Observations were taken with varying tyre sizes, loads, inflation pressures and speeds.

RESULTS AND DISCUSSIONS

The rolling resistance for the wheels (*i*) Jeep 5·90-15, (*ii*) Trolley 16 × 4 and (*iii*) Scooter 3·50-8 (Fig. 2) measured at 15, 25 and 35 p.s.i. inflation pressures and 8 kilometers per hour speed only are shown graphically in Fig. 3-5. It is seen that, in the case of tyre 5·90-15, the curves between the rolling resistance and load are linear at low loads, but concave towards the load axis at higher loads. In the case of tyres 16 × 4 and 3·50-8, the curves are linear throughout which indicates that the rolling resistance is directly proportional to the applied load. It is found that the bearing capacity of sand is so weak that it cannot support the wheel without appreciable sinkage. The deeper the wheel sinks, the greater the rolling resistance and firmer the grip. The extent of sinkage is limited to the depth where the base is firm enough to support the load. When the bearing capacity of the sand is sufficient to support the load, the sinkage does not increase with applied load and the rolling resistance is not proportional to it. This is more pronounced at low inflation pressures and at higher loads.

In fact the rolling resistance is primarily due to the displacement of the sand ahead of the wheel. At constant load with successive traversals of the same track, there is an increase in the track width and diminution of the rolling resistance. As the load is further increased, the sand/soil is compacted thereby increasing the bearing capacity of the surface hence the

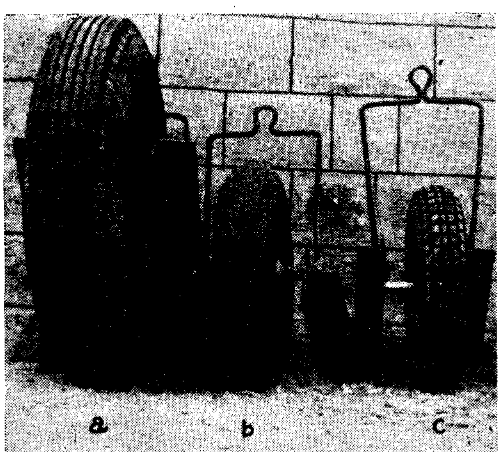

Fig. 2—Various wheels for which the rolling resistance on sand has been determined : (*a*) Jeep 5·90-15, (*b*) Trolley 16 × 4 and (*c*) Scooter 3·50-8.

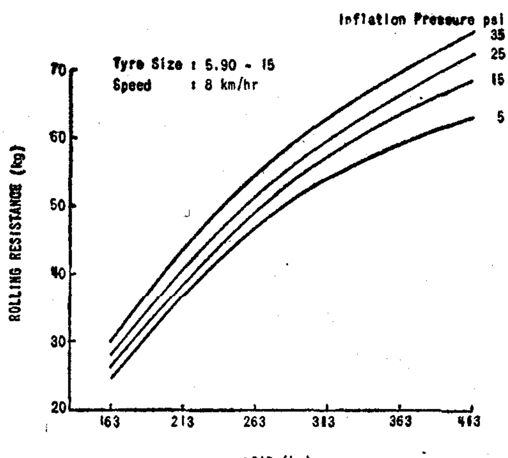

Fig. 3—Variation of rolling resistance with load at various inflation pressures for the wheel 5·90-15 at a speed of 8 kilometers per hour.

sinkage may become constant or may increase very slowly and because the rolling resistance is more or less dependant on the sinkage, it will increase slightly at higher loads this is why the curves at higher loads are concave towards the load axis.

Inflation pressure is one of the most important factors affecting rolling resistance of pneumatic rubber tyres. The coefficient of friction for tyre (*i*) Jeep 5·90-15, (*ii*) Trolley 16 × 4 and (*iii*) Scooter 3·50-8, at different inflation pressures, and at a speed of 8 kilometers per hour has been plotted in Fig. 6. It is seen that it first increases with inflation pressure and then becomes constant. At low inflation pressures, the tyre in contact with sand flattens, thereby decreasing the sinkage and hence the rolling resistance or the coefficient of friction as mentioned earlier. With the increase of inflation pressure, the sinkage increases and hence the coefficient of friction. Bekker[4] has also shown that there is a limit above which the wheel behaves like a rigid wheel and further increase of inflation pressure in loose sand does not produce any further increase in the coefficient of friction. The reduction in rolling resistance at low inflation pressures can also be explained by the fact that reducing the inflation pressure increases the work of flexing the tyre but decreases the energy expended in displacing the soil. On a hard smooth surface such as concrete, where there is no surface displacement, reducing the pressure, therefore, increases the rolling resistance. On an intermediate surface, changing the pressure has relatively little effect, but at the extreme, such as loose sand, reducing the pressure greatly decreases the rolling resistance. Therefore if a vehicle is to be operated intensively on soft, loose surfaces,

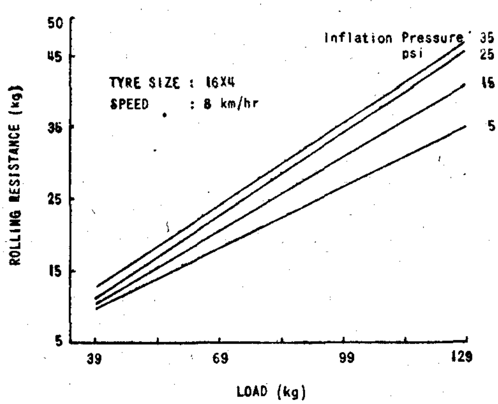

Fig. 4—Variation of rolling resistance with load at various inflation pressures for Trolley wheel 16 × 4 at a speed of 8 kilometers per hour.

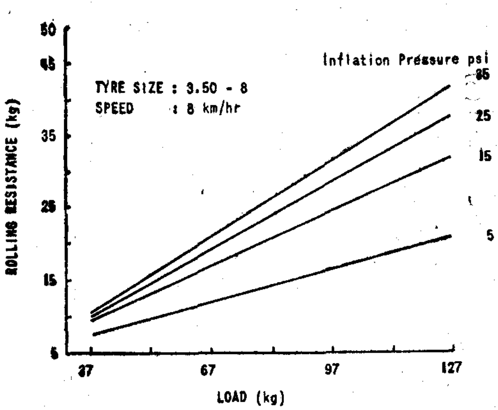

Fig. 5—Variation of rolling resistance with load at various inflation pressures for Scooter wheel 3·50-8 at a speed of 8 kilometers per hour.

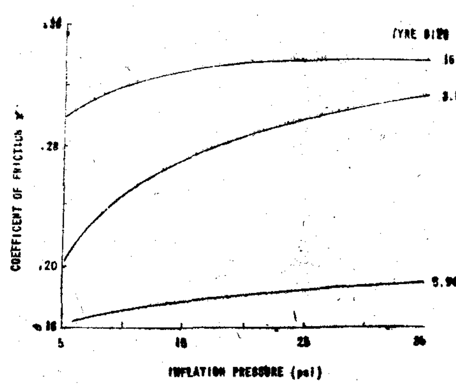

Fig. 6—Coefficient of friction vs inflation pressure for different wheels.

TABLE 1

MECHANICAL ANALYSIS OF SAND USED FOR CONTROLLED TESTS

B. S. Sieve No.	Sand retained (%)
16	..
25	..
52	1·80
72	8·22
100	47·12
150	3·50
200	36·92
Above 200	2·36

the use of larger capacity tyres which permit lower inflation pressures may be very useful on the basis of power economy. It is also important to note that the tyre pressure cannot be reduced to a very low value as the tyre surface will develop cracks thereby reduce the life of the tyre. For safe locomotion in a desert, the tyre pressure should be such that the load of the vehicle is uniform on the base of the tyre and the tyre does not sink. The theoretical treatment of the problem is extremely difficult because the soil/sand has no uniform properties. Its density and compactness depends upon the moisture content particle size. Its bearing capacity and load sinkage relationship cannot be expressed in a simple law because these are dependent upon the physical conditions of the soil/sand. A load, which is safe, because it can keep the vehicle on the ground surface afloat in one soil may not be safe in another. The inflation pressure will differ with size of tyre and ground conditions but generally low inflation pressure is found suitable for loose sandy terrains[1].

The coefficient of friction of pneumatic rubber tyres on sandy surfaces depends on a number of factors[5] such as diameter, width tread and the material of the tyres. It is seen that the coefficient of friction decreases as the diameter of the wheel is increased as shown in Fig. 6. The larger the wheel diameter, the better the performance. This decreased rolling resistance as the outside diameter of a pneumatic tyre is increased, can be explained thus : Less work is required to flex the tyre well enough to give an equal area of supporting contact. Less work is done in the forward movement of soil because of the smaller forward component of the tyre motion at the foremost point of its contact with the soil and less work is needed to compress the soil because of the narrower track resulting from the narrower soil contact needed to give an equal area of supporting contact. However, there is a definite limit of progress based on this trend since sooner or later the wheel size becomes prohibitive. It is hoped that in near future, "the skid suspension" device[6] may replace the large size wheels. This device may not be very useful on the roads but definitely, it would be an achievement for off-the road locomotion. Such devices would be useful for the troops operating on sandy/snow terrains. When a very hard wheel rolls on a very hard surface, the resistance to motion is very small but on softer tracks it is greater. The resistance decreases as the hardness of the surface increases. It's dependance on the width of the tyre is conflicting. If the width of the tyre is increased, the sinkage will decrease and hence the coefficient of friction but at the same time bulldozing effect will increase and the friction would not decrease to the extent as expected. In the same way, the tread of the tyre plays a very significant role. The diameter and the width of the wheels 16×4 and 3·50-8 are the same but their tread is different. Tyre 16×4 has a very simple tread and its central portion is slightly conical but tyre 3·50-8 has got a good tread and the central portion is flat as shown in Fig. 2. It is found that the coefficient of friction for the tyre 16×4 is higher than tyre 3·50-8 at all the inflation pressure (see Fig. 6). It is observed that a cone type of load distribution produces higher sinkage than a uniform load distribution. Thus tyre with a flat tread is considered better than one whose centre is conical. This is true only for soft surfaces; it is different for hard surfaces. The present results are in accordance with this conclusion. The main aim of the tread is to give better grip on the surface and minimize slippage. For better locomotion on sand, the tyre should be soft with pressure adjusted to enable it to yield before the obstacle. Though costly such tyres are necessary for safe locomotion on sand during an emergency.

The present apparatus for determining the rolling resistance of tyres has got certain limitations. Though it is suitable for small size tyres and low speeds, the depth and width of the circular path need be increased to two feet for bigger size tyres and high speeds. Generally it is observed that the soil/sand is affected to a depth of only 2 feet by the movement of the vehicle and observations taken under controlled conditions should be simulated to actual field conditions. Recently a new apparatus having circular path more than two feet deep and wide has been designed and fabricated. It will be suitable for working with large size of tyres at high loads and speeds. The soil/sand conditions, in respect of density, moisture content, particle size, bearing capacity and sinkage would be measured simultaneously. It is also proposed to measure the internal friction of soil/sand (ϕ), the coefficient of cohesion (C), the modulus of soil/sand deformation (K) and the exponent of soil deformation (M). These would be corelated with the vehicle mobility over sand. Work is in progress and the results could be published in due course.

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