Journal of Physics Special Topics

An undergraduate physics journal

A1_2 Pirelli's Plight

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December 2, 2021

Abstract

In this paper, we calculate the amount of time an F1 car could burnout for before wearing all its tyre tread off. By implementing the Archard equation using trigonometry and Newtonian mechanics, a value of $t = 30.3$ s was found.

Introduction

In vehicles, burnout occurs when a driver intentionally causes the driving tyres to spin whilst simultaneously holding the cars position. Burnout significantly wears tyres; this paper investigates the maximum time that an F1 car could burnout for.

Theory

In this scenario, abrasive wear is the predominant wear component; it occurs when a hard material cuts through a softer material during sliding. We can use the Archard equation to calculate the maximum burnout time:

$$t = \frac{QH}{KWv} \ . \qquad (1)$$

Here, Q is the volume of material lost (m^3) , K is the dimensionless wear coefficient, W is the total normal load (N), H is the hardness (Pa) of the tyre, v is the velocity difference (ms^{-1}) between the surfaces, and t is the time (s) spent undergoing sliding friction. F1 tyres have a slight inward camber. The rear tyres are inclined at 0.5° [1], meaning that the volume of tyre lost leaves a truncated cone, because one edge experiences more wear than the other. By calculating the original volume of tyre and subtracting the volume of the truncated cone left behind, the volume of the tyre lost (Q) can be found:

$$Q = \pi r^2 h - \frac{1}{3}\pi({r_1}^2 + r_1 r_2 + {r_2}^2)h \ . \qquad (2)$$

Here, r is the radius of the tyre, h is the width of the tyre, r_1 is the radius on the inner edge of the tyre after material loss, and r_2 is the radius on the outer edge after material loss. An F1 tyre has a radius of r = 0.165 m and a width of h = 0.405 m [2]. Tread depths are secret for F1, but a road tyre will have ~0.008 m of tread. The tread was assumed to be slightly larger at 0.01 m for an F1 tyre, owing to the increased width. All tread being worn away at the inner edge, whilst the outer edge will have less worn off due to the camber. This leaves a 2D right trapezium shape of material being worn off, with parallel sides equating to 0.01 (inner edge) and 0.01 - 0.405tan(0.5) = 0.0065 m (outer edge). Giving r_1 = 0.165 - 0.01 = 0.155 m r_2 = 0.165 - 0.0065 = 0.159 m. When values are substituted into Eq. (2), the volume of material lost is Q = 0.00328 m^3.

Treads are made of polybutadiene rubber, with F1 tyres being 100% synthetic in composition. This corresponds to a Shore A hardness of 68 [3], which converts to a hardness of H = 1.70 MPa [4]. The total normal load is computed by taking the weight of an F1 car and dividing it between each wheel. For a car mass of 752 kg [5], the total normal load W = 1.84 kN. The surface wear coefficient for abrasive wear is given by K = 0.055 [6].

The driver will first overcome the static friction, after which the tyres slip and accelerate due to a lower sliding friction. The coefficient of static friction is $\mu_{\mathrm{k}} = 1.7$ [7]. The average value of the coefficient decreases by 12% [7] from static to sliding; assuming this relation holds for an F1 tyre, the sliding coefficient will be $\mu_{\mathrm{s}} = 1.5$, equating to a difference of 37 N in friction. We assume it takes the driver 1 s to linearly reduce the power to match the lower sliding friction. By integrating the decreasing force over the 1 s period, we obtain the momentum imparted to the wheel, as

$$\int_0^1 x(1-t)\,dt = \frac{x}{2} = p\ , \qquad (3)$$

where x is original frictional difference. This gives a linear momentum of p = 18.5 kgms^{-1}. We can deduce velocity by using the equations of angular momentum and the moment of inertia for a hollow cylinder:

$$v = \frac{r^2 \cdot p}{I} = \frac{r^2 \cdot p}{\frac{1}{2}M(r^2+a^2)}\ . \qquad (4)$$

Here, a is internal radius that spans the nitrogen-filled cavity inside the tyre, M is the mass of the tyre, and p is the linear momentum. At this point, the tyre is an intact hollow sphere, and changes to the tyre shape occur mostly after the acceleration. An F1 tyre features two layers, the tread and the structuring, both of equal thickness 0.01 m; subtracting these from the wheel radius r gives $a = 0.145$ m. The mass of a rear tyre is $M = 11.5$ kg [8]. Substituting these values into Eq. (4), we obtain the linear velocity v = 1.82ms^{-1}.

Results

Our value of burnout time is given by

$$t = \frac{QH}{KWv} = \frac{0.00328 \times 1.70 \times 10^6}{0.055 \times 1.84 \times 10^3 \times 1.82} = 30.3\ s\ . \qquad (5)$$

Conclusion

This value seems reasonable but low. The accuracy is compounded by the difficulty in finding accurate data; without in-situ testing of materials and track conditions, the final result is expected to deviate. Overall, this paper shows that theoretical modelling is possible, but testing is strongly recommended to improve accuracy.

References

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