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An experimental study of creepage in rolling contact

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1 INTRODUCTION

We consider two elastic bodies in contact, rolling under the action of tangential friction forces whose magnitudes are less than that of limiting friction. They give rise to small apparent velocities of slip known as creep or creepage. In a coordinate system in which the *x*-axis is in the direction of rolling and the *z*-axis along the common normal, the creepages are defined: longitudinal $\xi_x = \Delta v_x / V$, lateral $\xi_y = \Delta v_y / V$ and spin creepage $\psi = \Delta\omega_z c / V$, where *V* is the velocity of rolling and $c = \sqrt{ab}$ in which *a* and *b* are the semi-axes of the ellipse of Hertzian contact. under a normal load *P*. All three creepages arise in the case of a railway wheel rolling on a rail (see figure): ξ_x arises from traction or braking forces, ξ_y from yaw of the wheel and ψ from the conicity of the wheel (see figure).

It was recognised by F.W.Carter in 1916 [1] that the relationship between these creepages and the tangential forces, together with coning of the wheel treads, play a fundamental role in the unstable hunting motion of railway vehicles. The first attempt to derive these equations theoretically using Hertzian contact mechanics was made by Carter in 1926 [2], who solved the 2-dimensional problem of a cylinder rolling on a flat surface. His solution established that the contact area comprised a zone adjacent to the leading edge where the surfaces move together without slip, followed by a slipping zone whose size increases with tangential force until full sliding occurs when the force reaches its limiting value $(Q_x = \mu P)$.

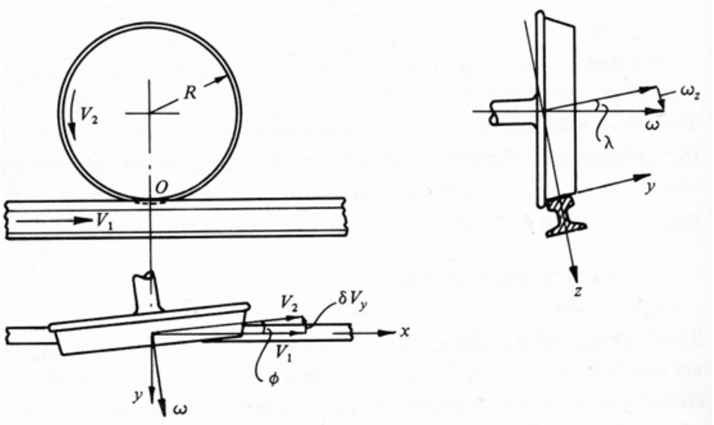
Most practical contacts are 3-dimensional, with circular or elliptical contact areas. A 3-D approximate theory in closed form was presented by Johnson in 1958 [4,5]. The experiments reported here were undertaken to check that theory, but were subsequently used to support Kalker's numerical theory [6]. The experiments were designed to measure the forces due to longitudinal, transverse and spin creepages separately.

2 EXPERIMENTAL

2.1 *Longitudinal & transverse creepage*

In this paper we shall be concerned with circular contacts, but the approximate theory of longitudinal and transverse creep was extended to elliptical contacts by Vermeulen & Johnson and a few experiments performed [7].

The apparatus used for circular contacts is show in ref.[4] figure 4. It comprised two smooth steel balls mounted on a rigid axle, free to roll on a flat steel block. To measure longitudinal creep the block was tilted through known small angles in the rolling direction and the rolling motion controlled by a string passing around the spindle. To measure transverse creep the block was tilted at right-angles to the rolling direction and the creep in one revolution of the spindle measured by micrometer. Experiments were carried out with the surfaces wiped dry and lubricated. The coefficient of limiting friction μ was measured in simple sliding. Longitudinal and transverse creepage measurements are compared favourably with Kalker's theory in ref.[6], figure 13.



2.2 *Spin creepage*

Spin creepage has long been known to play a major role in thrust and angular contact ball bearings. The first experiments, therefore, were made using a simplified thrust bearing, comprises three equally spaced balls rolling between two flat circular discs, in which the upper disc is free to turn about a central vertical spindle. It was observed that during a slow revolution of the upper disc, the balls rolled round a circumferential track, but *also crept radially outwards by a reproducible and measurable distance.* This showed that the imposition of spin creepage results also in transverse creepage. Hence to obtain pure spin creepage an inward radial force must be applied to the ball. To measure this force the apparatus was modified: instead of flat discs a shallow circumferential groove of circular profile was ground into the rolling surface of each disc. Starting from the bottom of the groove, the three equally spaced balls crept radially outwards rising up the side of the groove and thereby developing a transverse force at the contact proportional to the slope of the groove at that point. In the steady state radial creep stops and the transverse force is that arising from pure spin creepage.

With this experimental arrangement it was difficult to cover the small spin arising from the conicity of a railway wheel. An alternative apparatus was built, shown in ref.[8] figure 3. The measurements of the tangential force arising from pure spin creepage are favourably compared with Kalker's theory in ref.[6], figure 14.

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