A Study on the Applicability of the Conventional TTX Propulsion System on the High-speed Propulsion System for a Deep-underground GTX

Chan-Bae Park†, Byung-Song Lee* and Ju Lee**

Abstract

In order to develop the deep-underground GTX (Great Train eXpress) in domestic, the running performance analysis of the propulsion system by a variety of route condition must be carried out before studying the specification and the development of the high-speed propulsion system with inverter and traction motor. Then it is necessary to study the running resistance properties of the high-speed traction system for the variety of tunnel type and vehicle organization method at first. In addition, the properties of the power requirement of the traction motors needed to maintain the balanced speed of the high-speed traction system are next studied. We need to study properties of the emergency braking distance caused by the highest operation speed of the high-speed traction system and present the fundamental design technologies to develop the high-speed traction system for the deep-underground GTX. Finally, the paper analyzes the applicability of the conventional Korean Tiling Train eXpress (TTX) propulsion system on the high-speed propulsion system for the deep-underground GTX.

Keywords: Deep-underground tunnel, GTX, Propulsion system, Traction motor, TTX

1. Introduction

Recently, the traffic problem caused by population concentration of the capital region area of the Republic of Korea is becoming the serious situation. It is necessary to make the wide area traffic counterplan for the increase of long distance transit since the capital region area is extending due to the construction of the second new town, and construct the traffic network that connects between the central places of Seoul and the key points of capital region by the introduction of a new and timesaving public transportation below 30 minutes with nonstop. In general, it is hard to expend the base facility supply such as highway and railroad etc. due to high compensation expense on the ground and group civil appeal. In order to solve the problem, many researchers are proposing the necessity of the construction of the deep-underground Great Train eXpress (GTX), which is 2 times faster than a conventional subway and is possibly constructed straightly in depth of below 40 [m] to reduce the economic charge of the government, and the Korea government is progressing a feasibility study about that.

The deep-underground GTX is an underground railway system that makes use of the space of the underground 40~50 [m] the landowner does not use, and operates to minimize an intermediate stop through the straight route. Fig. 1 shows a construction concept of the deep-underground GTX line and station at a town. A long time ago, the advanced countries such as the United States, Russia and Ukraine already applied the deep-underground railroad to their subways. To develop the deep-underground GTX in domestic, the specification decision and development of the traction control system with inverter and electric motor to accommodate a variety of route condition should be made [1].

In this paper, the running resistance properties of a high-speed traction system for the variety of the tunnel type and the vehicle organization method are first studied. In addition, the properties of the power requirement of the traction motors needed to maintain the balanced speed of the high-speed traction system are next studied. We need to study properties of the emergency braking distance caused...
A Study on the Applicability of the Conventional TTX Propulsion System... by the highest operation speed of the high-speed traction system and present the fundamental design technologies to develop the high-speed traction system for the deep-underground GTX. Finally, the paper analyzes the applicability of the conventional Korean Tilting Train eXpress (TTX) propulsion system on the high-speed propulsion system for the deep-underground GTX.


2.1 Running Resistance Properties by the Variety of Tunnel Type and Vehicle Organization

The air resistance within the tunnel changes due to the structure and type of the tunnel when the train travels within the tunnel [2]. The air resistance is the important factor because the air resistance acts as a drag resistance when it operates. As the running resistance becomes large, the train will need a large traction power when the train travels at high speed, which causes an increase of the capacity of the traction control system. Then, it is necessary to calculate an exact running resistance based on the operation condition for a proper design of the traction control system. In this paper, the increasing coefficient of the air-resistance from the open-ground to 1 is set and put out the increasing coefficient value of the air-resistance by tunnel type in Table 1 [3]. Then, the increasing coefficient values of the air-resistance in Table 1 are substituted for the equation (1), and the running resistance by tunnel type is calculated. The equation (1) is cited from a running resistance equation of France electric railway vehicle and the applied train is a suburb commutation train in France (1 organization: 6 vehicles, 360 [ton]) [1]. Fig. 2 shows the running resistance properties by the variety of tunnel type of the traction system. As shown in Fig. 2, the running resistance of single line tunnel with By-pass tunnel (Interval: 500 [m]) is similar to double line tunnel with not having By-pass tunnel.

\[
R = \left( 1.3 \frac{10}{m} + 0.01 V \right) P + k + \frac{c_0 V^2}{100} \frac{PL}{L} + 0.002N_p
\]  

(1)

where, \( R \) is running resistance [kgf], \( P \) total weight of railway vehicles [ton], \( m \) axle load [ton], \( V \) railway vehicle speed [km/h], \( c_0 \) air-resistance coefficient at the open-ground, \( k \) increasing coefficient of the air-resistance, \( S \) cross-section of a vehicle front surface [m²], \( L \) length of railway vehicles [m], and \( N_p \) the number of pantograph [3,4].

2.2 Required Traction Power Properties to Maintain the Balanced Speed

It is important to design a traction control system that is able to endure the air resistance and keep the balanced...
speed when the train travels within the tunnel. Then, a necessary power of the traction motor according to the balanced speed is calculated using the equation (3), which considers a variety of tunnel type when the train travels within the tunnel.

\[ P_{\text{motor}} = F_{\text{trac}}(V/3.6)\eta R_{\text{equi}}(V/3.6)\eta \quad [W] \quad (3) \]

where, \( P_{\text{motor}} \) is power of traction motor [W], \( R_{\text{equi}} \) running resistance at balanced speed [N], and \( \eta \) (0.97) power transmission efficiency between wheel flange and traction motor [1].

Fig. 3 shows curves of the necessary traction force by the variety of tunnel type of the traction system and Fig. 4 depicts the necessary power properties by the balanced speed of the traction system (1 organization : 6 vehicles, 360 ton). Fig. 5 shows the variation property of the necessary power properties of the traction system by increasing the balanced speed within the single and double line tunnel. As shown in Fig. 5, it is necessary to restrict the design maximum speed of the traction control system below 170 [km/h] because the necessary power increases rapidly by an aerodynamic resistance when the balanced speed is above 170 [km/h]. Therefore, the decision of a maximum operation speed below 150 [km/h] is made.

### 2.3 Property of the Emergency Braking Distance by the Highest Operation Speed

According to the safety regulation revision for urban transit vehicles, the emergency braking distance is below 600 [m] when the transit vehicles travel on the railroad at the maximum operating speed [5]. In this paper, the Münden equation of Germany to calculate the emergency braking distance is applied [4].

\[ L = \frac{3.85 V^2}{6.1\psi(1+\lambda/10)+i} \quad [m] \quad (4) \]

### Table 2  Main Specifications of the High-speed Propulsion System for the Deep-underground GTX [6]

<table>
<thead>
<tr>
<th>Contents</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Operation Speed</td>
<td>150 km/h</td>
</tr>
<tr>
<td>Maximum Design Speed</td>
<td>165 km/h</td>
</tr>
<tr>
<td>Tunnel Pattern</td>
<td>Double line or Single Parallel</td>
</tr>
<tr>
<td></td>
<td>(By-pass Tunnel every 500 m)</td>
</tr>
<tr>
<td>Acceleration</td>
<td>2.3 km/h/sec</td>
</tr>
<tr>
<td>Average distance between 2</td>
<td>6 – 9 km</td>
</tr>
<tr>
<td>stations</td>
<td></td>
</tr>
<tr>
<td>Reaching Distance to the</td>
<td>Below 4.5 km</td>
</tr>
<tr>
<td>Maximum Speed</td>
<td>Below 15 %, (60 % in case of non-adhesive)</td>
</tr>
</tbody>
</table>
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where, $L$ is emergency braking distance [m], $\psi$ braking constant (0.5 ~ 1.25, 1.17), $\lambda$ braking ratio (200%) and $i$ rail gradient [%]. Fig. 6 shows a relationship between the emergency braking distance and the maximum operation speed of the traction system. In order to secure an emergency braking distance 600 [m], the maximum speed needs to be restricted below 150 [km/h] in case of 0 [%] rail gradient, and 140 [km/h] in case of 15 [%], respectively. Table 2 shows main specifications of the high-speed traction system for the deep-underground GTX.

Table 3 Main Requirements for Applying the Conventional Propulsion System to the Deep-underground GTX

<table>
<thead>
<tr>
<th>Contents</th>
<th>Conventional Propulsion system of TTX</th>
<th>Propulsion system for the deep-underground GTX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>1.8 km/h/sec</td>
<td>2.5 km/h/sec</td>
</tr>
<tr>
<td>Acceleration range</td>
<td>0 ~ 70 km/h</td>
<td>Over 0 ~ 55 km/h</td>
</tr>
</tbody>
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Fig. 6 Relationship with emergency braking distance and the maximum operation speed of the propulsion system

Fig. 7 The exterior of the TTX vehicles (4M2T, 344 ton)

required traction force at the starting point of the TTX vehicles and the equation (6) is for the traction force at the terminal speed of the constant output power region on the middle speed band. In addition, the equation (7) is for the traction force ($F_{trac}$) at 165 [km/h].

\[
F_{trac}\underline{S}=28.35 \times W \times 1.09 \times \alpha + R_s \times W \quad [kgf] \quad (5)
\]

\[
F_{trac}\underline{105}=P_M + 367.3 \times 105 \times \eta \quad [kgf] \quad (6)
\]

\[
F_{trac}\underline{165}=F_{trac}\underline{105} \times 105^2/165^2 \quad [kgf] \quad (7)
\]

where, $W$ is total weight of full-loaded vehicles [ton], $\alpha$ acceleration [km/h/sec], $R_s$ starting resistance of vehicles [kgf/ton] and $P_M$ output power of the traction motor [kW].

Table 3 represents the main requirements for applying the conventional propulsion system to the deep-underground GTX. In the deep-underground GTX, the acceleration should be 2.5 [km/h/sec] and the acceleration range should be over 55 [km/h] to keep the maximum speed within 4.5 [km]. Fig. 8 shows a requirement of the traction force by variations of total weight and acceleration of TTX vehicles at the starting and maximum speed points. Fig. 9 describes a terminal speed of the constant traction force region by a variation of total weight of TTX vehicles. A capacity requirement of 1 traction motor by variations of total weight of TTX vehicles is shown in Fig. 10. Fig. 11 o.u. a change of traction performance by an acceleration increase when the traction motors of the conventional TTX are applied to the deep-underground traction system. In order to apply the conventional TTX to the deep-underground GTX and meet the necessary acceleration (2.5 km/h/s), the conventional traction motors should be driven by boosting its traction power up to 36.3% at the starting stage. Fig. 12 depicts a change of traction performance by a weight decrease and an acceleration increase of TTX vehicles when the traction motors of the conventional TTX are applied to the deep-underground traction system. In this case, the conventional traction motors must be driven by boosting its traction power up to 26.4% when the lightweight TTX is used. Finally, it is necessary to modify the conventional traction motors and controllers to apply the conventional

3. Traction Performance of TTX Propulsion System for the Deep-underground GTX

TTX is an electronic multiple unit (EMU) train of 180 [km/h] classes and one of some candidate vehicles for the deep-underground GTX [6]. Fig. 7 shows the exterior of the TTX.

A traction performance of the traction motor when the TTX travels within the tunnel having double lines without By-pass tunnel or single line with By-pass tunnel every 500 [m] is analyzed. The equation (5) is for calculating the
TTX vehicles to the deep-underground GTX. In addition, it is desirable to investigate whether the specification of the conventional traction motor satisfies the necessary traction performance of the vehicles before the design modification of the traction motors.

4. Conclusion

The feasibility study about the development of the deep-underground GTX in domestic is being progressed by Korea government. In this paper, the running resistance properties of a high-speed traction system with the variety of the tunnel type and the vehicle organization method were first investigated. In addition, the properties of the power requirement of the traction electric motors needed to maintain the balanced speed of the high-speed traction system were next studied. The properties of the emergency braking distance caused by the highest operation speed of the high-speed traction system were studied and the fundamental design technologies to develop the high-speed traction system for the deep-underground GTX were presented. Finally, the applicability of the conventional Korean Tilting Train Express (TTX) propulsion system on
the high-speed propulsion system for the deep-underground GTX was analyzed. In conclusion, it is necessary to investigate the performance properties of the conventional TTX propulsion system and modify its capacity for applying the conventional TTX to the deep-underground GTX.

Reference


