The Study of Maglev Train Control and Diagnosis Networks Based on Role Automation Decentralization

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SUMMARY The control and diagnosis networks in Maglev Train are the most important parts. In the paper, the control and diagnosis network structures are discussed, and the disadvantages of them are described and analyzed. In virtue of role automation decentralized system (RoADS), some basic ideas of RoADS are applied in new network. The structure, component parts and application of new network are proposed, designed and discussed in detail. The comparison results show that new network not only embodies some RoADS' ideas but also better meets the demands of control and diagnosis networks in Maglev Train.

key words: Maglev Train, control network, diagnosis network, RoADS

1. Introduction

In terms of the magnetism between magnets and the magnetic components on the track, Maglev Train is attracted to suspend above the track. The travel of train depends on the traction of linear motors in the vehicles [1], [2]. During the travel of Maglev Train, efficient control and status messages involving train safety will be transmitted and carried through control network, and a great quantity of diagnosis messages in the electric and electronic devices will be produced and transmitted through diagnosis network. In order to deal with, analyze and respond the diagnosis messages, it is very necessary to adopt proper and efficient control and diagnosis networks. Taking the traditional Maglev Train as an example, the structure of control network in Maglev Train is the age-old hardware lines. The structure of diagnosis networks in Maglev Train is traditional supervision system frame, which includes two layers, the upper is Ethernet Network structure and the lower is Fieldbus Network structure. The fault of the frame is obvious compared with ADS (Autonomous Decentralized System) structure [3], [4]. With the in-depth study about ADS and its corresponding theory, traditional automation systems gradually have more demands for their applications and development. The requirements for space time dynamic evolution representation of automation system potential functions are coming out. Role automation decentralized system (RoADS) is the efficient solution for the requirements. In virtue of the idea about role automation decentralized system proposed in [5], [6], Maglev Train control and diagnosis networks based on role automation decentralization will be presented and discussed, and plan design is completed in this paper.

On the one hand, compared with many other train communication networks, such as in high-speed train, the research of communication network in Maglev Train is earlier, which makes some new ideas easier to be realized. On the other hand, the control and diagnosis networks are the different in Maglev Train, which results into the structure complexity and function confusion of the networks. It is very necessary and significant to adopt some new ideas for the design of new network.

2. Control and Diagnosis Network

2.1 Control Network Structure Discussion

The control system of high-speed Maglev Train takes charge of the transmission and performance of control orders & safe status signals (supervisory signals). It is the "Nerve Centre" of train safe traveling. The control network in Maglev Train is responsible with the control functions of electric and electronic devices. The main functions of control network includes: On the one hand, the control orders from Operation Control Centre on ground are sent, processed and transmitted to the corresponding electric and electronic devices in Maglev Train. The corresponding electric and electronic devices will carry out their functions, such as levitation, guidance, driving and so on. On the other hand, the supervisory signals related with safety will be produced by the corresponding electric and electronic devices in Maglev Train, such as levitation, guidance, driving and so on.

In order to ensure the transmission of messages, the age-old hardware line network is adopted in the traditional Maglev Train. In each vehicle, there are two Vehicle Control Units and one Vehicle Control Dispatch Units [2]. All control signals are synchronously sent by two Operation Control Systems in double redundancy means. Then, in the two Vehicle Control Units, after the "OR" boolean calculation, the control signals are transmitted and dispatched to the corresponding electric and electronic devices in double redundancy means. All supervisory signals related with safety are transmitted to two Vehicle Control Units in double redundancy means. In the two Vehicle Control Units, after the "AND" boolean calculation, the supervisory signals are transmitted to Operation Control System 1. That is to say, the transmission of control signals is bidirectional, but that of supervisory signals is unilateral. The conjoint Vehicle Control Units are connected in step connection means. The Vehicle Control Units in middle vehicle not only supervise

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Fig. 1 Structure of control network.

the status electric and electronic devices in self vehicle, but also receive and transfer the supervisory signals from Vehicle Control Units of conjoint vehicles. The structure of control network in Maglev Train [2] is shown in Fig. 1.

In order to ensure the security and correctness of control orders during the course of transmission, the control network must add many hardware lines' relations between operation control system above and electric and electronic devices below. In Fig. 1, the hardware lines actually represent many hardware line bundles, which mean complexity and redundancy of the control network. In the control network of Maglev Train, each control signal must be represented by voltage difference on twist two hardware lines. Considering the redundancy of control signals, corresponding spare hardware lines should be equipped in the control network, which results into very large number of hardware lines. In fact, there are about several hundreds of hardware lines for control signals' transmission in each vehicle, though the type number of control signals' is more than eight.

From the discussion above, the defects of control network are obvious.

(1) The large numbers of hardware lines will occupy the much space of vehicle, and result into the complexity and discommodiousness of wire connection. Actually, the hardware line control network has gradually fallen into disuse, for example the control network in high-speed train.

(2) The control network is one kind of centralized control method. It has no automation and autonomy. It means that there are no functions of on-line expansion, fault-tolerance and on-line maintenance.

The defects of control network in Maglev Train result into the difficulty on maintenance, expansion, fault-tolerance, dynamic change of control and so on. It is actual one of control network with fixed control means, fixed structure, fixed function and fixed performance.

2.2 Diagnosis Network Structure Discussion

The main functions of diagnosis network are on-line diagnosis of electric and electronic devices in the vehicles. Through the acquisition of status parameters of devices, the faults of electric and electronic devices can be found and lo-

Fig. 2 Frame of diagnosis system.

cated. The main devices in diagnosis system include Vehicle Diagnosis Computer and its Display Module, Vehicle Operation Computer and its Display Module, Vehicle-Section Diagnosis Computer, two-layer Transmission Networks and the Diagnosed Devices [2].

The main functions of Vehicle-Section Diagnosis Computer consist of the whole Fieldbus Controller, reading repeatedly signals of Fieldbus Nodes, identifying the fault Fieldbus Nodes, producing diagnosis message based on judgment, transmitting diagnosis message to Vehicle Diagnosis Computer. The main functions of Vehicle Diagnosis Computer consist of receiving the fault messages from Vehicle-Section Diagnosis Computer, transmitting fault messages to Control Center, displaying fault messages, storing fault messages, receiving control signals and transmitting to Vehicle-Section Diagnosis Computer, identifying the fault of Vehicle-Section Diagnosis Computer, transmitting and replicating data [2].

In Maglev Train, Ethernet and CAN-bus are respectively adopted. Because there are many electric and electronic devices in the vehicle, it is necessary to divide the CAN-bus into several parts, which not only improving the CAN-bus Network efficiency but also enhancing the security of network. Thus, the fault of any bus part in CAN-bus can't result in the collapse of the whole network. Diagnosed Devices include all electric and electronic devices in the vehicle. There are Magnet Levitation Control Unit, Magnet Guidance Control Unit, Magnet Brake Control Unit, Linear Generator Converter, Energy Network Distributor, Energy Network Controller, Vehicle Control Unit, Door Controller, Location Measurement Unit, Air Conditioning Controller, Inverter, Fan Unit and so on. The number of diagnosed devices is more than one hundred in each section of vehicle. The structure of diagnosis system is shown in Fig. 2.

Considering the convenience of discussion, the diagnosis system frame of Maglev Train is divided into 4 layers:

Device Node Layer, Fieldbus Layer, Diagnosis Layer and Decision Layer). The defects of the diagnosis network are listed below [7].

(1) Device Node Layer

Each device independently sends status parameters by itself. There are no relations with other electric and electronic devices. This means that all status parameters of electric and electronic devices must be sent to CAN-bus network. In fact, it is not necessary to send status parameters if status parameters of other electric and electronic devices are learned.

(2) Fieldbus Layer

It is not proper to simply divide Fieldbus into 4 CAN-bus. These corresponding factors should be thought about including the devices relativity in same bus, the number of bus and so on.

(3) Diagnosis Layer

In Diagnosis Layer, analyzing, synthesizing, processing fault messages from diagnosed devices and transmitting fault information is completed. But processing some fault information can be realized in Device Node Layer instead of in Diagnosis Layer, such as the diagnosis of single electric and electronic device.

(4) Decision Layer

The functions in Decision Layer consist of producing, displaying, storing, transmission fault information and diagnosing of the whole vehicle fault. There is some functions' overlapping with Diagnosis Layer.

2.3 Relation of Control and Diagnosis Networks

The control network and diagnosis network are independent each other in Maglev Train. There is only an interlace joint in Vehicle Control Units. In order to analyze and adjust the fault of electric and electronic devices, it is necessary to provide the supervisory signals of electric and electronic devices to diagnosis system. Similarly, the fault diagnosis of diagnosis network is required for the sending and action of control order from control network. As two important networks involving the safety of Maglev Train, the coordination and cooperation between control network and diagnosis network are very important and necessary. However, relationship and coupling between control network and diagnosis network are very poor. The message current about supervisory signals of electric and electronic devices from control network to diagnosis network is illustrated in Fig. 3.

The message current about fault diagnosis of electric and electronic devices from diagnosis network to control network is illustrated in Fig. 4.

From the discussion about relation of control and diagnosis networks in Maglev Train, the cooperation between control network and diagnosis network can be completed through four different media transmission including CAN-bus, hardware line, Ethernet and TTY (current loop serial communication), which brings about the difficulty of maintenance, expansion, fault-tolerance, dynamic change of control and diagnosis functions.

Fig. 3 The message current of supervisory signals in electric and electronic devices from control network to diagnosis network.

Fig. 4 The message current of fault diagnosis in electric and electronic devices from diagnosis network to control network.

In order to meet the demands including flexibility and cooperation of the whole control and diagnosis networks, real-time property of control orders and fault information transmission, on-line diagnosis of electric and electronic devices, correctness of control orders and fault message, and reliability of data communication, it is very necessary to design a whole network including all functions of control and diagnosis networks. The network should have on-line maintenance, on-line expansion, fault-tolerance, dynamic change of control and diagnosis functions.

3. The Concept of RoADS

As the breakthrough over the conventional automation systems, ADS have been proposed and their technologies have been developed [3]. Decentralized System is defined as such a living thing that is composed of largely autonomous and decentralized subsystems. Each autonomous system in Autonomous Decentralized System that is not controlled by other subsystems or systems is mutually independent and completes its own function. At the same time, these subsystems can initiatively transmit internal information to external subsystem. In this system, autonomous systems have two properties: autonomous controllability and autonomous coordinability [4]. These two properties assure on-line expansion, fault tolerance and on-line maintenance of the system. The key technology of ADS includes architecture technology based on data field (DF) and content code (CC) com-

munication technology based on publish/subscribe model.

With the in-depth study about ADS and its corresponding theory, traditional automation systems gradually have more demands for their applications and development. The requirements for space time dynamic evolution representation of automation system potential functions are coming out. The space time dynamic evolution representation model of system potential functions corresponds to a kind of special automation system technology. The technology is called Role automation decentralized system (RoADS). The corresponding concepts [5], [6] are defined as following.

(1) Role: it means special function which is external expression of object in the special time.

(2) Agent: it means a node or subsystem. Its structure elements include controllers, software, sensors, and actors.

(3) Automation System: it means the group of several agents. They can cooperate to realize the goal of system each other.

(4) Role of Automation System: it means special function which is external expression of an agent in the special time. Several roles of several agents consist of the role set of the automation system.

(5) Role Autonomy: it means the ability of different functions' independent expression for an agent according to the change of internal status or external conditions in different time and places.

(6) Role automation decentralized system: it means the automation system consisted of several agents with role autonomy. The agent has some properties as following. Function equity: every agent has the potential equal functions. Role autonomy: agent can independently express function according to status and conditions. Role coordination: for non-working status of every agent, other agent can exert its role according to coordination of different goals.

4. Role Field and Data Field Dual-Driven Architecture

The separation between the transmission strategy (anonymity and asynchronism) of content code (CC) data and data processing mechanism (subscribe and filter) in ADS realizes the on-line dynamic characteristic of system. In role automation decentralized system, the role expression actually means the dynamic recombination course of a function set. The separation between role description strategy (functions expression) and role control mechanism (functions recombination) is expected, which will realize the dynamic evolution of roles with the change of time space. In the most automation systems, the role description strategy (functions expression) and role control mechanism are syncretic, which results into the determinate expression functions of the whole system in the design phase. The role field and data field dual-driven architecture (RDDA) is named in [5]. In the architecture of RDDA, the main elements include role field, data field, role autonomous processor, data arbitrator, and role/function/object dispatcher and so on. All agents in the system have the same structure. The architecture of RDDA is illustrated in Fig. 5.

Fig. 5 The architecture of RDDA.

(1) Role Field

The autonomous agent embedded in a system frame can have several roles at same time. In addition, the role sets of the agent can dynamically change with time. The system frame is called role space. The role is available to the agent. Through the roles, agent can complete single or same goals. The role field is sharable information space. Every agent can send or receive role description information to the role field. The description information of the role includes role component files, function component files and object component files.

(2) Data Field

The data field is sharable data space. Every agent can send or receive data to the data field. Data includes the properties and examples of objects, internal and external status and so on. The internal status includes resource status, health status, and disposal ability and so on. The external status includes local event, remote event, communication event, and change of control object and so on. Data current is formed through the exchange of the agents.

(3) Role Autonomous Processor

The role autonomous processor is core elements of RoADS' realization. It can get the role component files from role field, get data from data field, arbitrate the current running roles of the agent, drive the corresponding role components, and activate the acting role. From the information viewpoints, there are data current and role current in RoADS. At the level direction (between the agents), the consistency of data and role should be achieved. At the upright direction (among the agents), the association of data and role should be achieved.

(4) Data Arbitrator

Each agent can run in decentralized conditions. There is a great deal of data for the transmission and updating timely. Considering the uncertainty of data during the course of transmission, data arbitrator can ensure the consistency of data in decentralized conditions.

(5) Role/function/object Dispatcher

Role dispatcher is driven by role autonomous processor to realize the circumstance configuration of role activation. It can have alternation with the control interface, and realize the automatic or constrained switch. Function dispatcher

is driven by role dispatcher, function component files, data and control interfaces to realize the function configuration of the role and activation of corresponding function component. Object dispatcher is driven by role dispatcher, object component files, data and control interfaces to realize the object configuration of the function and activation of corresponding objects.

In virtue of the RoADS' idea, the control and diagnosis networks in Maglev Train will be newly designed and realized below in the paper.

5. Design Principles

The new control and diagnosis network in Maglev Train should include some basic design principles below:

(1) One Network

It means that the new network should replace old control and diagnosis networks in Maglev Train. The new network should include and complete all functions of old control and diagnosis networks. The hardware lines network should be completely given up, and the new network should be intelligent network with better communication characteristic.

(2) Distinct Priority

Since the diagnosis and control messages are transmitted in one network, it is very necessary that there should be distinct priority's difference between diagnosis and control messages, for sake of ensuring the timely and correct transmission of control signals.

(3) Information Share

Different from the separation of control and diagnosis networks, all information of two networks can be shared. Thus, for the judgment of diagnosis and fault, control orders and supervisory signals should provide significance support and reference. Before the sending of control orders and judgment of supervisory signals, diagnosis information should strongly provide help and foundation.

(4) Function Change

Considering the redundancy of diagnosis and control systems in Maglev Train, the fault of any electric and electronic devices (including Magnet Levitation Control Unit, Magnet Guidance Control Unit, Magnet Brake Control Unit) can't result into the traveling halt. When one or some electric and electronic devices come forth fault, other same type nodes should own the functions of fault nodes. For the diagnosis information, there should be similar functions for diagnosed devices.

(5) Role Change

In all electric and electronic devices of Maglev Train, some devices act double roles. On the hand, the devices receive the request frame from diagnosis system and send status information to diagnosis network. On the other hand, they receive the control orders from control system and send supervisory signals to control network. These devices mainly include Magnet Levitation Control Unit, Magnet Guidance Control Unit, and Magnet Brake Control Unit and so on. Their double roles should provide the functions of

role change in the new network.

(6) Hierarchy Diagnosis

Different from the control message, the diagnosis message should be divided into different levels for sake of diagnosis convenience. In Device Node, some fault information of single electric and electronic device should be produced by itself before sending status parameters to Device Node Layer. The correlative Device Nodes should be coordinated each other. Corresponding fault message and integrated information should be sent to Device Node Layer expect for simple status parameters of electric and electronic device. That is to say, single electric and electronic device in Maglev Train should be independency and self-diagnosis. In addition, corresponding electric and electronic devices should co-coordinate each other, which is similar to Logic Node in Autonomous Decentralized System. In Device Node Layer, corresponding electric and electronic devices should be divided into same bus. Thus, some diagnosis function can be simplified. If some or a group device nodes in the same device node layer occur fault, the co-coordination mechanism of the whole device node layer will start up. The fault message will be divided into several levels including single device node fault, type device node fault and device node layer fault. The corresponding fault message will be different based on different fault levels. In Filedbus Layer, different buses should be coordinated each other and influence in them should be processed and embodied. That is to say, through the coordination of different buses, more complex fault information can be integrated and produced. To the whole Maglev Train, the production of diagnosis message or fault message depends on not only single electric and electronic device, but also several same devices even the different type devices. Thus the relations should be processed and embodied between different device node buses. In Diagnosis Layer, all the status parameters, fault message, some fault information and the whole diagnosis of Maglev Train Vehicle-Section should be completed. That is to say, the Diagnosis Layer is the last layer of diagnosis system. In Decision Layer, the decision function of the whole Maglev Train should be completed. The fault information of single or a group of electric and electronic devices should be displayed, stored and transmitted to Control Center. The logical algorithms of diagnosis should be carried out in lower layer, which can improve the reliability and real time of system. In different layers in diagnosis system, different logical algorithms will be circulated according to different diagnosis demands. In addition, these diagnosis algorithms should consider the whole demands including device maintenance, fault tolerance and so on.

6. Design Plan

Based on the introduction and discussion on Role automation decentralized system (RoADS), and design principles of control and diagnosis network in Maglev Train, the frame of new network is divided into several parts including agents, roles, data field, role field, role field and data

Fig. 6 The structure of agent.

field dual-driven, system frame. Each part will be described and discussed in detail below.

(1) Agent Structure

In the paper, the agent means the every node in control and diagnosis network including Magnet Levitation Control Unit, Magnet Guidance Control Unit, Magnet Brake Control Unit, Linear Generator Converter, Energy Network Distributor, Energy Network Controller, Vehicle Control Unit, Door Controller, Location Measurement Unit, Air Conditioning Controller, Inverter, Fan Unit and so on. For the sake of convenience, CAN-bus is adopted in the new network. That is to say, all control orders, supervisory signals, and diagnosis information will be transmitted through CAN-bus. An agent is generally consisted of system engines such as interface configuration and edit, properties and logical control, data packing and analysis, network communication middleware, configuration files transmission. The structure of agent is illustrated in Fig. 6.

The configuration files are produced through corresponding objects or devices' properties and action logical conditions. The validity of control order and diagnosis message is checked by property and logical control engines to realize the sequential operation in property and logic. Data packing and analysis engine can pack the data produced by property and logical control, or analyze the data from the CAN-bus network middleware. The autonomous decentralized protocol (ADP) is adopted in CAN-bus Communication Middleware. The files transmission engine can automatically receive and send configuration files between device node and network controller. Through the device node, the status parameters and supervisory signals through corresponding sensors in different locations of electric and electronic device can be obtained. The control orders from network controller can be checked and received in the corresponding agent. The status parameters and supervisory signals can be sent to Device Fieldbus through CAN I/O Port in Device Node. Some fault messages can be gained through combination different status parameters of electric and electronic device. If the result of logical judgment is true, a key fault device message can be produced and sent to Device Fieldbus through CAN I/O Port in Device Node. In the control and diagnosis network in Maglev Train, all devices nodes have same agent structure.

(2) Role and Role Field

In the control and diagnosis network in Maglev Train, role means special function which is external expression of electric and electronic device in the special time. For example, during the traveling course of Maglev Train, the functions of every electric and electronic device are different. Depending on the similarity and relativity of roles, all electric and electronic devices are divided into 12 sets. They are respectively Diagnosis Role Set of (Magnet Levitation Control Units, Magnet Guidance Control Units, Magnet Brake Control Units, Energy Network Devices, Location Measurement Units, other devices including Door Controller, Air Conditioning Controllers and Fan Units), Control Role Set of (Magnet Levitation Control Units, Magnet Guidance Control Units, Magnet Brake Control Units, Energy Network Devices, Location Measurement Units, other devices including Door Controller, Air Conditioning Controllers and Fan Units). The electric and electronic device can own several roles at same time, such as Magnet Levitation Control Units. Moreover, the role sets of the electric and electronic device can dynamically change with time. The control and diagnosis network frame can form the role space. Through the roles, electric and electronic device can complete single or same goals. Every electric and electronic device can send or receive role description information to the role field. The description information of the role includes role component files, function component files and device component files.

(3) Data Field

In the control and diagnosis network in Maglev Train, data field means the sharable data space. In fact, it is the memory of network controller. Every electric and electronic device can send or receive data to the data field. Data includes the properties and examples of electric and electronic device, internal and external status and so on. The internal status includes node's resource status, node's health status, and node's disposal ability and so on. The external status includes local network event, remote network event, network communication event, and network change of control device and so on.

(4) RDDA

In the control and diagnosis network of Maglev Train, all electric and electronic devices have the same agent structure. The architecture of RDDA is illustrated in Fig. 7.

In Fig. 7, Role dispatcher is driven by role autonomous processor to realize the circumstance configuration of role activation. It can have alternation with the control interface, and realize the automatic or constrained switch. Function dispatcher is driven by role dispatcher, function component files, data and control interfaces to realize the function configuration of the role and activation of corresponding function component. Object dispatcher is driven by role dispatcher, object component files, data and control interfaces to realize the object configuration of the function and activation of corresponding objects.

(5) System Frame

The frame of control and diagnosis network in Maglev

Fig. 7 The architecture of RDDA in control and diagnosis network.

Fig. 8 The frame of control and diagnosis network.

Table 1 The performance comparison of new and old networks.

Performance	Old Networks Diagnosis/Control	New Network
Production Time of Status Parameters (ms)	0.01~0.03/0	0.01~0.03
Total time (ms)	0.052~0.085/0	0.024~0.065
Hierarchy Diagnosis	No/no	Yes
Distinct Priority	No/no	Yes
Information Share	No/no	Yes
Function Change	No/no	Yes
Role Change	No/no	Yes

Train is shown in Fig. 8.

Considering computer CPU speed, CAN CPU speed, status parameters transmission time and delay, waiting time for status parameters, processing algorithms time, and the whole data quantity and so on, corresponding time can be

estimated, for example, Energy Network Fault, if supposing the transmission speed of CAN is 500 Kbps. In addition, some performance comparison between new and old networks is shown in Table 1, too.

7. Conclusion

The control and diagnosis networks in Maglev Train are the most important parts that ensure train traveling safely at high speed. The traditional supervision and control networks are adopted in the control and diagnosis system. Because of many disadvantages of the control and diagnosis networks, some RoADS' ideas are adopted in the new control and diagnosis network in this paper. The design principles and plan are proposed, discussed and analyzed in detail. Through comparison between old control and diagnosis networks and new one, it is concluded that new control and diagnosis network can better meet the demands of Maglev Train.

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