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Early failure warning systems for railway signalling mechanical equipment: 1 - Train stops

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Abstract

The scope and motivation of the paper relates to prediction and early detection, by means of active condition monitoring, of possible *right-side* failures in railway signalling mechanical equipment which would otherwise cause delay. Train-stops have been considered in the first instance. Modern condition monitoring techniques provide early warning signals. They can complement and direct the maintenance work of permanent way engineers in order to make efficient use of resources, save costs associated with too frequent maintenance routines and increase the quality of service by reducing delays. Train-stops are firstly described and their operation explained. Current maintenance routines are briefly outlined and the most common fault modes and processes which cause them are discussed. The paper follows with a survey of various fault prediction and condition monitoring techniques in other industries and analyses their possible usage in this particular application. Results from the application of two such techniques on a laboratory test rig are presented.

1. Introduction

In many existing rapid transit railways, there are still typically large numbers of electro-pneumatically operated safety-critical signalling equipment, such as Point Machines and Train Stops, of a mechanical nature. These are designed using *"fail-safe"* principles and cause delays to train service when they fail *right-side*. Failure rates of these items are sufficient to be a significant cause of service disruption. Indeed railway signalling equipment at the track side currently make up for approximately 60% of failure statistics related to delays due to signalling problems. Modern replacements tend to substitute the electro-pneumatical operation with electrical (point machines), eliminate such equipment (train stops), or ensure that there is sufficient redundancy to prevent major disruptions as a result of a single fault. The cost and scale of replacement with a modern equivalent is prohibitive [1] except for close to life-expired cases. It is therefore required to take best advantage of readily available and cheap electronics and computer technology to reduce possibilities of failure, limit its effects and predict developing faults and degradation in advance.

2. Train Stops - Description and Operation

Some rapid transit railways systems such as London Underground Ltd. have tended to fit trip cock arms underneath trains which allow the emergency brake system to be applied externally by a tripping mechanism called a *train stop* [2]. This equipment is located next to signal lamps along the track so that if a driver passes a red signal, the raised arm on the train-stop engages an air valve on the train and automatically applies the brakes to stop the train. The arm has to be lowered when the green signal lamp is illuminated. It therefore cycles up and down with the passing of trains along the track. It is designed to tend to fail in the *safe* position i.e. raised, but the consequence of a failure which locks it in this position is disruption to the train service.

An example of a London Underground Ltd. train-stop (oil-filled 'J type) is shown in Figure 1. Its operation is electro-pneumatic. When a signal post displays the green proceed aspect, the train-stop arm is lowered by the compressed air pressure (nominal 60 psi, critical 40 psi) activated by an electro-magnetic valve. This compresses the main spring, which in the absence of air pressure would normally force the arm back to the up/danger position. A conversion mechanism turns the angular movement of the arm into a lateral one, causing the movement of indication/detection rod which closes contacts in the *proving* box for indication of train-stop up/down state to the central control.

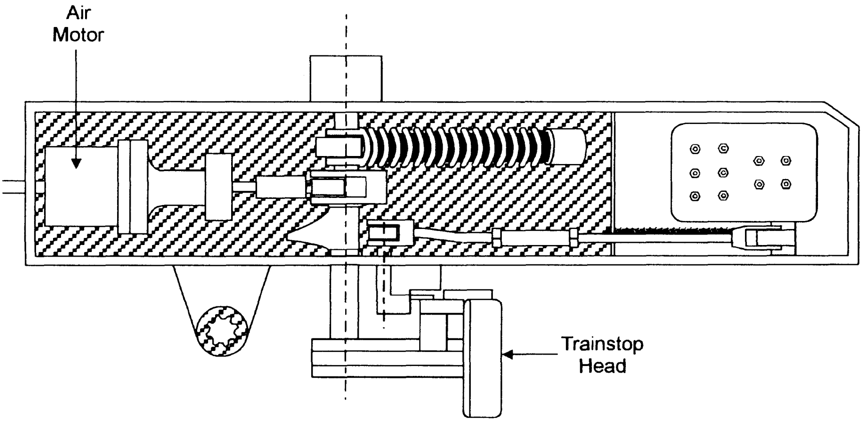

Figure 1: Schematic Diagram of Oil-filled J-Type Train Stop

3. Current Maintenance Procedure

The 6-12 weekly maintenance routines include: Checking gauge, fixing down bolts, checking air connections for leakage and possible chaffing of hose, manual check of mechanical operation, lubrication, contact adjustment, and two operation tests. As mentioned above, the train-stop will not be completely operational if the air pressure drops below 40 psi.

4. Failure Modes and Possible Causes

Two distinct categories of faults may be distinguished: those associated with the actual electro-pneumatic operation; others related to *proving* in order to confirm the train stop arm position (up or down) to the central control. Most likely causes of the first category of faults are: lack of sufficient air pressure, for example as a result of leaky air motor cup washer or air valve due to low quality air supply (damp, rust and glycol); or lack of de-icers in the air supply leading to accumulation of damp into ice and frozen parts during cold weather. Another cause of operational failures is abnormal return spring operation due to lack of lubrication or faulty mechanical components. The second category may result from short circuits, worn or broken contacts in the proving box or faulty angular to lateral displacement conversion mechanism. In general, components become unstable, drift or wear out as a result of harsh environment (dirt and cold) or normal wear and tear. The life-span of each train stop, as specified by manufacturers, is 7 to 9 years. Equipment undergo complete overhaul at such intervals but the above failures are occasionally observed with some 2 or 3 years old equipment.

5. A Survey of Industrial Failure Warning Systems

A range of condition monitoring and fault diagnosis techniques have been developed through many decades in different industries. These were carefully studied in order to assess their potential for this and other similar applications to the railway signalling equipment. Certain techniques such as hardware *redundancy* and later analytical/functional redundancy originated from the aircraft industry and have led to robust model-based fault detection and isolation (FDI) system now being used in process industries as well as aeronautics. Briefly, the concept is to mathematically model the nominal physical system and devise methods and algorithms to distinguish between process-model mismatch and failure instances/faulty behaviour [3]. Similar techniques may be used if the performance of the equipment is monitored and modelled during normal/healthy operation using *black box* approaches (system identification and parameter estimation or non-linear learning algorithms employing neural-networks), and compared with characteristics demonstrating faulty operation. Another traditional technique, from the field of hardware reliability analysis, still widely used and applicable to many industries is Fault Modes and (Criticality) Effects Analysis, FMEA/FMECA [4]. It was primarily developed to investigate the effects of component failures on systems. This is an *inductive* method in that it starts with a set of failure events and proceeds forward, seeking possible consequences resulting from the events. It requires a thorough consideration of all possible modes of failure of components and their consequences assigning a measure of criticality of such outcomes for equipment safe and reliable operation. It is also possible to recognise two more traits and approaches to fault prediction. Firstly, oil and debris analysis, particle counting, and noise and vibration analysis have traditionally been used in condition monitoring of rotating machinery [5]. Secondly, ultrasonic and more recently acoustic emission sensing have been used along with other non-destructive testing (NDT) procedures to monitor equipment health. Signature analysis of measurement data from transducers is for example used to locate metal cracks or fatigue developed as a result of mechanical impact or friction during operation [6].

Application of two of the above techniques are currently being assessed to provide early failure warning system for train stop operation. One method is based on performance monitoring of the most important parameter in the operation, namely the angular position of the train stop arm. The second method employs acoustic emission transducers and listens to the sound of down and up movement of the arm propagated through the metal casing.

6. Test Rig Development and Data Capture System

A test rig was developed consisting of an oil-filled J-type train stop, electric valve, supported on a wooden palette with an air lead extension. A compressed air supply, with maximum pressure of 120 psi and 50 litres capacity, was acquired with regulator in order to set air output pressure at 50, 60, and 70 psi for test purposes. A 24V ac voltage is directly provided to the valve rectifier, by-passing the valve 110V transformer. This is supplied from the mains via a 10:1 step down transformer. The 24V is switched on/off by means of a TTL driven logic directly from a Personal Computer. A PC-based Data Acquisition system was developed to activate the valve and register data from the angular position sensor and acoustic emission (AE) transducers. The PC is a standard 486 DX2 (66 MHz clock, 8 MB RAM, 280 MB hard disk). The Data Acquisition board is a standard PC lab. card which includes one 12-bit analogue output channel, set at 5V to drive the train-stop Valve, and 8 differential analogue input channels for capturing position and AE sensors data. The Analogue to Digital Converter is 12 bit with a maximum 100 KHz sampling frequency with DMA. A 10 KHz sampling was used to register sensor data (1 KHz for multi-channel input) during the train-stop operation of 1 second duration, i.e. 10,000 sample points each for up/down operations.

The data acquisition card provides Software libraries and example code (in C/C++, Pascal or Basic) to input/output data. A Microsoft Visual C++ was acquired to compile DOS executable files to carry out I/O facility. Appropriate software was developed to activate/deactivate the valve and capture sensor data into an ASCII file for consequent analysis. Matlab and

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two associated toolboxes (Signal Processing & Neural Networks) have been obtained which read the data, characterise it and provide distinguishable features for the healthy operating equipment versus faulty conditions. Two AE Sensors (one at 90 KHz, the other at 150 KHz resonant frequency) were acquired from different suppliers for comparison purposes, both of which provide two outputs with short (100 µsec.) and long (1 sec.) time constants. The rotary angular position sensor (RS) is a standard potentiometer type.

7. Test Results and Analysis

Results from the laboratory test rig are as illustrated in Figures 2-4 below. The 12-bit output from ADC represents 0 to 40 degrees angular displacement (120-1920) and 0 to 5V full scale (0-4095) for the AE sensor.

Fig.2a: TrainStop Down Operation - AE/RS O/Ps - 60 psi

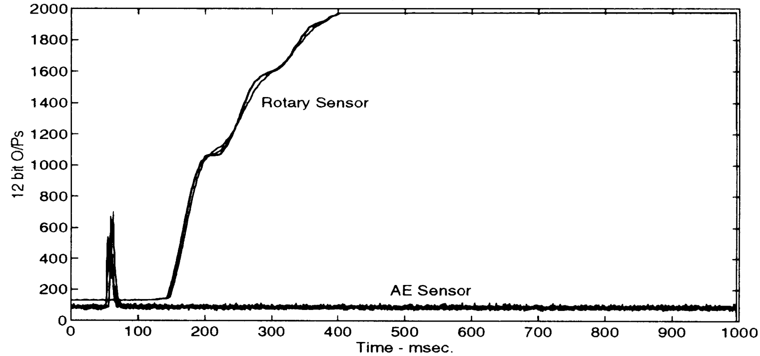
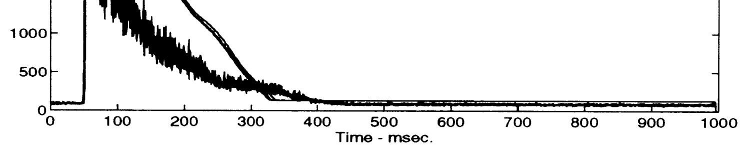


Fig.2b: TrainStop Up Operation - AE/RS O/Ps - 60 psi



During the down operation, there is a delay from energisation of the valve until the air motor is activated, i.e. air pressure pushes the piston to hit the spring, as shown by an impact after approximately 70 msec. There is typically another dead-time related to taking up slack in the mechanism. This is illustrated by the fact that the angular position does not change until 140 msec after the valve activation. The angular displacement graph can be approximated to a first or second order lag with significant non-linearity.

Fig.3a: TrainStop Down Operation - AE/RS O/Ps - 50 psi

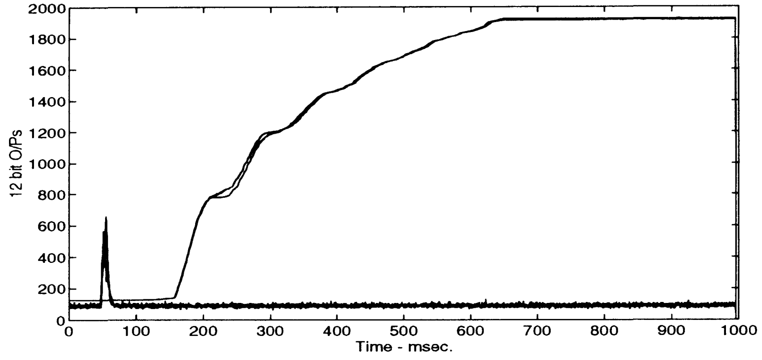
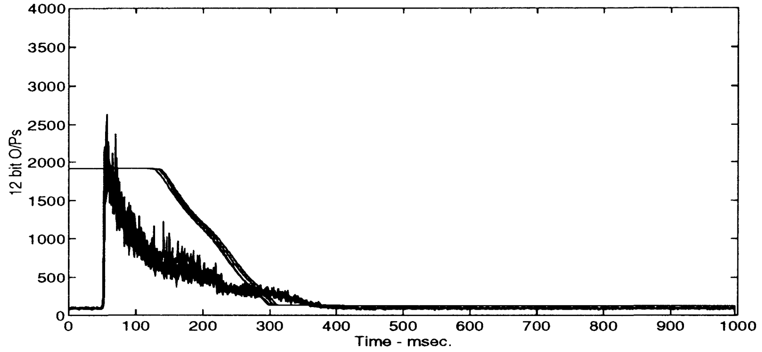
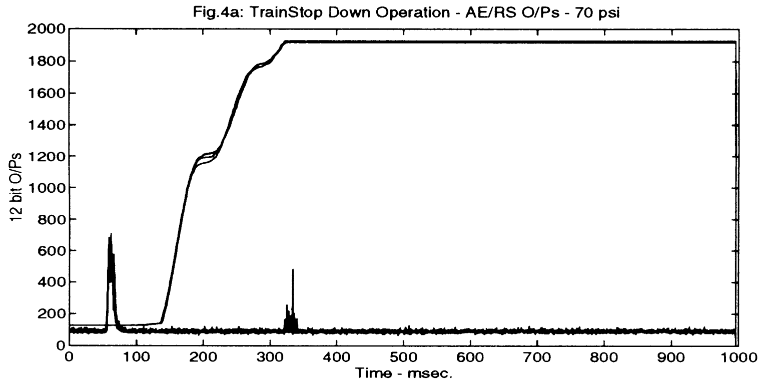
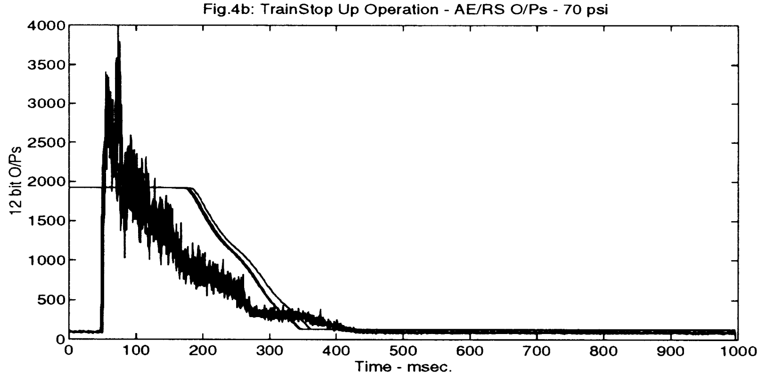


Fig.3b: TrainStop Up Operation - AE/RS O/Ps - 50 psi



As is clear from the graphs (Figures 2-4), the speed of operation is critically dependent on the air supply pressure. Also, interestingly, when the applied pressure is 70 psi, above nominal, a second impact is clearly visible during the down operation from AE signature. This is an unwanted impact where the arm rotation mechanism forcibly hits a mechanical stop, designed to limit rotation beyond a certain angle. Such impacts can reduce the operational age of the equipment. Similarly, the operation is very sluggish at 50 psi and lower air pressures. At such low pressures, the Train Stop is more liable to ineffective operation as a result of developing leaks or lack of lubrication.





During the up operation, there is a similar delay before the air motor is deactivated, i.e. the air starts to be discharged, as shown by the impact on AE sensor output (70 msec after the valve is switched off). The AE sensor output then shows an exponential trend which relates to the sound of air outlet. As the air pressure within the equipment drops, so does the rate of air outlet, hence an exponential decay. Another impact is however noticeable, superimposed on the exponential trend, which occurs at the instant when the angular displacement to its final (datum) position has been achieved.

The results showed a high degree of repeatability for the same equipment. However each equipment's normal operational signature is expected to vary slightly due to the very old original design of the assets (1930's) and design variations since then. Performance monitoring of critical characteristics of train-stop operation, using relatively simple and cheap equipment, has therefore led to a deeper understanding and characterisation of the normal (healthy) operation

8. Next Steps

As this paper is being prepared and by the time of its presentation at the conference, May - Sep. '94, the following steps are planned:

- Faulty versus healthy operation signature characterisation: possibly training neural networks to distinguish between normal and faulty operations
- Field trials: It is expected that environmental conditions such as dirt or cold have significant effects on the equipment operating on the tracks. The data acquisition and analysis system is to be transported to LUL locations to do field trials to assess these.
- Remote telemetry: It is expected that the above work leads to intelligent instrumentation to be installed on the equipment at the track-side. The questions regarding the amount of information and means of communication between this and central control will be investigated.

9. Conclusions

This paper reported the progress of an ongoing research project for failure prediction of existing mechanical railway signalling sub-systems. Train Stops were described, their principle of operation were outlined and their most common fault modes and processes which cause them were discussed. The paper presented an overview of various fault prediction and condition monitoring techniques in other industries. Results from the application of two such techniques on a laboratory test rig were presented. These demonstrated the possibility of characterisation of equipment's operation in its normal (healthy) mode. Plans for faulty versus healthy operation signature characterisation, field trials and remote telemetry issues were outlined. The outcome of these will be reported to the conference.

10. References

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