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P2_5 Heating in rim-brakes

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Abstract

This paper investigates the magnitude of heating caused by rim-brakes on bicycles, and determines the effect of this heating on tyre pressure. It is found that rim-heating appears to be a significant effect, increasing tyre pressure by up to 30% though is unlikely to cause a blowout if the tyre is inflated to the recommended pressure.

P2_1 Sports Science

Introduction

Rim-brakes are cheap to manufacture, powerful and mechanically simple. A vast majority of casual cyclists employ this type of braking mechanism. Rim-brakes transfer force applied by the rider on a handle to apply friction to the wheel rim, converting kinetic energy to heating [1]. Little thought is put into the magnitude of this heating, although it has been reported that this can be responsible for increasing tyre pressure enough to blow a pneumatic tyre from the wheel rim, known as a *"blowout"*. In this paper, we consider a cyclist riding downhill, applying his brakes constantly, to limit his speed to a constant.

Methodology

Treating the rubber brake pads and tyre as insulators, we are only interested in heat transfer to and from the metal wheel rim, and the air within the tyre. For a quickly turning metal rim, heating is taken to be uniform over the wheel rims. Convection is the dominant heat flow process in gasses and is relatively fast for a small system. As such, heat transfer within the wheel is assumed rapid, and both the rim and air in the wheel are taken to be at the same temperature always.

With these assumptions in place, the first step is to determine the rate of energy transfer between a cyclist's gravitational potential energy, and heat in the braking system. We define co-ordinates *x* and *y* such that

$$\frac{\mathrm{dx}}{\mathrm{dt}} = v \quad (1) \quad \text{and} \quad \frac{\mathrm{dy}}{\mathrm{dx}} = \sin\theta \quad (2)$$

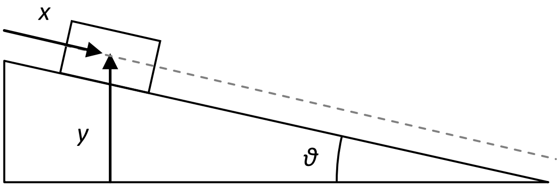


Figure 1 shows a cyclist on a plane inclined at an angle ϑ.

To remain at a constant velocity, their energy is dissipated by air resistance and braking. Combining this with (1) and (2), and multiplying by the cyclists-system's weight gives

$$\left(\frac{dU}{dt}\right)_1 = Mg\,\frac{dy}{dx}\frac{\mathrm{dx}}{\mathrm{dt}} = Mgv\sin\theta \quad (3)$$

where *M* is the cyclist-system's mass and *U* is the energy transferred in braking, in this case, as heating in the wheel. The power lost to air resistance is given by simple manipulation of Stokes' Law [2]

$$\left(\frac{dU}{dt}\right)_2 = -\frac{1}{2}A\rho v^3 C_d \quad (4)$$

where *A* and C_d are the cyclist-system's frontal cross-sectional area and drag-coefficient respectively. We assume all of this energy is transferred the conducting wheel rim and air in the tyre. Since the rubber tyre and brake-pads are taken to be insulators, the dominant heat-loss process is conduction into the surrounding air from the metal rim. For simplicity, we say conduction occurs across a temperature gradient from the rim at temperature T, through the boundary layer of slowly moving air and into the surroundings at a constant temperature T_A, the ambient temperature.

$$\left(\frac{dU}{dt}\right)_3 = \frac{-kS(T-T_A)}{\delta} \qquad (5)$$

where k is the thermal conductivity of the air sheath, S is the total surface area of the conducting rim for the front and back wheels and δ is the thickness of the boundary layer. The boundary layer is the distance from the surface to where the magnitude of the velocity field is 99% of that at infinity and can be found using the Blasius solution to the Navier-Stokes equation [3]. Combining (3), (4) and (5) gives the total rate of energy change for the wheel, zero at equilibrium. The equilibrium temperature, T_{max} can be found by rearranging for T.

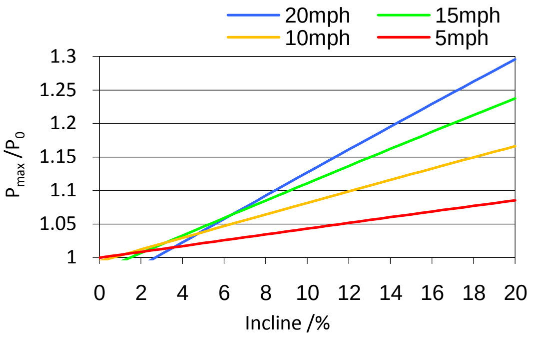
$$T_{max} = T_A + \frac{\delta\left(Mgv\sin\theta - \frac{1}{2}A\rho v^3 C_d\right)}{kS} \qquad (6)$$

Note that $T_{max} = T_A$ for $v = 0$ or $v = \frac{2Mg\sin\theta}{A\rho_{air}C_d}$

When stationary or moving at terminal velocity (without braking) there is no additional heating as expected. This equation therefore is only valid in the range $0 \leq v \leq v_T$, the terminal velocity for a given incline. The first interesting result of this investigation is how T_{max} varies with v. Differentiating with respect to v shows T_{max} is maximum when $v = (\sqrt{3}/3)v_T \approx 0.58\ v_T$. By treating the air in the tyre as an ideal gas at a constant volume, the pressure at T_{max}, P_{max} can be directly related to temperature by

$$P_{max} = P_0\left[1 + \frac{\delta\left(Mgv\sin\theta - \frac{1}{2}A\rho v^3 C_d\right)}{T_A kS}\right] \qquad (7)$$

where P_0 is the pressure of the tyres at T_A. For small inclines, this is approximately linear. The following parameters are estimated; A = 0.51m^2, C_d = 1.1, M = 88kg, S = 0.12m^2, T_A = 293K, $\delta = 2.2\cdot10^{-4}$m. All other parameters are given their standard values [4].



Graph 1 shows a plot of P_{max} with incline for different v

Discussion and Conclusion

This graph shows that for a combination of relatively high speed descents and steep inclines, tyre pressure can be expected to increase by 30% of P_0. Typically, manufacturers set the maximum recommended pressure at about half of the blowout pressure [5]. If the tyre is inflated at T_A, and kept within this limit, it is very unlikely rim-heating would pose a significant risk. However, worn tyres become thinner, more flexible and more prone to blowouts. Additionally many experienced cyclists experiment with higher pressures for better performance, which would also increase the risk.

Although these results seem feasible, there seems to be a trend of lacking data across sports science to fit such models to. As such, conclusions are sensitive to many of the approximations made. This appears to be a simple and effective model of heating in bicycle rim-brakes, but to make any real predictions we need data to tune the model parameters to.

References

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[4] Drag coefficient, air properties, *www.engineeringtoolbox.com*

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