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SHOCK AND VIBRATION REQUIREMENTS FOR ELECTRONIC EQUIPMENT MOUNTED ON FREIGHT CARS

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TD 97-022

Summary

An investigation of failed control modules for electronically controlled pneumatic (ECP) brake systems in a unit coal train operated by Conrail has yielded new recommendations to protect electronic equipment. The electronic modules were mounted on one of the car structural strength members which resonated during longitudinal impacts, amplifying the base-structure vibration levels. As a result of these studies it is now recommended that the module be mounted directly to the car base structure, or that vibration isolation be provided. For added protection, the shock requirements in the ECP brake performance specification were increased.

These tests were conducted in light of a small number of circuit-board mounting failures experienced on the electronic control modules for the ECP brakes which had been installed on this train as part of an ongoing industry evaluation of these systems. Since these were the first significant number of component failures reported in any service, attention was immediately focused on the mounting arrangement of the electronic module on these cars, and the resultant shock and vibration environment to which the electronic module is subjected.

The basic rotary dump service train moves coal from mines located near Pittsburgh to two power plants in the Philadelphia area. In early January 1997, a test was carried out in which accelerometers were applied to several of the cars to measure the shock and vibration response to impacts resulting from the coal-dumping operation at the power plant. In addition, acceleration measurements were made during the over-the-road moves.

Suggested Distribution:

- ❑ Equipment/Rolling Stock
- ❑ Train Handling
- ❑ Intermodal/Safety
- ❑ Car Department

Association of American Railroads
Railway Technology Department

June 1997

TECHNOLOGY DIGEST
June 1997

INTRODUCTION

A series of tests in 1997 evaluated the shock and vibration environment of unit coal-train equipment in a rotary dump service operated by Conrail. These tests were arranged as a result of a small number of circuit-board mounting failures experienced on the electronic control modules for Electronically Controlled Pneumatic (ECP) brakes, which had been installed on this train as part of an ongoing industry evaluation of this technology. Since these were the first component service failures that had been reported, attention was immediately focused on the mounting arrangement of the electronic modules and the shock and vibration environment to which they were being subjected. The subsequent tests, together with recommendations for changes in the environmental specifications, are the subject of this paper.

BACKGROUND

Since 1994, the Railway Technology (formerly R&T) Department of the Association of American Railroads (AAR) has been working closely with the member railroads and the supply industry to develop performance specifications for the application of ECP brakes to heavy-haul freight trains. The installation of electronic equipment on freight cars, other than for temporary testing purposes, is a new and radical step and the survival of this equipment in such a harsh service environment is a relatively unknown quantity.

The draft performance specification contains shock and vibration provisions, based mainly on measurements and experience derived from impact and over-the-road testing of coal cars for fatigue analysis, and of box cars for lading damage prevention. Furthermore, these data were based on measurements made on the base structure of the car and do not take into account any vibration amplification on individual structural strength members and side- or end-sheet panels due to local resonances.

CONCLUSIONS

The following conclusions were reached as a result of the test data analysis:

- The most significant vibrations, defined in terms of peak acceleration levels, occurred during the dumping operations at the power plant.
- The acceleration levels measured on the base structure of the car were consistent with previous data.
- Resonances of local structural members could significantly amplify the levels experienced by equipment directly mounted on these members.
- The test findings will be used for the establishment of recommended practices for the sensors and equipment being designed to monitor in-train health and safety monitoring.

RECOMMENDATION

It is recommended that the environmental requirements in the ECP brake performance specification be modified to read as follows:

Vibration and Shock Environment

The Car Control Device (CCD) shall be designed and mounted on the base structure of the car to withstand continuous vibrations, in the three major axes, of 0.4 g rms with a frequency content from 1 Hz to 150 Hz, containing peak values of ± 3 g in the 1 Hz to 100 Hz bandwidth. The CCD and its mounting shall also be designed to withstand a longitudinally oriented shock impulse (half sine wave) of 10 g peak with a ramp time of 20 msec to 50 msec. If the CCD is mounted on the car strength members (ribs, slope-sheet support columns, etc), then the bracket and mounting arrangements, together with the electronics packaging, shall be designed to provide protection from the amplification effects of any local vibration resonances. It should be noted that peak resonant acceleration levels in excess of 15 g in the 100-150 Hz range and values in excess of 50 g in the 200-500 Hz range have been measured on car strength members as a result of shock impulses sustained during yard impacts.

OPERATION OVERVIEW

The operation moves coal from mines located near Pittsburgh to two power plants in the greater Philadelphia area. Three train sets, each consisting of 115 cars, are used to service this operation. The three train sets are made up from a pool of cars dedicated to this particular service. It was for this reason that, during the spring of 1996, one of these train sets was equipped with ECP brakes, the main objective being to quantify the economic benefits of this technology compared with conventional braking equipment in identical service.

The trains are loaded at one of the two mines in the Pittsburgh area. The loaded trains are then routed over Conrail mainline trackage to Philadelphia, where they are delivered to the two power plants (Crombie and Eddystone) owned by the Pennsylvania Electric Company (PECO). After being unloaded, the empty trains are returned to Pittsburgh for loading. The round-trip sequence is accomplished in approximately five days.

ECP BRAKE INSTALLATION

In the Conrail conversion, the ECP brake equipment is mounted on the car, adjacent to the conventional air brake equipment. The ECP brake control manifold is mounted between the air brake pipe bracket and the service portion. The associated electronic control module, generally referred to as the Car Control Device (CCD), is mounted on a bracket welded onto the inboard side of a vertical pillar (strength member) which extends vertically upward from the car center sill to the top of the end slope sheet, see Exhibit 1. This location was chosen for convenience and to provide added protection from flying debris and the elements.

Exhibit 1. CCD Mounting Arrangement

TEST PROCEDURES

The test plan was developed by the Technical Services Marketing (TSM) Division of Rockwell International (the company which supplied the ECP brake equipment), endorsed by the AAR and approved by Conrail. The subsequent testing was carried out by personnel from TSM, Rockwell International Engineering and the AAR, with logistics support provided by the Operations and Mechanical Departments of Conrail and full cooperation from PECO.

The test plan was developed with two objectives in mind. The first objective (addressed by TSM) was to determine the cause of these particular electronic circuit board failures. The second objective (addressed by the AAR) was to ensure that the environmental requirements in the ECP brake performance specification were adequate.

The main focus of the testing was targeted at the coal-dumping operation at the power plant because this was where the highest acceleration levels were expected, due to the nature of the operation. However, test data was also collected for one round trip of the over-the-road operation and during the coal loading operation, to ensure that all possible options were covered.

The test data were collected using battery-operated, portable data-collection systems. The sensor package consisted of a triaxial (vertical, lateral, longitudinal) cluster of accelerometers, mounted on a rigid base plate. Both the data-collection system and the accelerometer package were rigidly clamped to the car structure, using heavy-duty C-clamps.

The AAR data was acquired using a Somat Series 2100 programmable digital collection system. The data collected by TSM / Rockwell, which will be the subject of a separate report, was acquired using EDR-3 and EDR-4 programmable ride-quality packages.

COAL-DUMPING OPERATION

The rotary coal dumpers at both of the power plants are designed to handle a single car. This requires that the loaded cars be separated and the empty cars reassembled into a train during the dumping operation. The testing described in this paper was performed at the Eddystone plant, near the Philadelphia International Airport, so the following description pertains to that operation.

Upon arrival at the power plant, the loaded train is separated into four cuts of cars for ease of handling. The unloading operation is performed using a “hump yard” approach. The cut of cars is pushed to the top of the “hump” using a switching locomotive. A single loaded car is released and rolls under gravity down to the dumper where it impacts into the empty car that has just been dumped, propelling it out of the dumper. The loaded car is captured by the dumper and rotated through approximately 150 degrees about its longitudinal axis, emptying the coal into an “underfloor” collection bin. In cold weather, a vibrator, placed against the side of the car during the clamping process, is used to provide a 15-second burst of energy to break the coal away from the car structure. Meanwhile, the previously ejected empty car rolls under gravity into a holding track, where it impacts into the string of empty cars. The maximum impact speeds, observed during the testing period, were estimated to be 6 mph.

TEST DATA

The test data collected during the dumping operation consisted of two-second bursts of acceleration, triggered by an exceedance of ± 0.5 g in any of the three axes, with a full-scale value of ± 20 G. A sample rate of 1,000 samples / second and a filter setting of 200 Hz was used. For the over-the-road testing, a trigger level of ± 0.4 g was

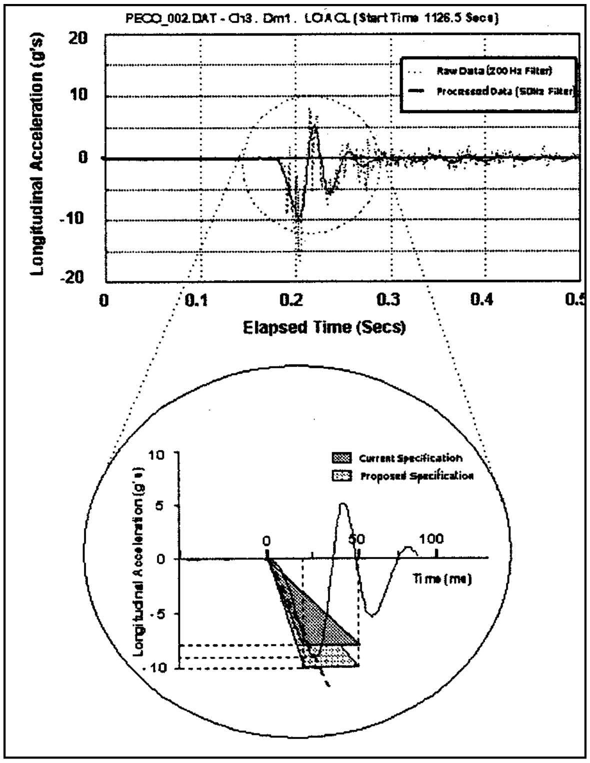

Exhibit 2. Longitudinal Impact Data

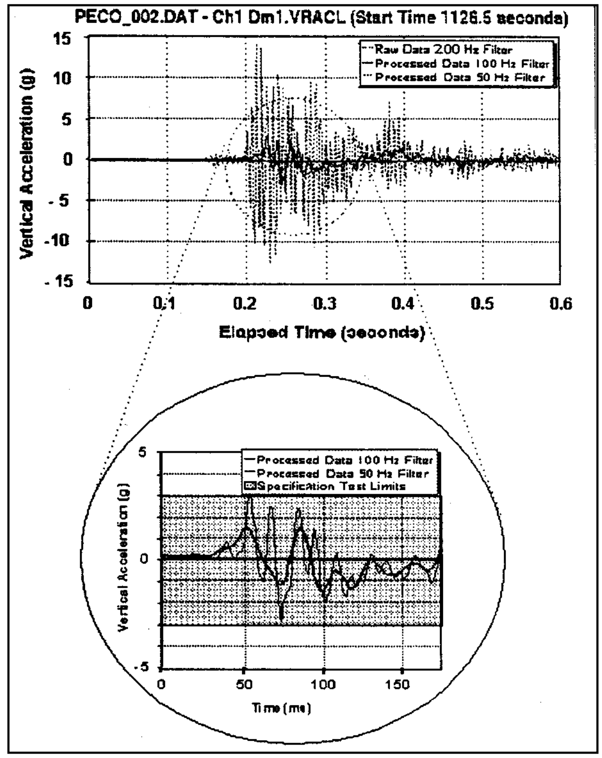

Exhibit 3. Vertical Acceleration Data

employed, with full-scale values of ± 10 G, a sample rate of 300 samples/sec and a filter setting of 100 Hz. The data-collection system was programmed to capture the 40 highest events between downloads and to perform a time-at-level analysis on all the data.

The data used to support the performance specification modification resulted from impacts sustained during the coal-dumping operation. The two limiting examples are presented in Exhibits 2 and 3.

In each case, the data has been processed by post-test filtering the "raw" data to extract the relevant details. Exhibit 2 illustrates this process for the longitudinal data. The "worst-case" impact data has been filtered at 50 Hz to remove the local structural resonant effects. The resultant "clean" waveform is deemed to represent the impact impulse function. The resultant peak value exceeds the existing 8 g limiting case and, on that basis, a recommended peak-value limit of 10 g has been proposed, with the same ramp time tolerance.

The "worst-case" vertical acceleration has been processed in a similar manner (Exhibit 3) to extract the rigid car body and fundamental bending frequency components. The effect of local structural resonances, which tend to occur above 60 Hz, are minimized and then eliminated by the filtering operations at 100 Hz and 50 Hz respectively. On the basis of these data, the general vibration level requirement of ± 0.4 g rms in the performance specification has remained unchanged, although a peak value limit of ± 3 g within the rms level has been recommended.

The data collected during the over-the-road operation fell well within the limits established by the impact data and did not warrant further modifications to the specification.

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A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH THE AAR, PUBLICATION ORDER PROCESSING, 50 F STREET, NW, 5TH FLOOR, COG, WASHINGTON D.C., 20001