Third Generation On-Board Monitoring and Control System Based on Controller Area Network Technology

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Summary: The Office of Research and Development of the Federal Railroad Administration (FRA) is sponsoring a project to integrate on-board monitoring systems with remote controlled mechanical components in freight railroad operations. The integrated system, called On-Board Monitoring and Control System (OBMCS), is being demonstrated in the FRA Advanced Concept Train (ACT) project, which features advanced mechanical components controlled remotely from the locomotive, including angle cocks, cut levers, and hand brakes. The system will also have a low-power wireless communication link between OBMCS and an ISO container tag tracking system. This interface provides a mobile gateway whereby communications tags installed on ISO containers could be able to maintain continuous two-way communication with remote monitoring centers when the containers are moving by rail. The third generation OBMCS has a modular architecture based on Controller Area Network (CAN) technology. It also has a standard physical interface for power and CAN bus communication. Low-cost, low-power CAN microcontrollers are dedicated to specific sensor monitoring and actuator control functions. Wireless transceivers based on Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 specification (ZigBee) provide remote wakeup capability and a communications link to other systems, such as a container tag tracking system. A wireless Local Area Network (WLAN) based on IEEE 802.11b specification (Wireless Ethernet) provides intra-train communication between the locomotive and cars. Cell telephone telemetry provides an Internet connection between the cars and a Web-accessible database server.

Index Terms: On-board monitoring system, real-time control system, on-board sensors

INTRODUCTION

The Federal Railroad Administration's Office of Research and Development (FRA) has been sponsoring development of on-board monitoring systems for freight trains. The multi-year project, which commenced in June 1999, is part of the Rolling Stock Program Element in *FRA's Five-Year Strategic Plan for Railroad Research, Development, and Demonstrations* [1]. In 2000, Science Applications International Corporation (SAIC) and Wilcoxon Research (WR) developed a prototype on-board condition monitoring system, designated Phase II-B. It was installed

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on a test vehicle provided by the Research and Tests Department of Norfolk Southern Corporation in Roanoke, VA and was tested during the period November 2000 through November 2001 [2].

In fall 2003 a second generation monitoring system, designated as Phase II-C, was installed on five 100-ton hopper cars owned by Southern Company Services in Birmingham, AL. These cars are currently deployed in revenue service operations on a BNSF route between Miller Steam Plant, 20 miles northwest of Birmingham, and coalmines in the Powder River Basin in Wyoming – a 3,000-mile round-trip journey. The Phase II-C system monitors bearings, wheels, trucks and brakes. It features the latest technology in wireless communications and railroad bearings ([3] and [4]).

The third generation monitoring system currently under development consists of a fully integrated network of passive sensors and mechanical actuators, which are controlled remotely from the locomotive or from the wayside by a hand-held computer. The integrated system, called On-Board Monitoring and Control System (OBMCS), has modular architecture. It consists of a network of microcontrollers linked by a Controller Area Network (CAN) bus. The protocol for communication on the CAN bus network is CANopen, an open standard for CAN systems maintained by the CAN in Automation (CiA) Consortium (http://www.can-cia.org/). Each microcontroller in OBMCS is dedicated to one or more specific monitoring and/or control functions. At this time the mechanical components integrated in OBMCS include angle cocks, cut levers, and hand brakes. CAN microcontrollers also manage the OBMCS power subsystem and various communication functions.

OBMCS is currently being installed on five freight cars, which were loaned to the project by various US railroads and fleet owners. FRA acquired an EMD GP40-3 locomotive (DOTX2000) for dedicated use in the project. DOTX2000 has several safety and security features, which were developed under FRA sponsorship. The special train consisting of DOTX2000 and the five cars equipped with OBMCS and the advanced mechanical components is called the Advanced Concept Train (ACT). The ACT will be featured in a series of demonstrations with U.S. railroads commencing in summer 2007.

This paper discusses OBMCS requirements, architecture, and potential benefits of the technology.

DEVELOPMENT OF SYSTEM REQUIREMENTS

The requirements for integrating and remotely controlling mechanical systems in OBMCS were driven by the need to develop a common approach for interfacing these systems with earlier generations of the on-board monitoring system, providing power to them and communicating with them. To address these needs, the OBMCS design team prepared an OBMCS Interface Requirements Document (IRD) for sensors and remote controlled actuators. The design team held weekly conference calls in summer 2004 to review successive drafts of the IRD. This document outlines general requirements for any device (sensor or actuator) with regard to form, capability, electrical interface, communication interface, timing, and operational and safety considerations. Various appendices to the IRD describe additional requirements for specific devices, such as angle cocks, cut levers, and hand brakes.

The selection of CAN bus technology for OBMCS architecture was based mainly on considerations of system cost and power consumption. It was also based on the desire to be compliant with well-established open standards, as much as possible, in developing OBMCS hardware, communication systems, and software. CAN is a serial bus system that supports standardized development of embedded systems. The CAN protocol was internationally standardized in 1993 as ISO 11898-1. During the last 15 years, CAN technology has been widely adopted in the automotive and other machinery industries. Presently dozens of manufacturers of produce CAN compliant

microcontrollers. Similar numbers of vendors provide software development tools for CAN systems.

Based on the interface requirements, the OBMCS design team developed a specification for the OBMCS CAN controller network in summer 2004. It defines message parameters, bus speed, and other important parameters of the network. The system design team adopted CANopen as the communication protocol for the OBMCS CAN network. The CANopen specification was developed by Bosch in the early 1990s. It handed over to the CAN in Automation Consortium in 1995. Off-the-shelf devices, software development tools, and CANopen protocol stacks are widely available to support development of embedded systems compliant with various CANopen standards. The OBMCS CAN specification document has undergone numerous revisions as details of the system design have been modified and refined. A major objective in development of this document was to maintain compliance with CANopen draft standard DS-301 for the CAN communication profile and message IDs and DS-401 for creation of the generic digital I/O and analog input functionality of the devices on the OBMCS CAN network.

SYSTEM ARCHITECTURE

This section discusses details of OBMCS architecture. We shall discuss communications and sensor signal processing algorithms in the following sections. Figure 1 shows a top-level diagram of OBMCS architecture. Sensors and actuators mounted on the cars are linked via a wireless Local Area Network (WLAN) to a computer in the locomotive, which displays system status information and transmits commands to the cars to operate the actuators. The sensors monitor freight car mechanical components. The actuators control and operate mechanical systems, such as angle cocks and cut levers. GPS receivers provide location, date, time, speed, and heading information for each car.

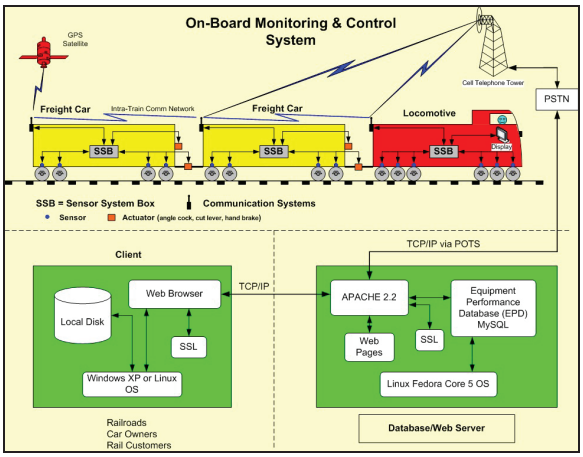

Figure 1: Top-level OBMCS architecture

Cell telephones transmit system performance and status information from each car to a database server and web site, which can be accessed remotely by clients. The Code Division Multiple Access (CDMA) cell phone provisioned with 1X Radio Transmission Technology (1XRTT) service provides a two-way Internet connection between the train and the database server. The 1XRTT connection can also be used for remote trouble shooting and to upload software modifications. Other wireless communication technologies, such as satellite and Global System for Mobile communications (GSM), could be used instead of or in addition to the CDMA cell telephone. When the system is not in an area having 1XRTT coverage, the data packets are stored on a solid state flash disk. The data packets are forwarded to the database server when the 1XRTT Internet connection is reestablished. The store and forward algorithm uses a Transmission Control Protocol (TCP) server process to transmit stored data packets and messages.

Figure 2 shows a diagram of OBMCS sensors, communications systems, and power subsystem components installed on the test cars. It also shows a list of the mechanical systems that can be controlled remotely from the locomotive. Currently only hand brakes, angle cocks, and cut levers have been integrated with OBMCS. The tri-coupler is a passive connection device that couples the cars, pneumatic line, and electric power line for an Electronically Controlled Pneumatic (ECP) brake system.

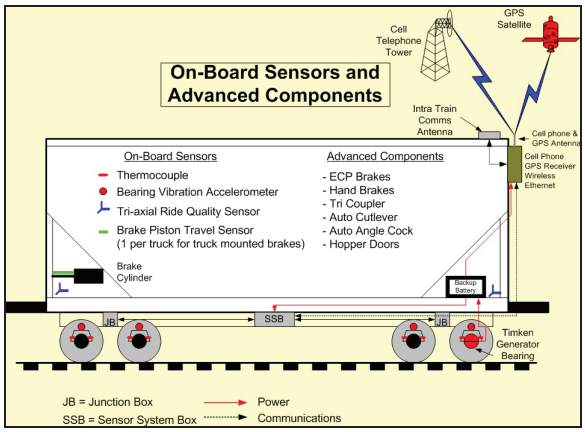

Figure 2: OBMCS sensors, actuators, and communication systems

Bearing Accelerometers

Vertically oriented accelerometers mounted on bearing adapters monitor bearings and wheels for defects and derailment. Derailment monitoring is performed continuously. Bearing and wheel defect monitoring is done intermittently. Algorithms for defect monitoring are discussed below.

Bearing Temperature Sensors

Temperature sensors embedded inboard and outboard on bearing adapters monitor bearing temperature continuously. An overheated bearing can be detected immediately with 100 percent certainty of the location of the defective bearing.

Ride Quality Sensors

Tri-axial accelerometers mounted on the main sill over the bolster bowls on the A and B ends of the car monitor ride quality. Laterally oriented sensors monitor low-frequency truck hunting motion. Vertically oriented sensors measure impacts imparted by the tracks and vertical pitching and bouncing motions. Longitudinally oriented sensors detect shocks during coupling and shocks from slack run out and run in during acceleration and deceleration, respectively.

Brake Piston Travel Sensors

Proximity sensors adjacent to the brake piston rod monitor its stroke during braking. These sensors provide an indication that the brakes are either applied or released with the brake cylinder in the proper retracted position. They can also indicate brake piston over-travel when the brakes are applied. An over-travel condition indicates the need to immediately service the brakes. These sensors permit automation of brake system tests at a freight terminal before the train departs from the terminal. A full-service brake application would be made while the train is stopped at the terminal. The brakeman would then check the status of the brake piston travel sensors shown on the locomotive computer display to determine whether any brake cylinders are beyond the safe operating limit. Automation of this procedure could eliminate the need for the brakeman to visually inspect the brakes of each car before the train departs from the terminal.

Figure 3 shows a diagram of the OBMCS distributed architecture. It shows various sensors and actuators connected on a CAN bus network.

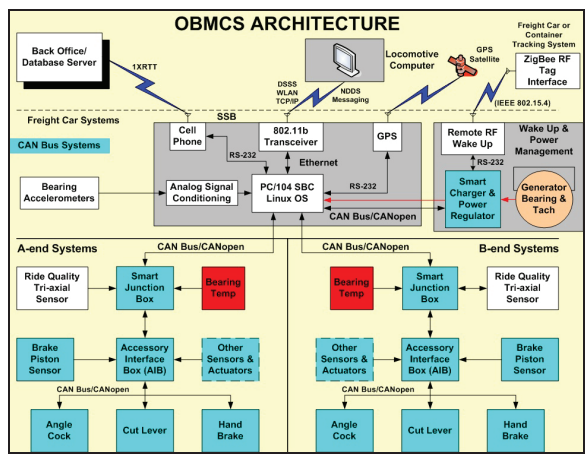

Figure 3: OBMCS distributed architecture

Sensor System Box

The Sensor System Box (SSB) has a single board embedded computer (SBC) system, which manages all communications between OBMCS and external systems including the locomotive. The SBC hosts a Linux operating system. The SSB SBC functions as the master node on the

CAN bus. It runs a fully CANopen compliant stack to manage communications between the SSB and other nodes on the CAN bus.

The embedded SBC has X86 architecture packaged in the PC/104 form factor, which implements the standard PC/AT bus specification (IEEE P996) in a compact 3.55" x 3.75" circuit board that eliminates the need for back planes or card cages through a self-stacking bus. It has four serial ports, USB ports, and a 10/100 Ethernet chipset integrated on the SBC circuit board. It also has 16 16-bit analog input channels and 24 digital I/O channels integrated on the circuit board. The SBC analog-to-digital converter samples the analog signals from the bearing accelerometers. The SSB SBC executes signal processing routines for detecting bearing and wheel defects and derailment. In future generations of OBMCS the functions of the SSB SBC will be supplanted by one or more microcontrollers. This will further reduce OBMCS cost and power requirements.

Smart Junction Box

The system is symmetric between the A-end and B-end of the car. CAN bus messages from various nodes at each end of the car are routed through the Smart Junction Boxes to the SSB. A CAN microcontroller in the Smart Junction Box processes signals from the tri-axial ride quality sensor and bearing temperature sensors.

Accessory Interface Box

The Accessory Interface Box (AIB) provides a standard physical connection scheme for interfacing sensors and actuators to the CAN bus. It has six identical ports for connecting sensors and actuators to the CAN bus. Each port provides 12 and 24 Volts DC power and signal lines for communication on the CAN bus. One of the ports can be used to daisy chain the AIB boxes if necessary. This connection scheme provides a pathway for future expansion of OBMCS capabilities. Presently CANopen networks can have up to 128 nodes attached to the bus. Since each node can support multiple sensors and actuators, many possibilities exist for future expansion of system capabilities, subject to the availability of adequate power.

Presently only angle cocks, cut levers, and hand brakes have been integrated with OBMCS. Figure 3 shows that these systems are connected to OBMCS through the AIB. They operate on 24-volt power supplied by the AIB. The AIB has a small 24-volt, 2 amp-hr battery that provides electric current to operate actuators. The AIB can provide up to 50 Watts of power for short-term operation of angle cocks, cut levers, and other actuators. The AIB has a 12 – 30 volt DC power supply to charge the 24-volt battery.

Smart Battery Charger, Wakeup, and Power Management System

The Smart Battery Charger System manages OBMCS power. A 12-volt, 100-amp-hr, lead-acid gel cell battery provides electric power to operate OBMCS. An electric generator (developed by The Timken Company) embedded inside a Class F railroad bearing provides power to charge the battery when the train is moving. The generator bearing provides up to 24 watts of power to recharge the battery. A voltage regulator rectifies the variable frequency AC voltage output from the generator bearing. The output of the regulator charges the battery.

The generator bearing also has an embedded tachometer, which produces a square wave signal having 12 pulses per revolution of the axle. A CAN microcontroller in the Smart Battery Charger monitors the tachometer signal to determine when to turn the system on and off based on train speed. The microcontroller also monitors the battery voltage to determine whether it is sufficient to run the system. The nominal wake up speed for the system is 10 mph if battery voltage is adequate to operate the system. The microcontroller in the Smart Battery Charger runs continuously. When it is not communicating on the CAN bus, its power consumption is typically less than 10 mA. A counter timer in the microcontroller can be programmed to wake up the system for a short communication burst when the car is not moving.

COMMUNICATION SYSTEMS

Intra Train Communication

Figure 3 shows various wireless communication systems operating in the SSB. Communication between OBMCS and the locomotive is via Direct Sequence Spread Spectrum (DSSS) based on IEEE 802.11.b specification for Wireless Ethernet operating in the 2.4 GHz frequency band. An ad hoc WLAN configuration is used. Optimized Link State Routing (OLSR) (OLSR.ORG) mesh networking software runs on the locomotive computer and the SSB SBC. OLSR is a routing protocol for wireless ad hoc networks. If a node in the WLAN does not have line of sight connectivity with another node in the network, OLSR will attempt to set up a route between the source node and destination node using intermediate nodes to relay the message through the network. For example, in a long train, the locomotive might not have line of sight connectivity with most of the cars in the train when it is going around a curve. In this situation, OLSR would determine a route between the locomotive and each car using intermediate cars to forward message packets to their intended destination.

Network Data Distribution Service (NDDS) software manages messaging between the locomotive computer and the cars. NDDS operates on a publisher/subscriber paradigm. It runs on top of the WLAN TCP/IP protocol software in both the locomotive computer and the SSB SBC. Publisher processes running on the locomotive computer transmit data topics (commands and status requests) to the cars. Subscriber processes running on the SSB SBC listen for specific data topics to which they subscribe. For example, when an SBC process that subscribes to angle cock operation commands receives a message to operate one of the angle cocks (A- or B-end), processes on the SBC react to the message and send the command to the appropriate node on the CAN bus. Similarly, publisher processes running on the SSB SBC transmit specific data topics to the locomotive, such as the status of a specific OBMCS subsystem. Subscriber processes running on the locomotive computer receive specific data topics from each of the cars and display them on the appropriate screens on the locomotive computer display.

GPS Receivers

The GPS receiver in the SSB provides continuous location (latitude, longitude, and altitude), date, time, speed, and heading information. Its output is sampled once a second. The reported GPS location is the location of the GPS antenna on the car.

Cell Telephone Telemetry

The CDMA cell telephone telemetry system is a Kyocera Wireless M200 tri-mode telemetry module provisioned with Verizon Wireless 1XRTT service. It operates over a serial connection to the SSB SBC using a point-to-point protocol (PPP) connection. The IXRTT service provides two-way Internet connectivity between the ACT test cars and a Web-accessible database server located at SAIC's facility in McLean, VA. The rated speed of the M200 module is 150 kbps. The realized transmission speed, which is dependent on the network connection, is typically around 70 kbps or less.

When it has a 1XRTT connection, the CDMA radio transmits summary information about monitored components and OBMCS status information to the database server according to a defined schedule. Each data packet is tagged with position, date, and time data obtained from the GPS receiver. The 1XRTT telemetry link supports remote query from a Web browser and real-time system diagnostics and software modification via standard SFTP and SSH connections.

Remote Wake Up

The OBMCS also has a remote wake up capability, which uses a low power wireless radio frequency (RF) communication system based on IEEE 802.15.4 specification (ZigBee). When OBMCS is asleep, the microcontroller in the Smart Battery Charger periodically turns on the ZigBee radio transceiver so it can check for

beacon message packets directing the system to wake up. For example, this feature is used to wake up cars on a siding when they are being coupled to a train. The wakeup sequence is necessary in order for the locomotive computer to properly configure the WLAN and graphical displays before train operations commence. The ZigBee radio wake up duty cycle requires very little power and can execute repeatedly while the rest of the system is asleep.

Figure 3 also shows that the ZigBee radio can provide a RF link between OBMCS and other external systems. For example, the ZigBee radio could communicate with low-power RF tags mounted on cargo containers. Such a communication link would enable OBMCS to function as a mobile gateway for low-power communication systems for tracking cargo containers moving by rail.

LOCOMOTIVE COMPUTER SYSTEM

The locomotive computer is a Wi-Tronix Wireless Processing Unit (Wi-PU) manufactured by Wi-Tronix, LLC. It is a PC computer packaged in PC/104 form factor and is housed in a rugged enclosure. It hosts Microsoft Windows XP Embedded (XPe) operating system. It has several communication systems including cell telephone telemetry, Wireless Ethernet, and a differential GPS receiver.

An extensive suite of software is required to provide the functionality necessary for the locomotive computer to display OBMCS status information and remotely control various actuators. To facilitate development of the required software, the OBMCS design team developed a requirements document and an IRD for integrating the locomotive computer with OBMCS. The IRD specifies the messages and data that must be exchanged between the locomotive and the railcars in order to display OBMCS status information and to implement remote control functions.

The locomotive computer display has a variety of Graphical User Interfaces (GUIs) for displaying OBMCS information to the operator. The GUIs are selected and operated by function keys at the bottom of the display. The screens on the locomotive computer display are compliant with the Association of American Railroads (AAR) Specification M-591 for Locomotive System Integration Operating Displays.

Figure 4 shows the Train Operations Screen. It enables the operator to control mechanical actuators such as cut levers, angle cocks, and hand brakes remotely from the locomotive. This screen shows the order and orientation of the cars. It also shows a list of the actuators installed on each car. This information must be available to the locomotive computer in order for the operator to be able to control the advanced components installed on the test cars. Using a function key, the operator scrolls left or right to select a car for remote control operation. The operator then scrolls up or down through the list of devices to select the operation to be performed. Soft keys, highlighted in blue at the bottom of the screen, indicate which functions can be performed by pressing the corresponding function key at the bottom of the display.

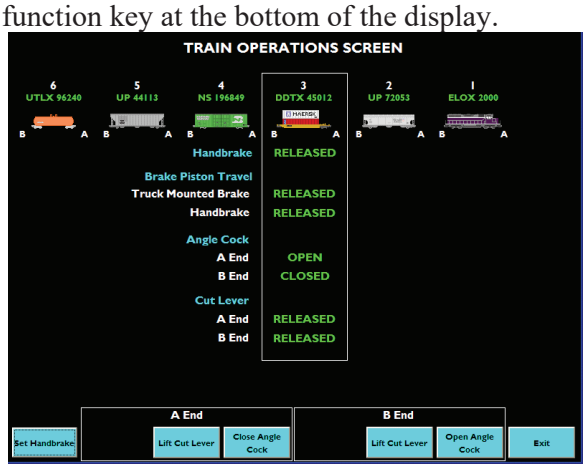

Figure 4: Locomotive Computer Train Operation Screen

The GUIs in the locomotive computer display must be self configuring. To achieve this objective, each car must transmit its position, orientation, and a list of devices installed on the car (both sensors and actuators) to the locomotive. A GPS receiver on each car provides car location information. A digital compass on each car provides car orientation information. Together these data provide the information the locomotive computer needs to

determine the sequence and orientation of the cars in the train. The list of devices on each car provides the information necessary to configure each GUI in the locomotive display. When cars are added to or removed from the train, the locomotive computer screens must be reconfigured to show the correct train consist information. When cars are picked up from a siding, they must wake up and transmit their location and configuration data to the locomotive computer so that the WLAN and locomotive compute GUIs can be properly configured. The ZigBee radio remote wake up system enables cars on a siding to wake up so they can join the train. Together these OBMCS features provide the capability necessary to automatically configure the locomotive computer GUIs.

ADVANCED COMPONENTS

In parallel with development of on-board monitoring systems, FRA also sponsored development of several advanced mechanical systems, including an auto angle cock, auto cut lever, hand brake actuator, and tri-coupler. Sharma & Associates developed the auto cut lever, auto angle cock, and tri-coupler. UTD Inc developed the hand brake actuator. These systems are intended to be operated remotely from the locomotive. They can also be operated manually from the side of the car. The tri-coupler couples the cars, the pneumatic brake line, and the power cable for an ECP brake system installed on each car. The auto cut levers, angle cocks, and tri-coupler increase crew safety and efficiency while retaining normal manual functionality. Together they allow for remote cutting in and cutting out of cars without the need for manually handling angle cocks, cut levers, brake line glad hands, and ECP brake power line connections. Figure 5 shows the auto angle cock. Figure 6 shows the auto cut lever.

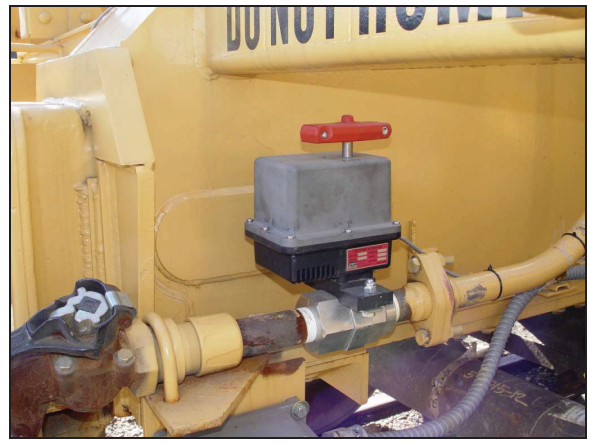

Figure 5: Auto angle cock

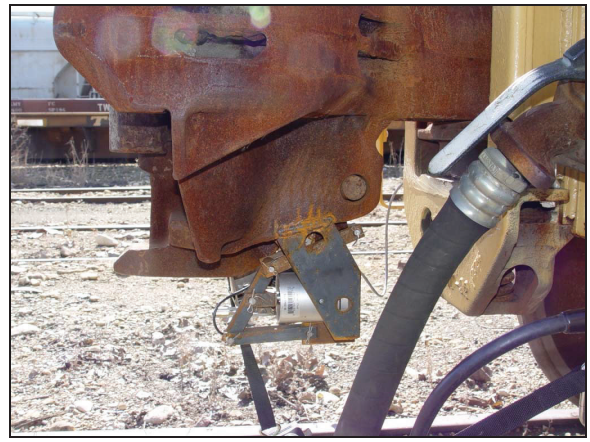

Figure 6: Auto cut lever

SIGNAL PROCESSING ALGORITHMS

Bearing Defect Analysis

The OBMCS monitors bearings, wheels, trucks and brakes. The SSB SBC samples the bearing vibration signals from accelerometers mounted on bearing adapters at a rate of 50,000 samples per second. A digital signal processing algorithm analyzes the data for large-amplitude spectral lines at frequencies associated with specific types of bearing defects. Large amplitudes at these frequencies can give an early indication of specific types of bearing defects. This processing is discussed in detail in [5].

Wheel Defect Analysis

Rain flow analysis is applied to bearing accelerometer data to detect wheel defects. Data from a single rotation of the wheel is used in this

analysis. Average counts from multiple wheel rotations improve the statistical significance of the results. Prototype algorithms for detection of flat spots and shell defects on wheel surfaces have been developed and will be tested in the ACT demonstrations. Since flat, out of round, and shell defects on wheels develop slowly, this analysis is performed once each day at speeds of 30 mph or higher.

Derailment Detection

Bearing accelerometer data are analyzed to detect derailment. Short data segments are checked for high amplitude bursts that repeat periodically. A large number of stress cycles at high amplitude in a short data segment could be indicative of a derailment in which the wheel below the bearing adapter accelerometer is rolling in the ballast or over the cross ties. This algorithm runs continuously on the SSB SBC when the train is moving.

Truck Hunting Monitoring

Analog to digital circuitry on the microcontroller in the Smart Junction Box samples the output of the lateral ride quality accelerometer mounted on the center sill above the bolster bowl. The sensor signal is filtered by a low-pass filter having 3 dB cutoff at 15 HZ and 40 dB per decade roll off. The filtered signal is sampled at 256 Hz. A data window corresponding to 2,000 ft of travel along the rail is used in the processing. Root mean square (RMS) and peak-to-peak values are calculated for the data window. If the car body lateral acceleration exceeds 0.26 g RMS or 1.5 g peak-to-peak, an alarm message indicating excessive truck hunting is transmitted to the locomotive. This processing is done only when the car speed is 30 mph or greater.

Vertical Ride Quality (Pitch and Bounce)

Analog to digital circuitry on the microcontroller in the Smart Junction Box samples the output of the vertical ride quality accelerometer mounted on the center sill above the bolster bowl. The sensor signal is filtered by a low-pass filter having 3 dB cutoff at 15 HZ and 40 dB per decade roll off. The filtered signal is sampled at 256 Hz. A data window corresponding to 400 ft of travel along the rail is used in the processing. RMS and peak positive values are calculated for the data window. If the car body vertical acceleration exceeds 0.6 g RMS or 0.96 g peak, an alarm message indicating excessive vertical motion is transmitted to the locomotive.

Longitudinal Ride Quality

Analog to digital circuitry on the microcontroller in the Smart Junction Box samples the output of the longitudinal ride quality accelerometer mounted on the center sill above the bolster bowl. The sensor signal is filtered by a low-pass filter having 3 dB cutoff at 30 HZ and 40 dB per decade roll off. The filtered signal is sampled at 256 Hz. Peak events both positive and negative are calculated for each data window. Peak values above selected thresholds are counted. The threshold values will vary depending on whether the car is loaded or not. Presently there are no AAR guidelines for longitudinal ride quality. At this time the OBMCS design team is still considering various criteria for longitudinal ride quality.

Bearing Temperature Sensor Processing

Analog to digital circuitry in the Smart Junction Box samples the output of the bearing temperature sensors once every 30 seconds. Exponential smoothing is applied to the temperature sensor data. If bearing temperature reaches 220 ºF, the signal is monitored more frequently. Above this level if the bearing temperature rises faster than 3 ºF per minute, a hot bearing alarm message is sent to the locomotive. If the bearing temperature reaches 240 ºF, an alarm message to stop the train is sent to the locomotive. These thresholds are soft-coded and can be modified if necessary.

POTENTIAL BENEFITS OF OBMCS TECHNOLOGY

The primary objective of this FRA program is to improve railroad safety and efficiency through the application of new technologies. Continuous on-board monitoring of mechanical components

can enable early detection of mechanical defects before they cause breakdowns and accidents. It also supports a movement toward condition-based maintenance by providing indications of needed maintenance. For example, the ability to detect excessive truck hunting in unloaded vehicles running at speeds of 30 mph or more could enable empty trains to run safely at higher speeds. It would also enable fleet owners to plan preventive maintenance in an orderly manner. Statistical analysis of performance data from large numbers of similar components could be used to determine percentage points in component lifetime distributions. It could also enable reliable prediction of the remaining useful life of individual components based on the indicated condition of a component obtained from continuous monitoring. The availability of on-board power, communication, and intelligent processing on freight cars supports a wide variety of useful monitoring applications that would not be possible otherwise.

GPS receivers on freight cars support a variety of asset tracking and management functions. Continuous monitoring and tracking of cargo containers moving by rail can increase cargo security and contribute to improved management of container freight operations.

Remote control of angle cocks, cut levers, and hand brakes could improve rail safety and efficiency since the brakeman would not have to get off the locomotive to operate these components. Adoption of this technology on a large scale could result in reduced injuries to train crews in addition to improvements in efficiency.

There are a number of obstacles in the way of wide scale adoption of OBMCS technology. However, none of them appear to be insurmountable. System cost, performance, and reliability will be among the major factors that will influence adoption of this technology. Having on-board power and communication systems enables independent monitoring of mechanical components. Remote control of mechanical components requires that the locomotive be equipped with the proper communication and computer hardware in order to be able to communicate with the cars. It also requires that most of the cars in a train be equipped with some version of OBMCS so that messages can be reliably routed between the cars and the locomotive.

TECHNOLOGY TRENDS

The experience gained in this project since its inception in 1999 has led to improvements in system design and performance, as well as reduction in overall system cost. For example, the cost the communication hardware used in the third generation system is about ¼ the cost of the components used in the prototype system developed and tested in 2000. The cost of embedded computer hardware has declined steadily, while performance and capabilities have increased dramatically.

Perhaps the most significant technology trend supporting advanced OMBCS development is the widespread availability of very powerful inexpensive CAN microcontrollers. In the future, this technology will lead to further improvements in system performance and reduction of system cost.

Analysis and critique of equipment successes and failures in earlier generations of monitoring system hardware has resulted in improved and more rugged system design. System performance analysis has also focused attention on development of capabilities that add value to the system. In addition, the project team continues to improve the OBMCS real-time software and to add new features to it in order to enhance overall system performance.

CURRENT STATUS AND ACT DEMONSTRATION PLANS

At this time, production of the third generation OBMCS hardware and development of the software to operate it are nearing completion. System integration testing is scheduled to begin in a laboratory in Chicago, IL in March 2007. An extensive laboratory test program is planned before the OBMCS hardware is installed on the ACT test cars and locomotive. Depending on the results of the laboratory test program,

hardware installation on the test cars will commence in late April or early May 2007 to be followed by full-scale system testing on a local rail line near Chicago.

FRA plans to conduct ACT demonstrations with the four major U.S. Class I railroads. It is expected that these demonstrations will occur in the second half of 2007.

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