Abstract

From an applied research project on the dynamic behaviour of heavy haul trains, which uses a computerized data acquisition system, the idea arose to develop a "Black Box - On-board Computer for Locomotives" to attempt to improve train performance. With this system, it is already possible to diagnose the causes of accidents and to identify locomotive equipment failures, and now it is possible to implant predictive maintenance for locomotives.

1 Introduction

Due to the high number of locomotive failures, causing a decrease in productivity of the railroad and a consequent reduction in income, an applied research project on this subject was started.

The state of art technology makes it possible to monitor and record data from several sensors installed in the locomotives.

After a train journey the PCMCIA card can be used to analyse and diagnose the operational performance of the train, the locomotive, and its various equipment.
2 Aims

- To demonstrate the importance of applied research to railroads;
- To implant predictive maintenance for locomotives;
- To facilitate train management and standardize train handling;
- To increase the reliability of locomotives.

3 Methodology

The project is divided into two parts:
- Installation of "Black Box - On-board Computer for Locomotives"
- Data transmission to the Control Center via satellite.

3.1 Installation of the "Black Box - On-board Computer for Locomotives"

3.1.1 System description

The project was developed by installing several sensors on certain equipment in the locomotives, using specific transducers linked with the data acquisition system.

All signals are insulated by using signal conditioners with 1500 Vcc insulation from input to output. These conditioners avoid noise interference from the locomotive in the Black Box system.

After the installation of the sensors, they are calibrated and then a locomotive power test is carried out. This test analyses the functional
conditions of the locomotive giving reference parameters for future analysis of data collected from this Black Box.

Alarm and supervisory circuits are also monitored, treated as digital signal and isolated by optical coupler to avoid electrical transients. Locomotive failures are simulated to check that the supervisory circuits are working and that the Black Box is correctly detecting and recording these events.

In order to power the Black Box a DC/DC converter is connected to the locomotive's batteries, supplying all the voltage levels necessary for powering the microcomputer-based data acquisition system and its associated sensors.

3.1.1.1 Hardware: System based on an ISA passive bus with 3 slots.

Slot 1: Single board computer with 80386-SX 33 CPU, 4 MB RAM, 2 RS-232-C serial ports, 1 CENTRONICS parallel port and a multi I/O controller and watchdog timer.

A RAM/ROM disk piggy-back board, with a PC-104 bus, 512 kB of non volatile memory.

A SVGA piggy-back board with PC-104 bus.

Slot 2: PCMCIA interface board linked to a PCMCIA drive with a 10 MB card.

Slot 3: Data acquisition board, with a 12 bits analogical/digital converter, 25 μs conversion time, 16 digital inputs and 16 analogical inputs.

Block Diagram of the Black Box

![Block Diagram of the Black Box](figure2.png)
3.1.1.2 **Software:** The whole system runs under DOS 6.2, and is booted from drive "A" (RAM/ROM disk).

The application software is written in TURBO PASCAL and is called from drive "A", white writing to drive "C", and monitors all signals with a 1 Hz sample rate and records data every 10 seconds (All 12 analogical and 14 digital inputs). The data for each cycle occupies 32 bytes and is stored sequentially.

3.1.1.3 **Parameters Monitored:**

- **Analogical signals:**
  - Main generator voltage;
  - Main generator current;
  - Speed;
  - Traction motor current;
  - Main generator excitation current;
  - Engine speed;
  - Manifold air pressure;
  - Fuel consumption (fuel pump input flow and fuel pump return flow);
  - Intake air pressure;
  - Temperature of cooling water;
  - Temperature of exhaust gases.

- **Digital signals:**
  - Acceleration notch (four governor solenoids);
  - Low oil pressure tripping;
  - Hot engine tripping;
  - Ground relay tripping;
  - Wheel slipping;
  - Foot pedal operation;
  - Dynamic operation;
  - Overspeed tripping;
  - Traction motors in parallel/series;
  - Forward/reverse control position;
  - Fuel pump state (ON/OFF).

3.2 **Data transmission via satellite to Operational Control Center**

This system is under test, with successful data transmission from the locomotive in current operation to the Control Center, which enables on-line train and maintenance management, that is to say evaluation of the performance of the locomotive and the consequent automatic decision as to whether it should be taken out of service for maintenance.

This system covers the entire area of the train’s movement and the information becomes available to all company managers immediately after analysis.
3.2.1 System description

The OmniSAT system is a two way data communication system via satellite that transmits at approximately 51 bps.

This system covers the whole of Brazil. Data is transmitted from a MCT (Mobile Communication Terminal) to the Autotrac Company Management Centre, where the user (in this case RFFSA) has access by dialling, by means of a dedicated line, or by VSAT. The data transmitted from the Control Centre goes in the opposite direction and is received immediately by the MCT.

With this system, known as "Store and Forward", text or binary data can be transmitted, and can be controlled from the OBC (On-board Computer) connected to the "Black Box - On-board Computer for Locomotives" of the OmniSAT system.

3.2.1.1 Types of communication

**Periodic data transmission:** Performed in order to optimize analysis of the following situations:
- On-line analysis of train performance;
- Predictive maintenance.

The Black Box transmits the following parameters at regular intervals:
- Locomotive power: maximum, minimum and mean;
- Speed;
- Traction motor current: maximum, minimum and mean;
- Acceleration notch;
- Temperature of exhaust gases: maximum, minimum and mean;
- Main generator excitation current: maximum, minimum and mean;
- Air intake pressure: maximum, minimum and mean.
Transmission in the case of exceptional state of parameters: When any abnormal situation occurs in the performance of the locomotive, such as:
- Low oil pressure;
- Hot engine;
- Ground relay operation;
- Wheel slipping;
- Foot pedal operation;
- Overspeed tripping;
- Power below nominal value;
- Speed under steady state speed in the 8th. notch;
- Traction motor overcurrent,
the corresponding data is sent from the Black Box to the Control Center, automatically.

Transmission on request: In this case the operator in the Control Center requests a data transmission in order to analyse the train performance. The data transmitted may be complete, a synopsis, or instantaneous.

4 Results Obtained

4.1 For maintenance

The diagnostic software generates a report on the performance of the various instruments in the locomotive, evaluating the necessity of stoppage for maintenance and the action to be taken, reducing the down-time, as in table 1.

<table>
<thead>
<tr>
<th>Locomotive</th>
<th>Date</th>
<th>Failure</th>
<th>Diagnostic</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE 903286-0F</td>
<td>28/3/95</td>
<td>Power varying in notch 8</td>
<td>Power unit damaged</td>
</tr>
<tr>
<td></td>
<td>30/8/95</td>
<td>Fluctuations in main generator current: ground relay operating</td>
<td>Bearings of main generator short-circuiting</td>
</tr>
<tr>
<td>GE 903338-6F</td>
<td>8/3/95</td>
<td>Series/parallel transfer at 48 Km/h</td>
<td>Transfer contactors out of calibration</td>
</tr>
<tr>
<td></td>
<td>4/7/95</td>
<td>Low power in notch 8</td>
<td>Injector nozzles, filter and fuel valve damaged</td>
</tr>
<tr>
<td>GE 903203-7F</td>
<td>17/8/95</td>
<td>Main generator overcurrent</td>
<td>Contactors S and P out of adjustment</td>
</tr>
<tr>
<td></td>
<td>24/1/96</td>
<td>Ground relay operating</td>
<td>Bearings of traction engine no. 5 short-circuiting</td>
</tr>
<tr>
<td>GE 903263-1F</td>
<td>9/3/95</td>
<td>Low power in notch 8</td>
<td>Rack out of adjustment and leakage in air intake tubing</td>
</tr>
</tbody>
</table>
4.2 For operation

As a result of the locomotive performance analysis report, it becomes easier to manage the train and evaluate the train-driver’s handling of the train, with the idea of standardizing train operation.

Table 2 - Locomotive performance analysis report

<table>
<thead>
<tr>
<th>RFFSA - SR 3 - DIVMAP 3 - GEPCM 3</th>
<th>Performance of Locomotive GE U23CA 90-3605-9F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period: 5/10/95-4:43:24 to 8/10/95-10:11:57</td>
<td></td>
</tr>
<tr>
<td>Energy used</td>
<td>31.600,60 kWh</td>
</tr>
<tr>
<td>Available energy</td>
<td>150.360,81 kWh</td>
</tr>
<tr>
<td>Percentage used</td>
<td>21.0%</td>
</tr>
<tr>
<td>Distance travelled</td>
<td>1.337,00 Km</td>
</tr>
</tbody>
</table>

Time analysed:

| Stopped | 33.50 h | 43.2% | Switched off | 13.09 h | 16.9% |
| Running | 43.97 h | 56.8% | Switched on | 64.39 h | 83.1% |
| Total | 77.47 h | 100.0% | Total | 77.48 h | 100.0% |

Running time:

| Forwards | 1.29 h | 2.9% | Traction | 27.82 h | 63.3% |
| Reversing | 42.68 h | 97.1% | Low idle | 2.73 h | 6.2% |
| Total | 43.97 h | 100.0% | Idle | 0.83 h | 1.9% |
| | | | Hauled | 3.51 h | 8.0% |
| | | | Dynamic | 3.16 h | 7.2% |
| | | | Dynamic + air brake | 1.78 h | 4.0% |
| | | | Air brake + traction | 0.87 h | 2.0% |
| | | | Air brake | 1.37 h | 3.1% |
| | | | Undefined notch | 1.90 h | 4.3% |
| | | | Total | 43.97 h | 100.0% |

Aceleration notch | Time | % | Fuel | %
Notch 00 (Low idle) | 2.73 h | 8.0 | 65.52 liters | 0.8 |
Notch 0 (Idle) | 0.83 h | 2.4 | 29.88 liters | 0.3 |
Notch 1 | 3.67 h | 10.7 | 220.20 liters | 2.5 |
Notch 2 | 3.60 h | 10.5 | 324.00 liters | 3.7 |
Notch 3 | 3.95 h | 11.5 | 426.60 liters | 4.9 |
Notch 4 | 2.43 h | 7.1 | 481.14 liters | 5.6 |
Notch 5 | 2.12 h | 6.2 | 572.40 liters | 6.6 |
Notch 6 | 1.52 h | 4.4 | 556.32 liters | 6.4 |
Notch 7 | 1.99 h | 5.8 | 799.98 liters | 9.2 |
Notch 8 | 11.38 h | 33.3 | 5.189.28 liters | 59.9 |
Total | 34.22 h | 100.0 | 8.665.32 liters | 100.0 |
From a statistical analysis of data from the Black Box, we can define the best way of handling the train over the entire journey. An example is shown in figures 4 and 5.

**Track Profile**

**Stretch: Humberto Antunes (FHA) - Posto Km 2 (FGD)**

![Track Profile Graph](image)

**Dynamic Test with the Black Box**

**Train type: 3 Locomotives U23C + 108 wagons**

**Stretch: Humberto Antunes (FHA) - Posto Km 2 (FGD)**

**Test n° 3 - Train NFG0108**

![Dynamic Test Graph](image)
This work demonstrates an increase in the productivity of railroad transportation.

5 Conclusion

Using this system the aim is to gain a fuller knowledge of the railroad, on an automatic basis, making the railroad competitive in the transportation market through the increase of availability of equipment and a consequent improvement in productivity.

6. References


