A Centralised Interlocking System for Low-density Line Signalling with a Predictive Monitoring System

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Summary

The methods adopted to provide cost effective signalling systems for the low-density lines have evolved over many years. In Japan, a typical conventional signalling system for single lines consists of three kind of equipment: centralised traffic control (CTC) equipment at the control centre and each station where an interlocking equipment is also located with a single line signalling equipment. This system structure thus has complex function layers that cause problems of capital and maintenance costs.

In order to overcome these problems, we developed a centralised interlocking system (CIS), which provides all facilities available in both interlockings and a CTC system at significantly reduced cost while maintaining high levels of safety and reliability. The CIS, based on an electronic interlocking system technology, provides a direct interlocking between starting signals reading into each end of a single line section by means of the route locking logic. In addition to this normal interlocking logic, we produced a diversity train detection method in this development to reinforce safety at the single line signalling.

Furthermore, in order to reduce maintenance costs we also developed a predictive monitoring system. The main reason is that we had to provide more satisfactory solution for the low-density lines. This system enables us to monitor condition of signalling infrastructure equipment such as track circuits, points, signal lamps, level crossings and power supplies at the control centre.

Keywords

Electronic interlocking system, centralised traffic control, single line signalling, predictive monitoring system.
1. Introduction

Four years ago, we started a development of centralised interlocking system (CIS) for the Ibara line, which has been satisfactorily in operation since the opening in January 1999.

The beginning of the Ibara-line construction dates back to 1966, then in 1980 it was suspended due to a serious financial management problem of the Japan National Railway (JNR), which has been privatised to the JR Group since 1987. Afterward, in 1986 the Ibara Railway, a small third-sector company, was founded in order to resume the construction to come up to the local communities' expectations, then the construction had been undertaken by the Japan Railway Construction Public Corporation (JRCC), a government body. We are succeedingly working to apply the CIS to the Asa line, of which the overall scheme and background is very similar to the Ibara line.

For this reason, we had been led to pursue a cost effective signalling system for the low-density line which the small company operates such as the Ibara line to reduce capital costs maintaining the safety level while we had to provide facilities which enable us to lower maintenance costs for the signalling system.

2. System description of the Centralised Interlocking System (CIS)

2.1 Overview

The first CIS was applied to the Ibara line, which is non-electrified single line of 41.7 km in route length linking Soja, Okayama Prefecture, to Kannabe, Hiroshima Prefecture, in a rural area of west Japan. There are nine interlocking stations and one depot on the line where 23 train services using single or double diesel engine passenger vehicles are operated daily in each direction. Fig. 1 shows the Ibara control centre operation room.

The Ibara-line signalling system structure is shown in Fig. 2. As shown here, the CIS, of which system structure and its condition are displayed on a screen of the interlocking monitor as shown in Fig. 3, is regarded as being divided into control centre and lineside subsystems. At the heart of the control centre subsystem, there is an electronic interlocking controller, which is a fail-safe multiple processor system which implements all the logic necessary to generate safety commands for lineside signalling equipment. At the centre a programmable traffic control (PTC) system, which is a computer-based system for the automatic route setting according to the timetable and train running information, is also installed to implement advanced control functionality. The lineside subsystem consists of vital electronic controllers and fail-safe data links using single mode (SM) optical fibre cables.

Therefore the CIS provides the three major signalling functions: centralised traffic control (CTC), interlockings and automatic block working.
Fig. 1. Ibara control centre operation room

Fig. 2. Ibara-line signalling system structure
Fig. 3. CIS system condition display on the interlocking monitor

Fig. 4. PTC operating workstation
2.2 The control centre

In the development of the CIS we applied a vital programmable logic controller to the electronic interlocking equipment. This type of controller, a duplicated system, is in extensive use as the electronic interlocking K5 series in Japan. The controller does no more than carry out safe evaluation of logical instructions, which are defined by the signal designer in terms of Boolean expressions. This application method is well known as the ‘LDC (logical data compiler) method’, which has been pioneered by the K5 series since 1990.

In such systems, every detail of the operation of the interlocking logic must be defined from first principles for every signalling object on every scheme. This process is exactly analogous to relay circuit design. Fig. 5 and 6 show visual displays of the interlocking logical operation states and timing sequence chart on the interlocking monitor.

![Interlocking logical operation states display](image)

Fig. 5. Interlocking logical operation states display
2.3 The lineside

The lineside subsystem is consists of lineside data cables using SM optical fibre and vital electronic controllers forming a fail-safe local area network which drives signals, points, and other signalling equipment via vital relays according to command telegrams generated by the interlocking controller, and transfers back to the interlocking information from track circuits, points and other signalling equipment.

These electronic controllers are located at each station on the line. Each controller is a dual system which consists of two modules without changeover subsystems in order to provide fault tolerance.

For the CIS we developed a long distance data transmission system by means of the SM optical fibre technology which enables the interlockings to link with the electronic controllers at each station directly over 20 km without repeaters. This network is also duplicated in order to enable normal operation to continue in the event of a complete failure of one system.

3. Improving safety at single line signalling

3.1 The operation of single lines by the normal interlocking

Both ends of each single line section are controlled from one control centre by the same interlocking, and only the normal interlocking logic is required to prevent opposing
movements. This method had been only used where the section is short until the CIS was
developed. The long distance data transmission system at the CIS enables this simple
method, direct interlocking between starting signals at the both ends, to be applied to the
single line signalling at the Ibara line where the maximum length of the single line
section is 8.6 km.

3.2 Train detection at the single line sections

The previous method requires continuous track circuits through the section. In each
single line section, the long length control type track circuits are installed as one of the
standard methods. The track circuits are designed so that any failures will result in
signals being set at danger; that is, the track circuit system is fail-safe.

However, if a track circuit of single line section falsely clears momentarily, because of
poor rail surface conditions or maloperation by lightweight vehicles for instance, the
normal interlocking logic can not protect against operations for the starting signals at the
opposite end. This is important for lightly used lines or lines where lightweight vehicle in
use.

In the conventional systems, therefore, to guard against this problem the interlocking
circuit for the single line signalling uses relays designated ‘TUR’ which, in the Japanese
standard signalling alphabet, stands for track circuit repeating relay which remains
released for maximum 20 s after energisation. This measure however can cause
excessive decrease in line capacity of train services.

3.3 Reinforcement of train detection at the single line sections

In this system, therefore, we developed a train detection logic which reinforce the
single line signalling. This new logic does not cause increase in signalling facilities, and
enables the system to protect, without using the previous ‘TUR’ measure, against the
danger condition like that a track circuit of single line section falsely clears.

The point about the new logic, which improves both the safety level and the line
capacity, is highlighted in bold in Fig. 7. Here consider a down, right direction, train
travelling from A station toward B station.

When the train strikes in advance of starting signal 4R (or 5R), releasing 4ASR (or
5RASR), standing for the approach locking of 4R (or 5R), and releasing 7TUR release
10RSR, which means the single section is occupied by a down train. This release of
10RSR is maintained until the train strikes in advance of B station's home signal when
both ABTUR and 16TUR are released. Thus another train occupation information at the
single line section is generated as 10RSR in addition to ABTUR; that is, the new logic
provides a diversity of train detection at the single line section. Without any additional
equipment, therefore, the logic can protect the interlocking between the staring signals
against wrong-side failures on the track at the single line section

Here we would like to show how the additional logic reinforces safety of the single
line signalling. On this purpose it is well known that the fault tree analysis (FTA) method
is very useful. Fig. 8 is a part of fault tree which analyses the reinforced logic for an
undesired event that opposite starting signal is controlled to the proceed aspect while a
train travelling. The fault tree describes graphically that the bolded ‘AND’ gate which is
added by the logic protects 10RFLR, standing for the direction locking of 10R, operation
against ABTUR maloperations; that is, the probability of pre-defined undesired state is lowered.

![Diagram](image)

Fig. 7. The new train detection logic
4. **Introducing a predictive monitoring system**

4.1 **Overview**

The estimated severe management environment of the Ibara Railway, a small scale company, had required to been introduced the facilities which enable the company to carry out its railway operation efficiently since it was founded. That is the reason why we pursued a development of condition monitoring system in order to reduce the maintenance costs.

The monitoring system watches over the signalling system condition including telecommunications and electrical substation equipment in real time, and has the ability to accurately predict likely failures and generate alarms to give advance warnings. The system structure of this monitoring system is shown in Fig. 2.

4.2 **Principle functions and benefits**

At the centre, the system enables us to continuously monitor the signalling operating condition of all facilities such as track circuits, points, signal lamps, level crossing equipment and power supplies using contactless sensors which we developed for this system. The data measured from the sensors and relay contacts information are stored as database in the system so that the system contributes to allow us a predictive maintenance, unlike preventive one, to reduce maintenance costs and to minimise traffic.
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delay costs.

The characteristic functions are to:
- record the monitoring data automatically to fewer routine testing being required,
- print out the monitoring data to support reporting tasks for periodic inspection,
- manage trends of the monitoring data to be analysed, and raise alarms when threshold settings are reached for the predictive maintenance,
- find out potential failures to rectified in a planned manner before they occur,
- provide diagnostic information graphically to technicians in order to reduce the time taken to repair the equipment such as truck circuits or points, which are affected by the weather condition changes and has no redundancy system, in particular.

4.3 The system structure

As shown in Fig. 9, the system is divided into three function layers: centre, lineside and trackside subsystems.

The centre subsystem consists of a processing unit, consoles and remote monitoring consoles forming the server/client system by means of the Ethernet and TCP/IP technology, which can connect to the other systems such as the interlocking monitor. The remote monitoring allows either manufacturers or component-suppliers to support maintenance work efficiently.

The lineside subsystem consists of the lineside data links (M-NET), which connects stations to the centre, and data transmission terminals at the rate of 10 M bits/s using optical fibre cables. The total number of the terminals is ten, and each of them collects the data from the trackside.

The trackside subsystem consists of the trackside data links, which connects sites to the interlocking station, transmission terminals and signal transducers on the ARCNET at the rate of 156.25 k bits/s using metal cables. That rate allows trackside data links without repeaters at a maximum range of 4 km. 72 terminals and 112 transducers are installed at equipment rooms and trackside equipment boxes for measuring various types of equipment.

This structure was developed in order to being able to handle a very large number of data significantly taking account of capital and maintenance costs.
4.4 Monitored objects

The system inputs relay contacts and measures voltage and amperage values at various signalling equipment. The monitored objects are:

- **Signalling power supplies:**
  - AC voltages from electrical substation and DC supply voltages.
- **Signal lamps:**
  - Currents of LED type colour light home/starting signals.
- **AC commercial frequency type track circuits (for station areas):**
  - Output currents at power source side end,
  - Track circuit voltages, current phases and relay drive voltages at receivers end.
- **Long distance type track circuits (for single line sections between stations):**
  - Output voltages and currents at transmitters,
  - Track circuit voltages, attenuator output voltages, local DC supplies voltages and track relay coil voltages at receivers.
- **Electric points:**
  - Voltages and currents on the motor circuits, and movement times
- **Level crossing power supplies:**
  - AC voltages from electrical substation and DC supply voltages.
- **Audio frequency type track circuits (for level crossings):**
  - Power supply voltages and output voltages at transmitters,
  - Power supply voltages, receiving carrier voltages, modulation frequency voltages
and receiver relay coil voltages at receivers.

- Relay contacts of failure detection for:
  power supply units, shunting signal lamps and various equipment such as
  level crossings, interlockings, PTC, telecommunication, electrical substation.
- Relay contacts of level crossing operations:
  crossing control states such as alarming.

4.5 Operator interface

Using standard personal computer technology, the system console provides displays
and/or setting commands as follows:
- Menu (see Fig. 10).
- System information for the monitoring functions.
- Historical data of equipment failures and/or faults.
- Printing out the daily reports.
- Equipment monitoring from sensors in real time.
- Equipment monitoring from sensors in details.
- Pre-setting threshold values.
- Trend-graph chart (see Fig. 11).
- Level crossing operation sequence charts (see Fig. 12).
- Transmission terminals monitoring.
- Relay contacts monitoring.
- Points monitoring.
- Setting types of point machines for monitoring.
- Point movement charts (see Fig. 13).
- Telecommunication and electrical substation equipment condition.
Fig. 10. Menu display

Fig. 11. Trend-graph chart of LED type signal
Fig. 12. Level crossing operation sequence chart

Fig. 13. Point movement charts
5. Conclusions

The paper has described that safety of the single line signalling is improved under the centralised interlocking system (CIS) structure and that introducing a predictive monitoring system enables us to lower maintenance costs for the signalling system. The both systems are designed taking account of lowering both capital costs and operating costs for the low-density line signalling.

The system development and configuration depend upon following major points:

- To introduce the SM optical fibre technology for both a large amount of data and long distance transmission.
- To introduce the concept of efficient centralised system for both operations and maintenance.
- To pursue improving the level of both safety and maintenance not depending on the human operations.