A study of the train performance simulation for Korean next Generation high-speed train

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Abstract

The next generation high-speed train system, HEMU-400X, has been developed in Korea since 2007. HEMU-400X means High-speed Electric Multiple Unit – 300 experimental. Objectives of HEMU-400X project is development of next generation high-speed electric multiple unit with maximum operation speed 370km/h and maximum test speed 400km/h, energy efficiently and environment friendly. At present, the detailed design and component manufacturing are in progress. Because of no experience for high-speed electric multiple units, the train performance simulation is used in the detailed design. The Simulation provides a valuable tool in the design of new high-speed train. Simulation systems are being used to validate the final designs prior to any manufacturing. The train performance simulation software is developed during the previous project. This paper presents the procedure and method of the train performance simulation that have been carried out during the development of the HEMU-400X. For the train performance simulation, the train resistance model is suggested. Also suggested in this paper are the coefficients, such as the adhesion coefficient and the rotational inertia. Many simulations are studied for the performance satisfaction of HEMU-400X. It was found that the detailed design specification of HEMU-400X satisfied the traction performance criteria.

Introduction

Simulation provides a valuable tool in the design of new rolling-stock. Simulation systems are being used to validate the final designs prior to any manufacturing. In the design stage, the performance models of new rolling-stock are required. The performance models of new rolling-stock have the train resistance model, the effective mass, the operation speed and the tractive/effort-speed curves. Through the model, the power and number of motor, time and distance to maximum speed, energy consumption are determined. And using line profiles like gradients, curves and speed restrictions, running time and energy consumption are calculated.

The next generation high-speed train system, HEMU-400X, has been developed in Korea since 2007. HEMU-400X means High-speed Electric Multiple Unit – 400 experimental. Objectives of HEMU-400X is development of next generation high-speed electric multiple unit with maximum operation speed 370km/h and maximum test speed 400km/h, energy efficiently and environment friendly. At present, the detailed design and component manufacturing are in progress. Because of no experience for high-speed electric multiple units, the train performance simulation is used in the detailed design. The train performance simulation software is developed during the previous project.

Firstly, the length, dimensions, operation speeds and axle weights of HEMU-400X are defined based on the domestic condition and abroad technology, such as the Shinkansen, ICE(Inter City Express) and TGV(Train Grand Vitesse). HEMU-400X consists of 8 trains (6 motor cars and 2 trailer cars) in case of revenue service. As a result, the running resistance model is defined based on Japanese Shinkansen train. From these parameters, the power and number of motor are established. Finally, through train performance simulation, the maximum speed and time/distance to maximum speed is validated. Also, the results of train performance simulation are used for establishing the minimum distance of test line. The characteristics of HEMU-400X are more energy efficient and more environment friendly than the existing high-speed train.

Absolutely, when the detailed design is changed, mainly, train length, axle weight, tractive/braking efforts and dimensions, train performance simulation is conducted again. The modified design is validated.

HEMU-400X will provide the passenger service more energy efficiently and more environment friendly on the domestic and international high-speed lines.
The overview of train performance simulation

Many different Train Performance Simulators (TPS hereinafter) to analyze the train transportation system have been developed through the years [1-7]. TPS calculates trip time, energy at wheel rim in traction and braking phase, and the sharing of braking energy between different types of brake. High speed train development project requires a very heavy investment for a country, mainly due to the cost of civil works. This high investment must be balanced by the reduction of the trip time. The most worsening elements affecting trip time are speed restrictions. During the project, it is necessary to compare cost of investment with savings of trip time, we can choose the policy. TPS is a very efficient tool for the purpose and maximum performance run has to be taken into account. TPS has been utilized for the following purposes:

a) To determine the characteristics of traction and braking components in order to balance cost and trip time
b) To study the load on the substation
c) To analyze the influence on trip time due to a perturbation
d) To analyze minimum headway between trains
e) To predict energy consumption

It accepts input data describing the characteristics of a train and information about stations, grade, curvature and speed restriction profiles of a line. These data are used to obtain the trajectory of the train (speed and time versus distance along the line) as well as energy consumption profiles. An example of the trajectory calculations is illustrated with the help of Fig. 1. To move from point A to B in the figure, the following steps would be taken if a minimum time trajectory was taken.

a) A forward trajectory would be developed from A to C by using maximum tractive effort followed by maintaining the speed determined by the speed limit until the lower speed limit at C was encountered.
b) A backward trajectory calculation would then follow using maximum braking from C to F using negative time or backward distance steps. The point F is determined by the intersection of the backward trajectory with the forward trajectory.
c) A forward trajectory is continued from C to D, the point at which a higher speed limit is encountered.
d) A forward trajectory is developed from D to B by using maximum tractive effort until the lower speed limit at B is encountered.
e) A backward trajectory using maximum braking effort from B to E using negative time or backward distance steps. The point E is determined by the intersection of the backward trajectory with the forward trajectory.
f) Adjustments are made in the time or distance increments to bring the forward and backward trajectories into synchronization.

Train length is accounted for in obeying speed restrictions; namely, the speed of the train is less than or equal to the speed limit when the head of the train enters the restricted zone and the same condition is true when the tail leaves the zone.

![Fig. 1 TPS trajectory calculation](image-url)
Trainset and dimension of HEMU-400X

One trainset of HEMU-400X is composed of 8 cars (6M2T), where M and T means power car, trailer car, respectively and the prototype train is composed of 6 cars (5M1T) as shown in Fig. 2. Shape of the forepart of the leading car was designed to enhance aerodynamic performance and to emphasize Korean traditional beauty as shown in Fig. 3. Cabins are equipped with luxurious and comfortable chairs that can be rotated as shown in figure 4.

Basic dimensions of HEMU-400X are shown in table 1.

![Fig. 2 Trainset layout](image)

![Fig. 3 The exterior and interior of HEMU-400X](image)

<table>
<thead>
<tr>
<th>Table 1. Dimension of HEMU-400X</th>
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<tbody>
<tr>
<td>Items</td>
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<tr>
<td>Axle Load</td>
</tr>
<tr>
<td>Total Length</td>
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<tr>
<td>Car Length</td>
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<td>Width * Height</td>
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Running resistance

For train performance simulation, not only weights of trainset but also running resistance of trainset are needed. For straight and level track, zero wind conditions, in open air and at a constant speed, the running resistance, \( R \) in daN, can be expressed by quadratic function such as equation (1), which is known as the Davis equation.

\[
R = a + bV + cV^2 \quad [\text{daN}] \quad (1)
\]

Where, \( V \) is the train speed in km/h and the coefficients \( a, b \) and \( c \) are obtained by fitting the coefficients of the Davis equation to the curve obtained from coasting test for a particular train.

But because of no experience for high-speed electric multiple units, the running resistance equation is predicted by similar train, Japanese high speed train like FASTECH (FAST TECHNOLOGY), Shinkansen 300 and 100 series, and domestic high speed train, like KTX (Korea Train Express), KTX-Sancheon and HSR-350X. As a result, the running resistance equation is derived such as equation (2)
\[ R = ((1.356+0.001363V)W+0.5Fp(0.0035+0.00033L)V^2)^9.8 \text{ [N]} \quad (2) \]

Where, \( W \) is the train weight in tons, \( F \) is cross section in \( m^2 \), \( p \) is air density in \( 0.1244kgsec^2/m^4 \) and \( L \) is train length in m.

For domestic high speed trains and HEMU-400X, the running resistance value is compared such as Fig. 4. The running resistance of HEMU-400X is lower than domestic high speed trains. For Japanese high speed trains and HEMU-400X, the running resistance value is compared such as Fig. 5. The running resistance of HEMU-400X is lower than Shinkansen 100 series and higher than FASTECH and Shinkansen 300 series.

Fig. 4 The running resistance comparison between domestic high speed trains

Fig. 5 The running resistance comparison between Japanese high speed trains
Tractive and Braking Effort

The traction system consists of main transformer, converter/inverter and traction motors. Main transformer receive electric power of 25kV from the catenary through the pantograph of single arm type and supply electric power to two main propulsion systems (MPS) and an auxiliary power system (APS). One MPS includes a combination of converter and inverter, and drives two motor bogies. Traction power is generated by the induction motors. Prototype train is driven by 20 motors of 410kW up to 400km/h. Especially, the permanent magnet synchronous motors were applied to the prototype train. IGBT (Insulated Gate Bipolar Transistor) was applied to the inverter and the converter in the MPS for control of traction motors to increase switching speed and reduce electric power loss. Fig. 6 shows the traction curve. Braking forces of HEMU-400X come from friction brake and regeneration brake. Wheel disk braking devices are equipped in the wheels of the power bogies. Axle disk braking devices are equipped in the trailer axles of the trailer bogies. Regeneration braking devices controlled by the MPS generate electricity, which is transferred to the catenary system. Fig. 7 shows the regeneration braking curve.

Train Performance Simulation for HEMU-400X

On the basis of parameters mentioned above like the running resistance, train weights, traction curve and braking curve, etc, the train performance simulation was conducted on the high speed line. The train performance simulation software which has developed during the previous research project is used [8,9]. It is verified that the detailed design specifications of train meet the target performances. The target performances mean possibility to run to the maximum test speed, the running time and distances to the maximum speed 400km/h and the required test distances considering traction and braking performances.

The running time and distances to the maximum test speed 400km/h are 455.79sec and 35.342km respectively such as Fig. 8. The balance speed is 430km/h. So the detailed design specifications of HEMU-400X can run to the maximum speed.

The running time and distances to run above 400km/h are 447.7sec and 51.6km respectively such as Fig. 8. The running time and distances to run above 430km/h are 11sec and 1.31km on the high speed test line respectively such as Fig. 9.

The required test distances considering traction and braking performances is 100km from KP (Kilo Post) 280km to KP 380km in the direction of backward.
Results and Discussion

On the basis of parameters which are developed in detailed design like the running resistance, train weights, traction curve and braking curve, etc, the train performance simulation was conducted on the high speed line. It is verified that the detailed design specifications of HEMU-400X meet the target performances as follows.

- The possibility to run to the maximum test speed
- The running time and distances to the maximum speed 400km/h and above 430km/h
- The required test distances considering traction and braking performances

In the future, the detailed design specifications of HEMU-400X will be verified through component test, subsystem test, integrated test and trial test.

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