Chapter 6

Rolling Contacts in Land Locomotion

The power–weight ratio of railway locomotives has been increasing consistently over the past two decades mainly owing to enlarged power plants, the extensive use of lightweight materials, and improved construction methods. The only limiting factor to a continued increase in this ratio seems to be the traction developed between the driving wheels and rails **(1)**. This statement is supported by the pronounced tendency for wheel slip to occur, especially in starting from standstill and under wet conditions.

Another major area of land locomotion and transportation involves the rolling performance of pneumatic tyres on road surfaces. The contact interface between tyres and road is determined by complex interaction events during free rolling, braking, driving, cornering, skidding, or any combination of these modes, and its properties reflect the result of these interactions **(2)**. Nevertheless, in practice it is useful to separate the individual contributions of tyre and road in order to understand the fundamental events that subsequently determine the frictional coupling in the contact area.

6.1 Rail–wheel systems

In order to gain a clear understanding of the fundamental mechanism governing the traction between wheel and rail, a memory effect also known as secondary conditioning has to be recalled. This phenomenon arises from the fact that, when certain substances, especially oils, are spread upon a rail, secondary effects take place which are manifested by the creation of a minute quantity of the substance so closely associated with the surface as virtually to form a part of the main material. Therefore, it is possible for two apparently identical steels to possess widely different coeficients of surface friction despite all the efforts to clean the track. This memory capability, which is generally detrimental for surfaces previously contaminated with oil, can have beneficial effects when the spark discharge method is employed to improve traction.

6.1.1 Traction at the rail–wheel interface

Basically, there are only three methods for improving rail–wheel traction, namely:

- employing additives on the rail surface (chemical),
- scoring, abrading, and sanding of the railhead (mechanical),
- plasma arc or spark discharge between an electrode and the rail (electrical).

It appears that both the chemical and mechanical methods have either failed to provide satisfactory improvement in traction or they tend to introduce other unwanted effects. The list of undesirable effects given below is by no means comprehensive but illustrates well the problems involved:

(1) The use of a colloidal dispersion of silica in water produces a considerable improvement in the traction of dry or wet rails having medium or low values of secondary conditioning. However, this treatment show little improvement on rails covered by an oil.

(2) Sodium hydroxide solutions are able to reduce the effects of oil contamination by attacking traces of oil which give low secondary conditioning, thus increasing adhesion. However, excess or long-term use of these compounds produces a sludge which may have an adverse lubricating effect.

(3) Sanding of the rail surface provides a practical way of securing an instantaneous increase in rail–wheel traction. However, the sand must be absolutely dry, and there are practical difficulties with appropriate storage and particle size control. Besides, sanding is not permitted near switch gears and switching points because of the danger of clogging. Also, an increase in surface damage occurs owing to pitting.

(4) Rails previously treated with silicone fluids tend to give high traction values even when subsequently treated with oil. On the other hand, initially clean rails give low traction when covered with oil. However, when the silicone-treated rails are covered with water,

the formation of innumerable droplets brings about a large reduction in traction.

The method of spark discharge, consisting of ionizing the air gap between an electrode placed ahead of each driving wheel and the rail, effectively removes the contaminants that normally appear on the rail, and thereby produces a marked improvement in traction under the most adverse conditions.

Table 6.1 shows values of rail–wheel traction under dry, wet, or greasy condition **(3)**. It is apparent that a large variation in the values of the traction coefficient exist, from a minimum value of 0.07 on damp rails to a maximum of 0.35 under dry, clean conditions. Lower traction values usually point to the presence of an oil contamination on the rail surface. Also, the slippery conditions are usually found on curves, near points, near stations, and at road crossings. Oil contamination from axles and lubricating pads flows on to the wheel rims and finds it way into the contact path.

The traction coefficient values listed on Table 6.1 are approximate and most appropriate for two speeds. When speed is considered as a variable, then it can be seen that the traction systematically decreases with increasing locomotive speed. A number of empirical relationships have been put forward to approximate the adhesion versus speed. Usually, they take one of two forms

$$f_{\mathrm{T}} = k_1 + \frac{k_1}{V + k_3} \tag{6.1}$$

$$f_{\mathrm{T}} = k_4 - k_5 V^n \tag{6.2}$$

Table 6.1 Examples of rail–wheel traction coefficients

Condition of rail surface	*Traction coefficient*
Dry rail (clean)	0.25–0.30
Dry rail (with sand)	0.25–0.33
Wet rail (clean)	0.18–0.20
Wet rail (with sand)	0.22–0.25
Greasy rail	0.15–0.18
Moisture on rail	0.09–0.15
Sleet on rail	0.15
Sleet on rail (with sand)	0.20
Light snow on rail	0.10
Light snow on rail (with sand)	0.15
Wet leaves on rail	0.07

Where f_T denotes the traction coefficient, k_i represents positive constants ($i = 1–5$), and n has the value 1 or 2. From the result of many investigations, the following approximate and simplified equations can be used for dry rail surfaces.

(a) $0 < V < 60$ km/h

$$f_T = 0.25$$

(b) $60 < V < 225$ km/h

$$f_T = \frac{30}{V + 75}$$

In the case of a wet rail surface, the following is recommended: $f'_T = 0.6\, f_T$.

In general the traction coefficient decreases with increasing brake block pressure. This can be expressed by the following relationship

$$f_T \sim p^{-0.38} \tag{6.3}$$

Where p is the pressure exerted by the brake block.

The inverse dependence of f_T on p is in accordance with the simple theory of adhesion for metals and is valid for pressures of up to about 2 MPa. It can be shown that at greater contact pressures the traction coefficient, which is directly related to the adhesion at the interface, begins to increase with increasing p and, at the same time, becomes independent of speed. The reason for this is probably the combination of high pressure and speed causing overheating of the brake block, softening it, and eventually bringing about more intimate contact with the rail. In order to secure an acceptable wear resistance, the brake blocks should have a hardness of 220–240 HB (Brinell hardness) and the wheel rims a hardness of 240–300 HB.

There are a number of other variables affecting traction between rail and wheel, namely wheel load, wheel size, and braking or driving mode. The wheel load seems to have an insignificant effect on the traction coefficient f_T. This largely due to the fact that, for very high loading, the case of rail–wheel contact, the real area of contact approaches the apparent area size. The mean contact pressure is close to the yield limit in compression for steel, and, according to the simple theory of the adhesion component of friction, the traction coefficient remains invariant

$$f_T = s/p^* \tag{6.4}$$

Where *s* represent the shear strength of the weaker material in contact and $p*$ denotes plastic flow or yield pressure. Increased wheel load will also increase the apparent area of contact, but this affects both the numerator and the denominator in equation (6.4) so that there is no overall change in f_T. For clean surfaces, the value of $s/p*$ is about 0.8 for steel–steel contact. In most cases, however, the usual presence of oxides, rain, oil, or other contaminations reduces the effective shear strength of the interface, *s*, so that the adhesion values in Table 6.1 are obtained. With increasing wheel diameter, there is a small reduction in mean pressure and a corresponding increase in apparent contact area. Also, it appears that the traction coefficient is little different whether braking or driving conditions prevail at the wheel–rail interface.

6.1.2 Braking process

It is instructive to consider the effect of braking a railway wheel from an initial travel speed of 100 km/h. The time taken for wheellock to develop is approximately 1 s or less from the instant of brake application. During this period, both tractive effort and wheel angular velocity decrease progressively, whereas the velocity of slip between wheel and rail in a non-linear way to attain a final locked-wheel skidding value of 100 km/h. The contact area between wheel and rail consists, during that time, of a region of adhesion and slip zone. This is schematically shown in Fig. 6.1. Both theory and experiment indicate a longitudinal shear stress distribution within the area of contact, which takes the form of the upper curve in Fig. 6.1. It should be noted that the shear stress is confined to relatively low values within the adhesion zone and reaches its maximum value within the slip region. Thus, the well-known requirement that a certain relative slip velocity between surface is essential for a maximum friction is satisfied by the above observation. The distribution of longitudinal slip velocity in the contact zone tends to have a non-linear increase towards the rear of contact according to the lower curve in Fig. 6.1. The slip region is followed by a kind of overshoot as the band velocity attempts to return to its undeformed value just outside the contact area. Another interesting fact is that, although the apparent area of contact could be quite substantial, the real area of contact is much smaller.

6.1.3 Traction enhancing techniques

One of the techniques used with considerable success in practical situations is the spark discharge method of volatilizing rail–wheel contaminations. It has shown a considerable improvement in traction values after