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Determination of the dynamic characteristics of locomotive drive systems under re-adhesion conditions using wheel slip controller

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Stick-slip vibration theory

Stick-slip vibration mechanism

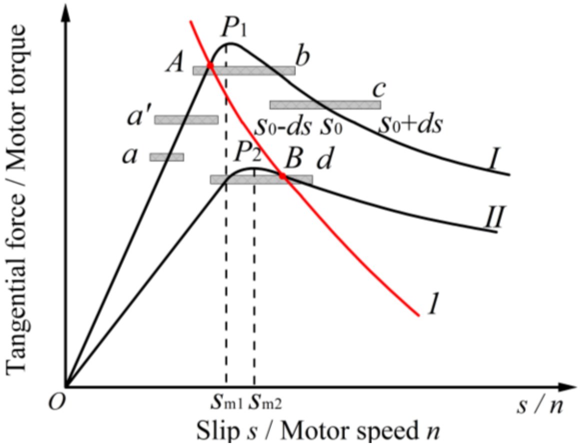

Fig. 1. Stick-slip vibration mechanism.

$$s = \frac{v - \omega r}{v} = 1 - \frac{(\omega_0 + \dot{\theta})r}{v_0 + \dot{x}} \qquad s = s_0 + ds$$

1 — the mechanical characteristics of traction motor
I, II — the different adhesive characteristics curves
a — stick state
b, *d* — stick-slip state
c — slip state

Stick-slip vibration characteristics

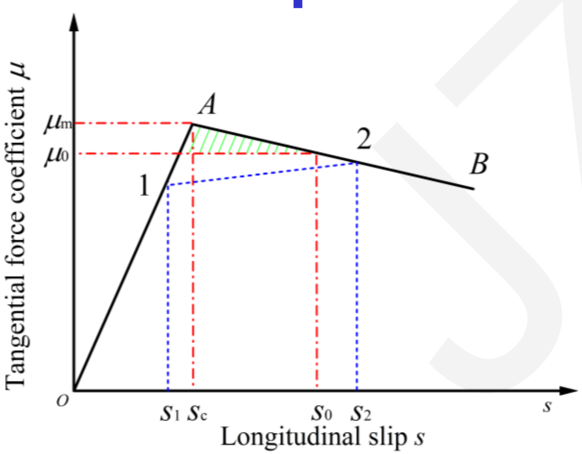

Fig. 2. Stick-slip vibration characteristics.

$s \le s_c$, rotary vibration acceleration of wheelset is negative

$s > s_c$, rotary vibration acceleration of wheelset is positive

$\mu \le \mu_0$, longitudinal vibration acceleration of wheelset is negative

$\mu > \mu_0$, longitudinal vibration acceleration of wheelset is positive

Model and Simulation conditions

■ Drive system model

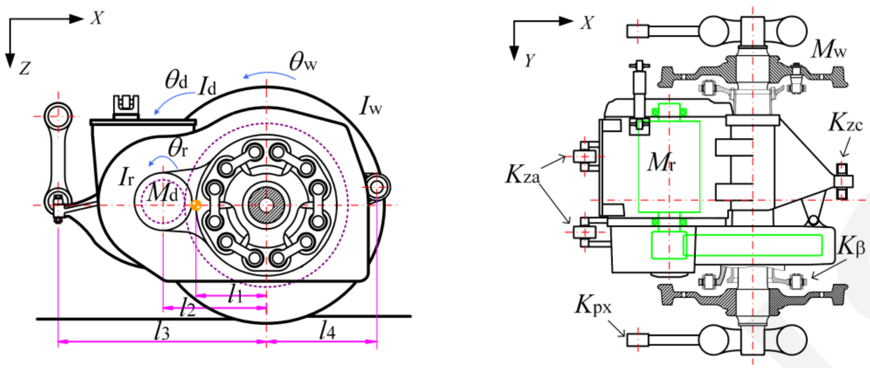

Fig. 3. Frame suspension drive system model.

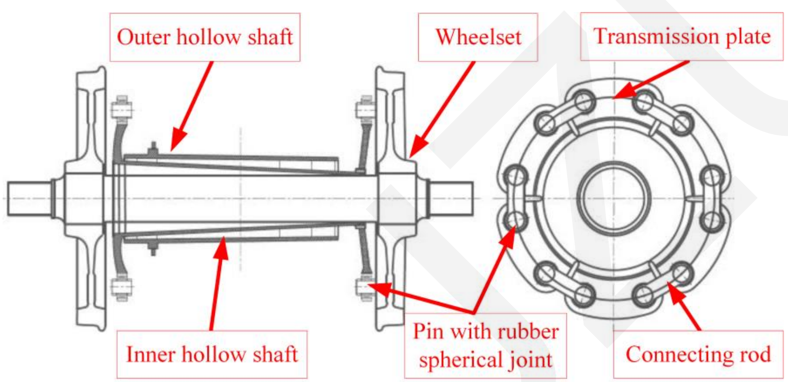

Fig. 4. Six-bar double hollow shaft transmission device.

Symbol	Physical meaning
M_w	Mass of wheelset
I_w	Pitch inertia of wheelset
M_d	Mass of motor stator
I_d	Pitch inertia of motor stator
M_r	Mass of rotor
I_r	Pitch inertia of rotor
l_1	Longitudinal distance from mass center of drive system to wheelset
l_2	Longitudinal distance from rotor to wheelset
l_3	Longitudinal distance from motor suspension rod to wheelset
l_4	Longitudinal distance from motor reverse suspension rod to wheelset
K_β	Torsional stiffness of six-bar double hollow shaft coupling
K_{px}	Longitudinal axle guidance stiffness

Model and Simulation conditions

■ Dynamic simulation model

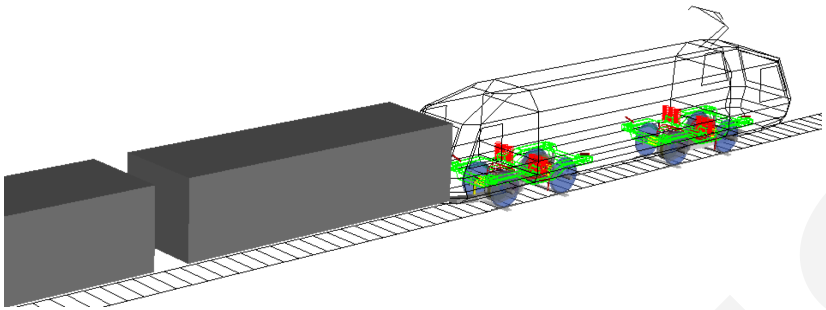

Fig. 5. Train system model.

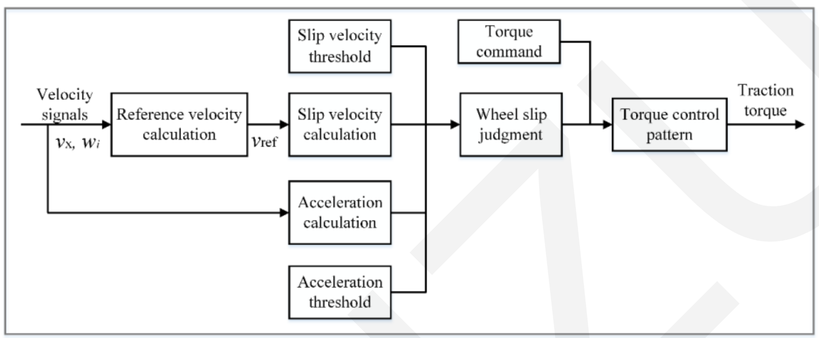

Fig. 6. Control strategy.

Symbol	Physics mean	Value
a_t	Acceleration threshold (m/s^2)	0.5
v_{st}	Slip velocity threshold (m/s)	1
r_d	Slope of torque reduction stage (N m/s)	2000/5000/10000/40000
t_k	Fixed torque time (s)	0.1/0.2
r_1	Slope of torque recovery stage 1 (N m/s)	3000
r_2	Slope of torque recovery stage 2 (N m/s)	1500
r_3	Slope of torque recovery stage 3 (N m/s)	600

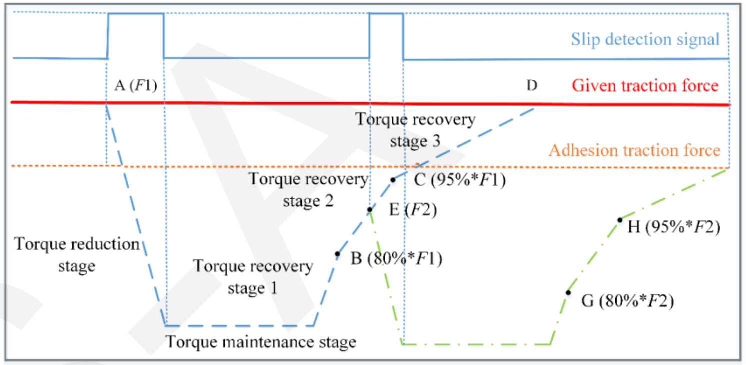

Fig. 7. Torque control pattern.

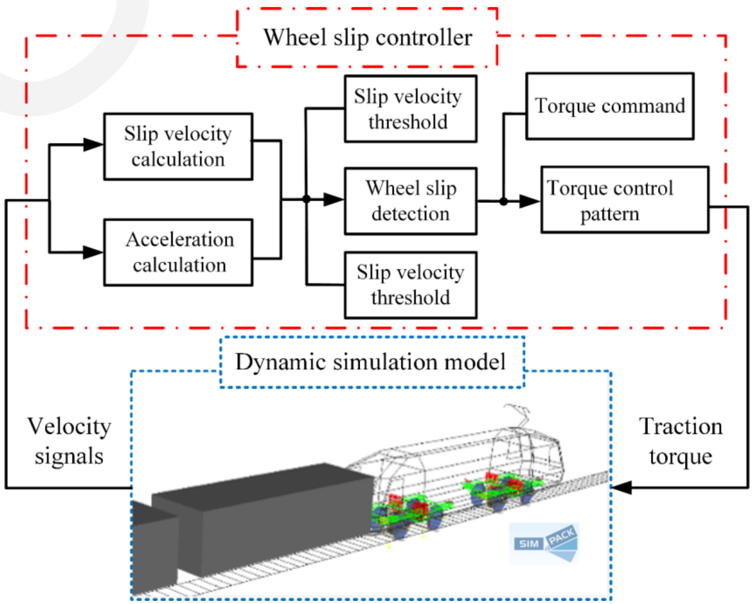

Fig. 8. Co-simulation model.

Results and discussion

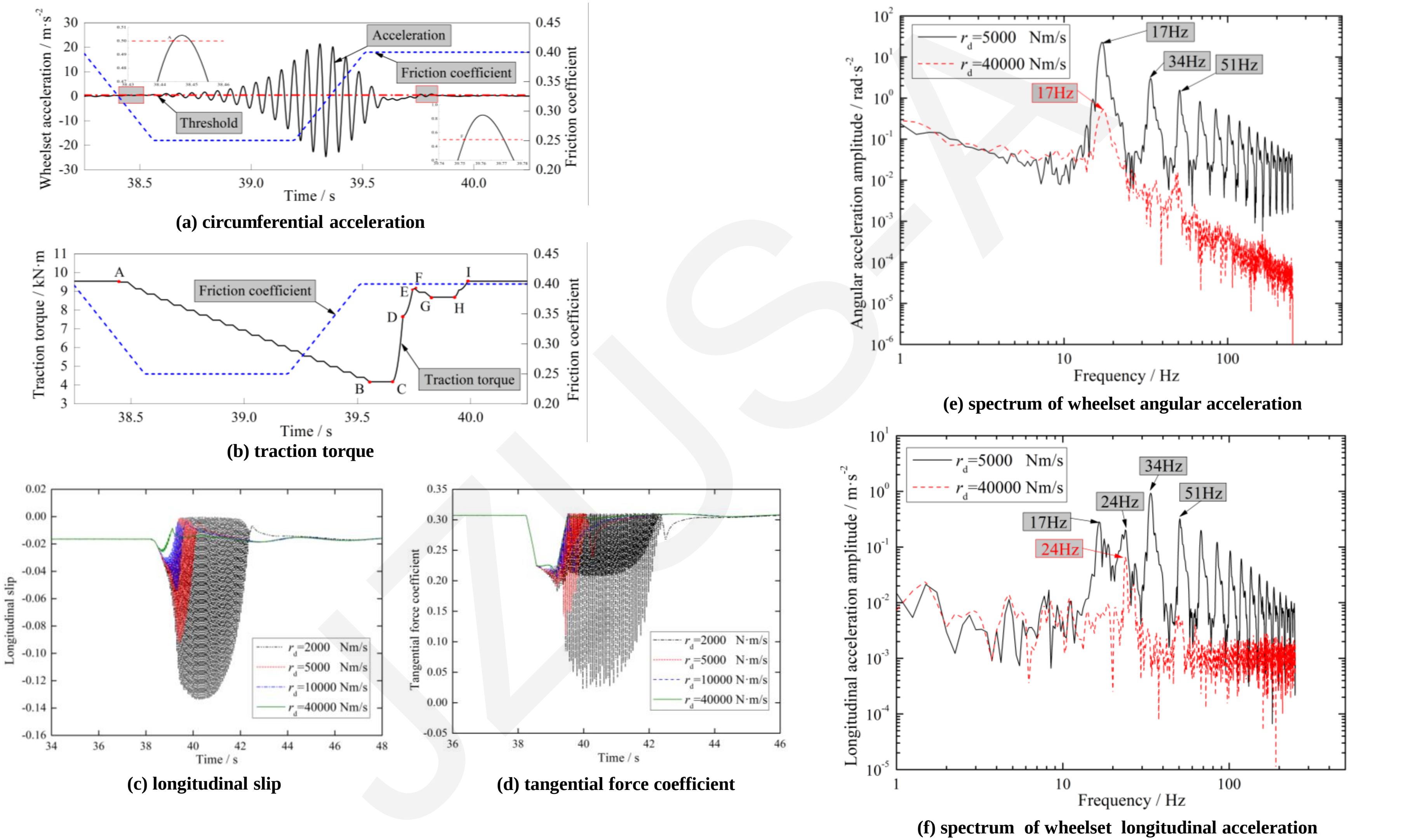

Fig. 9. Simulation results under constant speed condition.

Results and discussion

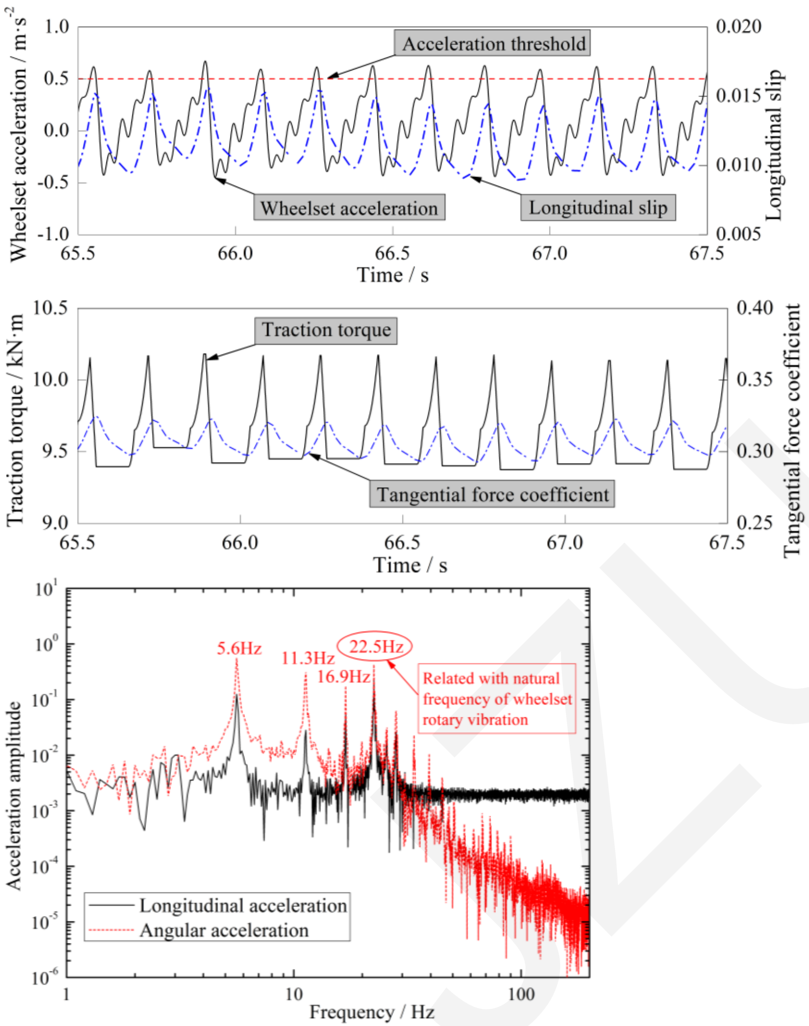

Fig. 10. Simulation results under starting condition (t_k=0.1s, K_β=8 MN·m/rad).

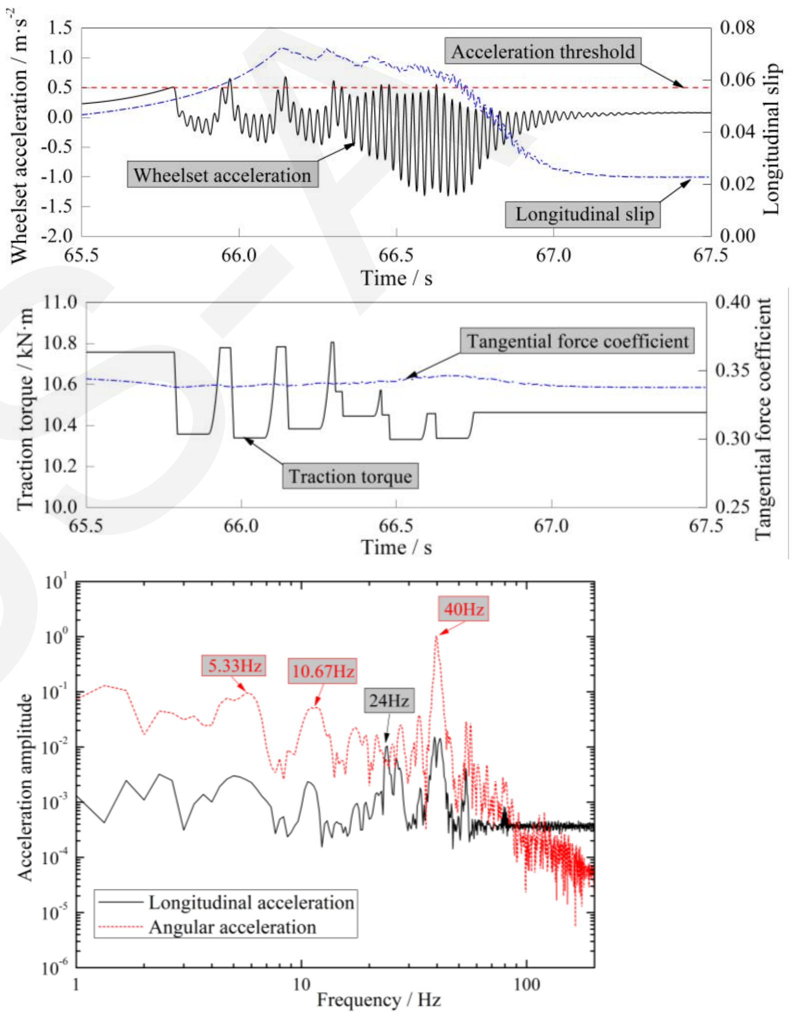

Fig. 11. Simulation results under starting condition (t_k=0.1s, K_β=30 MN·m/rad).

Results and discussion

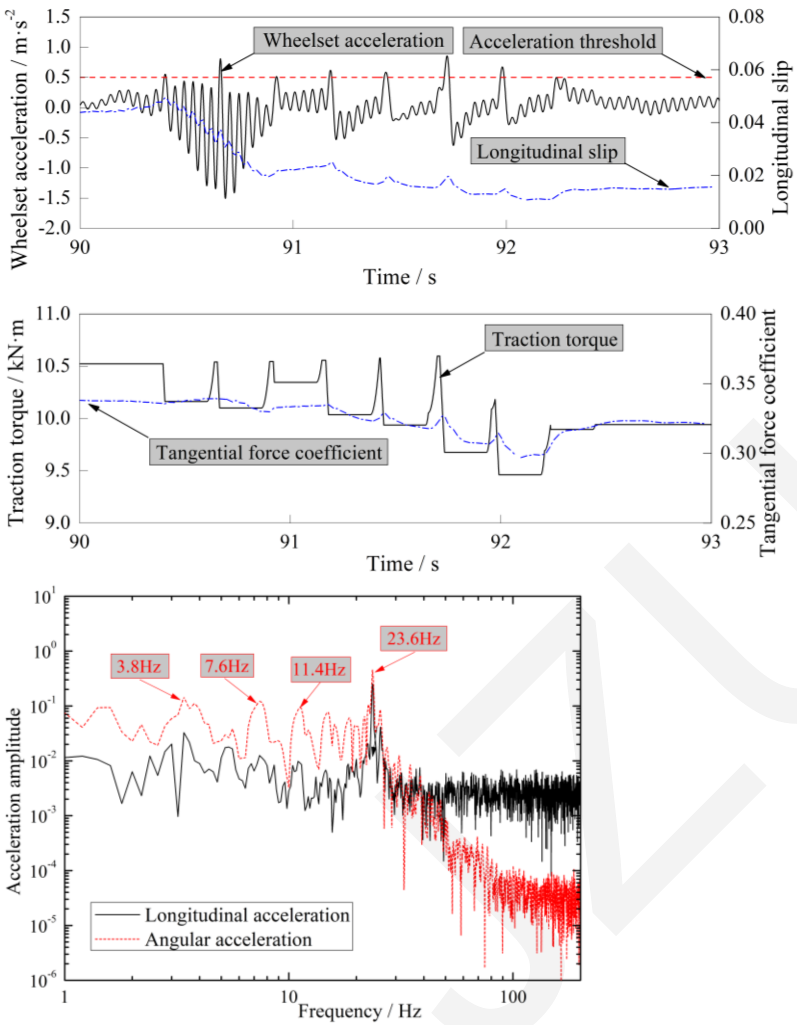

Fig. 12. Simulation results under starting condition (t_k=0.2s, K_β=8 MN·m/rad).

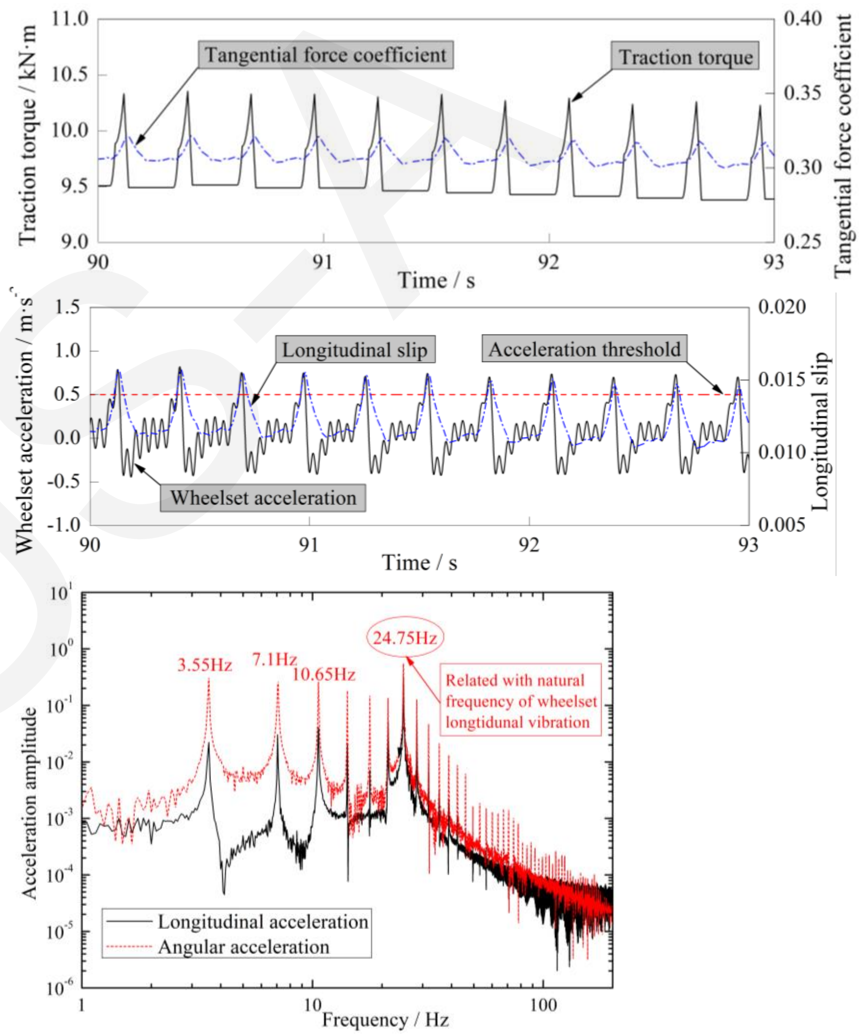

Fig. 13. Simulation results under starting condition(t_k=0.2s, K_β=12 MN·m/rad).

Conclusions

- The stick-slip vibration is characterized by the natural vibration of drive system, and the longitudinal and rotary vibration of wheelset are coupled by wheel-rail tangential force when stick-slip vibration occurs, which brings about some complex frequency components.

- The stick-slip vibration can be suppressed by rapidly reducing the energy input to the system, such as rapid reduction of traction torque. The structural stiffness of the drive system has significant influence on the acceleration performance of locomotive. In general, higher traction effort and greater average starting acceleration can be obtained if a larger torsional stiffness of six-bar double hollow shaft coupling is adopted. Moreover, a large primary longitudinal stiffness is favorable for high traction effort as well.

- The wheel slip controller plays a quite important role in re-adhesion performance and acceleration performance of the locomotive. The unreasonable matching of wheel slip controller and driving system structural stiffness can lead to the unreasonable electro-mechanical coupling vibration of driving, which should be avoided during the design process of bogie system and wheel slip controller.