Tire Pressure and Rolling Friction of a Road Bicycle Tire

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Abstract

The rolling friction of a road bicycle tire was measured as a function of changing tire pressure. Five different tire pressures, ranging from 40 to 120 psi, were tested in increments of 20 psi. The power input to the pedals and wheel speed were collected using a crank-based power meter and speed sensor. It was found that rolling friction increases with decreasing tire pressure in an inversely proportional relationship.

Keywords**:** bicycle tire, tire pressure, rolling friction, hysteresis

I. INTRODUCTION

When riding a bicycle, everyone makes sure the tires are pumped up to minimize effort. It is common knowledge that riding a bike with low-pressure tires is harder. Currently, no data has been published on the effect of tire pressure on rolling friction in road bicycles. This limits amateur competitive cyclists, who lack private testing resources, from optimizing their tire pressures when racing. Here the relationship between tire pressure and rolling friction was studied and compared to past research on automobile tires and fuel consumption.

In a bicycle, part of the retarding force of friction comes from the interaction between the tire and the contact surface. Other forces include air resistance and friction within the chain and sprockets. A phenomenon known as hysteresis occurs in pneumatic tires and is the primary source of energy loss caused by the interaction of the tire and contact surface.[1] When a tire rolls, the sidewalls on the bottom deform, as seen in Figure 1, and then return to their original shape when the same part of the tire leaves the ground. This deformation of the tire compound causes net energy loss in the form of heat, thus creating a retarding force.[2] Energy is also lost through slippage of the contact patch between the tire and the ground as the bottom of the tire flattens.[3]

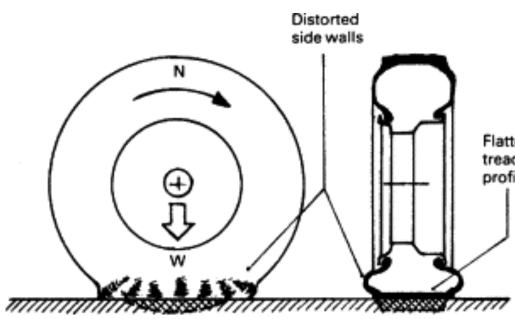

Figure 1. The flattening and deformation of a pneumatic tire when interacting with the ground.[1]

A study by researchers at the Silesian University of Technology (SUT)[4] found a negative linear relationship between an automobile's fuel consumption and the average tire pressure, as shown in Figure 2.

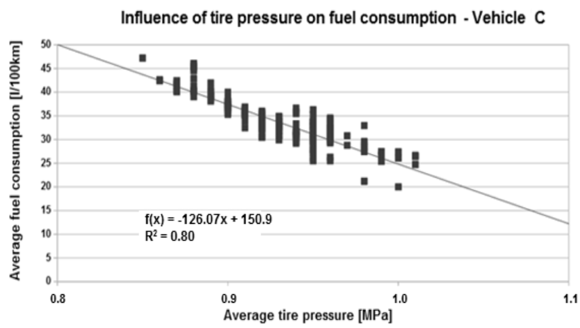

Figure 2. Linear fit on average tire pressure and average fuel consumption graph.[4]

Although the researchers interpreted their results as a negative linear relationship,[4] the nature of the relationship may be different for a bicycle tire tested over a wider range of pressure compared to the automobile tire tested. While here rolling friction is measured rather than fuel consumption, fuel consumption measures energy over a distance, which is equivalent to a force. Thus, a similar relationship can be expected for rolling friction.

To determine rolling friction for a bicycle on stationary rollers where there is no wind drag, total friction (F_{net}) can be split into two components:

$$F_{net} = F_r + F_s \quad (1)$$

where F_r is the rolling friction, and F_s is the sum of all the other resistive forces in the system. Since the only factor changing is tire pressure, with the system components, temperature, and speed staying the same for all trials, F_s is expected to be constant, while F_r is expected to increase with decreasing pressure. Because the Power (P) required to move an object at constant velocity (v) is the product of the total force (F_{net}) and velocity,

$$\frac{P}{v} = F_r + F_s \quad (2)$$

Thus, if the quantity (P/v) is graphed against pressure (p), the fit would produce an equation for $F_r + F_s$ vs p. Since F_s is expected to be constant in this situation, the relationship between rolling friction and pressure can be determined.

Figure 3. Photo of the experimental setup.

II. METHODS

A Continental Ultra Sport III 25c and a Vittoria 700c Standard Tube 20-28c were used, as shown in the experiment set up in Figure 3. The power data was recorded for 30 seconds each trial on a Garmin bike computer using a crank-based power meter at a constant speed of 25±1.5kmh^{-1} measured by a speed sensor. The tire pressure was adjusted in intervals of 20 psi, ranging from 40 to 120 psi, using an air pump, with five trials conducted at each pressure. There was a 2-minute cooldown period between each trial to allow the tire to return close to room temperature. It should be noted that trials with higher pressures felt cooler to the touch after the 2-minute cooldown period. Considerations were made to keep rider and equipment mass, room temperature, and bicycle components constant.

III. RESULTS AND DISCUSSION

As pressure increases, the power input from the rider required to maintain the constant speed decreases, as shown in Figure 4. This was expected, as everyday cyclists feel more resistance when tire pressure is low. This declining trend is similar to how increasing automobile tire pressure resulted in decreased fuel consumption.[4]

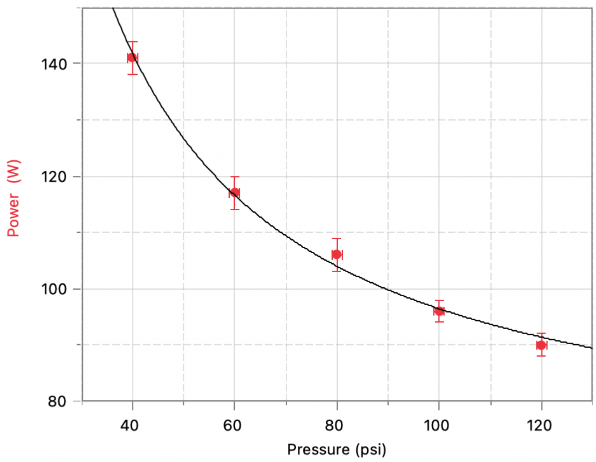

Figure 4. Relationship between power and tire pressure

Figure 5 displays the relationship between the ratio of power over velocity (P/v) and pressure modeled by

$$P/v = A/p + B \qquad (3)$$

where the value of A in the equation represents F_r and B represents F_s. The value of B gives an estimate of the system friction (F_s) of 9.5 N, as shown in Figure 5. The values of rolling friction for each power value were then calculated by subtracting 9.5 N from P/v, following equation 2. The values of rolling friction (F_r) are then graphed against pressure, as shown in Figure 6.

Finally, an inversely proportional relationship was found between rolling friction and pressure. This decreasing trend aligns with the negative linear trend found by the SUT researchers.[4] However, the inversely proportional fit may differ because the researchers only tested pressure over a range of 15% while this experiment varied pressure by a factor of three.

In the inversely proportional relationship between tire pressure and rolling friction shown in Figure 6, a high correlation of 99.77% was identified, justifying a strong alignment with the modeled equation found:

$$F_r = (430 \pm 6\ Npsi^{-1})/p \qquad (4)$$

The proportionality constant of rolling friction and tire pressure is approximately 430 ± 6 $Npsi^{-1}$ for the bicycle tire setup used in this experiment. While an inverse relationship was expected, a different tire (such as a wide and flat Formula 1 tire) may not necessarily give an inverse relationship with a power of -1, like the relationship found from this tire. Even with the same tires, the constant of proportionality is still expected to differ among different tire setups.

Although the results clearly show that maximizing pressure minimizes rolling friction, further research should be conducted on rolling friction in real world race situations, where the surface is not smooth like the indoor rollers. Realistically, at high pressures on rough surfaces, the tire begins to bounce up and down. This not only creates energy loss between the rider's power output and forward motion, but also endangers the rider by reducing the handling ability of the bike. The point where the tire pressure is sufficient to start bouncing is explained by a concept called the impedance breaking point.[2] With further investigation, a model can be created to determine optimal tire pressure prior to impedance on various road surfaces.

IV. CONCLUSION

An inversely proportional relationship was found between tire pressure and the rolling friction produced by a road bicycle tire at a speed of $25kmh^{-1}$. This decreasing trend aligns with common knowledge that biking with lower tire pressures requires more effort and the negative linear relationship found in a similar study on car tire pressures and fuel consumption.[4]

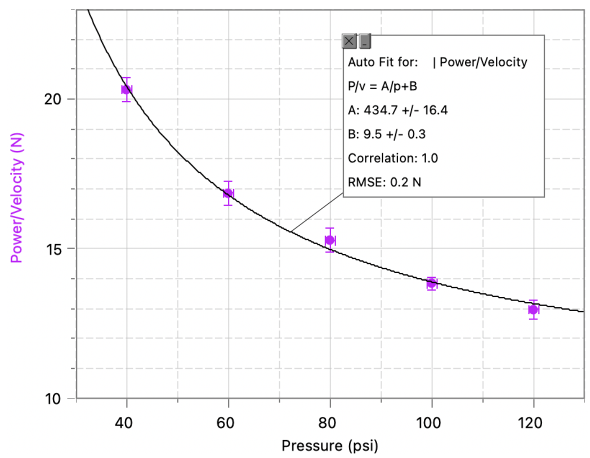

Figure 5. Relationship between power/velocity and pressure.

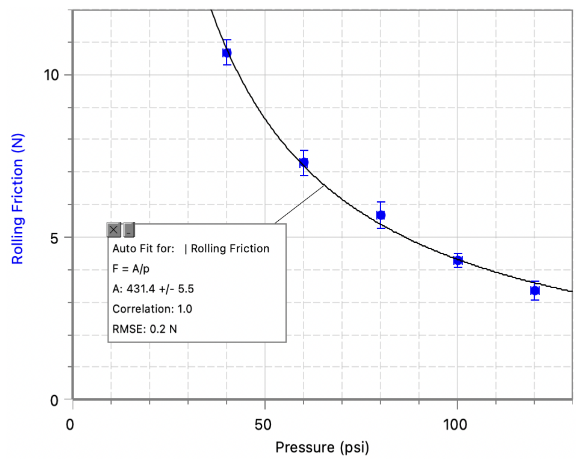

Figure 6. The inversely proportional relationship between rolling friction and tire pressure.

V. REFERENCES

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