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STUDY ON THE CONTROL METHOD OF HIGH-SPEED TRAIN TRACTION MOTOR CONTINUOUS LOAD

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ABSTRACT

Load torque of the high-speed train traction motor is discussed in this paper, including constituent elements of the load torque（Hyung-Min Ryu etal.,2002） and how to simulate the torques. This paper establish the mathematical model of the traction motor from the energy point of view, the equivalent damping torque and the equivalent inertia loads has been obtained under continuous load conditions(Akpolat etal.,1999). In order to emulate the actual operation, algorithms were tested and verified with the use of Matlab/Simulink first, and then a emulation platform was built under laboratory conditions, the platform is consisted by two induction machines and a small flywheel. Experiments of emulating a high-speed train traveling on certain given line is executed with the use of the DASPACE system.

KEYWORDS

High-speed train; load simulation; traction motor; load torque.

INTRODUCTION

Nowadays, high-speed train is playing a more and more important role in Chinese daily life, because of the widely used of high-speed train, we need to carry out a more general study of traction drive system on condition of continuous operation, while with certain limits, some experiments especially experiments about high-speed train traction motor can not be done on actual train, so a continuous load emulation platform would be a good choice, we can use a motor to play the role of the train traction motor, and with the help of another motor or mechanisms, we can provide load torque for the traction motor, which can help the traction motor simulate the actual operation. Via the platform, we can obtain reference experimental data under laboratory conditions without experiment on the actual train, by which we can do analysis and research on traction motor's characteristic and control methods of the traction system. It overcomes the shortcomings of actual-train experiments such as the high cost, low feasibility, hard to change the outside conditions of the train and long cycle of a complete test. Based on DSPACE system, a 5.5kW load emulation platform is built, in accordance with the same acceleration time, the continuous load emulation experiments on given line is finally achieved on this platform.

ANALYSIS ON LOAD TORQUE

Constituent elements of the load torque

The basic physical model:

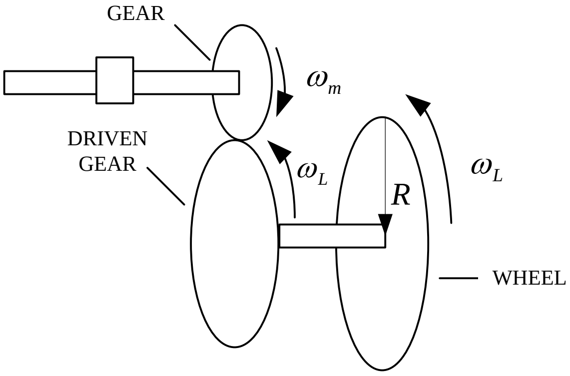

Fig. 1 The structure of traction system

From Fig.1 we can obtain the single motor's energy distribution of traction system:

$$W = \frac{1}{2}J_m\omega_m^2 + \frac{1}{2}J_w\omega_L^2 + \frac{1}{2}m(R*\omega_L)^2 + \frac{f}{N_\mathrm{m}}*(R*\omega_m)*t \tag{1}$$

J_m is the sum of rotational inertia of traction motor and initiative operator, J_w represents sum of rotational inertia of wheel and driven operator, f represents total damping of the vehicles, N_m stands for number of traction motors, m means maneuvering quality of single axle. Take ratio of gear i_g and gear drive efficiency η_Gear into consideration:

$$W = \frac{1}{2}\omega_m^2(J_m + \frac{J_w}{i_g^2\eta_{Gear}} + m\frac{R^2}{i_g^2\eta_{Gear}}) + f*(R*\omega_m)*t\frac{1}{\eta_{Gear}N_m i_g} \tag{2}$$

Hypothesis:

$$T_{Lf} = \frac{R}{\eta_{Gear}N_m i_g}f \tag{3}$$

$$\hat{J} = J_m + \frac{J_w}{i_g^2\eta_{Gear}} + m\frac{R^2}{i_g^2\eta_{Gear}} \tag{4}$$

$$T_{Ld} = \hat{J}\frac{d\omega_m}{dt} \tag{5}$$

From (3)、(4)、(5), we can obtain mathematical formula of the traction drive system:

$$T_m - (T_{Lf} + T_{Ld}) = J_m\frac{d\omega_m}{dt} \tag{6}$$

$$T_L = (T_{Lf} + T_{Ld}) = (J_m + \frac{J_w}{i_g^2\eta_{Gear}} + m\frac{R^2}{i_g^2\eta_{Gear}})\frac{d\omega_m}{dt} + \frac{R}{\eta_{Gear}N_m i_g}f \tag{7}$$

As you can see in the formula (7), constituent elements of the load torque would be inertia torque and damping torque. In order to build simulation system we must know how to simulate inertia torque and damping torque respectively(Temeltas etal.,2001).

How to simulate damping torque

Research on damping shows that it can be divided into basic damping、 additional damping、 start damping，in accordance with its causes(Rodic, M etal.,2004). Because they are directly proportional to the weight of the train and they all can be calculated by the empirical formula, while analyzing damping load, this paper take only basic damping into consideration.

Direction of damping load is always opposite from the direction of the speed, and basic damping and speed meet the following empirical formula:

$$f = a + bv + cv^2 \tag{8}$$

The values of a, b, c depend on different situations. With the use of Matlab/Simulink, it is easy to achieve the goal of simulating damping torque, so this paper does not focus on how to simulate damping torque.

How to simulate inertia torque

Inertia torque is not like the damping torque, its value and orientation change while the value and orientation of speed change. This paper analyzes the inertia torque based on electric power simulation, which means we try to simulate the inertia torque by a load motor(Betz,R.E etal.,1994) with the use of DSPACE.

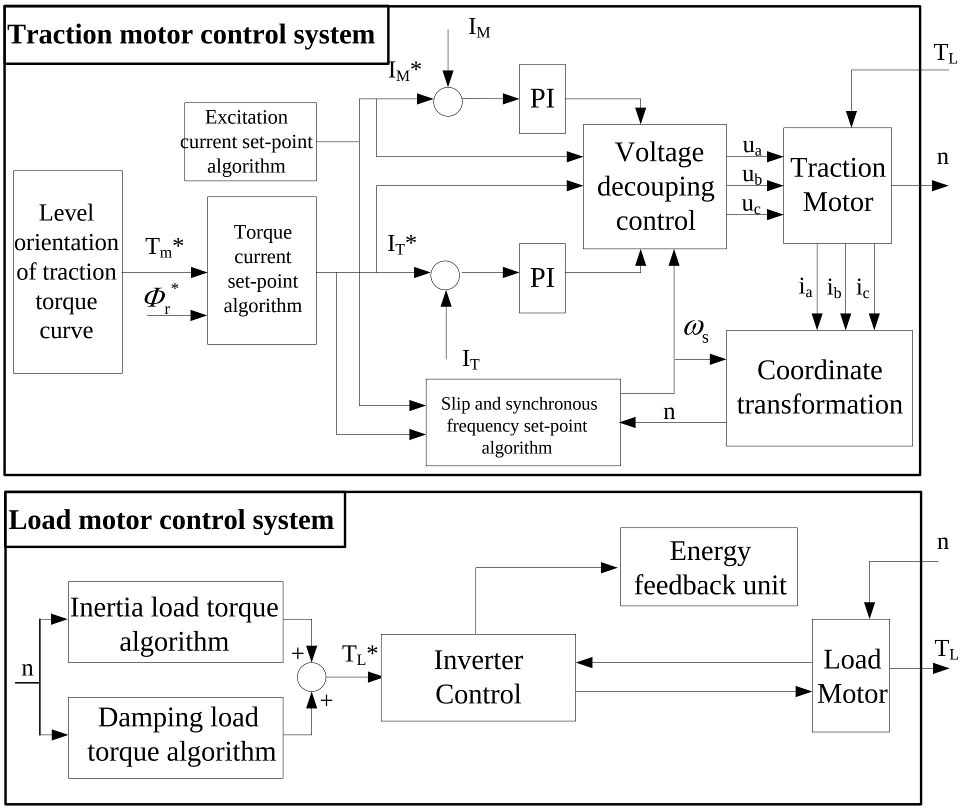

Fig.2 Block diagram of the system control algorithm

Ignore effects of damping load, consider only the inertia load, traction motor output torque and speed meet the following formula:

$$\frac{\Omega}{T_e}=\frac{1}{J^{'}s} \tag{9}$$

$J^{'}$ is the total inertia that needs to be simulated. T_e is the traction motor output torque.

Considering that the control method of load motors is vector control, control block diagram for the load motor is obtained:

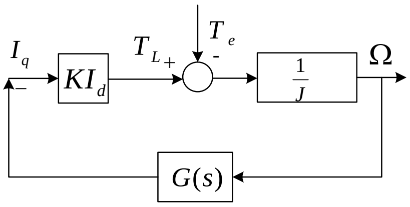

Fig.3 Schematic diagram of motor control with current regulator

System transfer function:

$$\frac{\Omega}{T_e}=\frac{1}{(J+\frac{KI_dG(s)}{s})s} \tag{10}$$

Because traction motor and load motor are connected by a shaft, so they share the same speed, it means if look from the load motor side, (9) is also correct, so for (9) and (10), they are equal both on the left side of the equal sign and the right side. We can obtain:

$$G(s)=-(\frac{J_N}{KI_d})s \tag{11}$$

$$J^{'}=J+J_N \tag{12}$$

(11) is a complete integrator, incomplete integrator can work better than that, so (11) can be change into:

$$G(s)=-(\frac{J_N}{KI_d})\frac{s}{1+\tau_N s} \tag{13}$$

τ_N is the filter time constant. System transfer function become:

$$\frac{\Omega}{T_e}=\frac{1}{(J+J_N)s}\frac{(1+\tau_i s)(1+\tau_N s)\frac{J+J_N}{J\tau_N\tau_i}}{\frac{J+J_N}{J\tau_N\tau_i}+\frac{(\tau_N+\tau_i)}{\tau_N\tau_i}s+s^2} \tag{14}$$

The only unknown parameter in the formula is τ_N. If its value is obtained then the inertia controller is built.Make use of closed-loop characteristic function:

$$D(s)=\frac{J+J_N}{J\tau_N\tau_i}+\frac{(\tau_N+\tau_i)}{\tau_N\tau_i}s+s^2 \tag{15}$$

Remove two zeros and then compared with typical second-order transfer function:

$$G(s)=\frac{\omega_n^2}{1+2\xi\omega_n s+\omega_n^2 s^2} \tag{16}$$

$$\xi=\frac{1}{\sqrt{2}} \tag{17}$$

Define the inertia time constant:

$$\tau_{inertia}=\frac{1}{\omega_n} \tag{18}$$

From (15) (16)(17)(18), we get the relationship between τ_N and $\tau_{inertia}$:

$$\tau_N=\tau_{inertia}\sqrt{(1+\frac{J_N}{J})[\frac{J_N}{J}+\sqrt{(\frac{J_N}{J})^2-1}]} \tag{19}$$

The value of J_N is far greater than J, then (19) is approximate to the following formula:

$$\tau_N=\sqrt{2}\tau_{inertia}\frac{J_N}{J} \tag{20}$$

SIMULATION AND EXPERIMENT

Experimental platform and emulation target

Under laboratory conditions, we connected two identical induction machines and a flywheel by shaft to build a continuous load emulation platform, which is used to emulate CRH_{2A} EMUS actual operation. Because the power rating of the experimental motor is different from the traction motor of CRH_{2A} EMUS, we must run the experiment after scaling.

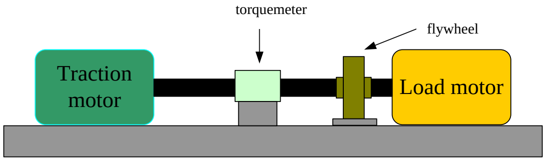

Fig.4 Model of load emulation system

Tab.1 Equivalent torque and rotate speed
(Based on ten notch traction curve of CRH_{2A} EMUS).

	Experimental motor	CRH_{2A}EMUS traction motor
Start torque($N \bullet \mathrm{m}$)	7.8	1560
Rotate speed($r/\min$)	1450	6000

From Tab.1, we can see the torque scaling factor: $k_t = \dfrac{1560}{7.8} = 200$ .speed scaling factor: $k_t = \dfrac{6000}{1450} \approx 4.1$, and When rotate speed of CRH_{2A} is $6000\,r/\min$,it travel $300\,km/h$, according to the same conversion factor we can obtain when when rotate speed of CRH_{2A} is $5000\,r/\min$, it travel $250\,km/h$. According to the laboratory motor and traction motor of CRH_{2A} EMU data, we obtain the value of inertia that needs to be simulated by electric power under Laboratory conditions:

$$J_{ad} = 10.2kg \bullet m^2 \tag{21}$$

Simulation

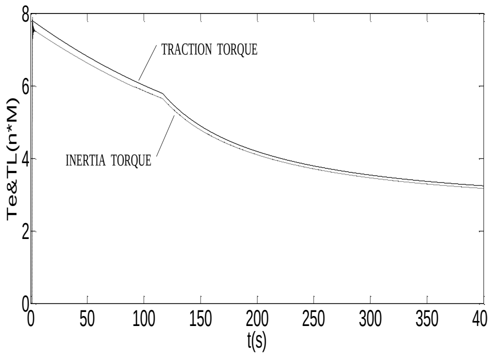

Fig. 5 Traction torque and load torque of traction course

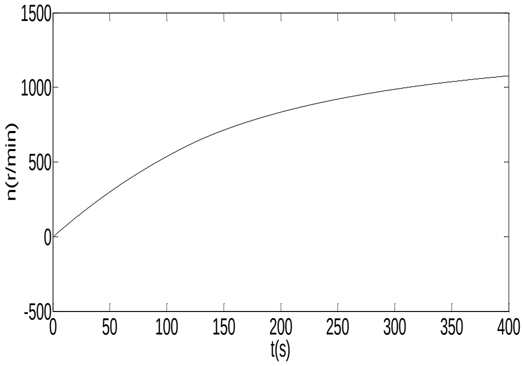

Fig. 6 Relationship of speed and time

For CRH_{2A} EMUS, ten notch traction curve would help it accelerates from 0 to 250 km/h in 375s, from Fig.6 we can see that simulation based on laboratory conditions, speed accelerates from 0 to 1190 $r/\min$ in 375s, transfer the rotate speed into real train speed with the help of speed scaling factors: $V = \dfrac{1190 * k_v * 300}{6000} = 243.95 km/m$. Their error is 6.05 km/h.And from Fig.5, we can see the traction start torque (solid line) is nearly 7.8 $N \bullet \mathrm{m}$, which means when transfers into real torque for CRH_{2A} it match with $T = 7.8 * \mathrm{k}_t = 1560\,N \bullet m$. Results of simulation are basically consistent with the actual train operation.

Simulation and experiment on given line

Ta.2 Given line condition

	$T_{\max}$ traction	Cruising mode	Cruising mode	Cruising mode

Line conditions	Flat and straight road	Flat and straight road	Uphill	Downhill
Running distance	0-8km	8-10km	10-16km	16-22km

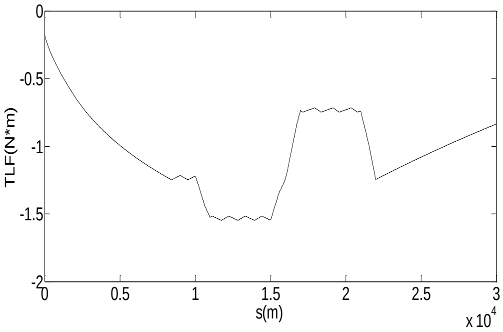

Fig.7 Relationship between damping torque and distance

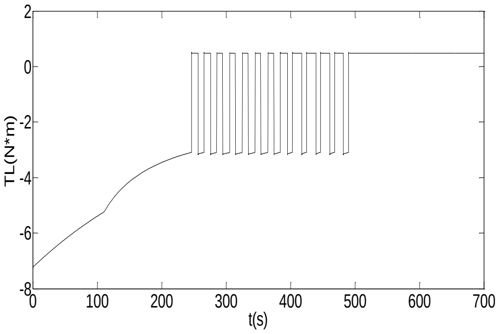

Fig. 8 Relationship between load torque and time

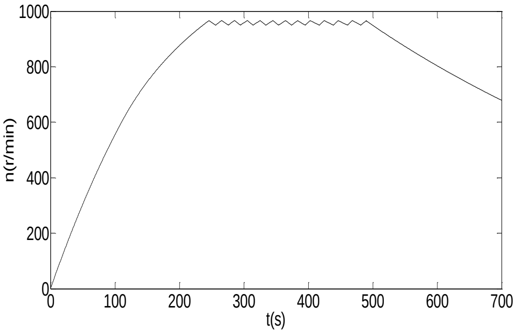

Fig. 9 Relationship between speed and time

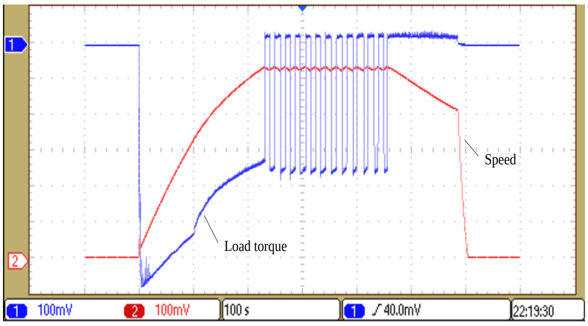

Fig.10 load torque and speed

These figures shows the speed, the damping torque and inertia torque curve during the straight road traction, uphill, downhill, flat and straight line when coasting. Fig. 7 shows that damping torque is different on different line conditions and its orientation is always the opposite from the speed.In Fig. 10 each unit of the horizontal axis represents 100s. Each unit of Oscilloscope channel one (blue) axis represents 100 mV (1 $N \bullet \mathrm{m}$), and that of channel II (red) vertical axis represents 100 mV. In the first 236s, the system is in the process of traction, traction motor torque output by ten notch, and the speed accelerates from 0 to 970 $r/\min$ (corresponding to the actual speed of 202km / h),which you can see both from the simulation figure 9 and experimental figure 10(red line), when after traveling 10km, it meet a uphill, from figure 7 you can see the damping load torque increase, at that moment it is at cruising mode, from both figure 9 and figure 10 we can see the speed vary between 950 $r/\min$ and 970 $r/\min$,load torque in figure 8 and figure 10 share the same vary trends. When meet the next downhill the damping decrease as it is show in figure 7.From 490s to 612s it is at coasting state until its speed is 750 $r/\min$.

From the figures shown above, we can see the figures of simulation closely meet the figure of experiment.

CONCLUSIONS

Based on laboratory conditions, this paper analyze the load torque of high-speed train, and via the simulation and experiment this paper tested and verified the mathematical model control algorithm that was established. Seen from the compared results between simulation and experiment, the emulation system can emulate the CRH$_{2A}$ EMUS actual operation. With the help of the emulation platform we can do further research from which we can acquire performance index and experimental data of assumed programs and disturbance conditions to improve the traction drive system structure and control methods, is meaningful.

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