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# Condition monitoring of railway single-throw equipment

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## Abstract

This paper presents the research carried out to improve the reliability of single-throw equipment used in railway signalling, rolling stock and power systems. The motivation is to achieve improved operational availability and quality of service to passengers as well as the need for more cost-effective and efficient maintenance management.

A number of railway equipment have so far been considered such as point machines, train-stops, DC Circuit Breakers (DCCB) and train doors. In this paper, the DCCB is presented as a case study for the development of an on-line condition monitoring system providing early-failure warning to maintainers.

## 1. Introduction

The motivation for railway condition monitoring research is the need for improved reliability of equipment, operational availability, and quality of service to passengers, as well as a requirement for cost-effective and more efficient on-condition maintenance management; e.g. Fararooy & Allan[1]. This is achievable by robust and intelligent measurement systems which can distinguish between drift and other non-critical variations in the performance of the equipment, and instances that relate to an unacceptable degradation in system performance as a result of incipient faults.

All railway equipment rely for their successful operation on the time-based maintenance routine which can be expensive, inefficient and ineffective. The trend towards high speeds, and ever increasing train services schedules on the tracks of modern railways necessitate improved availability by means of the implementation of condition-based maintenance employing electronic control systems. Electronic data processing of actual equipment performance, the trend visualisation and comparison with normal behaviour enables early warning to be given if a certain threshold is exceeded. It also leads to a more cost-effective condition-based maintenance management of assets.

The results of earlier research e.g. Fararooy & Allan[2,3,4] have demonstrated the possibility of a cheap, practical and feasible solution to the condition monitoring of railway signalling equipment. This can be achieved by means of an intelligent microprocessor-based sensor attached to each equipment. The embedded software would implement the neural network-based learning algorithms which model the behaviour of the equipment during healthy operation and provide 'pre-failure warning' when there is a significant deviation from the expected performance.

The DCCB is considered as the case study in this paper. This includes description and principles of operation of equipment; their prominent failure modes and effects; failure statistics; current maintenance routines; and the condition monitoring approach. This paper also describes the development of a laboratory test rig for PC-based data acquisition and data analysis for fault prediction. Experimental data for both healthy and a number of simulated faulty conditions will be discussed. These would demonstrate how a normal operation can be characterised as well as situations which relate to instances of failure.

## 2. Case study-DC circuit breakers

The type MM74 high-speed DCCB (rated at 800V and 4kA), as illustrated in Figure 1, is electrically operated with a mechanical latch-in feature. The successful use of the latch has been made possible by adaptation of a two-stage method of closing the circuit breaker (Figure 2). During the first stage the front contact is moved into position and the latch set (Fig. 2b). The second stage of operation results in the closing mechanism being retracted and the rear contact moving to the closed position. Stage two is achieved by the action of powerful springs (Fig. 2c). The springs serve a dual purpose, in so much that they provide ample contact pressure avoiding the need for an electromagnetic device during holding, and ensure rapid acceleration of the moving contact when the circuit breaker trips on fault. The circuit breaker is free to trip the instant the latch is set and cannot be closed and held closed against overload conditions.

The closing mechanism is based on a DC solenoid actuating the main contacts through a toggle linkage. Tripping is achieved by the action of an electromagnetic trip device acting on the trip latch, either directly or through a secondary trip shaft. The bi-directional overload tripping device is used in this

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case. The main contacts are of butt type faced with silver tungsten. These are situated inside the arc chute such that the arc is initiated inside the arc chute.

Arc extinction is achieved by the specially designed removable arc chute of the cold cathode steel splitter plate type. The series of specially shaped metal plates produce a magnetic field inside the arc chute, which is excited by the arc itself, thus eliminating the need for series or shunt coils and external iron circuits. Arc control is initiated by the specially designed contacts which ensure rapid transfer to the runner system within the magnetic field. This effectively drives the arc into the final arc extinction region of the arc chute. Exhaust gases are vented into an insulated chamber supported by the circuit breaker cubicle above the arc chute. The de-ionised gases then exhaust through side events in the insulated chamber.

### 2.1. Failure modes and possible causes

The most common failures experienced by railway equipment in general, and circuit breakers in particular, are those due to mechanical wear, high temperature variations, dust and damp conditions.

Circuit breaker failures are mostly connected to mechanical problems of some kind as a result of overheating e.g. Balgard & Leif[5]. Whenever an increase in temperature occurs without any limit, as it does when the temperature gets high enough in a bad contact or connection, it leads to failure. The heating of the contacts will destroy the equipment by moving the relative position of parts and by changing the contact shape, decreasing the number of microscopic contacting points and by oxidation. The fault situation develops further until the system suddenly disintegrates and complete failure occurs.

In general, components become unstable, drift or wear out as a result of harsh environment (dirt and cold) or normal wear and tears leading to failure. For example the failure records of the type MM74 circuit breaker taken from London Underground Limited (LUL) log book for the year 1993/94 are mostly due to defected latching mechanism, arcing contacts and arc chute disintegration, and closing coil overheating.

LUL's 1994-95 DCCB failure statistics show an average of 2.5 faults per 100 assets. In total, 600 DCCB are operated twice daily within the LUL's high voltage supply system.

### 2.2. Current maintenance routine

General maintenance will depend on the duty imposed on the circuit breaker/negative contactor. The prototype circuit breaker/negative contactor has been mechanically tested to 10,000 operations without renewal of components. It has been mechanically tested in excess of 250 full load break duties as required by BSI standards.

Service intervals are only established after an 'In service' period. The basis for an inspection period is currently 500 no load operations, 100 load tripping, 20 short circuit tripping or after the first one month of operation.

The circuit breaker/negative contactor and cubicle should be generally kept clean to reduce the possibility of flashovers due to dirty conditions.

## 3. Test rig development and data capture system

A test rig for MM74 DCCB was set up at the University of Birmingham. The circuit breaker (control unit) is directly supplied by a 110V dc from a control panel at the rating of 50-60A. The condition monitoring equipment were supplied from 15-24V dual power supply. The test rig set up in the University could not be tested at high voltage/high current, i.e. simulating normal operation, due to the lack of specialised facilities. Therefore, only mechanical failures associated with defective latching mechanism and arching contacts could be simulated and effects observed.

A PC-based data acquisition system was developed for registering data from appropriate sensors. The PC is a standard 486DX2 (75 MHz clock, 8 MB RAM, 510 MB hard disk). The data acquisition board is the DAQCard-700 PCMCIA card from National Instruments. The board contains a 12-bit successive approximation Analogue to Digital Converter (ADC) with 8 differential analogue input, 8 lines of TTL-compatible digital input, and 8 lines of digital output. The ADC is a 12-bit with a maximum 100KHz sampling frequency. LabWindows/CVI from National Instrument is used as data acquisition and display software development environment. This is a visual instrumentation software used to develop Graphical User Interface (GUI) based windows programs written in C-language to control the DAQCard-700. Appropriate software was developed to capture the sensor data into an ASCII file for consequent analysis using Matlab and its associated Neural Network toolbox.

The signatures for various parameters of the DCCB were monitored during the healthy and some induced fault conditions using several sensors. The movements of the two contacts of the DCCB were detected using two linear displacement sensors, situated as marked in Figure 1. One sensor is used to detect the *lateral* displacement of the *rear* contact, the second to measure the *vertical* displacement associated with the movement of the *front* contact. The two sensors are of Linear Variable Differential Transformer (LVDT) type.

Two current probes (0-200A) were obtained from LEM HEME with 4-20mA output. These current probes are used to look at the signature of the close and trip currents of the DCCB. Two Acoustic Emission (AE) sensors, one from Holroyd Instruments (AE1 at 90 kHz resonant frequency) and the other from Stresswave Technology (SW at 150kHz), were acquired and attached to different locations of the DCCB as marked on Figure 1. Each sensor provides two outputs with short (100 ms) and long (1 s) time constants, the former of which was only used. The two sensors are used to detect the Acoustic Emission as a result of impacts during the closing and tripping of the DCCB.

## 4. Test Results and Analysis

Electronic condition monitoring based on frequency domain analysis is found to be wasteful for single-throw equipment such as DCCB, as it discards phase information [6]. In many applications such as DCCB it is better to work in the time domain where all information is used.

Signatures from all sensors during the Close operation in the normal (healthy) mode are presented in Figure 3. The results show a high degree of repeatability enabling the healthy operation to be characterised clearly. The two-stage method of closing the circuit breaker is demonstrated in the signatures from the two displacement sensors. The vertical displacement sensor shows the operation involved with the movement of the front contact until it is latched. While, the lateral displacement sensor signature demonstrates the two-stage movement where the back contact is displaced to a larger extent and then sprung back into contact with the front contact. The two contacts then settle in their final position in a near critically damped oscillation, marked with large amounts of AE activity.

## 5. Further Work

Further work is currently being carried out to push the results of research forward in two areas. Firstly, although some incipient fault modes were simulated and they showed a number of distinctive characteristics, for example a marked increase in oscillations in contacts displacement profiles during closing in the case of their misalignment, it was felt that more theoretical work was needed to integrate the results from all sensors in such cases. More experiments are also required and are planned to verify the tests carried out for a variety of induced failures. Secondly, for on-line condition monitoring, the Matlab analysis software is planned to be translated into C code using its recently available compiler and incorporated with Labwindows CVI developed for data acquisition and display. This enables the user to monitor the signature and characteristics of consecutive operation if required but would also provide on-line fault reporting if significant deviation from previously learned signature is observed.

## 6. Conclusion

In this paper the motivation for condition monitoring of railway equipment, in terms of improved reliability and more efficient maintenance was outlined. Condition monitoring is becoming an essential elements of any pro-active maintenance management strategy. DCCB was considered here as a case study for implementation of on-line condition monitoring system. A test rig with PC-based data capture system, was developed and used to investigate the proposed condition monitoring system. Several failure modes are currently being simulated. The results will be presented at the conference.

## 7. Acknowledgement

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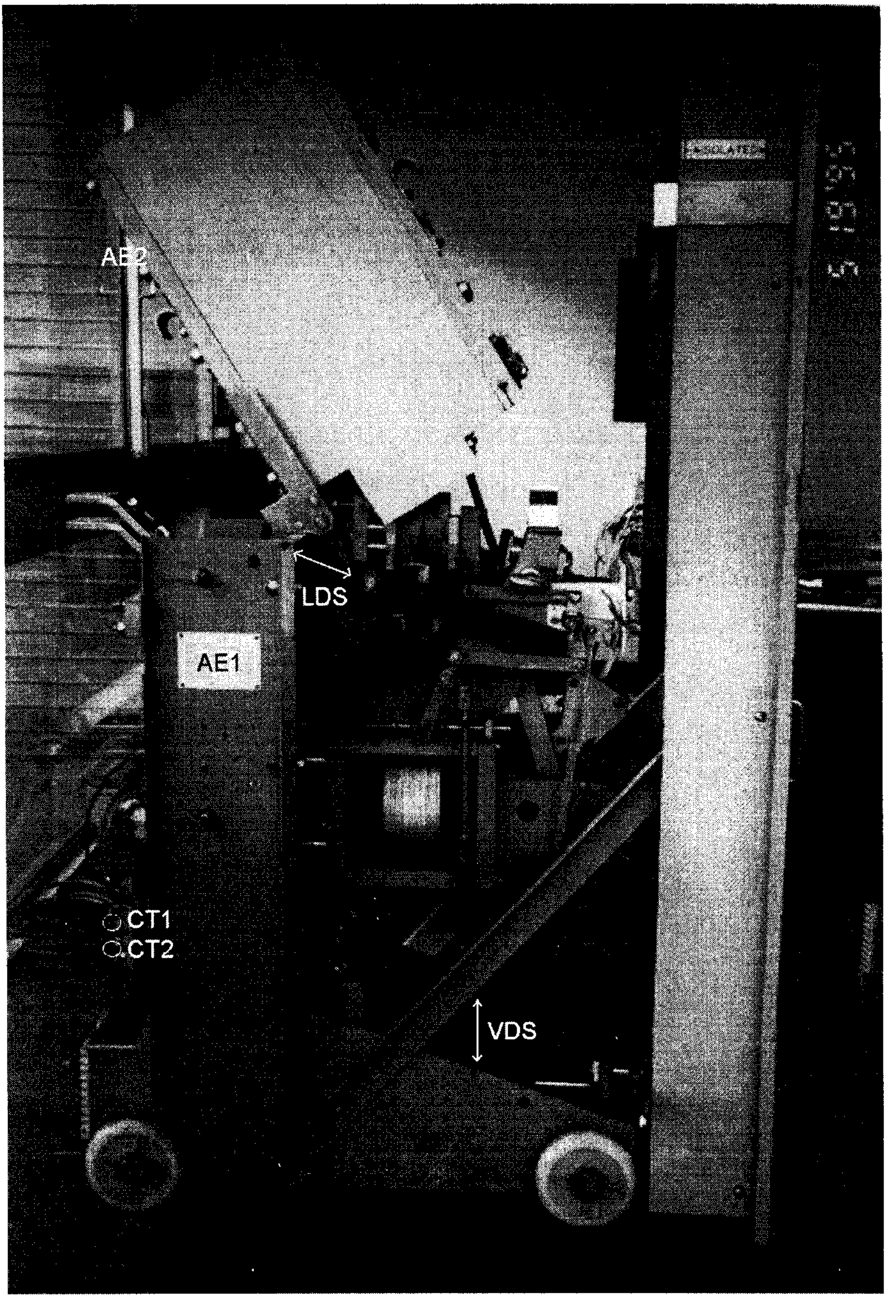


**Figure 1: MM74 DC Circuit Breaker**

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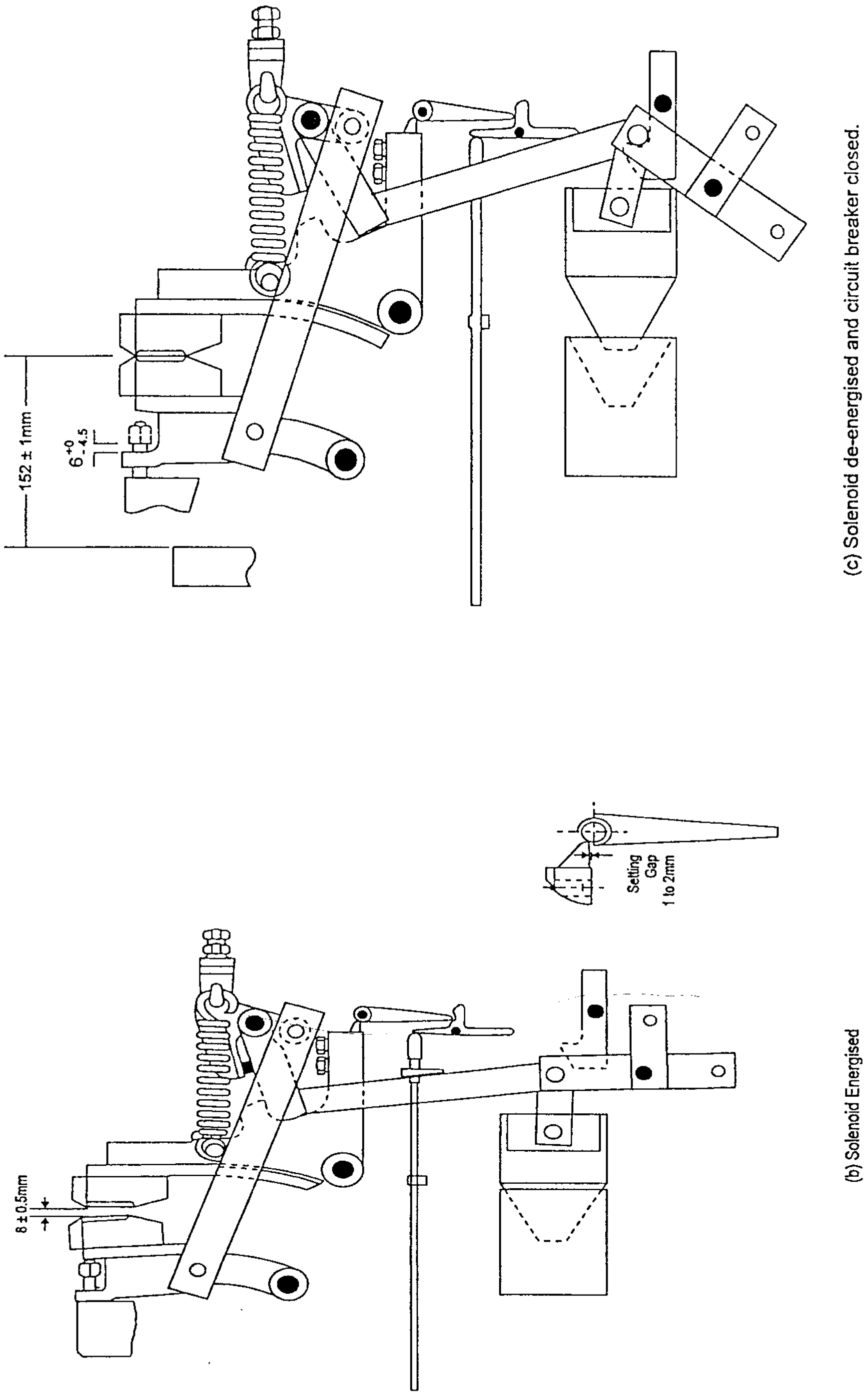


Figure 2: MM74 DCCB-principle of operation

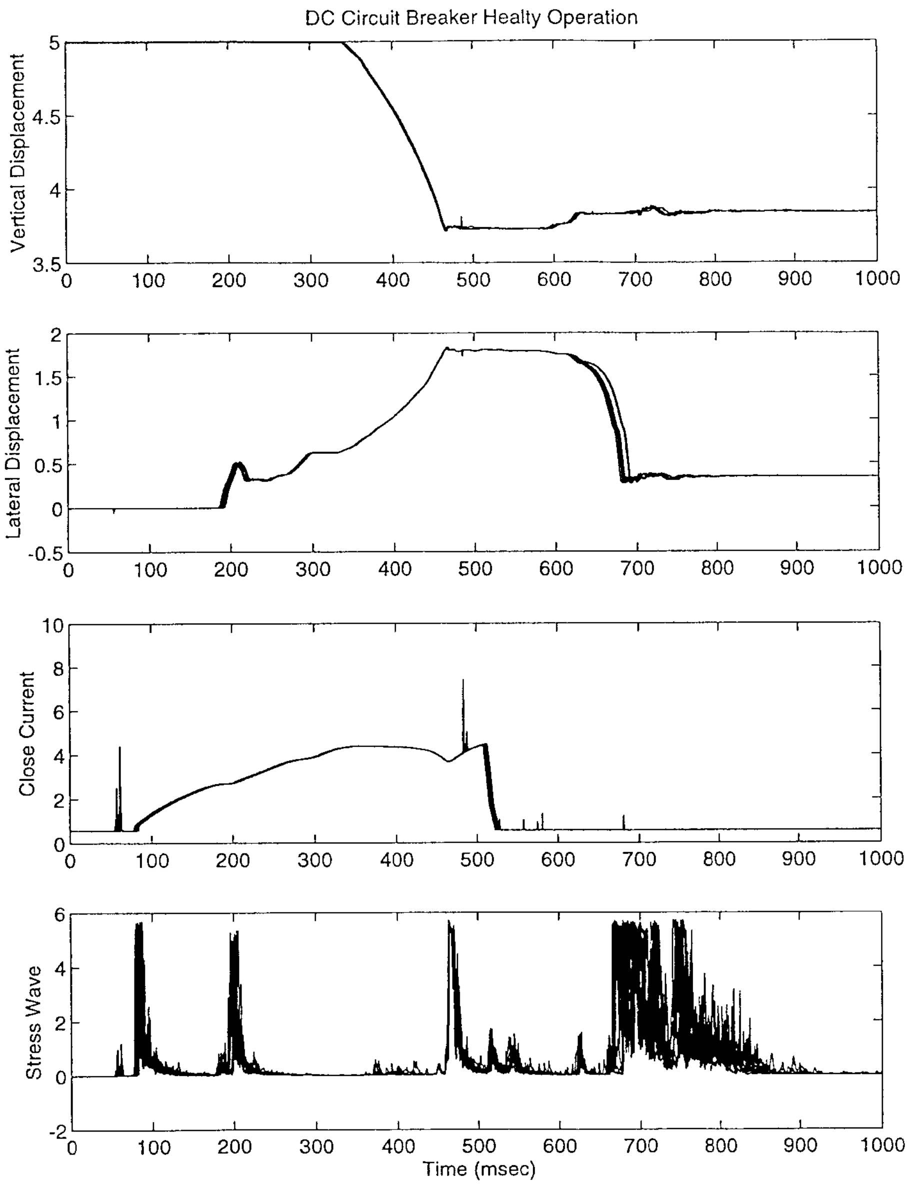


**Figure 3: Sensor signatures for DCCB healthy operation**

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