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# Development of electro-hydraulic proportion control system of track-laying machinery for high speed railway construction

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ABSTRACT

This paper mainly deals with the development of electro-hydraulic(EH) proportion control system for travelling and track-laying work in the track-laying machinery (TLM) for high speed railway construction. Different from TLM used to low speed railway construction, TLM for high speed railway construction is a kind of the full-automatic continuous track-laying work machinery, and it is characterized by flowchart process and self-travelling. In order to increase the operation production rate and work quality of the track-laying machinery, a distributed electro-hydraulic proportional control system to be based on controller area network(CAN) bus type of networked control network which can realize the coordinated control among multiple hydraulic implement mechanisms is proposed. In this system, the travelling speed of the TLM is chosen as the primary connected variable of sleeper-working. Using the measured travelling speed of TLM via the triggering-wheel, the developed system can implement the control for the wheel-rail travelling speed and tractive force, the sleeper-laying and sleeper-conveying is constructed. Addressed the coordinated control of the travelling system, a compound cooperated control system is designed for coordinating between the tractive forces and the travelling speeds of the crawler vehicle and the wheel-track work vehicle. For the speeds coordination of multiple-sleeper-conveying-motor, the relative coupling control law is presented based on the threshold type of fuzzy PID. The simulation, the worksite test and the practical application show that the developed control system can meet the requirements of the sleeper-laying operation.



## 1. Introduction

The track-laying machinery (TLM) is a kind of large-scale full automatic continuous track-laying work machinery in high speed railway construction, and it is characterized by the cooperation of the complicated and networked mechatronic systems. In general, the train operating speed of high speed railway is over 200 km/h. The common rail-sleeper raft TLM used in the low speed railway construction is only a simple mobile gantry, and its work mode is serial. Different from the common rail-sleeper raft TLM, TLM used in high speed railway construction is supposed to lay 500 m long tracks and sleepers under continuous and coordinated working mode. This kind of TLM plays the important role during the construction process of the high speed railway. The constitution and configuration of TLM are shown in Fig. 1. It is mainly composed of crawler vehicle, wheel-rail operation vehicle, sleeper-conveying gantry crane, sleeper-transporting chains, hydraulic system and manipulation control system. In the TLM, traction drive, sleeper-conveying and sleeper-laying systems are three important subsystems. These three subsystems are responsible for completing travel driving, conveying sleeper and laying sleeper respectively, and their performance and cooperation will directly determine the operation performance of the overall TLM. Because TLM is of gigantic vehicle size, and distributed numerous actuator mechanisms, controllers and sensors arrangement, a real time of distributed control and measurement based on CAN bus is adopted to realize measurement and synthesis control. With the fast development of high speed railway, the higher automation level, the higher operation quality, efficiency and reliability are desired during the construction process. Thus, the control system of TLM is expected to design as a physical information system with flow process work features to achieve the more flexible manipulation and more excellent synthesis control ability. Therefore, the motion synthesis and coordinated control of multi-hydraulic-actuator in TLM under network framework is a challenge problem to be imperatively solved.

As shown in Fig. 1, TLM mainly consists of the crawler vehicle and wheel-rail vehicle. The crawler vehicle is the front supporting and guiding mechanism of the wheel-rail vehicle when the TLM is in the operating state, in the mean time, it can also provide the auxiliary driving force when the traction force of the wheel-rail

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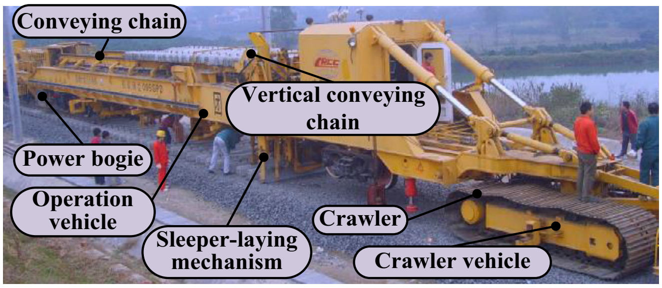


**Fig. 1.** The Track-laying machinery for high-speed railway construction.

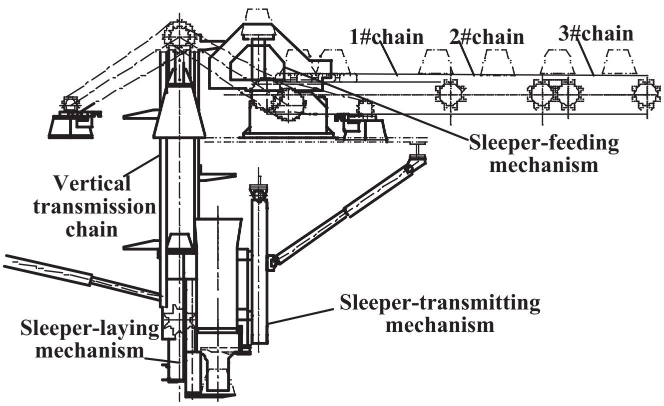


**Fig. 2.** Schematic diagram of the sleeper-conveying system and the sleeper-laying mechanism.

vehicle can't meet the requirement of the traction force. The two vehicles are hinged by swing bearing, and they are respectively driven by two separate pump-controlled motor volumetric speed systems. Compared with valve-control hydraulic actuating system [1], pump-controlled-motor system has the advantages of high transmission efficiency and large power [2–4], and the response speed of the system is also acceptable for the travelling system with large power and large load. In comparison, because of good control accuracy and fast responses, hydraulic valve-controlled systems are often employed to position control and speed control, and the issue of low efficiency is solved by load-sensing flowrate control. Yin et al. [1–4] studied respectively valve-controlled loading [1] for pitch system simulating of wind turbines and the pump-controlled pitch system for pitch system [2–4], and also the corresponding control methods were proposed. For the TLM traction driving, we focus on the issue of traction travelling synchronization. Because the vehicle body is very long and large, the slipping phenomenon will happen when the driving speed of each wheel is different. Therefore the speed synchronization between the two vehicles and among multiple motors in the hydraulic systems of two vehicles must be guaranteed for keeping the sufficient traction force and anti-sliding.

The working devices of TLM contain the sleeper-conveying system and the sleeper-laying mechanism, and their constitution diagram is shown in Fig. 2. The sleeper-conveying system contains three horizontal chains and a vertical chain. When the track-laying machinery travels ahead, the sleeper-laying work is conducted in cooperation with TLM. In order to realize the smooth and uniform sleeper-transmitting work, and to avoid sleepers being piled or lacked on the three horizontal chains, it must be guaranteed that sleeper-conveying speeds among three sleeper-conveying chains are synchronized with sleeper-receiving speed of the vertical chain, meantime the matching with the vehicle speed is also very necessary. In the practical operation, sleepers are piled on No.3 chain in group by the sleeper-conveying gantry crane, which will inevitably cause large intermittent load disturbance to No.3 chain. In order to execute the continuous sleeper-laying operation, firstly, the sleeper spacing is demanded to be gradually increased by the order from No.1 chain to No.3 chain, thus the robust control and coordinated speed control for multiple sleeper-conveying motors are necessary; secondly, the operation motions in the sleeper-transmitting and sleeper-laying process are continuous and coordinated. Due to the differences among the driving motors and sleeper-conveying chains in actual operation, it is very difficult to realize the coordinated speed control. Therefore, the coordinated control for traction drive and sleeper-laying work has become a pivotal problem in the research on the control system of Track-laying machinery.

The steering of the track-laying machinery is realized by controlling the extending and contracting of the steering hydraulic cylinder based on the relative deflection of the crawler vehicle to the wheel-rail vehicle. The automatic steering control is accomplished by detecting the path deviation of the crawler vehicle and regulating the steering angle of the crawler vehicle. The steering control will not be discussed in this paper.

Traction drive of TLM is similar to the chassis control of the vehicle. The relevant researches on coordinated synchronization for traction drive of the chassis were made. Mokhiamar and Abe studied the cooperative chassis control of four-wheel drive car, and an optimal tire force distribution method was proposed [5]. Anwar [6] researched the generalized predictive control of the yaw system of the vehicle with hybrid brake by wire. Bachinger et al. [7] carried out the modeling and simulation of drive train in the vehicle. Addressed the traction travelling synchronization problem of the Track-laying machinery, Gan [8] used the flow equilibrium technology to synchronize four motors of the crawler vehicle, and synchronous flow-dividing with electronic antiskid was employed to the wheel-rail traction system. However, because the mathematical model of the system is simplified as a single variable pump and fixed displacement motor, it can't analyze the implementation effect of the synchronization control strategy. Meanwhile, for the proposed synchronization problem between crawler traction and wheel-rail traction, the related research report has been not seen yet. Although the forced synchronization via flow-divider valve can reach some extent synchronization, the temperature rising to be caused by thermal power loss of the system will affect the synchronization effect.

At present, the researches on the control for large-scale construction machineries mainly focused on travelling system [9,10], steering system [9–11] and network-based coordinated motion control [11–13]. However, researches associated with coordinated synchronization network control for conveying sleepers, matching speeds between laying sleeper and vehicle travelling in the track-laying machinery have been not found yet. Classical synchronization control methods mainly include the synchronized master command mode, the master-slave synchronized mode and the cross-coupling synchronized mode, and they have been used to the coordination of transmission control systems. Lorenz et al. [14] incorporated the synchronized master command approach and the master-slaved approach in CNC controllers used for multiple axes synchronously driven. Karpenko et al. [15] proposed a decentralized coordinated motion control approach to be used to two hydraulic actuators handling a common object. Yang et al. [16] designed a control law to realize the synchronization between cylinders of the hydraulic thrust system in the shield tunneling machine by using master-slave PID. Heertjes et al. [17] realized synchronization of high-precision stage systems by master-slave control based on self-tuning. Mi et al. [18] studied the coordinated multi-cylinder movement of the jacked box tunneling by combining synchronized master command approach with master-slave method. Ouyang et al. [19] studied the application of the