

Study on Motor Characteristics due to Deviation of the Wheel Diameters with Parallel Operation

Hyung-Woo Lee[†]

Abstract – It is desirable and advantageous to feed parallel propulsion with induction motors by a single voltage source inverter. However, effects of deviation of the wheel diameters on motor current, rotor speed and torque should be also considered for parallel operation. In order to understand the behavior and characteristics, a simple simulation model is developed by using a commercial Matlab Simulink. From the results, it is clear to manage the diameter deviation of the wheels which are connected to traction motors.

Keywords: Deviation of wheel diameters, Parallel operation, Traction motors, 1C2M

1. Introduction

A synchronous motor fed by a CSI(Current Source Inverter) has frequent maintenances for slip-ring and high possibility of mechanical fault. In addition, each inverter per synchronous motor is required. As induction motor has been dramatically developed, compactness, high-speed operation, high power factor, and high efficiency have been achieved for traction drives. As railway traction motors are equipped with several motors it is desirable to control them with only one inverter to reduce size, weight and cost of the main propulsion system.

However, parallel operation with induction motors fed by a VSI(Voltage Source Inverter) has different motor speeds and loads due to different wheel diameters and adhesion characteristics between front and rear wheels in traction drives.

Table 1. Specifications of the railway propulsion system

Variables	Metro	KTX	KTX-II
Propulsion type	1C4M	1C1M	1C2M
Traction motor	IM	SM	IM
Inverter	VSI	CSI	VSI
Total power	210kW×24	1.13MW×12	1.1MW×8
Rated current	136A	696A	718.6A
Maximum speed	5,780rpm	4,000rpm	4,300rpm

* IM : Induction motor, SM : Synchronous motor
VSI : Voltage source inverter, CSI : Current source inverter

Therefore, it cannot be overlooked that the characteristics of torque, current and speed of the propulsion system, particularly for common VSI drives with 1C2M (One Controller Two Motors). Table 1 introduces the specifications of Korean railway propulsion systems briefly. Urban subway and KTX-II have parallel operation and

KTX has single operation propulsion system.

2. Parallel Operation and Its Characteristics

Several motors with a VSI always have load unbalance because diameters of the front and rear wheels cannot be symmetric perfectly. In order to minimize the currents and torque unbalance in parallel operation, slip of the motors is generally bigger than that in single operation but it increases secondary copper loss and decreases motor efficiency. This unbalance characteristic is worse in high-speed operation than in low-speed operation. Besides, vector control based on one rotating position of a rotor has always carried the torque unbalance because the positions of the rotors are different.

2.1 Deviation of the wheel diameters

Even though the wheel diameter is managed within certain constraints, deviation is occurred all the time by spinning with no traction, sliding, friction, adhesion, and so on [1]. Once the deviation is occurred, it is getting worse and period of the wheel turning is getting shorten. In general, the deviation of wheel diameters is managed within 6[mm] from 880[mm] of wheel in case of 1C2M and 20[mm] from 920[mm] of wheel in case of 1C1M to prevent torque unbalance but detailed characteristics should be taken into account. Besides mechanical constraint of maintenance such as wheel turning, increase of the rated slip is one of ways to prevent torque unbalance as well but it reduces the efficiency.

2.2 Characteristics of parallel operation

Fig. 1 shows two different sizes of wheels (Here, $0 < x < 1$). In case the diameter of wheel 'A' is bigger than that of

[†] Corresponding Author: Advanced Traction and Noncontact feeding System Research Team, Korea Railroad Research Institute, Korea. (krhwlee@krri.re.kr)

Received: February 15, 2012; Accepted: June 15, 2012

wheel 'B', the speed of the motor 'A' which is connected to wheel 'A' is lower than that of the motor 'B' which is connected to wheel 'B'. Because the speed of motor 'B' is bigger, the induced voltage of the motor 'B' is bigger than that of the motor 'A'. From a common VSI, the current of motor 'B' is smaller than that of motor 'A' according to the voltage equation. This bigger current of motor 'A' produces bigger torque and the wheel 'A' gains traction force mainly. Therefore, wheel 'B' will slide and be worn out gradually. As a result, this trapped in vicious cycle.

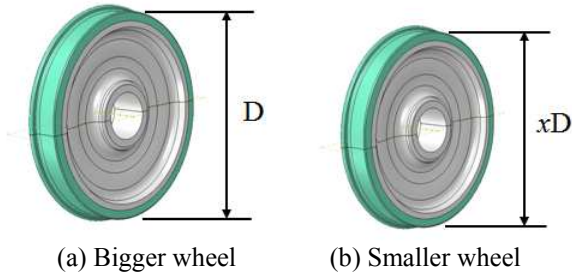


Fig. 1. Deviation of the wheel diameters

Eqs. (1)-(7) represents the electrical equations and Eqs. (8)-(10) represents the mechanical equations of both motors in parallel operation, respectively.

$$D_A > D_B \quad (1)$$

$$\omega_A < \omega_B \quad (2)$$

$$E_A < E_B \quad (3)$$

$$I_A = \frac{V - E_A}{R} > I_B = \frac{V - E_B}{R} \quad (4)$$

$$Torque_A > Torque_B \quad (5)$$

$$Wear_A < Wear_B \quad (6)$$

$$D_A \gg D_B \quad (7)$$

D : Diameter of the wheel
 ω : Rotating speed of the motor
 E : Electromotive force

$$\frac{T}{r} = \frac{T_A}{r_A} + \frac{T_B}{r_B} \quad (8)$$

$$\omega = \int (T - T_L - R_w \omega_m) / J dt \quad (9)$$

$$r_A \omega_A = r_B \omega_B = r \omega_m \quad (10)$$

Besides, for vector control, position information of the rotor flux should be calculated or measured. Nevertheless, vector control is performed by one of position information because both position information of two motors are different [2-5]. Therefore, precise vector control cannot be achieved inherently and the situation is steadily worsening.

2.3 Modeling of 1C2M

In order to understand the behavior of motors in parallel operation, the model of the system as described in the previous chapter is developed as shown in Fig. 2.

The traction motors are described by means of space vector variables in a stationary reference frame. The rotor speed is measured by one of motors and speed controller controls it. Both SVPWM inverter and rectifier are treated as ideal switches [6].

For simple analysis, small induction motors and drives which are provided by Matlab Simulink, are used in the simulation. The nominal power rating of the motors is 2,238[VA]. The speed reference is 2000[rpm] and load torque is 17[Nm]. Wheel diameter is assumed 880[mm] which is used for urban subway, and the deviation is assumed as 2, 4, 6, 8, 10, 30 and 50[mm]. In the case of 880[mm] of wheel diameter and 1:4 of gear ratio(ρ), the speed of the train would be around 83[km/h].

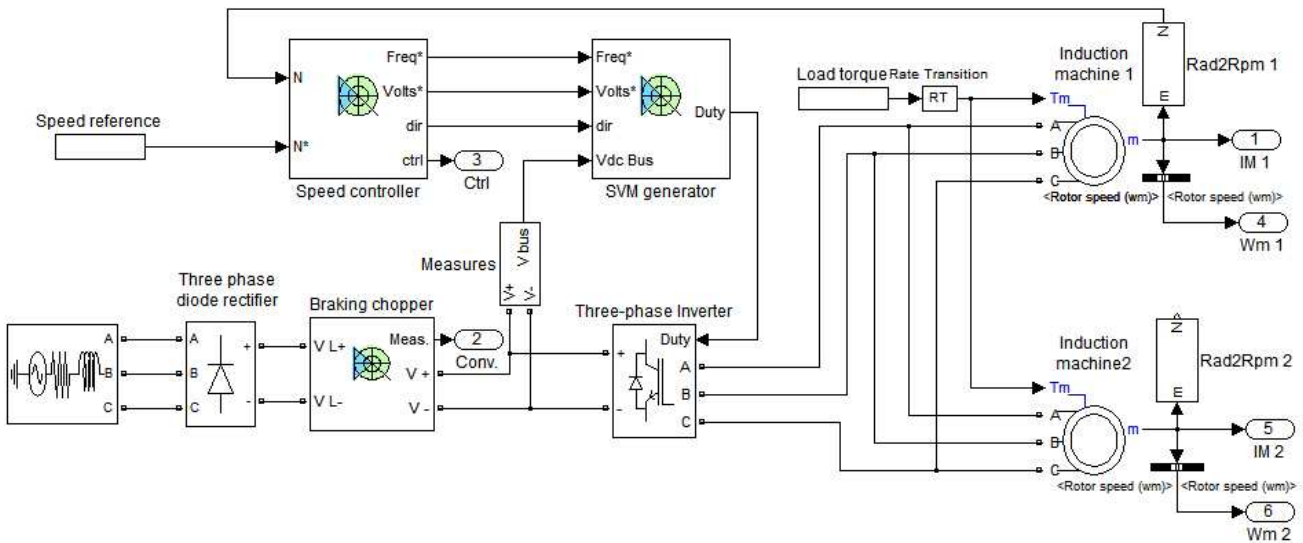


Fig. 2. Diagram of the 1C2M

$$\begin{aligned}
 \text{Velocity [km/h]} &= \frac{\omega_{rpm}}{\rho} \times D \times \pi \times 60 \times 10^{-6} \\
 &= \frac{2000}{4} \times 880 \times \pi \times 60 \times 10^{-6}
 \end{aligned}
 \tag{11}$$

3. Simulation Results

Based on the Matlab modeling, 1C2M operation is simulated. Speed reference motor(A) is always controlled by 2,000[rpm] with feedback and the speed of the smaller diameter motor(B) is not controlled as shown in Fig. 2.

Steady state values instead of the transient state values are shown in the simulation results because the trend of the convergence is similar to both smaller and bigger diameter motors.

Fig. 3 shows the rotor speed of the smaller diameter motor. As the deviation is increased, speed of the smaller diameter motor is also increased almost linearly. When the deviation is 6[mm] which is the managed constraint of 880[mm] of wheel, the speed of motor 'B' reaches 2,014[rpm]. That is, 14[rpm] of spinning with no traction is occurred.

In the worst case of 50[mm] of deviation, the speed

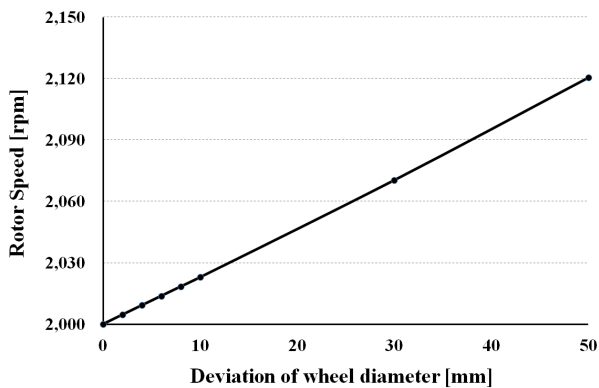


Fig. 3. Rotor speed of the smaller diameter motor 'B'

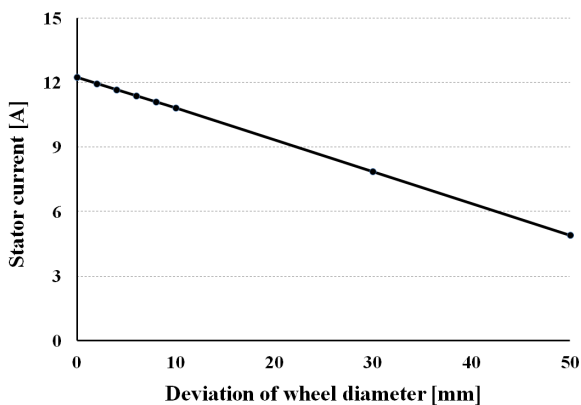


Fig. 4. Stator current of the smaller diameter motor 'B'

difference is around 120[rpm] which is 6[%] increased speed of the rated speed of motor 'A'.

As expected in the previous chapter, the stator current of the smaller diameter motor 'B' is represented in Fig. 4. In the same manner, the stator current of the motor 'B' decreases almost linearly with the increase of the deviation of wheel diameter. It is worthy of attention that the decrease of the current of motor 'B' is sharper than the increase of the speed of motor 'B'. In the worst case of 50[mm] of deviation, the current difference reaches around 7.34[A] which is 40[%] decreased value of the motor 'A'. In other words, rush current from a common VSI will flow into the bigger diameter motor 'A' and causes circuit braking and train stop.

Fig. 5 shows the torque of the motor 'B'. As the deviation of wheel diameter increases, the torque of the motor 'B' decreases. That is, main traction force is generated by the bigger diameter motor 'A'.

When the deviation of the wheel is 6[mm], the traction force of motor 'B' is 93[%] of motor 'A'. However, in the worst case of 50[mm] of deviation, the torque of motor 'B' is just 33[%] of motor 'A'. From the result, it is known that the deviation affects seriously to traction effort.

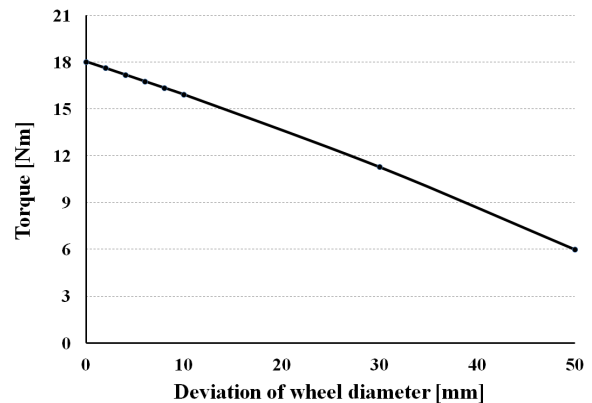


Fig. 5. Torque of the smaller diameter motor 'B'

4. Conclusion

Parallel operation with induction motors fed by a VSI driving front and rear wheels in traction drives, has been investigated. For steady-state operation, effects caused by the deviation of wheel diameters on motor current, rotor speed and torques have been discussed. Even though the power rating of both induction motors is very small for the simple simulation, it is sufficient to understand the motor characteristics of parallel operation with different wheel diameters. From the simulation results, it is clear to be important to manage the diameter deviation between front and rear wheels for traction drives.

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Hyung-Woo Lee He received the B.S. and M.S. degrees from Hanyang University, Seoul, Korea, in 1998 and 2000, respectively, and the Ph.D. degree from Texas A&M University, College Station, TX, in 2003, all in electrical engineering. In 2004, he was a Post-doctoral Research Assistant in the Department of Theoretical and Applied Mechanics, Cornell University, Ithaca, NY. In 2005, he was a contract Professor at the BK division of Hanyang University, Seoul, Korea. Since 2006, he has been a Senior Researcher at the Korea Railroad Research Institute, Uiwang, Korea. His research interests include design, analysis and control of motor/generator, power conversion systems, and applications of motor drives such as Maglev trains, conventional railway propulsion systems, and modern renewable energy systems.