ICSV14

Cairns • Australia

9-12 July, 2007

STUDY ON USING NOISE FOR ADHESION CONTROL SYSTEM OF RAILWAY VEHICLE

Maksym Spiryagin, Kwan Soo Lee and Hong Hee Yoo

School of Mechanical Engineering, Hanyang University
Seoul, 133-791, Korea
spimaks@hanyang.ac.kr

Abstract

Many existing control systems for vehicles use an effect of a prediction of a friction coefficient between wheels and rails. It is connected with the impossibility of measuring a friction coefficient at the moment of running vehicle movement. One of the ways to solve this task is to use noise spectrum analysis for friction coefficient detection. At the present time different noise sources are localized, calculated and measured for railway vehicles. Research shows that at a speed up to 300 km/h, the noise of wheel rolling on the surface is predominant. And the noise can be subdivided into three categories: rolling noise, grind and scream on the curve parts of roads and dynamical noise (usually, this noise depends on impact loads). However, the noise for wheel-rail interaction is less researched. The researches also have not done a diagnostic or a monitoring of technical conditions for the wheel-road contact (for example, third body in the contact zone between rail and wheel). Some of these conditions are able to have a negative effect on adhesion characteristics. The form of working contact surfaces has a major influence on the tense distribution, which also has a strong influence on the spectrum of noise. Based on this approach it is possible to develop an adhesion control system of railway vehicles. Results from this study will be presented and the effectiveness of this work will be discussed.

1. INTRODUCTION

Effective application of power, as well as the consumption of energy by railway vehicles, depends on how the adhesion process goes between a rail and a wheel during the mode of realization of tractive and braking efforts.

For developing of railway vehicles, it is necessary to give proper weight to design adhesion coefficients. However, real adhesion coefficients are quite different from design adhesion coefficients. For example, the difference for locomotives can reach ±40%. It is shown that we have some reserves on the one hand, and we have some costs connected with slip and tractive loss on the other hand.

Different materials are used for the improvement of the adhesion coefficient in rail-wheel contact; one of these materials is sand, which is one of the most used. The application of sand brings some negative consequences – increased wavy scalloping wear of rails, pollution of the upper part of railroad tracks and environment of near districts, and also increased level of the noise from the movement of wheels. The low precision of sand feeding in the contact zone brings ingress of sand on a lateral surface of a wheel flange, which increases wear rate of wheel flanges.

At the present time we do not have absolutely perfect systems, which are allowed to make a very effective realization and increase the adhesion coefficient.

The experience of leading companies and research institutes that do research in this field, shows that the application of microprocessor systems gives goods results for the control of adhesion processes in tractive and braking modes.

One of perspective solutions for this task is the development of methods of adhesion control and adjustment, which are based on data from diagnostics of noise for wheel-rail contact.

2. WHEEL-RAIL CONTACT

The adhesion force is realized on small surfaces of a rail-wheel contact. Many factors have an influence on an adhesion process for those surfaces (environment, pollution, parameters and technical conditions of railway vehicle, track etc.).

A very good review, analysis and mathematical description in the field of rail-wheel contact were made by Prof. Golubenko [1]. The linear dimensions of contact surfaces are really small in comparison with determining the dimensions of wheels and rails. Furthermore, these dimensions are changed in a very wide range depending on the wheel diameter, forces, which are brought from a wheel on a rail, materials of wheel tread and rail, and also on size deviations of wheels and rails from design drawing. These size deviations can be classified as technological defects or received from exploitation. But in any case, such definitions could be described as macro and micro geometric characteristics.

Macro geometry is described with a wheel diameter, which can be changed by wear process, wheal thread profile, different deviations from a correct cylindricity etc.

Micro geometry can be described with corrugation, roughness and sub micro roughness.

Friction and adhesion coefficients are related definitions, which determine the ratio of the tangential and normal forces. The difference between these two coefficients is that the friction coefficient characterizes the condition for the contact of two bodies, and the adhesion coefficient characterizes the properties for a tribological system that includes many elements. The vector of a slip velocity for wheels is different from their movement direction, a friction force is not equal to a tractive or braking force, and the normal load from a wheel to a rail is also not equal to the adhesion weight of a vehicle.

What is more, it is necessary to say, if the coefficient of sliding friction depends on the physical state of surfaces, then the adhesion coefficient is also dependent on construction characteristics of rail tracks and vehicles (a value of unaccounted slipping motion; a difference between wheel diameters of wheel pairs; conicity and eccentricity of wheels; track curvature; reallocation of loads between wheels; irregular loads of wheels for a wheel pair, a bogie, a car, a train; vibrations etc.).

The main theories of wheel-rail interaction consider only the interaction between two bodies. However, in real conditions, the third body is present in the contact. We can see from [2] that the presence of a third body has a different range of thickness from a few micrometers to several dozen micrometers. The third body makes contact interaction analysis more complex. Under these conditions, the third body has a major influence on friction and adhesion coefficient in the contact zone.

The friction coefficient can increase or decrease depending on the presence of a third body in a rail-wheel contact. As seen from article [3], the change of contact conditions is possible by means of directions and modification of friction surfaces.

It is necessary to say that at the present time we have no technologies for the determination of a friction coefficient at the moment of vehicle movement.

3. ROLLING NOISE

A large number of research works are being done for the detection and simulation of noise for railway transport at the present time. We can see from [4] on Figure 1 that there are three main railway sources with their relative strength, which are speed dependent:

- up to ~50 km/h, railway noise is dominated by traction noise which consists of motor noise and auxiliary noise;
- from ~50 km/h up to ~300 km/h, noise emission is dominated by rolling noise with a speed exponent of around 3;
- above ~300 km/h, aerodynamic noise becomes predominant with a speed exponent of around 6.

The wide range of speeds explains why most research efforts are focused on the rolling noise.

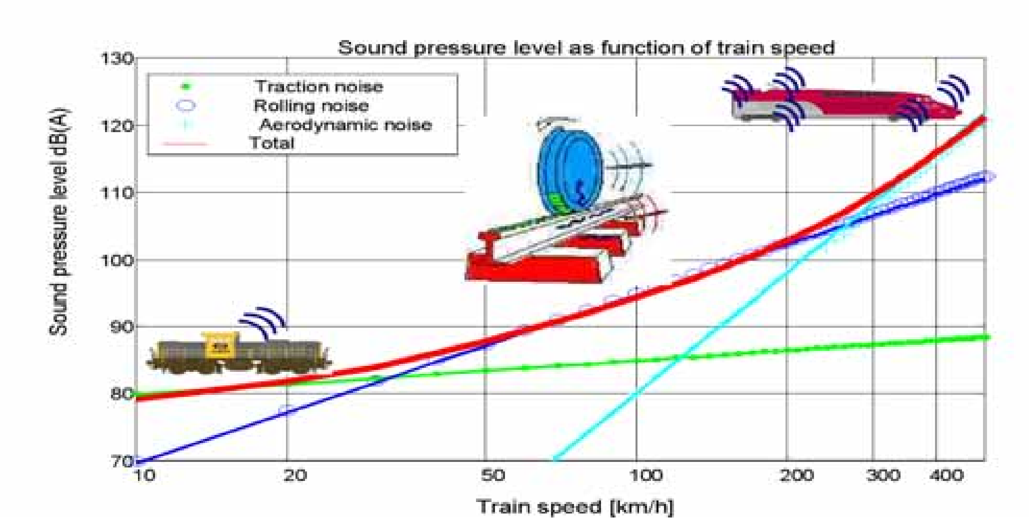

Figure 1. Relative strength and speed dependence of railway sources [4].

According to research in [4, 5], we have the factors which have a big influence on noise creation. The following factors can be split into three categories:

1. Parameters influencing the noise generation
   - Roughness (type of braking system and wheel maintenance, rail maintenance);
   - Contact patch (wheel load, wheel and rail profiles);
   - Number of wheels;
   - Wheels and rails defects (wheel flats and etc.);
   - Train speed, sleeper spacing, and statistical variation of mechanical characteristics of track components.
2. Parameters influencing the track radiation
   - Wave propagation (vertical and lateral decay rates, rail pad stiffness and damping loss factor);
   - Radiation efficiency of track (rail, sleeper, pad).

3. Parameters influencing the rolling stock radiation
   - Train speed;
   - Wheel characteristics (diameter, wheel vibration eigen modes).

These factors were accounted in the development of models for the prediction of rolling noise (for example, Twins and SFE ACUSRAIL). The modelling process allows the separate components of noise from the wheel, rail and sleeper to be identified. The flow diagram of rolling noise calculation for the TWINS model is shown in the Figure 2 [5].

From works describing these models, we can see that they use simplified mathematical models for the calculation of wheel-rail interaction. Application of these simplified models for noise calculation does not into account many parameters which have a big influence on the interaction process in the contact zone.

From research described in [6] for automotive transport, we can see that the conditions of surfaces have a big influence on noise level. Also, in [7] measurements were made in this field. The data for these measurements are shown in Table 1.

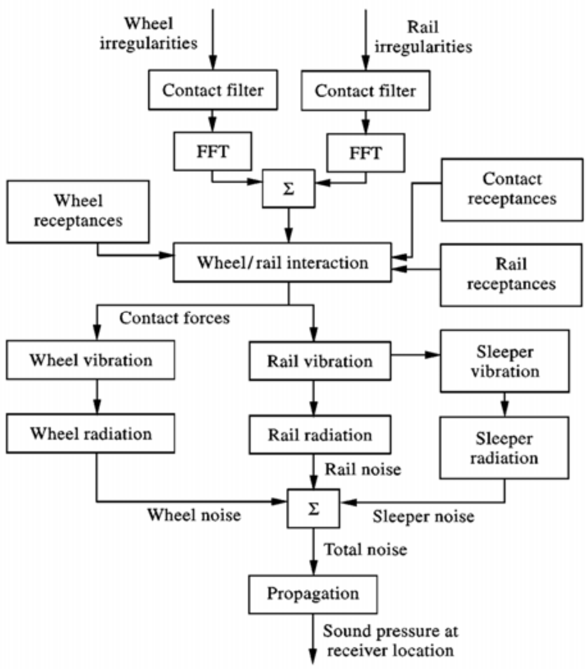

Figure 2. Flow diagram of the TWINS calculation model [5].

Table 1. Dependences of road roughness, adhesion coefficient, noise level and velocity for automobile transport.

Level of roughness	Minimal adhesion coefficient	Noise level, dB(A)	Maximal velocity, km/h
no roughness	≥ 0,35	50	90
low roughness	≥ 0.40	60	100
medium roughness	≥ 0.55	70	110
high roughness	≥ 0.60	80	120
extra roughness	≥ 0.65	90	150

Similar researches are being done in the field of railway transport. For example, the influence of the roughness of rail head on noise level is described in the work [8]. From this work, we can see that rail head roughness can have significant effects on levels of rolling noise from trains. This can be a major issue locally, as some trains can be 20 dB or noisier on very rough, or corrugated, rails than on smooth rails.

Therefore, we can make an analytic conclusion that the presence of a third body in the contact zone between a wheel and a rail should assist to change the friction coefficient in this contact, and it means that the friction coefficient has a big influence on a noise level in the contact zone.

Based upon what is written above, it is possible to develop an adhesion control system, that allows accounting for the adhesion characteristics depending on noise analysis in the rail-wheel contact.

4. ADHESION CONTROL SYSTEM

Principles and algorithms of existing adhesion control systems (anti-slip control systems) do not provide absolutely perfect adhesion between wheels and rails.

For more quality work of the adhesion control system it is required to know the value of an adhesion coefficient. In our case, we propose for the determination of an adhesion coefficient to use an acoustic diagnostic method of the contact zone.

For getting a noise spectrum, it is necessary to mount directional microphones in vertical and horizontal planes for scanning of noises.

For our proposed system, we can use control algorithms described in Patent UA65187 A B60T8/58. As distinct from the existing patent, the system can adjust the adhesion of railway vehicles in real-time mode by means of the correction data about adhesion coefficient which depends on noises in rail-wheel contacts.

The proposed control system is presented in Figure 3. The variables and parameters presented in Figure 3: F_a – adhesive force; T_m – real motor torque; T_{in} – input motor torque; ω_{wh} – real angular velocity of a wheel; ω_{ref}–reference angular velocity of a wheel; ε – relative slip; V_l – real locomotive velocity; V_{ref}–reference locomotive velocity.

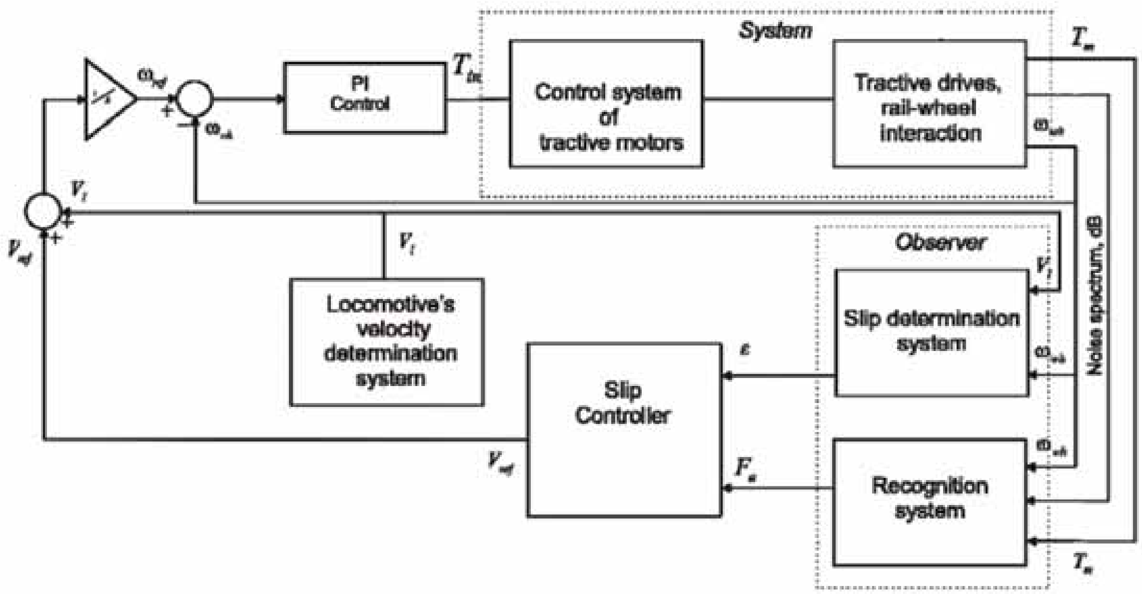

Figure 3. Block diagram of the adhesion control system.

As the base of our system, the relation of determination of adhesive force F_a between a wheel (wheel pair) of a railway vehicle and rail (rail track) was taken. This relation was received as the result of experimental and analytical researches. The proposed dependence also can be used for the equations of movement of a railway vehicle for modeling of adhesion processes between wheels and rails:

$$\vec{F}_a = N \frac{\vec{S}}{|\vec{S}|} / \left(A_1 / \exp(\varepsilon \cdot B) + A_2 \ln(\varepsilon \cdot B) + A_3 / (\varepsilon \cdot B) + A_4 (\varepsilon \cdot B) + A_5 \right) T_2 T_4 T_9 / T_7 T_8 \qquad (1)$$

where A_1, A_2, A_3, A_4, A_5 – coefficients of relation; $\vec{S}$ - vector of wheel slip; ε - relative slip, [%]; $B=T_1T_3T_5T_6$; T_1, T_2 – coefficients, which can be changed depending on noises in rail-wheel contacts; T_3, T_4 – vertical load coefficients; T_5 – velocity coefficient depended on a velocity of a locomotive; T_6, T_7 – coefficients, which are dependent on cross motion of wheel relative to the rail; T_8 – coefficient of angle of attack of the wheel; T_9 – braking mode coefficient, which are dependent on railway vehicle design.
In Table 2, the coefficients for the proposed dependence are listed. The variables presented in Table 2: μ - adhesion coefficient between a wheel and rail; N – weight load from a wheel to a rail, kN; v – vehicle velocity, m/s; y – cross motion of the wheel pair on track; φ - angle of attack.

Table 2. Coefficients of the relation (1) for different contact bodies.

	New wheel and new rail	Worn wheel profile and new rail	Worn wheel profile and worn rail profile
A_1	0,754629766265	-	-
A_2	-0,22379766858	-0,1419381	-0,193
A_3	2,2154859175	0,026201	0,0379415
A_4	0,0476785	4,3642	3,31448
A_5	2,218	2,0729	2,115
T_1	0,009+2.38μ	0,026+2.38μ	0,026+2.38μ
T_2	0,4164/μ	μ/0,40907	μ/0,406
T_3	$1/(9{,}18P^{0.479}$ -0,011) P	0,635+0,00368P	$12{,}4/(23{,}89371-0{,}16353P+0{,}000476P^2)$
T_4	$1{,}026-0{,}000194P-0{,}0000012P^2-0{,}0000000053P^3$, P	$0{,}9713+0{,}0003454P-0{,}0000005674P^2$	0,429348-0,0000696802P
T_5	$1/(3{,}498v^{-0{,}536}- 0{,}018)$, v	$(0{,}10108v-0{,}108)^{0{,}5}$	12,25/exp(-.523ln(v) +3,725)
T_6	-	$1{,}0002+0{,}1026y+$ $+0{,}002419y^2-0{,}000728y^3$, y[m]	$12{,}25/(0.0000050377/\exp(y)+$ $+0.000352571y^2+0.083)$, y[mm]
T_7	-	$0{,}99976+0{,}0059684y-0{,}00006288y^2+$ $+0{,}0000577856y^3$,y[m]	1/(0,00000747/exp(y) x x 0,00063638y +2.37), y [mm]
T_8	-	$1-0{,}0056\|\varphi\|(0{,}1057$ $+0{,}087y+0{,}01156y^2))$ φ [rad]	-

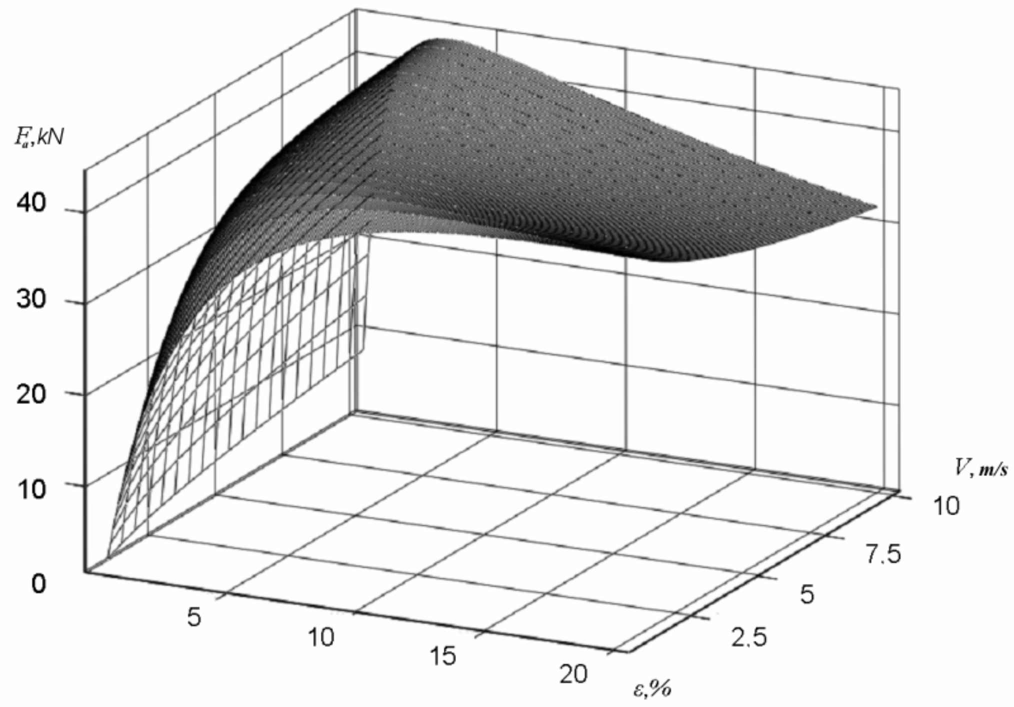

Figure 4. Calculated dependence of adhesion force F_a from relative slip ε, vehicle velocity V for new wheel and rail profiles of a railway vehicle

This relation is confirmed with a great deal of experimental research [9, 10]. The example of calculation with the relation (1) is shown in Figure 4.

The change of values for adhesion coefficient μ depending of noise in the contact zone allows adjusting values for coefficients T_1 и T_2.

The mathematical description and principles of the proposed adhesion control system are described in [11].

5. CONCLUSIONS AND FURTHER RESEARCH

The proposed design is able to develop an adhesion control system, which makes it possible to account for adhesion characteristics at the moment of vehicle movement by means of the detection of adhesion coefficient depends on noises in rail-wheel contacts.

The results of any theoretical researches and questions of design are always defined by values of their "output data", as well as the estimation of possibility for their practical application.

Therefore, it is necessary to do further research in the field of stability, robustness and convergence for the proposed system. Also, the system needs to be studied jointly with other systems of railway vehicles.

For more detailed study of the influence of the third body in the contact zone, much needs to be done to do experimental research on the dependence of adhesion coefficient from noises in rail-wheel contacts for different friction conditions. After that, it's necessary to improve the mathematical model of noise prediction by means of taking into account tribological characteristics of bodies' interaction.

Finally, to improve the results of the study and the proposed research and develop a more accurate definition of the values of noise spectrum and level, it is necessary to do a real test operation with high speed railway vehicles.

ACKNOWLEGMENTS

This research was partly supported by BK21 Program and Center of Innovative Design Optimization Technology (iDOT), Korea Science and Engineering Foundation.

REFERENCES

[1] A.L. Golubenko, Sceplenie kolesa s relsom, Kiev, 1993.

[2] Y. BERTHIER, S. DESCARTES, M. BUSQUET, E. NICCOLINI, C. DESRAYAUD, L. BAILLET, M. C. BAIETTO-DUBOURG, “The role and effects of the third body in the wheel-rail interaction”, Fatigue & Fracture of Engineering Materials and Structures, Volume 27, Issue 5 , 2004, pp. 423–436.

[3] Scherbak P.N., “Upravlenie processom treniya I scepleniya v sisteme koleso-rel’s”, Trenie i smazka v mashinah i mechanizmah, No. 6 , Moscow, 2006.

[4] *Rail Sources, Technical Report HAR12TR-020118-SNCF10, SNCF R*ESEARCH AND TECHNOLOGY DEPARTMENT PHYSICS OF THE RAILWAY SYSTEM AND COMFORT, France, 05 August 2002.

[5] D.J. Thompson, C.J.C. Jones, “A review of the modelling of wheel/rail noise generation”, *Journal of Sound and Vibration*, 231(3), 2000, pp. 519-536.

[6] U. Sandberg, “Tyre/road noise – Myths and realities”, *Proceedings of INTERNOISE 2001*, The Hague, The Netherlands, August 2001.

[7] “O primenenii polozhenij gosudarstvennogo standarta pri ustrojstve sherohovatyh poverhnostnyh obrabotok avtomobilnyh dorog”, official site OAO "SNPC "ROSDORTECH", 2001, http://www.rdt.ru/publications/tehnologija/

[8] *Rail and wheel roughness - implications for noise mapping based on the Calculation of Railway Noise procedure, Report number AEATR-PC&E-2003-002,* AEA Technology Rail, Derby, United Kingdom , March 2004.

[9] Golubenko A., Kashura A., Gorbunov N., Spiryagin V., Spiryagin M., “Results of experimental research of friction properties for a wheel-rail interaction with a friction machine”, Volume of Scientific articles, Omsk railway state university, Russia. - 2000. - p. 274-277.

[10] Spiryagin V. Improvement of dynamic interaction between the locomotive and railway track// PhD thesis on a speciality 05.22.07 – rolling stocks and train traction, East Ukrainian National University named after Volodymyr Dal, Lugansk, Ukraine, 2004.

[11] Spiryagin, M.; Vivdenko, Y.; Spiryagin, V. & Klipakov, M., “ANTI-SLIP CONTROL SYSTEM OF A LOCOMOTIVE”, *Annals of DAAAM for 2006 & Proceedings of the 17th International DAAAM Symposium*, Vienna, Austria, 2006, pp. 387-388.