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论文题目：高速铁路列控系统应答器应用原则验证与优化方法研究

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**高速铁路列控系统应答器应用原则验证与优化方法研究**

**摘 要：**应答器作为车地通信的重要设备[[[1]](#endnote-2)-][[[2]](#endnote-3)]，其报文数据是保证列车安全高效运行的重要数据支撑[[[3]](#endnote-4)]。而且应答器报文数据的正确性以及整条线路应答器布置的合理性直接影响到列车安全高效的运行[[[4]](#endnote-5)-][[[5]](#endnote-6)][[[6]](#endnote-7)][[[7]](#endnote-8)]。本文针对应答器应用提出一种应答器报文数据验证的方法，并通过对现有应答器布置方案进行学习提出一套理论布置方案，并通过综合考虑行车效率、安全等因素对该方案进行优化，最后通过仿真测试和理论评价两种方法对应答器布置的合理性安全性进行验证。

**关键字：**高速铁路列控系统，应答器应用原则，数据验证，优化方法

## 引言

列控系统作为一个复杂安全苛求系统[[[8]](#endnote-9)-][[[9]](#endnote-10)][[[10]](#endnote-11)]，对系统安全质量要求很高，而应答器作为地面设备的重要组成部分，负责向车载设备传输地面数据，是实际应用中列车安全高效运行的重要数据支撑[[[11]](#endnote-12)-][[[12]](#endnote-13)][[[13]](#endnote-14)]。列控系统应答器应用原则详尽的规定了应答器的设置规则[[[14]](#endnote-15)-][[[15]](#endnote-16)]和应答器报文的编制原则，是实际应用中应答器布置[[[16]](#endnote-17)]和报文编制的依据。

由于应答器报文错误导致的紧急停车等事故常有发生，严重影响列车的安全高效运行[[[17]](#endnote-18)]。因此在列控车载设备使用应答器数据时，亟需对应答器报文有效性可用性等作出判断，以避免类似事故的发生。此外在实际应用中单方面按照列控系统应答器应用原则对应答器进行设置，并未从列控系统整体的安全性、运营效率、功能、工程造价、运营维护等诸多角度对布置进行优化，从而出现应答器布置过密（或过疏）、 应答器设置不合理、关键信息应答器缺失等问题，所以亟需一套切实可行的应答器布置优化方案是非常必要的。

首先论文从应答器报文的结构入手，判断其是否符合规范中所要求报文长度、报文结构。进而通过解析报文内容对应答器的报文内容与工程数据进行验证，以确保报文数据的正确性。对于报文结构不符合规定、报文内容内部逻辑错误或报文内容与工程数据不一致的应答器所得报文无效。

论文选取应答器布置对运行效率、ATP控车曲线的影响、是否满足列控系统运行速度和最小追踪间隔的运营需求、应答器报文数据对应答器布置的影响[[[18]](#endnote-19)]、成本分析等角度分别采用适当的算法建立模型，采用合理的优化算法对应答器应用原则中所述应答器布置方案进行优化，最后采用DEA与HAP方法对所得应答器布置方案进行评价[[[19]](#endnote-20)-][[[20]](#endnote-21)]，并通过建立列控系统仿真测试平台进行仿真测试，以期得到最合理、最优的应答器布置方案，并对现场应答器应用有一定的现实指导意义。

## 国内外研究现状

目前，国内外应答器应用的研究主要包括应答器功能、应答器故障及其影响、应答器设置、应答器报文等四个方面的研究。

首先在应答器功能方面，马文俊、王留灿、吕向东等人通过介绍应答器的功能，进而对应答器的典型故障及其处理方法进行了叙述[4,][[[21]](#endnote-22)--][[[22]](#endnote-23)][[[23]](#endnote-24)]；王东、李亮等人分析现场中出现的应答器报文错误问题，分析了原因并给出了处理方法[6-7]；陈大伟、赵阳等人在阐述应答器丢点现象的基础上，从应答器系统的角度，充分分析了造成应答器丢点的原因，并最后给出了解决问题的方法[[[24]](#endnote-25)-][[[25]](#endnote-26)][[[26]](#endnote-27)]；陈德旺、赵东旭等人，着重对基于应答器的定位方法及其在列控系统应用惊醒了深入研究[3,][[[27]](#endnote-28)]；另外蔡伯根、王剑、张雅静等人深入研究了基于全球卫星导航系统GNSS（Global Navigation Satellite System）的虚拟应答器[[[28]](#endnote-29)-][[[29]](#endnote-30)][[[30]](#endnote-31)][[[31]](#endnote-32)]。

其次应答器报文数据方面，首先邢毅简明分析了列控系统应答器报文应用原则[[[32]](#endnote-33)]；李开成、朱晓航等人通过FPGA等对应答器编码译码做了充分研究[[[33]](#endnote-34)-][[[34]](#endnote-35)][[[35]](#endnote-36)][[[36]](#endnote-37)][[[37]](#endnote-38)][[[38]](#endnote-39)][[[39]](#endnote-40)]；另外，当前应答器报文的验证主要集中在对无源应答器报文和工程数据表的一致性比对上，如：人工在线路纵断面图上清楚地标注出应答器报文的内容，对所有正线应答器报文进行核对，该方法建立在人工核对的基础上，虽可以降低人工核对的错误率，但人工核对的正确性对该方法有较大影响；为了解决人工比对效率低的问题，赵俊伟[[[40]](#endnote-41)]等人使用计算机软件实现用户数据表和报文数据的可视化，并自动验证部分报文数据的有效性，从而提高应答器报文验证工作的效率和准确性；刘长波提出了用仿真进行应答器报文动态验证的方法：通过模拟联锁和列控中心，验证了与进路信息和临时限速信息相关的部分有源应答器报文，该方法保证了应答器报文的准确性，为验证正线无源应答器提供了良好的思路。

在应答器布置方面，现场中依据应答器应用原则对应答器进行布置，王红军简明介绍了应答器设置的原理和应用[[[41]](#endnote-42)]；曹峰分别建立了基于通信的列车运行控制系统CBTC（Communication Based Train Control System）[[[42]](#endnote-43)]三种模式下轨旁设备布置的数学模型，定量分析其对列车追踪距离和追踪间隔的影响，得出信号机、计轴器和应答器之间的位置相互制约关系，从而科学地提出CBTC系统的轨旁设备布置原则[[[43]](#endnote-44)]；田晓平从应答器天线和列车过顶传输延时两个角度分别研究了两个相邻应答器之间的最小间隔的确定和应答器组中最大数量问题[[[44]](#endnote-45)-][[[45]](#endnote-46)][[[46]](#endnote-47)][[[47]](#endnote-48)]；豆雯雯等人从应答器容量角度对应答器布置进行了优化方法研究[[[48]](#endnote-49)]；姜守轩等人结合现场数据对定位应答器（DW）等几种特殊的应答器进行了解释说明[[[49]](#endnote-50)]；王素娇、刘莉等人结合现场数据通过计算机技术提取应答器布置规则，但并未给出优化方法[[[50]](#endnote-51)-][[[51]](#endnote-52)]；陈建球对应答器设置评价方法的研究[19]。

综上所述，应答器报文角度国内主要是针对应答器报文的编码译码的研究和正线应答器报文数据的验证[[[52]](#endnote-53)]并未系统的进行应答器报文结构和报文内容两方面进行验证。应答器布置方面国内主要是从单一的应答器报文内容角度对应答器的布置进行探讨，并未从功能、效率、成本全面考虑应答器的布置。而国外主要是对应答器数据分析和报文数据验证方法的探索，极少有对应答器布置的深入研究。简而言之，目前，国内外还没有针对应答器应用原则整体的验证与优化算法研究。

## 基本概念

应答器是一种基于电磁耦合原理[[[53]](#endnote-54)-][[[54]](#endnote-55)]，用于列车定位、判断列车运行方向、车地数据交换的点式高速数据传输设备[[[55]](#endnote-56)-][[[56]](#endnote-57)]。它包括地面应答器（Balise）和车载查询器（BTM）。应答器安装于股道中间，当车载天线经过应答器上方时，应答器被车载天线发送的电磁能量激活，并开始连续发送报文，当车载天线离去后，应答器停止发送。



按设备类型，应答器可分为无源应答器和有源应答器两种类型。无源应答器发送自身存储的线路数据、坡度数据、线路限速等固定报文；有源应答器与地面电子单元（LEU）连接，所发送的报文存储在列控中心设备中，列控中心设备根据联锁设备提供的列车进路信息以及行车指挥中心CTC设备下达的临时限速命令，根据存储的报文模板，实时组帧生成相应的控车报文，周期地向LEU发送，LEU通过电缆与有源应答器连接，将列控中心发送的报文连续无缝隙地向有源应答器发送，当有源应答器被激活时，有源应答器发送来自于LEU传送的报文，当电缆开路/短路或外部信息无效时，有源应答器发送自身存储的默认报文。

## 研究任务及主要技术

**主要任务：**

1. 针对应答器应用提出一种应答器报文数据验证的方法；
2. 通过对现有应答器布置方案进行学习，提出一套理论布置方案；
3. 通过综合考虑行车效率、安全等因素对该方案进行优化；
4. 通过理论方法对所得应答器布置方案进行评价；
5. 通过搭建仿真平台，通过仿真的方法对应答器布置的合理性安全性进行验证。

**技术路线：**

1. 结合武广线应答器数据，依据应答器应用原则提出一种应答器数据验证方法，并通过编程实现，试图开发数据验证平台以完成对武广线数据的验证，并对所得应答器数据验证方法进行合理性完备性进行验证；
2. 根据实际线路应答器数据（武广线），以应答器应用原则为依据，结合应答器布置的相关规则，采用机器学习的方式提取现有应答器布置方案；
3. 从行车效率、安全、功能、应答器容量、工程造价、运营维护等因素充分考虑对应答器布置的影响考虑，并将影响因素逐一量化为可以操作的影响因子，通过进一步调节这些影响因子以对所得应答器布置方案进行优化；
4. 采用DEA与HAP结合的方法或其他合适的理论方法对上述所得方案进行分析和评价，以得到相对最优的应答器布置方案；
5. 针对不同的应答器布置方案制定测试案例，通过搭建简化列控系统仿真测试平台，进行跑车实验，记录运行数据，通过分析各次测试记录的数据，考虑其合理性和安全性进行分析，以期得到最佳的优化方案。

## 结束语

应答器作为地面设备的重要组成部分，负责向车载设备传输地面数据，是实际应用中列车安全高效运行的重要数据支撑。课题通过结合应答器应用原则，以武广线工程数据为基础，针对现场应答器应用提出一种应答器报文数据验证的方法，并通过对现有线路数据应答器布置方案进行学习提出一套理论布置方案，通过综合考虑行车效率、安全、应答器容量、线路数据等因素对应答器布置的影响，得到几套应答器布置优化方案，最后通过仿真测试和理论评价两种方法对应答器布置的合理性安全性进行评价。以期对现有的应答器应用原则进行验证和优化，并对现场应答器应用有一定的指导意义。

## 主要参考文献

**Study on the Verification and Optimization Method of the Application Principles of Balises in High-speed Railway Train Control System**

**Abstract:**

As the key of wayside equipment, the telegram data of balises provide significant support for the high-speed train-set running safely and efficiently. And, their correctness and the rationality of the arrangement of balises influence the safety and efficient of high speed railway. Focusing on the application of balises, this paper find a way to verify the balise telegram, put forward to a new and academic layout plan by learning the used one in the real railway, and optimize it via considering the factors, such as driving efficiency, safety and so on. At last, the rationality and safety of those layout plans will be research by the theory evaluation and some simulation test.

**Keywords:**

High-speed Railway Train Control System, the Application Principle of Balises, Data Verification, Optimization Method

## Introduction

As a complex safety-critical system, a high quality requirement for system security is required by the train control system. And, as an important part of wayside equipment, a balise, with responsibility to up-link track data to on-board equipment, is an important data supporting for safe and efficient operation of the train in practical application. The application principle of the balises in high speed railway train control system stipulates detailed for the principles of setting rules and packaging telegram of balises, and is the basis of setting balises and packaging telegram in the practical application.

In reality, emergency stop and other accidents often take place due to the error messages of a balise, and it seriously affects the safe and efficient operation of trains. So, the on-board equipment should judge the validity and the usability of the telegram to avoid an accident happening before it’s used. Moreover, we usually set balises only according to the application principle, without setting balises by considering the factors, such as safety, efficiency, function, construction cost, safeguard and so on, which lead to setting them too close (or too sparse), unreasonable, missing the key information and so on. So, it’s urgently needed to put forward to a feasible optimum layout plan to set balises.

At first, starting with the structure of the balise telegram, this author judge whether it is in keeping with the real length of message and message structure requirements, and verify the contents with engineering data to ensure the accuracy by decoding balise telegram. It should be accounted as invalid massage that the message does be not up to specification, or with internal logic error, or not in keeping with the engineering data.

Moreover, selected the influence between layout and operational efficiency, and ATP curve, and cost analysis, and whether satisfy with the speed and with the minimum tracking interval or not, and the influence between the capacity and the layout and so on, build a right model after study some algorithm and choose a right one. Then, an optimization algorithm will be used to find out the optimum plan in many different ones. Finally, DEA with HAP, or the other theoretical approaches will be used to evaluate the remaining plans, which will be measured and tested by setting up a reduced train control system to succeed in finding the most rational and the most optimum one, which has some practical significance in the on-site application.

## Research Status at Home and Abroad

Currently, researches about balise applications include several aspects as follows: the functions, failure and its impact, telegram, and balise settings and so on.

Firstly, in terms of functionality, they, Ma Wen-jun, Wang Liu-can, Lv Xiang-dong and someone else, told us the functionality, typical fault with its solution of balises. And Chen De-wang and Zhao Dong-xu, who intensive studied location method based on balise, delved into the application of balise in train control system. In addition, Cai Bo-gen, Wang Jian, Zhang Ya-jing and the others delved into the virtual balise system based upon GNSS(Global Navigation Satellite System).

Secondly, in the way of balise fault and its influence, Wang Dong and Li Liang analyzed some kinds of balise telegram error problems, clarified the true reasons, and provided some basis method to dealing with them. Chen Da-wei and Zhao Yang and others focused on the balise system, on the basis of describing lost points-one or more balises, and had a full analysis of the causes to give a way to solve the problem finally.

Furthermore, in the aspects of balise telegram, Xing Yi explained the balise telegram redact rules clearly. Li Kai-cheng and Zhu Xiao-hang researched on coding and decoding of Eurobalise based on FPGA. In addition, at the present time, the verification of messages always generally focus on the consistency comparison of a passive packets of balise and engineering data , for example, Artificial view on the line profile clearly, with marking out the contents of packets, which has been plotted all positive line information. We can reduce the error rate by the way based on manual checking, but artificial have a greater impact on the validity of the method to check. In order to raise efficiency, Zhao Jun-wei make it possible to show the balise telegram and engineering data on computer by programming a software, which can verify the validity of balise telegram easily. Liu Chang-bo came up with a way to verify the validity by simulating interlocking and train control center to verify the information with the approach and temporary speed limit information related to the portion of the active balise packets. By the way, this method ensures the accuracy of the packets, and provides a good idea to verify the passive balise telegram in positive wire.

Finally, in the arrangement of the balise, it’s arranged based on the application of the principles. Wang Hong-jun introduced briefly to the theory and application. Cao Feng were established mathematical model of the layout of trackside equipment of the three modes in CBTC system (Communication Based Train Control System) ,based on quantitative analysis of its distance from the train track and trace spacing effects, derived signal, location axle and response relationship between mutual restraint, in order to raise the scientific principles of rail equipment layout beside CBTC system. Tian Xiao-ping studied the BTM antenna and propagation delay over the top two angles to determine the maximum number of balise group and the transponder transponder set minimum between two adjacent intervals. Balise capacity from the perspective of the layout optimization methods have been studied by Dou Wen-wen and others. Jiang Shou-xuan and others particularized, by combined with field data, several special balise like DW. Wang Su-jiao and Liu Li combined with the field data extraction rules transponder arranged through computer technology, but did not give optimization method. And Chen Jian-qiu studied the method to evaluate the balise setting plan.

In summary, in terms of balise telegram, the main sight is coding, decoding and research on its verification in the main line. But, do not verify the same data by considering its structure and content. Moreover, we usually set balises only according to the application principle, without setting balises by considering the factors, such as safety, efficiency, function, construction cost, safeguard and so on. The overseas researcher just seek for the way to verify and analyze the balise telegram and does not delve into the setting plan. In short, at present, there is no overall study of the principles of validation and optimization application for balises both here and abroad.

## Basic Conception

A balise, based on the principle of electromagnetic coupling always, is used to locate the position of a train, judge the direction and up-link the route information. It include the two parts: balise on ground and BTM on board. The balise that is installed between the two track, when the train run over the balise and down-link tele-power to activate it, up-link telegram to BTM. And it will stop after the train departs.



Based on device type, balises are of either fixed type or controlled type. The passive balise is in store of route information, gradient information, restricted speed and the other fixed information. And the active one, which keep in touch with LEU(Line Electronic Unit), up-link data that comes from TCC(Train Control Center). With a template of telegram, TCC, based on route information that came from interlock, TSRS information that came from CTC facilities, codes a real-time telegram to control the running train and it will be transmitted to LEU periodically. And then, LEU, connecting with an active balise, sends it to the active one uninterruptedly. When it was activated by tele-power, the valid telegram would be transmitted while a strip of acquiescent one would be send, either the cable is open circuit or it is short, or the basic information is useless.

## Study Tasks and Main Technologies

**Main Task:**

1. Focusing on the application of balises, a method should be came up with to verify the telegram;
2. Put forward to a new and academic layout plan by learning the used one in the real railway;
3. Optimize it via considering the factors, such as driving efficiency, safety and so on;
4. Some theoretical approaches should be used to evaluate the remaining plans to get some more effective ones.
5. At last, the rationality and safety of those layout plans should be research by some simulation test.

**Research Approach:**

1. Focusing on the application of balises, a method ought to be come up with to verify balise telegram by analyzing telegram come from Wuhan-Guangzhou high-Speed railway. And then, a data verification plat will be set up by programming to ensure the safe and efficient.
2. Put forward to an existing layout plan by learning the used one in the real railway: Wuhan-Guangzhou high-Speed railway;
3. Via considering the factors, such as safety, efficiency, function, construction cost, safeguard and so on, and quantifying the factor of influence one by one, the existing layout plan will be optimized by regulating above-mentioned variables.
4. DEA with HAP, or the other theoretical approaches should be used to evaluate the remaining plans to get some more effective ones.
5. Some test case should be developed for every layout plan, and a reduced train control system will be set up to run the test case. The rationality and safety of those layout plans should be research by analyzing on experimental data, on rationality and on security to find out the most optimum one.

## Conclusion

As the key equipment of wayside, the telegram data of balises provide significant support for the high-speed train-set running safely and efficiently. By means of the application principles of them, a method, aimed at the applications in real environment, is putted forward for verifying packet data combined with Wuhan-Guangzhou line engineering data. Then, a theoretic layout plan will be proposed by learning an existing one used in the existing lines, and some filtered plans will be found out, after considering the factors, such as safety, efficiency, function, construction cost, safeguard and so on. At last, the rationality and safety of those layout plans will be research by the theory evaluation and some simulation test. Furthermore, as the author, I look forward to seek a method to verify telegram and an optimum plan to set it, and to have some significance in real environment.

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