Creep force analysis at wheel-rail contact patch to identify adhesion level to control slip on railway track.

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.***Abstract***:

Creep forces and creepage has a huge weightage in railway vehicle transport and wheel;-rail contact dynamics for detecting adhesion level to avoid the slippage of wheels from track for smooth running. In this paper, the wheelset dynamics comprising the longitudinal, lateral and spin moment creepage and creep forces along with their respective creep co-efficient has been enumerated and its mathematical modeling has been framed. The creep forces and creepage are analyzed under different adhesion levels to detect slip and slide of railway wheelset to prevent derailment.

Keywords: creep, adhesion, creepage, slip

1. INTRODUCTION

The interactive forces of the rail and the wheel have a significant effect on the dynamical behavior of the rail vehicle. The creep, Adhesion and wear can significantly affect the railway vehicle dynamics. The adhesion depends on the rough surfaces and environmental conditions upon rail runway. The concerned Creep forces depend on the dimensional profile of the rail and the wheel like the materials of the wheel and the rail. In order to calculate the sliding forces on the wheel/rail contact mechanics must be studied.[1]

There are various rolling contact theories in the literature that calculate longitudinal and lateral creep forces at the wheel/rail interface. Some of the more useful theories are Kalker's linear theory, Kalker's empirical theory, Johnson and Vermeulen's model, and the Heuristic nonlinear model [2]. Kalker's theories are often used for rail dynamics studies. Johnson and Vermeulen's theory is less accurate but has greater simplicity [1].

Wheel/rail contact creepages and creep forces are important in understanding the railway vehicle dynamics. For safe train operations, wheel/rail adhesion conditions are very important to consider when studying creep forces in order to avoid wheel skid during braking. In [3], The Polach (researcher) observed an advanced model of creep force for railway dynamic vehicle when running on proper adhesion limitation. He considered in his study, the influence of lateral, longitudinal, spin creepages, and the shape of the elliptical contact on the railway vehicle dynamic system. He also considered the friction co-efficient for dry and wet conditions and it is assumed that it is fixed for each simulation.

In [4] rolling contact phenomena, creepages on wheel/rail contact, and creep force models for longitudinal train dynamics are presented. Matsumoto, Eguchi and awamura [5] have presented a re-adhesion control method for train traction. Watanabe and Yamashita [6] have presented an anti-slip re adhesion control method using vector control without speed sensor.

Mei, Yu, and Wilson have proposed a new approach for wheel slip control [7]. The study is based on the detection of torsional vibration of a wheelset when slipping. Considering the shaft elasticity, a simplified model that consists of dominant modes of the wheelset is developed to investigate slip detection and re-adhesion scheme.

The de Beer et al. [8,9] searched a similar theoretical model based upon the excitation by unstablity lateral creepage. They have also invented an experimental rig based on a reduced scale wheel and roller representing the rail dynamics [10,11].

The Lateral creepage is thus likely to exist in combination with longitudinal creepage and the influence of longitudinal creepage on the mechanism of squeal noise behavior specifically the creepage/creep force relationship is of interest to learn. This paper presents some experimental results obtained for combined longitudinal, lateral and spin creepage. The correlation has been simulated to investigate the relationship between creepages and creep forces in the presence of 3-D creepages. Some of the simulated results from this investigation are presented and discussed below.

2. RAIL WHEELSET DYNAMICS

2.1 Creepage Computation

The Creepages can be formed when the two bodies do not have the exact same velocities. The term creepage or creep is used to define the slip ratio. These creepages can be, longitudinal creepage, lateral creepage and spin creepage.

Figure-1 below shows the graphical representation of creepages and associated creep forces in longitudinal, lateral and vertical directions. Since the wheel and rail are elastic bodies, the contact ellipse has a slip region and adhesion region.

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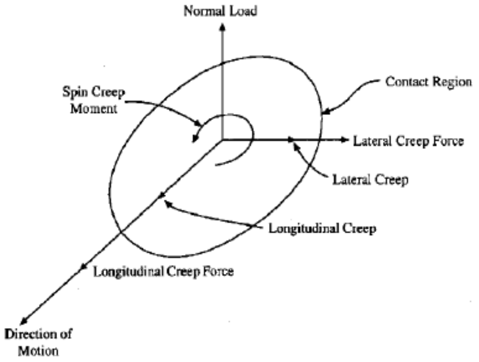

Figure-1 creep and forces acting on wheelset

Sliding occurs when the contact ellipse entirely becomes a slip region. In other words, when there is not enough adhesion between the two bodies, they will slip with respect to each other [2].

Following are the mathematical formulation is framed on each wheel depending upon its dynamics in terms of creep forces and total creepage of rail wheelset system.

2.1.1 Longitudinal creep on Rail wheelset

In case of rolling without slipping, the distance traveled by the wheel in one revolution is equal to the circumference of the wheel. But when torque is applied to the wheel, the distance traveled by the wheel in the forward direction is less than the circumference [12].

$$W_R = \frac{v}{r_R} and\ v = W_R * r_R$$

$$W_L = \frac{v}{r_L + ro} and\ v = W_L * ro$$

Above are angular/forward wheel velocities

Creepage of left wheel $= \lambda_L = \frac{r_o \omega_L - v}{v}$ (1)

Creepage of right wheel= $\lambda_R = \frac{r_o \omega_R - v}{v}$ (2)

Total longitd; creepage $= \lambda_x = \lambda_L + \lambda_R$ (3)

2.1.2 Lateral creep on Rail wheelset

The Lateral creepage is likely to exist in the combination with longitudinal creepage and the effect of longitudinal creepage on the mechanism for created squeal noise behavior, specifically the creepage and creep force relationship, is of interest to study and work on. [13].

lateralvel=$\dot{y}$= $v * \Psi$ Where $\Psi = 0.9250\ rad$

Creepage of left wheel (4)

Creepage of right wheel=Creep of left wheel

Total lateral creepage $= \lambda_y = \lambda_L + \lambda_R$ (5)

2.1.3 Spin/moment creep on left/right wheels

The longitudinal creepage λx is related with the difference between the rolling forward velocity and the circumferential velocity |V − Vcir|, the lateral creepage λy characterize the non alignment of the wheel with respect to the rail, while the spin creepage λsp is related with the concity of the wheel [14].

Spin$_L$(Ω_L $= w\frac{L}{V}$ and spin$_R$ $(\Omega_R) = \frac{wr}{\square}$

Total spin creepage$(\Omega) = (\Omega L + \Omega R)$ (6)

Thus combining all above creepages we get total creepage of rail wheelset as under.

$$\lambda = \sqrt{\lambda_x^2 + \lambda_y^2 + \Omega} \tag{7}$$

2.2 Tangential contact forces

It may be possible to compute the tangential contact forces using one of the models available in the literature with the knowledge of the normal contact forces that procure between the wheel and rail and its creepages, i.e., the relative velocities. Three models arc presented here in order to allow for a comparative study between them to be developed. The Kalker linear evaluates the longitudinal and lateral components of the creep force and the spin creep moment, that develop in the wheel-rail contact region. The figure-2, displays the forward (v), lateral velocity (y) along with yaw motion (ψ), which have been used in calculating the creep analysis above. The creep forces acting upon left and right of rail wheelset in longitudinal, lateral and spin moment creep directions have been shown and calculated as under.

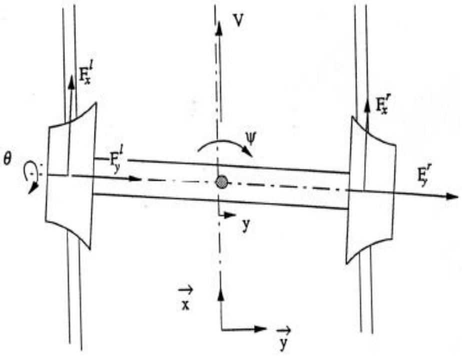

Figure-2 creep forces on left & right wheels

The longitudinal creep forces on right/left wheel are $F_{xR} = f_{11}\lambda_{xR}$ and $F_{xL} = f_{11}\lambda_{xL}$

The lateral creep forces on right/left wheel are $F_{yR} = f_{22}\lambda_{yR}$ and $F_{yL} = f_{22}\lambda_{yL}$

The Spin moment creep forces on right/left wheel are $F_{\Omega R} = f_{23}\lambda_{\Omega R}$ and $F_{\Omega L} = f_{23}\lambda_{\Omega L}$

Total creep forces = $Fx + Fy + F\Omega$

Where f_{11}, f_{22} and f_{23} are the creep coefficient of longitudinal, lateral and spin moment.

The tangential contact problem resolves the tangential creep forces acting on the contact patch. A deviation from pure rolling motion of the wheelset is caused by acceleration, traction, braking and the presence of lateral forces acting on the wheel-rail interface.

3. SIMULATION RESULTS

The mathematical model of wheelset dynamics presented in section-2 has been simulated and the simulation results are given as under

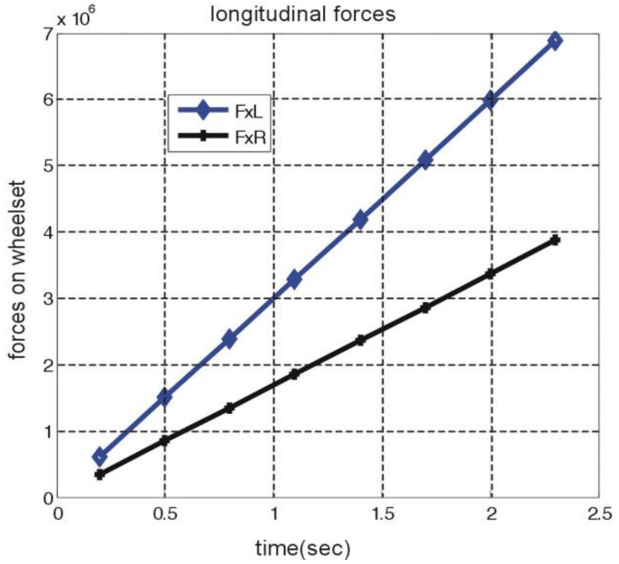

Fig-3 longitudinal forces on left/right wheels

In above figure-3, the relationship of longitudinal creep forces on each left and right wheels of railway wheelset contact have been shown. In this figure, left wheel creep force denoted by blue diamond reacts upper the black+ representing right wheel creep force. Both lines start from same origin point below 1 mN, then left wheel force increases upward and ends on 7 mN, while right wheel force increases but lower than that of left wheel ending at 4*10^6 N.

In the figure-4, the behavior of the lateral creep forces relationship for left and right rail wheelset has been denoted as under. Here lateral forces of left and right wheels start nearly below 0.2 mN to $1.8*10^{-9}$ N. These both lines overlap eachother as the lateral forces for left and right wheels is same as their creepages are also same.

The spin moment forces of left and right wheels relationship has been described as under.

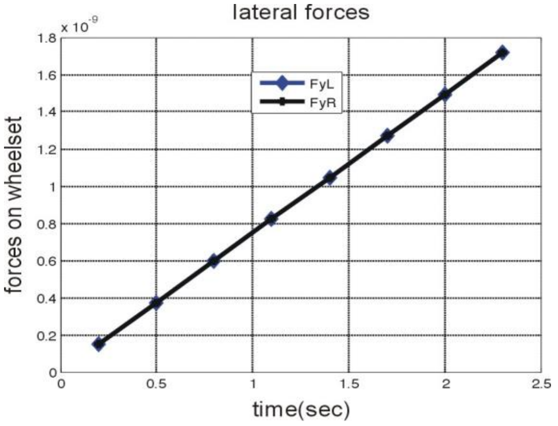

Figure-4 lateral forces on left/right wheels

Here spin force of right wheel denoted by black+ line of right wheel increases above spin force of left wheel increment. Both start below 1000 mN, whereas creep force of right wheel ends upto 6000 mN, while creep force ends 2000mN. From this diagram, it resembles differently as that of longitudinal creep forces for right and left wheels, where left wheel creep force is increasing above left wheel. While here in spin creep force of right wheel is replacing it

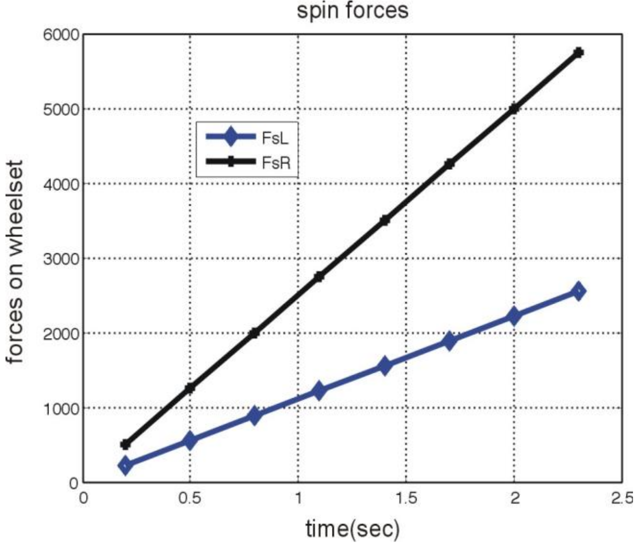

Fig-5 Spin moments on left/right wheels

In above fig-6, the total creep forces are compared with total creepage.

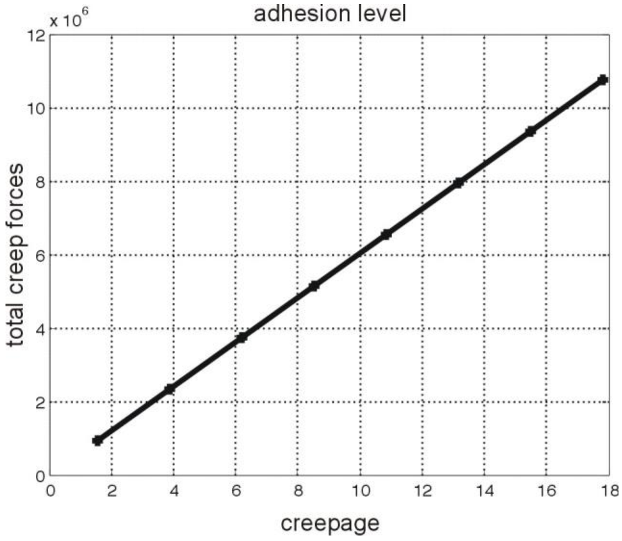

Fig-6 Relation of total creep force/creepage

Here the behavior of both has been shown in straight line, which shows that there is no tension of slippage which is ideal condition. Here total creep forces are increasing upward vertically with rise of total creepage horizontally.

CONCLUSION

In this paper, the creep forces acting upon each wheel of railway wheelset has been discussed, calculated and simulated by its expected results. These creep forces are determined by applying concerned creep coefficient $f_{11}= f_{22}=$ 6.728e6 for longitudinal and lateral creepages while that of spin creep co-efficient as 1000 N/m^2. The correlation of these forces has been graphed and determined. However the fig-6 is shows apparent importance as it enumerates that creep forces and creepage behave linearly. This linearity of curve shows that there is no any slip due to sufficient adhesion level. This linear line proves the maximal of columb's law of motion which states that if the tangential forces (creep forces) are equal or greater than normal forces (creepage,μN). This creepage is perpendicular to creep forces giving relation creep coefficient.

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