Reliability Assessment of Electric Traction System on Korea High Speed Train

Sung Il Seo, Choon Soo Park, Young Jae Han, Ki Hwan Kim and Tae Geun Park
Korea Railroad Research Institute,
360 Woulam-Dong, Uiwang-City, Kyonggi-Do, Korea, 437-050, siseo@krri.re.kr

Abstract

In this paper, to assess and enhance the reliability of Korea High Speed Train, electric traction system is selected and reliability analysis is carried out. The electric traction system is classified into subsystems and the functional block diagram and the reliability block diagram are drawn. Expressions to calculate the reliability are deduced and Mean Kilometer Between Service Failure is calculated using the trial test results on the track. Calculated results show reliability growth of the electric traction system.

1. Introduction

KHST(Korea High Speed Train) has been developed for last 7 years and the prototype KHST completed trial test on the test track. It attained the speed of 300 km/h on August 1, 2003. Nowadays, test for stabilization and reliability assessment is performed. KHST is the next generation high speed train to which home-grown advanced digital technologies are applied. KHST is different from KTX(Korea Train eXpress) designed by a French company. One of the differences is the traction system. KHST adopts the induction motor, while KTX adopts the synchronous motor.

Since various new advanced technologies were applied to KHST, reliability assessment and demonstration is necessary for KHST to be used commercially. In this study, to stabilize the systems of KHST and improve the reliability, reliability assessment technology is developed. Reliability analysis for the electric traction system is carried out based on the failure reports from the test running and reliability growth trend is investigated.

2. Reliability assessment procedure

Reliability assessment is conducted through the procedure shown in Fig. 1. First, reliability target and requirements are determined by the trade-off study for performance, life, construction cost and maintenance cost. Service distance is the basic parameter for reliability target of train system, which is classified into subsystems taking into account system function and project work breakdown. Functional block diagram to define the intrinsic function of the components and their relations is drawn. And then, reliability block diagram is drawn to calculate the reliability of the electric traction system based on the functional block diagram. Failure rates are analyzed by using the failure data from the FRACAS(Failure Reporting and Corrective Action System). The system failure rate and reliability are calculated by applying the mathematical technique to the reliability block diagram. The calculated results are compared with the reliability target and reliability assessment is conducted.

3. System Classification of KHST

The trainset of prototype KHST is composed of seven cars(1P+1M+3T+1M'+1P),

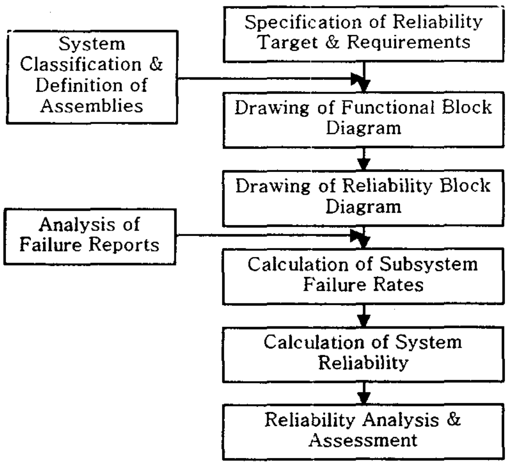

Fig. 1 Procedure for reliability assessment

where P, M, T and M' mean power car, motorized trailer, trailer and intermediate motorized trailer, respectively. Fig. 2 shows the prototype KHST running on the high speed line. The train system may be further broken down in systems, subsystems and LRU's(Line Replaceable unit). For example, the systems of KHST are classified functionally into movement system, electric traction system, mechanical braking system, compressed air treatment and storage system, auxiliary power system, comfort function utility system, driving system and train control and data transmission system.

Fig. 2 Prototype KHST running on high speed track

To grow the system reliability, the reliability of the critical core system should be improved. In this study, the electric traction system is selected as the critical core system and its reliability assessment and demonstration are conducted. The electric traction system is broken down into the subsystems as shown in Table 1.

Table 1 Classification of Electric Traction System

Subsystem	LRU
PANTOGRAPH	PANTOGRAPH
	AIR SUPPLY HOSE UNIT
HIGH VOLTAGE SAFETY DEVICE	SENSING TRANSFORMER
	VACUUM CIRCUIT BREAKER
	RETURN CURRENT DEVICE
	CURRENT MEASUREMENT TRANSFORMER
	LIGHTENING ARRESTER
ROOF LINE	ROOF LINE 25kV
	HV ISOLATING SWITCH
	ROTARY HEAD
TRANSFORMER	MAIN TANK
	VENTILATION FAN UNIT
	OIL PUMP UNIT
	OIL PUMP CONTACTORS
	COOLING FAN CONTACTORS
MOTOR BLOCK	POWER CONVERTER STACK
	POWER INVERTER STACK
	CHOPPER STACK
	VENTILATION FAN
	VENTILATION INVERTER UNIT
	ISOLATION TRANSFORMER
	DISTRIBUTION UNIT
	RHEOSTAT
	ACTIVE FILTER UNIT
	ELECTRIC COMPONENTS
	CONVERTER/INVERTER CONTROL UNIT
	TRACTION CONTROL UNIT
TRACTION MOTOR	TRACTION MOTOR
	VENTILATION FAN UNIT

The system specification for KHST regulates that the reliability of the systems be tested and assessed according to the MDBF(Mean Distance Between Failure) criteria[1]. The MKBSF(Mean Kilometer Between Service Failure) for the whole train system should be more than 121,000 km and the MKBSF for the electric traction system should be more than 783,000 km. The service failure means more than 5 minutes delay of service running.

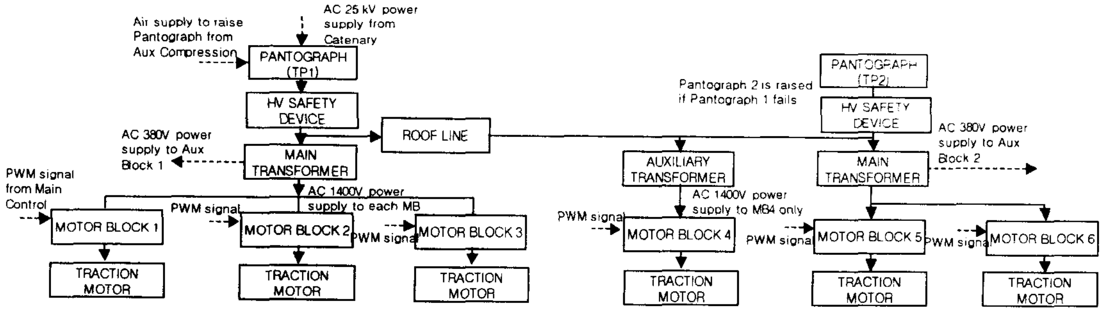

Fig. 3 Functional block diagram of electric traction system

4. Functional block diagram

The functional block diagram of the electric traction system can be drawn as the following Fig. 3. In normal operating mode, the backward pantograph is used to collect the current of AC 25 kV from the catenary. The pantograph is raised by the auxiliary compression system on the roof, of which power is supplied from the battery of DC 72 V. After the pantograph is raised, VCB (Vacuum Circuit Breaker), the LRU of high voltage safety device, is put on and electric power is supplied to the main transformers. The electric power is supplied to the auxiliary transformer on the intermediate motorized trailer and the main transformer on the other power car through the roof line. The auxiliary transformer supplies power only to the motor block on the intermediate motorized trailer. In case that the backward pantograph fails, the forward pantograph is raised in emergency mode and electric power is supplied to the transformers as the previous procedure. The main transformers supply the power of AC 380 V to the auxiliary power system and the power of AC 1400 V to the motor blocks. A motor block is composed of one set of converter and inverter and controls two traction motors simultaneously by transmitting the PWM (Pulse Width Modulation) command signal from the master controller on the driver's desk. When the braking signal is transmitted, the motor block functions as an electric generator and transmits the generated power to the catenary through the pantograph.

5. Reliability block diagram

To calculate the reliability of the electric traction system, the reliability block diagram is drawn, based on the functional block diagram.

In normal operating mode, the backward pantograph is used to collect current. When the backward pantograph fails, the forward pantograph is used as an emergency case. Therefore, the forward pantograph plays the

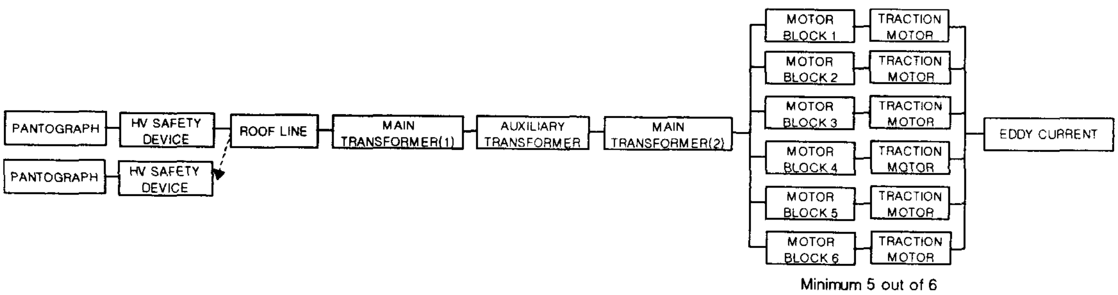

Fig. 4 Reliability block diagram of electric traction system in case of normal operation of auxiliary transformer

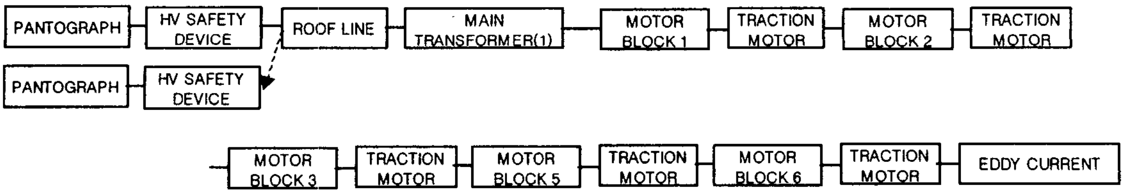

Fig. 5 Reliability block diagram of electric traction system in case of failure of auxiliary transformer

role of standby redundancy.

In normal condition, six motor blocks generate the traction power required to move KHST. According to the basic specification for KHST[1], three quarters of the motor blocks should be operating to start running. Therefore, the reliability is calculated for the case that more than five motor blocks among six motor blocks are operating. Since the auxiliary transformer is operating independently of the main transformers, it determines the system reliability block diagram.

In case that the auxiliary transformer operates normally, the reliability block diagram can be expressed by Fig. 4. Five motor blocks out of 6 motor blocks should be operating to produce traction power.

In case that the auxiliary transformer fails, the reliability block diagram can be expressed by Fig. 5. Five motor blocks except motor block 4 should be operating to produce traction power.

For the above two cases, Bayes' theorem is applied[2] and the following Eq. (1) is deduced.

$$\begin{aligned} R_{ETR} &= R_{panto}R_{HV}R_{roof}R_{TR(1)}R_{auxTR}R_{TR(2)} \\ &\times[6(R_{MB}R_{TM})^5-5(R_{MB}R_{TM})^6] \\ &\times[1+(\lambda_{panto}+\lambda_{HV})t]R_{eddy} \\ &+R_{panto}R_{HV}R_{roof}R_{TR(1)}R_{TR(2)}(R_{MB}R_{TM})^5 \\ &\times[1+(\lambda_{panto}+\lambda_{HV})t](1-R_{auxTR})R_{eddy} \end{aligned} \quad (1)$$

where, R and λ are reliability and failure rate, respectively. Subscripts ETR, panto, roof, TR, MB, TM, HV and auxTR mean electric traction, pantograph, roof line, transformer, motor block, traction motor, high voltage safety device and auxiliary transformer, respectively.

To obtain MKBSF, the reliability given by Eq. (1) is integrated. The integrated result is expressed by Eq. (2).

6. Calculation of reliability

The prototype KHST ran on the test track between Cheonan and Daejeon every week[3]. During test running, failure reports are accumulated and the data is analyzed.

$$\begin{aligned} MKBSF_{ETR} = &\frac{5}{\lambda_{panto}+\lambda_{HV}+\lambda_{roof}+\lambda_{TR(1)}+\lambda_{auxTR}+\lambda_{TR(2)}+\lambda_{eddy}+5(\lambda_{MB}+\lambda_{TM})} \\ &+\frac{5(\lambda_{MB}+\lambda_{TM})}{[\lambda_{panto}+\lambda_{HV}+\lambda_{roof}+\lambda_{TR(1)}+\lambda_{auxTR}+\lambda_{TR(2)}+\lambda_{eddy}+5(\lambda_{MB}+\lambda_{TM})]^2} \\ &-\frac{5}{\lambda_{panto}+\lambda_{HV}+\lambda_{roof}+\lambda_{TR(1)}+\lambda_{auxTR}+\lambda_{TR(2)}+\lambda_{eddy}+6(\lambda_{MB}+\lambda_{TM})} \\ &-\frac{5(\lambda_{MB}+\lambda_{TM})}{[\lambda_{panto}+\lambda_{HV}+\lambda_{roof}+\lambda_{TR(1)}+\lambda_{auxTR}+\lambda_{TR(2)}+\lambda_{eddy}+6(\lambda_{MB}+\lambda_{TM})]^2} \\ &+\frac{1}{\lambda_{panto}+\lambda_{HV}+\lambda_{roof}+\lambda_{TR(1)}+\lambda_{TR(2)}+\lambda_{eddy}+5(\lambda_{MB}+\lambda_{TM})} \\ &+\frac{\lambda_{MB}+\lambda_{TM}}{[\lambda_{panto}+\lambda_{HV}+\lambda_{roof}+\lambda_{TR(1)}+\lambda_{TR(2)}+\lambda_{eddy}+5(\lambda_{MB}+\lambda_{TM})]^2} \end{aligned} \quad (2)$$

The motor block is the critical item to determine the system reliability. To stabilize the electric traction system and grow the reliability, intensive management is conducted for the motor block. Owing to the efforts, the failure rate of the motor block is reduced as the running distance increases. Fig. 6 shows the variation of the failure rate of the motor block. Since debugging to correct initial failures is conducted nowadays, only failure rate ratio referring to the initial failure is shown. Fig. 7 also shows the variation of the MKBSF ratio of the electric traction system referring to the initial MKBSF. Figs. 6 and 7 verify the reliability growth of the electric traction system.

7. Conclusion

KHST is one of the most excellent achievements in the railway research fields of Korea. In this study, to grow the system reliability of KHST and prepare commercial service, the electric traction system which is the core system of KHST was selected and reliability assessment was conducted. The system classification was conducted and the functional block diagram and the reliability block diagram at subsystem level were drawn. Based on the reliability block diagram, the equations to calculate the reliability were deduced. Failure reports after test running were collected and analyzed. The reliability was calculated by using the failure data. As the test running was repeated, it was proved that the failure rate of the motor block is reduced and the reliability of the electric traction system grows.

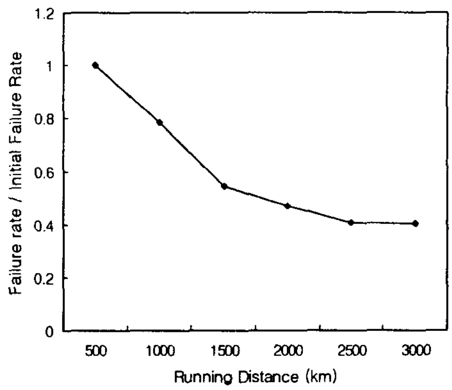

Fig. 6 Variation of instantaneous failure rate of Motor Block

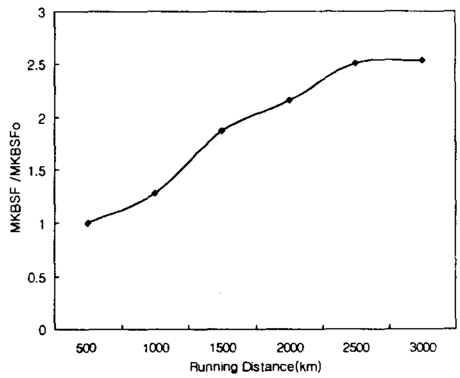

Fig. 7 Variation of MKBSF of Electric Traction System

References

[1] Kim, K. W., Choi, G. Y., Jung, G. R. and Lee, B. S.(2002), The basic specification for Korea High Speed Train, Korea Railroad Research Institute, 5-6.

[2] Kim, W. K.(2001), System Reliability Engineering, Kyowoosa, 165-198.

[3] Choi, G. Y., Kim, K. W. and Kim, S. W.(2002), Technology Development for Test and Evaluation of performances of High Speed Train, Korea Railroad Research Institute.