Project no. TIP5-CT-2006-031415

INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D3.3.2 – Available Sensors for Railway Environments for Condition Monitoring

Due date of deliverable: 2008/02/29

Actual submission date: 2009/02/13

Start date of project: 1 September 2006 Duration: 36 months

Organisation name of lead contractor for this deliverable: UNIBHAM

Revision Final

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Table of Contents

Table of figures

1. Executive Summary

European infrastructure managers currently use a number of different condition monitoring systems to assess the health of point machines on their networks. The aim of these systems is to both detect failures before they occur (fault detection) and to aid with diagnostics (failure diagnosis).

This report outlines the initial findings from phase one of a research project undertaken by the University of Birmingham's Centre for Railway Research and Education, on behalf of Network Rail. The work aimed to assess the potential for point condition monitoring to predict and diagnose incipient failures. This report focuses on the groups of failure modes which can be detected and diagnosed using condition monitoring.

In the context of the INNOTRACK project, this work demonstrates effectively how sensors, measuring the key parameters identified in D3.3.1, can detect the changes in switch performance which appear when incipient faults are developing. The work is support by failure data from Network Rail's failure management system, a priori knowledge in the form of failure mode effects analyses and experimental data collected during the research at a Network Rail training facility (Escrick, York).

Further work, which will be reported separately, will concentrate on generic data acquisition hardware systems and algorithms for automatic detection of point machine faults.

2. Introduction

The work reported here aims to assess the potential for point condition monitoring to predict and diagnose incipient failures using currently available sensors.

Switch failure modes can be considered to lie in one of three categories, either those which can be:

- Eliminated via maintenance – failure modes which should be eradicated using improved maintenance (or renewal) strategies
- Eliminated via conventional condition monitoring - failure modes which can be clearly observed in data collected from conventional sensors, either with or without pre-processing
- Eliminated via research and development – including changes to the design, novel sensing and measurement, etc.

It follows that one of the principle objectives of condition monitoring systems is to detect incipient failures, and hence eliminate certain failure modes entirely by being able to predict them prior to failure. However, points condition monitoring systems not only offer the opportunity to detect incipient failures, they should also be capable of:

- assisting with diagnosis of faults and failures
- reducing the number of “no fault found” reports
- recording details of operations (number of movements, number of trains passed)
- providing assurance that points are correctly installed
- giving assurance that maintenance has been correctly undertaken.

3. Technical description

3.1 Overview of switch actuators

3.1.1 Phases of operation of a typical DB switch

At DB the point machines have integrated one adjusting gate valve (Stellschieber) and two detection valves (Prüferschieber) each of them connected to a switch rail, as can be seen in Figure 1. Adjusting gate valve and detection valves operate independent from each other. They are connected to the drive arm and the detection rods.

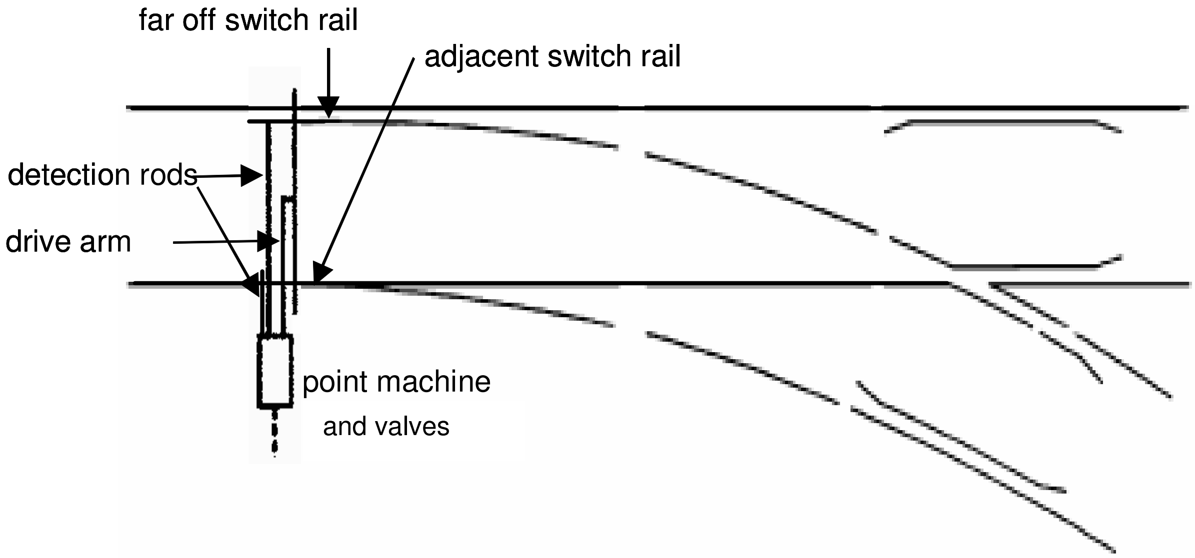
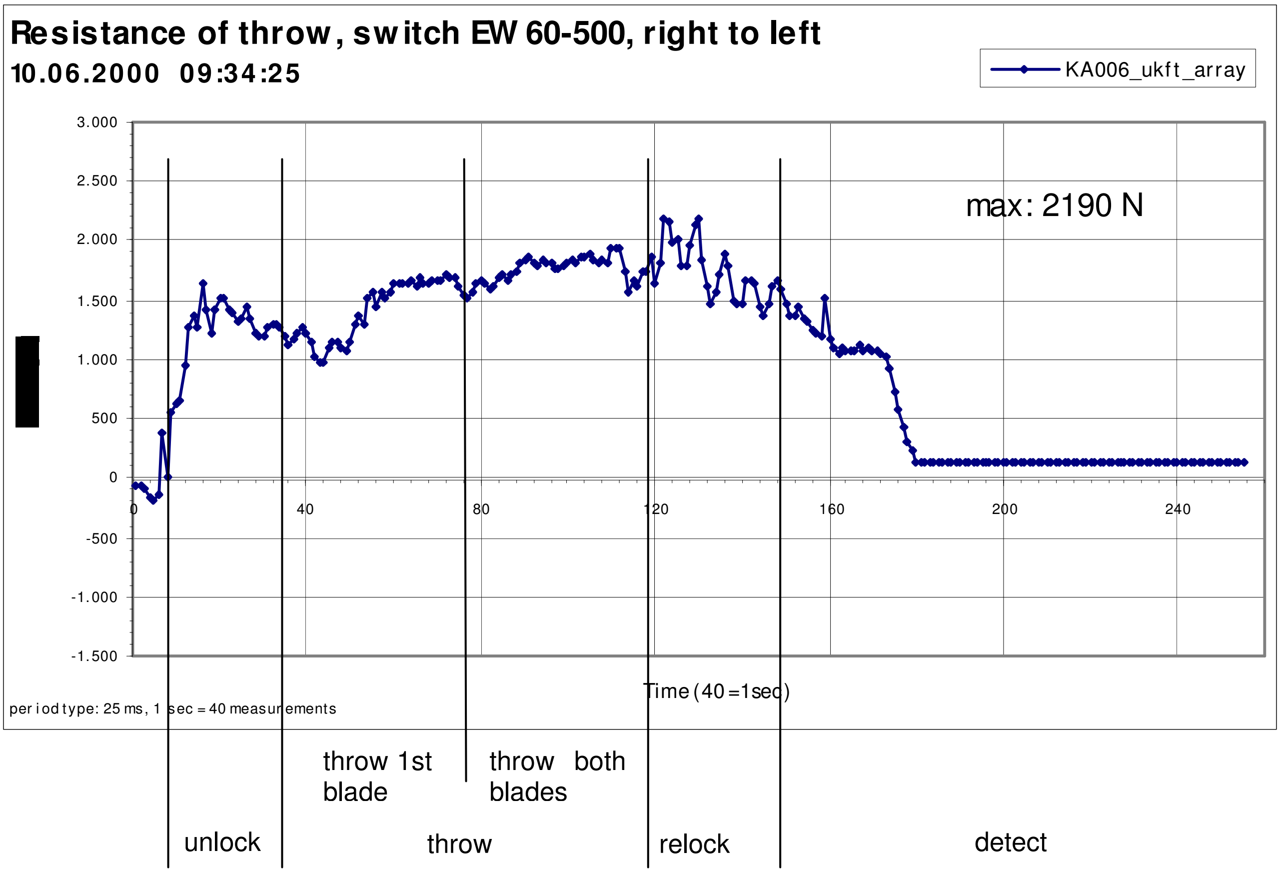


Figure 1 - An electric point machine and switch layout

The operation of a point machine at DB takes typically up to 6 sec (in Figure 2 about 4.5 sec).

Four phases of a point machine throw:

i. unlock
ii. throw (with two phases: throw of 1st blade followed by throw of both blades)
iii. relock
iv. detect (after operation is complete)



Switch: EW 60-500 1:12 (UIC 60, simple switch)

Point machine: S700 (electro mechanical) Measured with a force pin.

Figure 2 - Phases of a point machine throw at DB

3.1.2 Phases of operation of UK Switch

As discussed in detail in D3.3.1, switch actuators are used to change the routing of trains from a current track (normal position) to an adjacent track (reverse position). The point machine is connected to the drive arm which in turn is connected to the switch blades, as can be seen in Figure 3. The switch blades can be set into two positions (normal and reverse). In the UK, which is fairly typical of European standards, the operation of a point machine should take less than 7.5 seconds (typically 2 to 4 s). The operation of the point machine can be considered to comprise of five distinct phases:

i. Initiation (~0.4 s);
ii. Unlock (~0.2 s);
iii. Throw (~1 to 3 s);
iv. Relock (~0.4 s);
v. Detect.

To demonstrate this, Figure 4 shows a typical profile of the hydraulic pressure taken from a normal to reverse throw of a clamp lock point machine. The five distinct phases (i to v) are clearly visible.

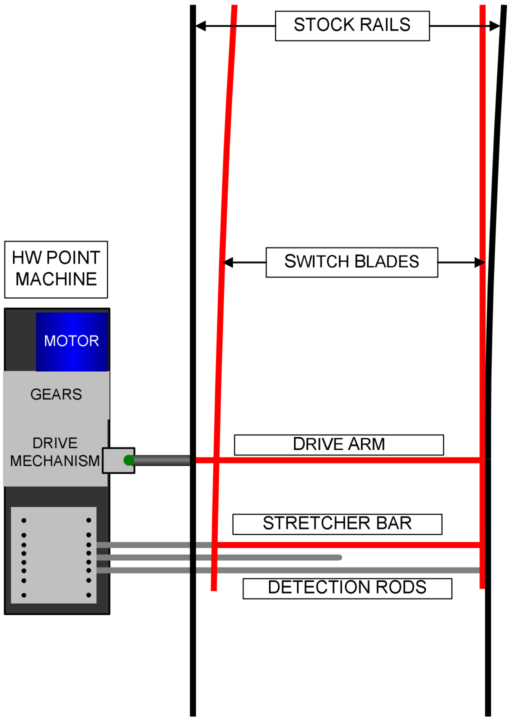


Figure 3 – An HW electric point machine and switch layout

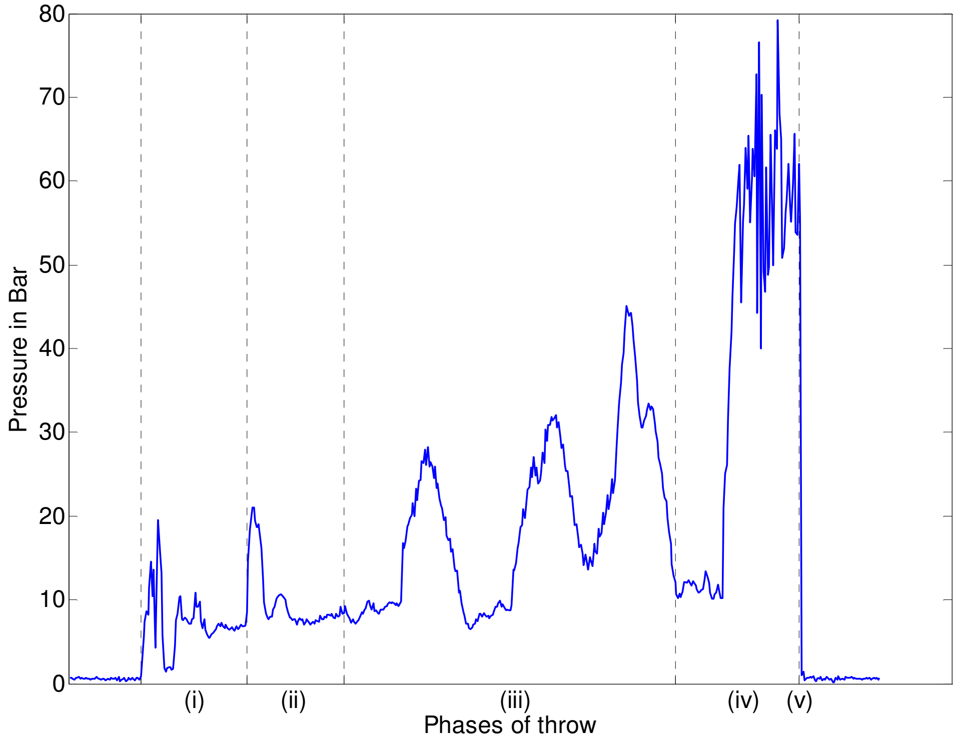


Figure 4 - Five phases of a point machine throw

In order to perform a throw within specification, a point machine must be comprised of three basic functions:

1. a drive (actuation) to produce the mechanical energy to move the points;
2. a lock to secure the points in a safe position when the points are at rest;
3. a detection mechanism to inform the signalling system of the a completed throw.

In the UK these functions are performed by one device – the point machine; on long turnouts, supplementary detection of the rail position may be provided near the heel of the switch. In most of continental main land Europe a separate device is used for detection on turnouts of all sizes.

3.1.3 Overview of UK Point Machines

For the Alstom HW DC electric point machine, as shown in Figure 3, the primary functions of a switch actuator are performed by the following subsystems:

1. an electric motor to drive the points;
2. a clutch which slips at a predetermined load setting to prevent damage to the motor if the points are obstructed. Early machines (HW1000) had a mechanical clutch, while more recent machines (HW2000) have an electro-mechanical clutch;
3. a snubbing device to bring the motor rapidly to rest at the end of the throw;
4. a mechanical 'lock dog' which ensures the points are locked when the points are at rest;
5. a set of motor contacts to allow the direction of movement to be set;
6. a set of detection contacts which indicate the switch rail positions;
7. a provision for manual operation in the case of an emergency.

For a hydraulic clamp lock point machine the drive is provided by pumping oil through a hydraulic circuit, as shown in Figure 5. The five phases of movement are performed in the following manner:

i. In an initial de-energised state one of the front hydraulic actuators is extended in order to hold one of the switch rails closed and locked. The control valve spool rests in the central position, blocking off the oil feed and return lines, which hydraulically locks the extended actuator. Requesting the points to throw from normal to reverse energises the pump motor and the reverse valve solenoid simultaneously (marked (i) in Figure 4);
ii. The valve spool moves to open the actuator feed/return lines and oil under pressure is fed in to the reverse actuator (marked (ii) in Figure 4);
iii. The reverse actuator extends and the normal actuator retracts by the action of the tie bar between the drive lock slides. The oil from the retracting actuator returns to the tank (marked (iii) in Figure 4);
iv. At the end of the throw and when detection of the points in completed, the detection relay opens the point control circuit to de-energise the motor and the solenoid control valve (marked (iv) in Figure 4);
v. When the power pack solenoids are de-energised, the control valve spool returns to the central position once more to lock the actuators hydraulically (marked (v) in Figure 4).

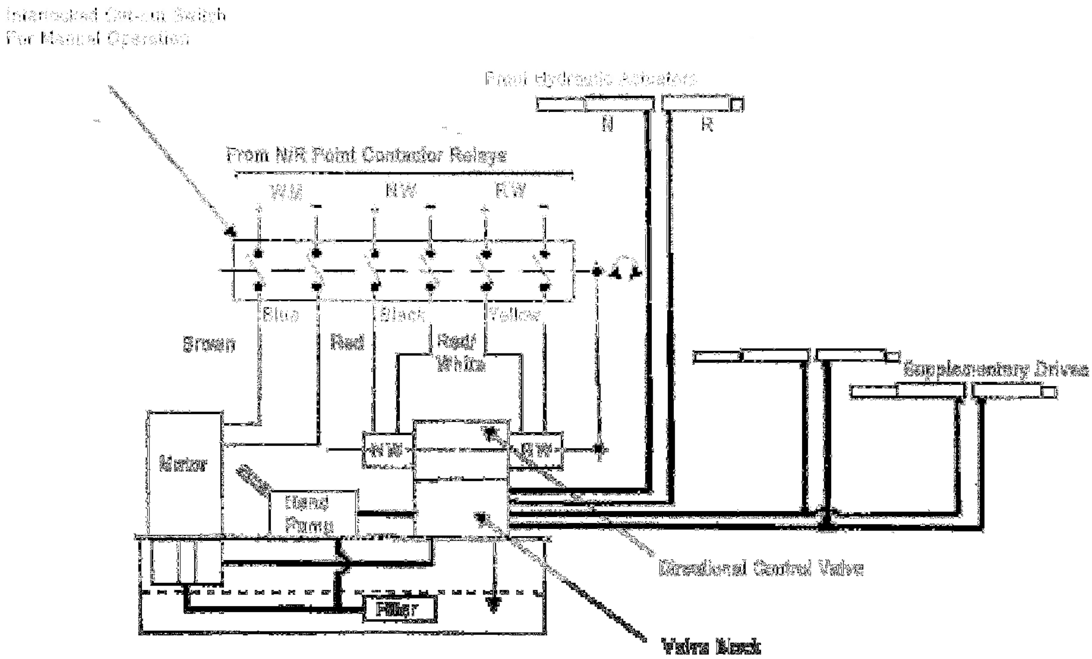


Figure 5 - Schematic overview of a clamp lock switch actuator

A hydraulic clamp lock and an electric Alstom HW machine were instrumented during the course of the research. The hydraulic machines were fitted with pressure transducers on the feed to the normal and reverse hydraulic actuators, an oil level sensor and a hall-effect current transducer on the pump motor supply. The electric machines were fitted with a load pin on the drive arm, a hall-effect transducer on the motor supply and a draw string displacement sensor on the drive arm.

3.2 Faults in switches and their actuators

It is commonly difficult to ascertain the actual failure modes for failures which occur on an operational railway. Technical staff do not always have an intricate understanding of the design and operation of switch actuators. This is compounded by the fact that it is not always possible to diagnose the underlying cause of a failure using human senses alone.

The result of this is that fault categories, as reported under the FRAME reporting system used by Network Rail, are very vague. In reality, each category will encompass several distinct failure modes of the actuator. However, an examination of the numbers of faults reported in each category reveals some interesting trends. The following sections examine failure statistics gathered during a research project which was performed by Advantage Consulting for Railtrack Southern Zone [1].

3.2.1 Failure rates for railway equipment

Table 1 shows the yearly failure rates for some examples of common railway equipment. Each asset in the table has a population of many thousands on the UK railway network. It is fair to conclude from these statistics that switch actuators are a weak point of the railway infrastructure, in terms of reliability, since they are some of the least reliable components of the network.

Equipment type	Failures per year	Population (Kent and Sussex regions)
Clamp Lock switch actuator	0.91	718
M63 switch actuator	0.70	326
HW switch actuator	0.52	1441
FS2600 track circuit	0.46	528
TI21 track circuit	0.40	1326
AC track circuit	0.35	3634

Table 1 - rates and populations for examples of widespread distributed railway components

3.2.2 Types of switch actuator failure

Tables 2 and 3 show the top 25 failure codes for the HW and Clamp Lock switch actuators, along with the number of failures recorded.

The raw data contained in these tables are of limited use in determining the true failure modes present in the actuators, because the codes are cryptic and not always linked exactly to what caused the actuator to fail. The most obvious point to note is that the code "T.O.K. Right on arrival" is the most common entry in both tables. This code means that no fault was found when technical staff attended the asset following a failure.

There is a link between the high incidence of no-fault-found diagnoses and the large number of poor adjustment failures. Components whose adjustment is on the edge of design tolerance will cause the actuator to fail intermittently until they slip so far out of adjustment that the actuator can no longer recover itself. When the actuator is failing intermittently it is common for technical staff to attend the site of the asset, only to find that they cannot replicate the failure. They then have no choice but to record "no fault found" [1].

This is significant because adjustment faults, whilst sometimes caused by maintenance errors, generally occur over a period of time and gradually increase in severity. An opportunity exists, therefore, to detect these faults before they cause the switch to fail, if the right observations can be made in a timely manner.

Deliverable 3.3.1 established the key parameters that condition monitoring equipment should measure in order to have visibility of fault conditions in switch actuators. In order to diagnose faults, the key parameters measured by the condition monitoring system must exhibit changes during the early development of incipient faults. For complete diagnosis, it is essential that each different fault has a unique set of effects on the parameters, so that no ambiguity remains over the nature of the fault. However, from a practical point of view, complete diagnosis is less important than the early warning that some failure is imminent. Narrowing the possible cause down to a handful of possible faults is sufficient to aid technical teams.

Defective Subassembly	Defect code	Defect text	Count of fail no	% of total	Cum. %
....	HW1	T.O.K. RIGHT ON ARRIVAL	666	17.02%	17.0%
ROD DETECTOR	HW2	OUT OF ADJUSTMENT	356	9.10%	26.1%
ROD DRIVE	HW3	OUT OF ADJUSTMENT	348	8.89%	35.0%
FACING POINT LOCK	HW4	OUT OF ADJUSTMENT	245	6.26%	41.3%
ROD DRIVE	HW5	OUT OF ADJUSTMENT/GAUGE	196	5.01%	46.3%
ROD DETECTOR	HW6	OUT OF ADJUSTMENT/GAUGE	148	3.78%	50.1%
<null>	HW7	<null>	139	3.55%	53.6%
FACING POINT LOCK	HW8	OUT OF ADJUSTMENT/GAUGE	101	2.58%	56.2%
MOTOR	HW9	DEFECTIVE	88	2.25%	58.4%
....	HW10	ERROR/NEGLIGENCE	47	1.20%	59.6%
STRETCHER	HW11	FRACTURED/BROKEN	45	1.15%	60.8%
MOTOR	HW12	WORN/DET/OUT OF TOLERANCE	45	1.15%	61.9%
CUTOUT RESET	HW13	ERROR/NEGLIGENCE	44	1.12%	63.1%
MOTOR	HW14	HIGH RESISTANCE	42	1.07%	64.1%
ROD DRIVE	HW15	LOOSE	37	0.95%	65.1%
SNUBBING GEAR	HW16	DEFECTIVE	34	0.87%	65.9%
DETECTION ASSEMBLY	HW17	HIGH RESISTANCE	34	0.87%	66.8%
....	HW18	DEFECTIVE	33	0.84%	67.7%
ROD DRIVE	HW19	LOOSE/INSECURE/LEAKING	26	0.66%	68.3%
....	HW20	NON-FAIL (MAINTENANCE)	24	0.61%	68.9%
....	HW21	T.O.K. S/R WHILE TESTING	23	0.59%	69.5%
....	HW22	HIGH RESISTANCE	21	0.54%	70.1%
CIRCUIT CONTROLLER	HW23	HIGH RESISTANCE	21	0.54%	70.6%
MOTOR	HW24	ELECTRIC FAILURE	18	0.46%	71.1%
DETECTION ASSEMBLY	HW25	OUT OF ADJUSTMENT/GAUGE	17	0.43%	71.5%

Table 2 – top 25 failure codes for the HW switch actuator, Kent and Sussex regions, 01/04/1996-18/08/2001

Defective Subassembly	Defect code	Defect text	Count of fail no	% of total	Cum. %
	CL1	T.O.K. RIGHT ON ARRIVAL	935	22.44%	22.4%
CAM ADJUSTABLE	CL2	OUT OF ADJUSTMENT	292	7.01%	29.4%
DETECTION ASSEMBLY	CL3	DEFECTIVE	229	5.50%	34.9%
ROD DRIVE	CL4	OUT OF ADJUSTMENT	171	4.10%	39.0%
LOCK ARM	CL5	POOR LUBRICATION	147	3.53%	42.6%
<null>	CL6	<null>	131	3.14%	45.7%
DETECTOR SLIDE/CAM	CL7	OUT OF ADJUSTMENT/GAUGE	103	2.47%	48.2%
CAM ADJUSTABLE	CL8	OUT OF ADJUSTMENT/GAUGE	80	1.92%	50.1%
ROD DRIVE	CL9	OUT OF ADJUSTMENT/GAUGE	79	1.90%	52.0%
TAPPETS	CL10	OUT OF ADJUSTMENT	68	1.63%	53.6%
LOCK ARM	CL11	OUT OF ADJUSTMENT	56	1.34%	55.0%
HOSE	CL12	DAMAGED BY FIRE / BURNT	55	1.32%	56.3%
TAPPETS	CL13	OUT OF ADJUSTMENT/GAUGE	50	1.20%	57.5%
....	CL14	ERROR/NEGLIGENCE	49	1.18%	58.7%
PUMP (ELECTRIC)	CL15	DEFECTIVE	43	1.03%	59.7%
HOSE	CL16	LEAKING	40	0.96%	60.7%
HOSE/PIPE/CONNECTOR	CL17	DAMAGED BY FIRE / BURNT	38	0.91%	61.6%
POWER PACK ELECTROHYDRALC	CL18	DEFECTIVE	33	0.79%	62.4%
HOSE/PIPE/CONNECTOR	CL19	LOOSE/INSECURE/ LEAKING	32	0.77%	63.1%
	CL20	DEFECTIVE	31	0.74%	63.9%
LOCKING PIECE	CL21	OUT OF ADJUSTMENT	30	0.72%	64.6%
....	CL22	NON-FAIL (MAINTENANCE)	29	0.70%	65.3%
....	CL23	INSPECTED O.K.	28	0.67%	66.0%
DETECTION ASSEMBLY	CL24	FRACTURED/BROKEN	27	0.65%	66.6%
<null>	CL25	<null>			

Table 3 - top 25 failure codes for the Clamp Lock switch actuator, Kent and Sussex regions, 01/04/1996-18/08/2001

3.2.3 Determining if faults can be detected through the key parameters

Condition monitoring equipment is only beneficial if it is capable of detecting enough faults to financially justify its installation. This can be determined by simulating known faults and measuring the key parameters, to see if there is any variation when the fault is introduced.

To this end, the top 25 faults for the HW switch actuator were regrouped into categories according to the basic nature of the fault. Suggestions were then made for experiments which simulate faults in these categories. The results of this investigation are shown in Table 4.

Defect Codes	Failure Mode Group	Experiment	Percentage of Failures
HW3, HW5, HW14, HW19	Drive faults	1. Overdriving point machine (normal and reverse)	15.49%*
		2. Incorrectly setup backdrive (overdriving and underdriving)	
HW2, HW4, HW6, HW8, HW11, HW25	Change of fulcrum	3. Shim insertion	23.3%
HW9, HW12, HW15, HW22, HW23, HW24	High resistance in motor circuit	4. High resistance brushes	5.89%
HW1, HW7, HW10, HW13, HW18, HW20, HW21	Tested OK		24.93%
HW16, HW17	Other (including not classified)		30.39%

Table 4 – Regrouping of HW switch actuator fault codes

**Not including "No Fault Found" diagnoses – although it is likely that a fair proportion of them are in fact due to poor drive adjustment*

3.3 Experimental setup

The experiments suggested in section 3.2.3 were carried out at Network Rail's infrastructure training school at Escrick, North Yorkshire. An 'F' switch, with a HW2000 actuator, was instrumented with transducers to measure force, motor current and drive displacement. An automatic testing unit was used, comprising of the Switching and Detection Interface Unit (SDIU) and the Portable Control and Measurement Unit (PCMU).

The PCMU is a laptop PC with a National Instruments data acquisition card. The PC runs a NI LabVIEW program which allows the user to remotely control the switch, including setting up loops for multiple operations. The program also stores measured data from the acquisition card and displays it on graphs.

The SDIU is a wheel-mounted rack unit containing a DC power supply capable of driving the switch actuator in place of the local power supply. This reduces the risk of interference, since some remote DC power supplies are crudely rectified from AC, resulting in the imposition of 50 Hz half-sine interference on the current waveform, which virtually obliterates any useful information without filtering. Mounted above this is a rack with control circuitry, which interprets commands from the PCMU and switches the power outputs. Separate outputs are provided for normal to reverse and reverse to normal operation, but the control circuitry ensures that both outputs are not energised simultaneously.

During experimentation at Escrick, the power switches in the SDIU failed, so it was necessary to use the local power supply, which was full-wave rectified AC. The current data was filtered using a 1:20 sample moving window which effectively removed the 50 Hz without affecting the other information in the waveforms. The SDIU has since been upgraded with more robust power switches and a higher-voltage power supply, so the same problem is unlikely to happen again when further testing is carried out.

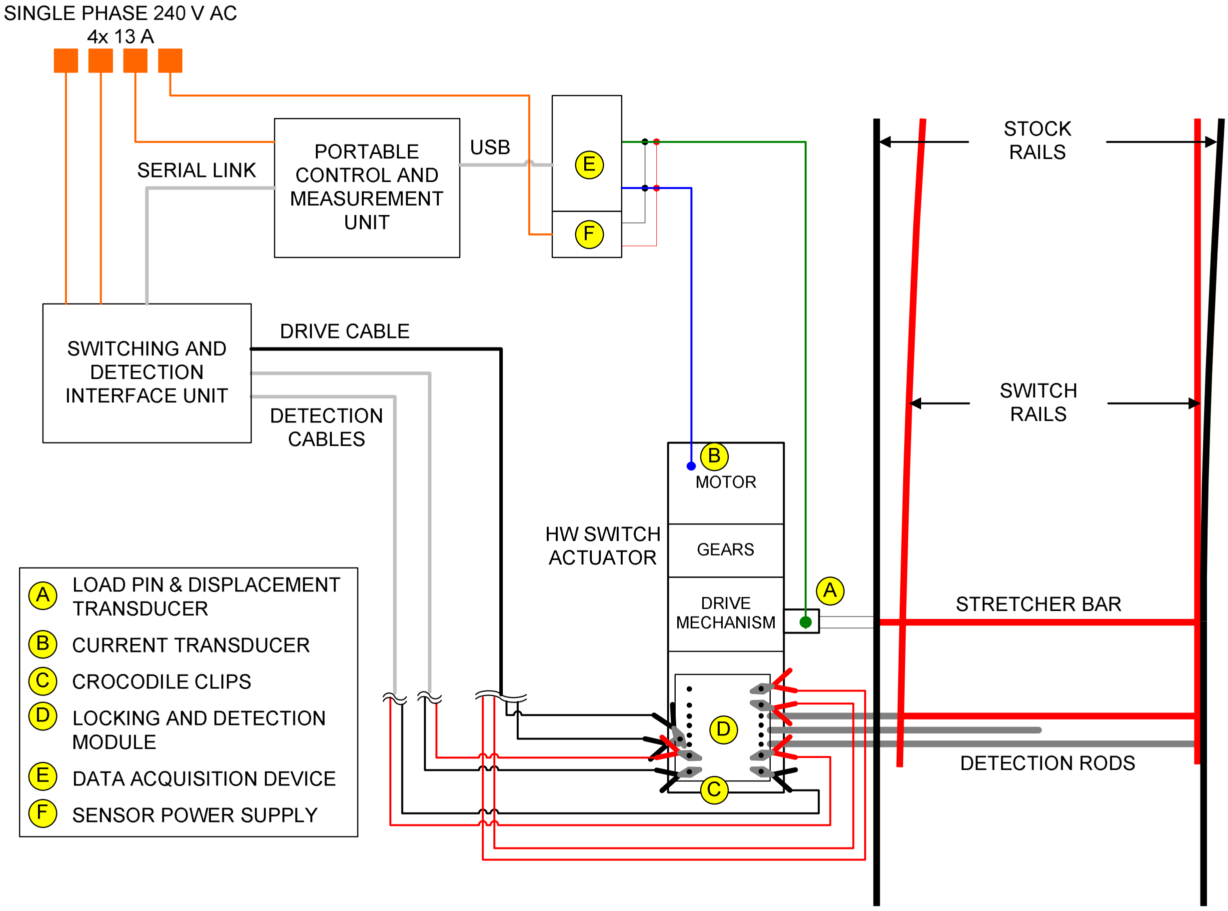


Figure 6 – Diagram of the experimental setup for fault simulation on the HW actuator at Escrick

Figure 7 – 'F' switch under test at Escrick

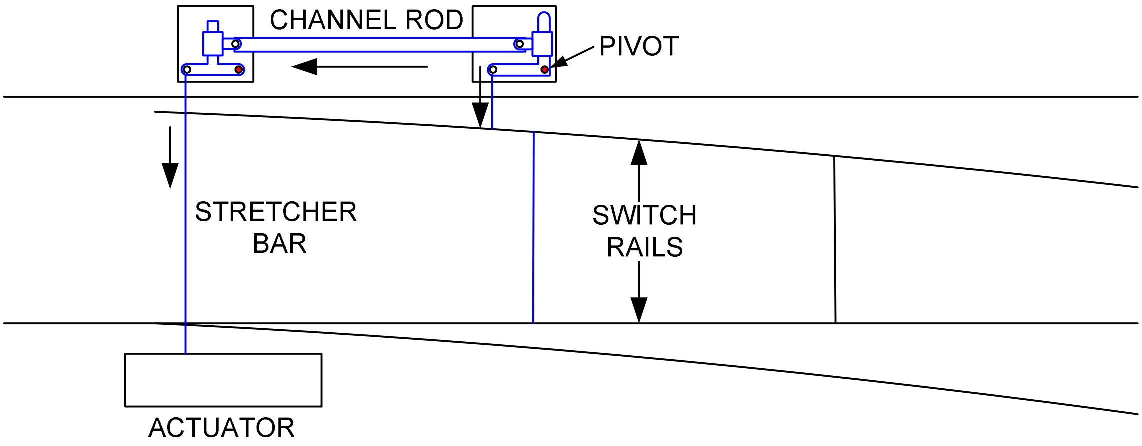


Figure 8 - Transmission of forces in a backdrive

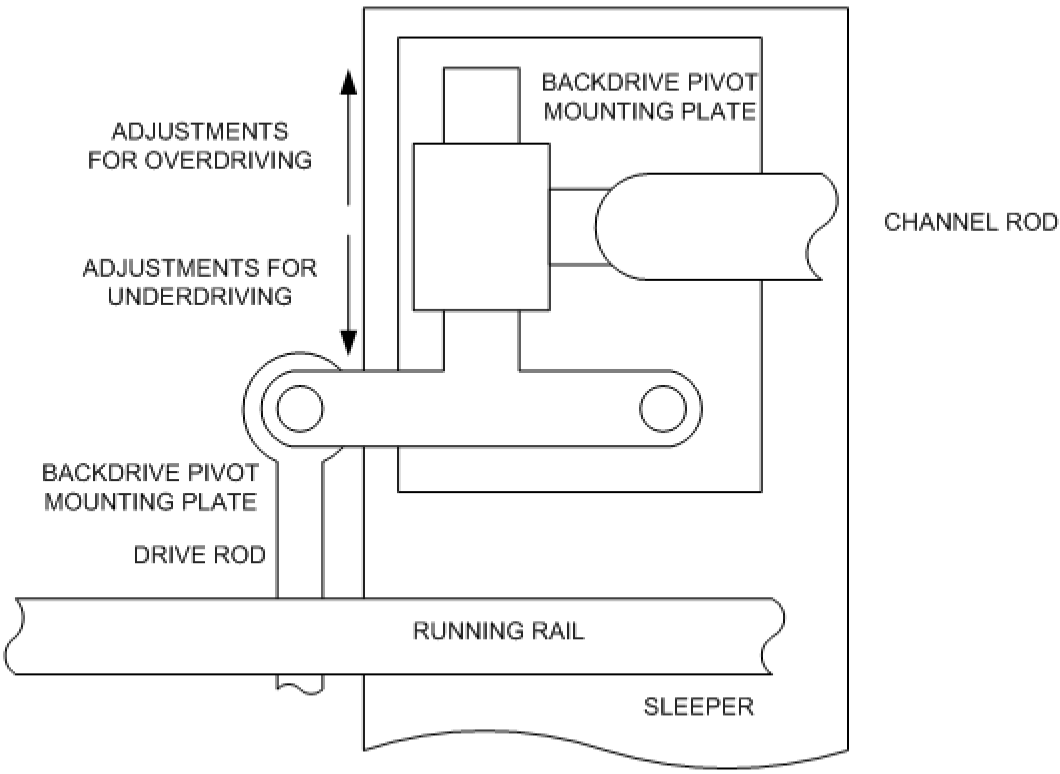


Figure 9 – Adjustment of the backdrive – view from above, at the opposite end of the sleeper to the actuator

3.3.1 Overdriving the backdrive

The backdrive is a mechanism which distributes force throughout the length of the switch in order to move the rails more smoothly. It is a system of levers which are bolted together, with fulcrums mounted on the sleepers. Figure 88 shows how the backdrive assists the movement of the switch.

It is possible to adjust the backdrive to provide more or less force, by adjusting the leverage applied between the drive rod and the channel rod. Figure 99 shows where these adjustments were performed. They were made by tapping the block connected to the channel rod away from the fulcrum so that the channel rod moves further than usual.

The block was moved away from its normal position by increments of a few millimetres, up to a maximum of 25 mm, at which point the adjustment prevented the actuator from completely throwing the switch. This was expected, because the adjustments increased the force required of the actuator, to the point where the force was so great that the magnetic clutch in the actuator was overcome.

3.3.2 Underdriving the backdrive

The block connecting the backdrive fulcrum to the channel rod was progressively moved towards the fulcrum, giving less leverage to the drive and therefore reducing the force transmitted through the backdrive.

Adjustments were made of up to 51 mm from the usual position of the block. This fault did not prevent the actuator from throwing the switch, even at maximum severity. This was expected, since the actuator is capable of moving the rails without the assistance of the backdrive; the force produced by the actuator was simply distributed in a different manner because of the adjustments made.

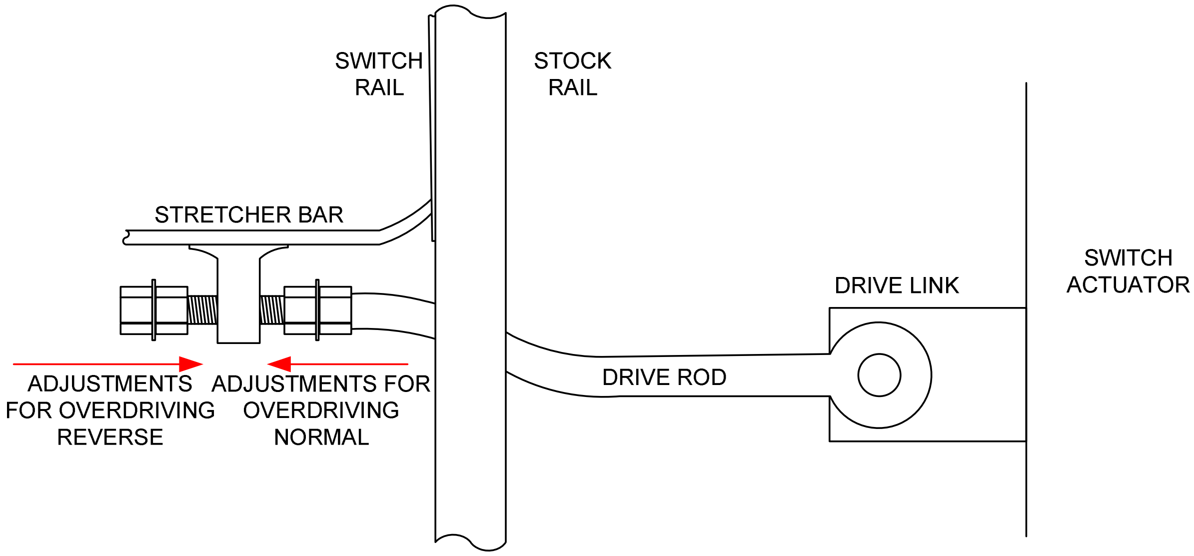


Figure 10 - Adjustments made to overdrive the switch

3.3.3 Overdriving the switch towards reverse

The drive rod from the switch actuator is attached to the stretcher bar, but is free to move laterally within the fixing. This allows adjustments to the distance that the actuator attempts to drive the switch to either side. These adjustments are carried out by turning the nuts on either side of the attachment, as shown in Figure 1010. When the actuator starts, the drive rod moves freely until the adjusted nut makes contact with the attachment to the stretcher bar, at which point it starts to push the stretcher bar, and therefore the switch.

Even small changes to the adjustment of these nuts can have a large effect on the operation of the switch, especially the forces involved. Adjustments were made in increments of $^{1}/_{6}$ turn (i.e. one nut face) up to a maximum of $1^{1}/_{3}$ turns, at which point the actuator was unable to complete the throw. This was expected, because the adjustment was forcing the actuator to continue attempting to throw the switch, despite it already being hard against the stock rail on the reverse side.

3.3.4 Overdriving the switch towards normal

Adjustments were made to the nut controlling the amount of drive towards normal, in increments of $^1/_6$ turn. The actuator failed to throw when the total adjustment reached $^5/_6$ turn. As with overdriving towards reverse, it was expected that the actuator would fail because the adjustment was forcing the actuator to continue applying force to the switch, despite it being hard over against the normal side stock rail.

3.3.5 Changing the fulcrum point of the switch

This experiment simulates obstructions between the switch and stock rails. Steel shims were used to change the fulcrum point of the switch, as shown in Figure 1111. Normally, the fulcrum point is the point where the switch rails are firmly attached to the stock rails. On the 'F' switch, this is 19 sleepers from the end of the switch rails. The shims were inserted between the switch and stock rails at progressively shorter distances from the ends of the switch rails, until the force was so great that it stalled the actuator. This occurred when 3 shims were inserted level with the 15th sleeper.

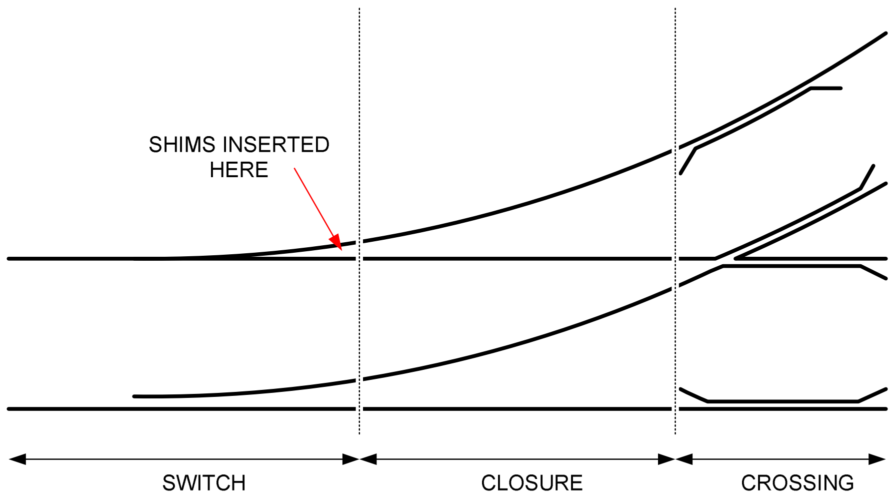


Figure 11 - Insertion of shims to simulate obstructions

3.3.6 Increasing the resistance of the motor winding

The resistance of the motor was increased by introducing defaced brushes in place of the undamaged ones. The defaced brushes had a smaller surface area and therefore a higher resistance. This fault did not cause the actuator to stall. Unlike the other faults simulated, this was a one-off test, since it was not possible to gradually induce the damage to the motor brushes.

3.4 Test results

The following subsections contain graphs of the three variables measured for each experiment, along with short comments on the observations made. Each section contains a table which gives a qualitative assessment of the effects of each fault on the variables. The table entries signify the magnitude of the effects as follows: +++ = major change; ++ = change; + = minor change; 0 = no change.

The variables are denoted by **I** for current, **F** for force and **s** for displacement; throw directions are noted as (n-r) and (r-n) for normal to reverse and reverse to normal respectively.

3.4.1 Control

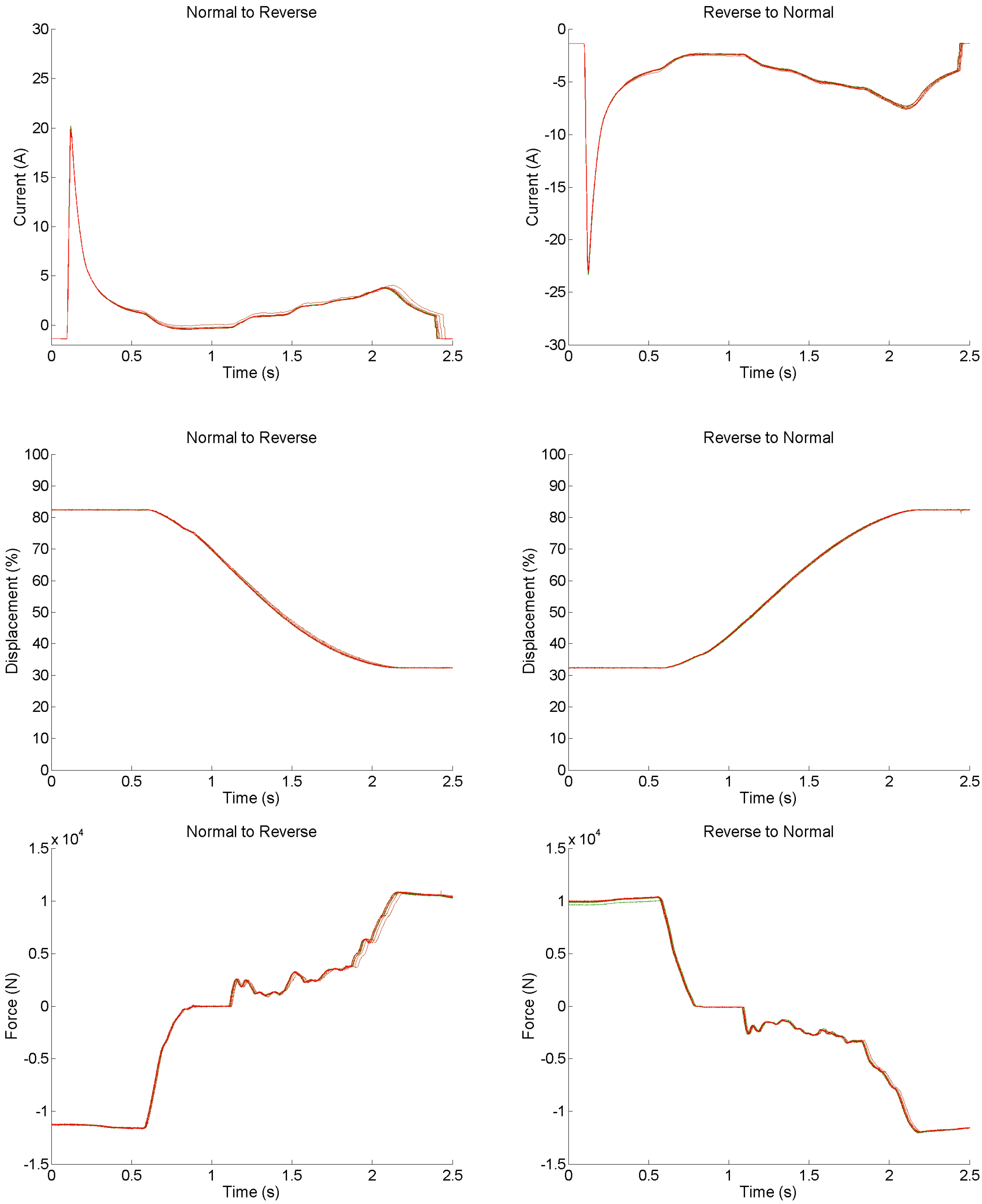


Figure 12 - Results of control test

The graphs show a consistent set of data taken during a control test of 10 throws in each direction.

3.4.2 Overdriving the backdrive

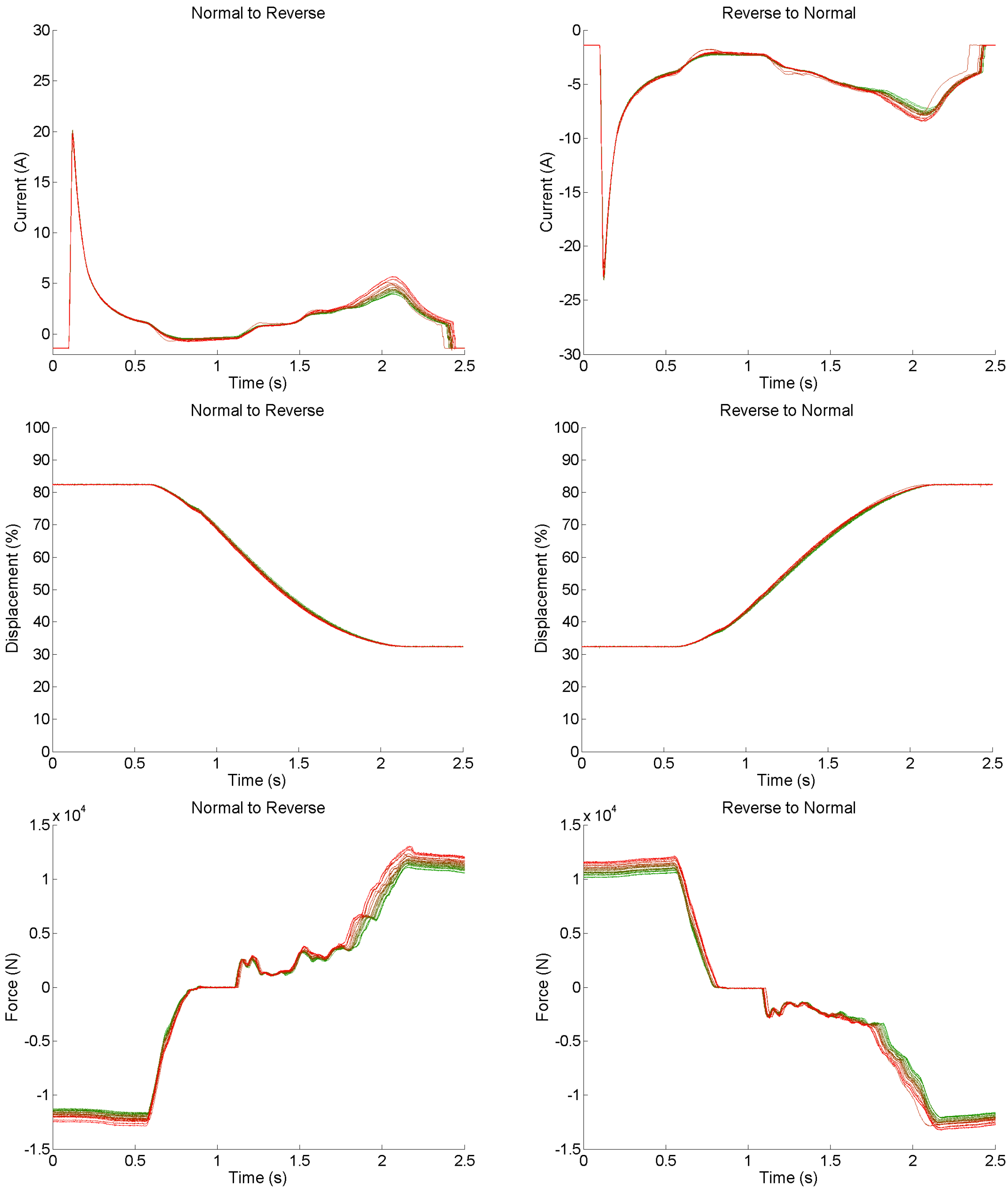


Figure 13 - Results of overdriving the backdrive

Changes were noticeable at both ends of the throw in all three variables, although the effects on displacement were very small.

I (n-r)	I (r-n)	F (n-r)	F (r-n)	s (n-r)	s (r-n)	t (n-r)	t (r-n)
+	+	++	++	+	+	+	+

Table 5 – Effects on measured variables of overdriving the backdrive

3.4.3 Underdriving the backdrive

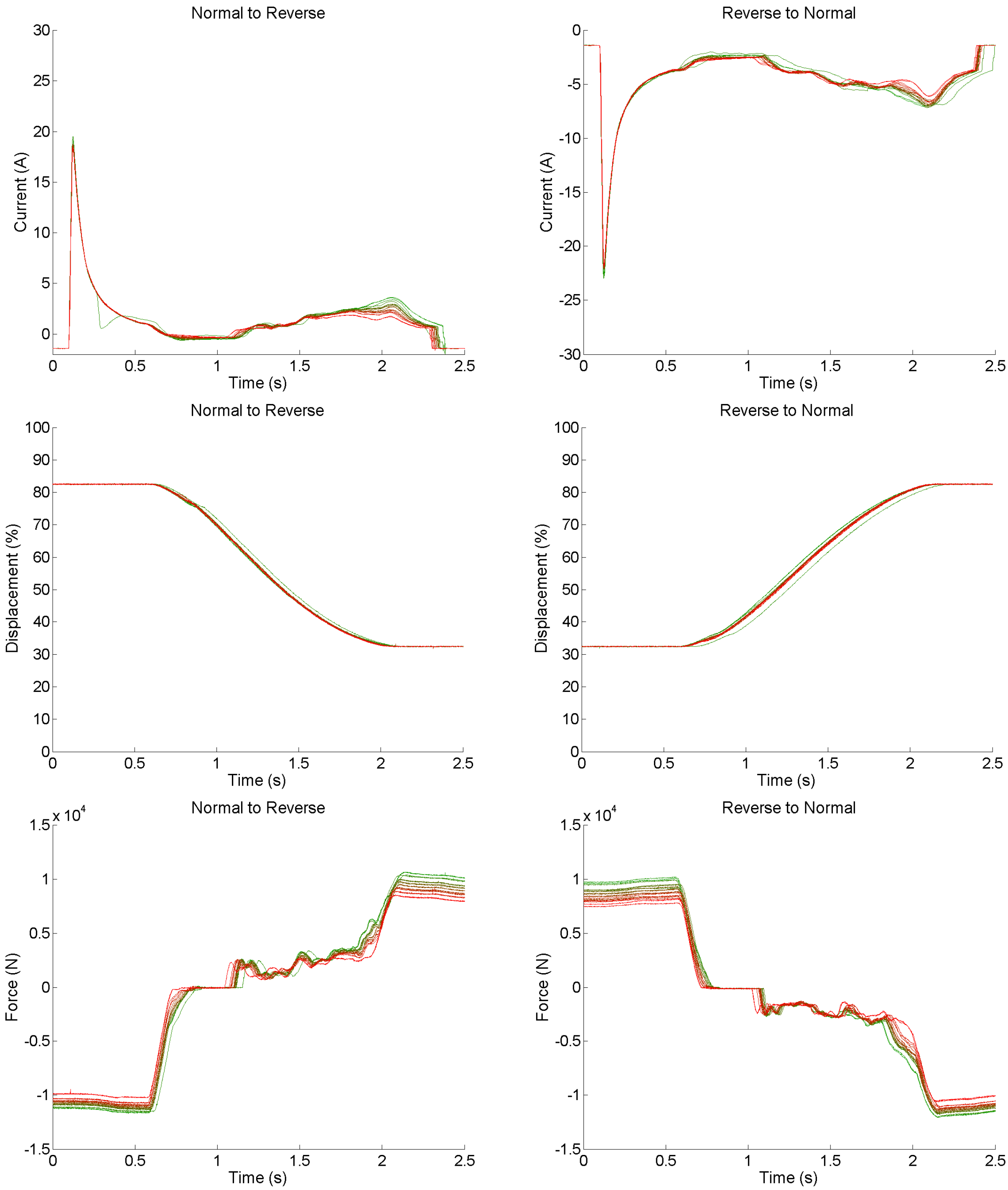


Figure 14 - Results of underdriving the backdrive

The effects of this fault are most evident at both ends of the force waveform, but there is also a small trend in the current waveforms. The displacement waveforms are quite varied with no overall trend.

I (n-r)	I (r-n)	F (n-r)	F (r-n)	s (n-r)	s (r-n)	t (n-r)	t (r-n)
+	+	++	++	0	0	+	+

Table 6 - Effects on measured variables of underdriving the backdrive

3.4.4 Overdriving towards reverse

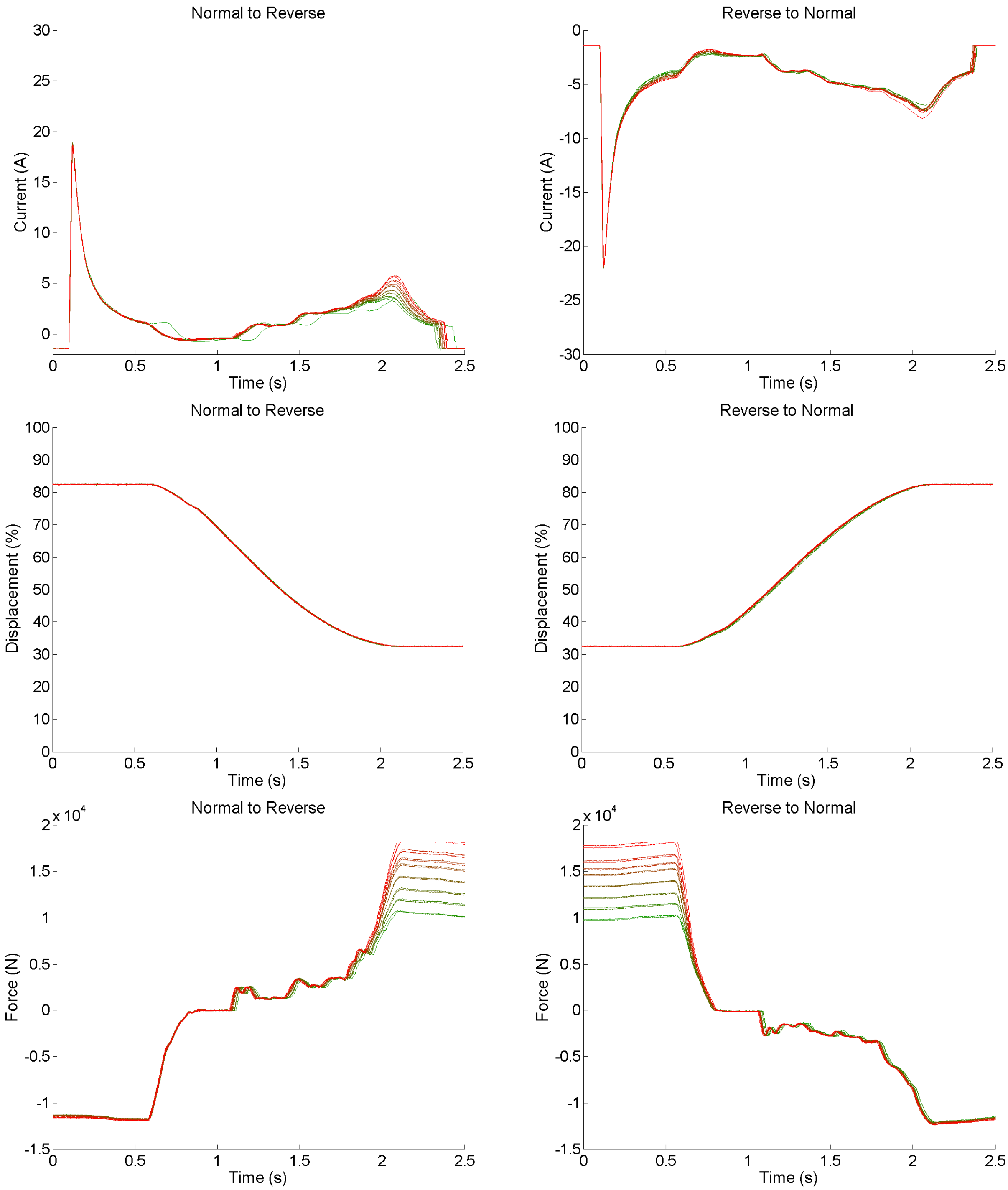


Figure 15 - Results of overdriving the switch towards reverse

Large effects can be seen on the reverse side force as the switch drives further towards it. The current in normal to reverse throws can be seen to increase at the reverse end as the fault worsens.

I (n-r)	I (r-n)	F (n-r)	F (r-n)	s (n-r)	s (r-n)	t (n-r)	t (r-n)
++	+	++	++	0	+	0	0

Table 7 - Effects on the measured variables of overdriving the switch towards reverse

3.4.5 Overdriving towards normal

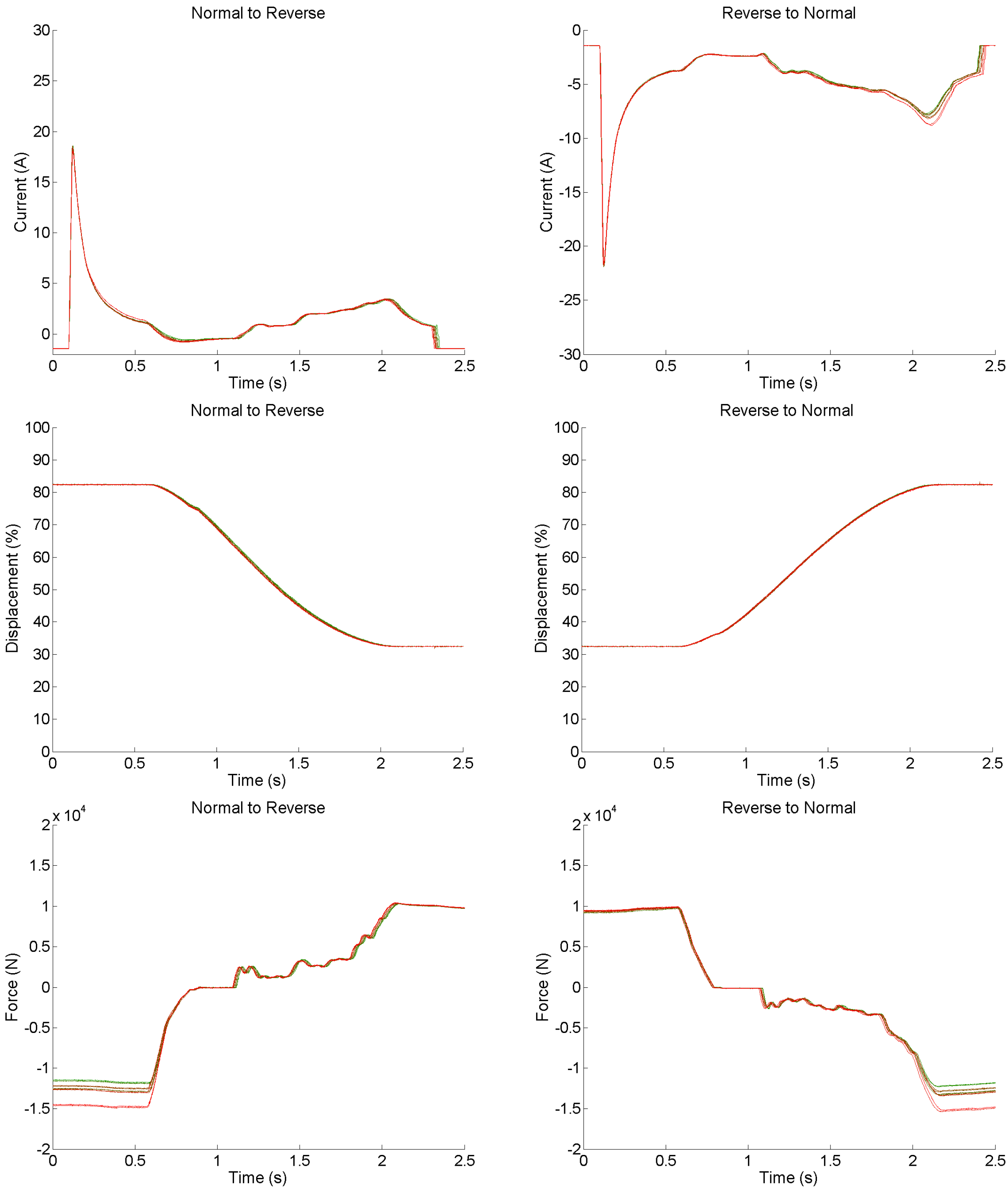


Figure 16 - Results of overdriving the switch towards normal

Significant effects can be seen in the force waveforms at the normal end; similarly to the previous fault, the current increases at the normal side as the actuator continues to push hard at the end of the throw.

I (n-r)	I (r-n)	F (n-r)	F (r-n)	s (n-r)	s (r-n)	t (n-r)	t (r-n)
0	+	++	++	+	0	+	+

Table 8 - Effects on the measured variables of overdriving the switch towards normal

3.4.6 Shim insertion

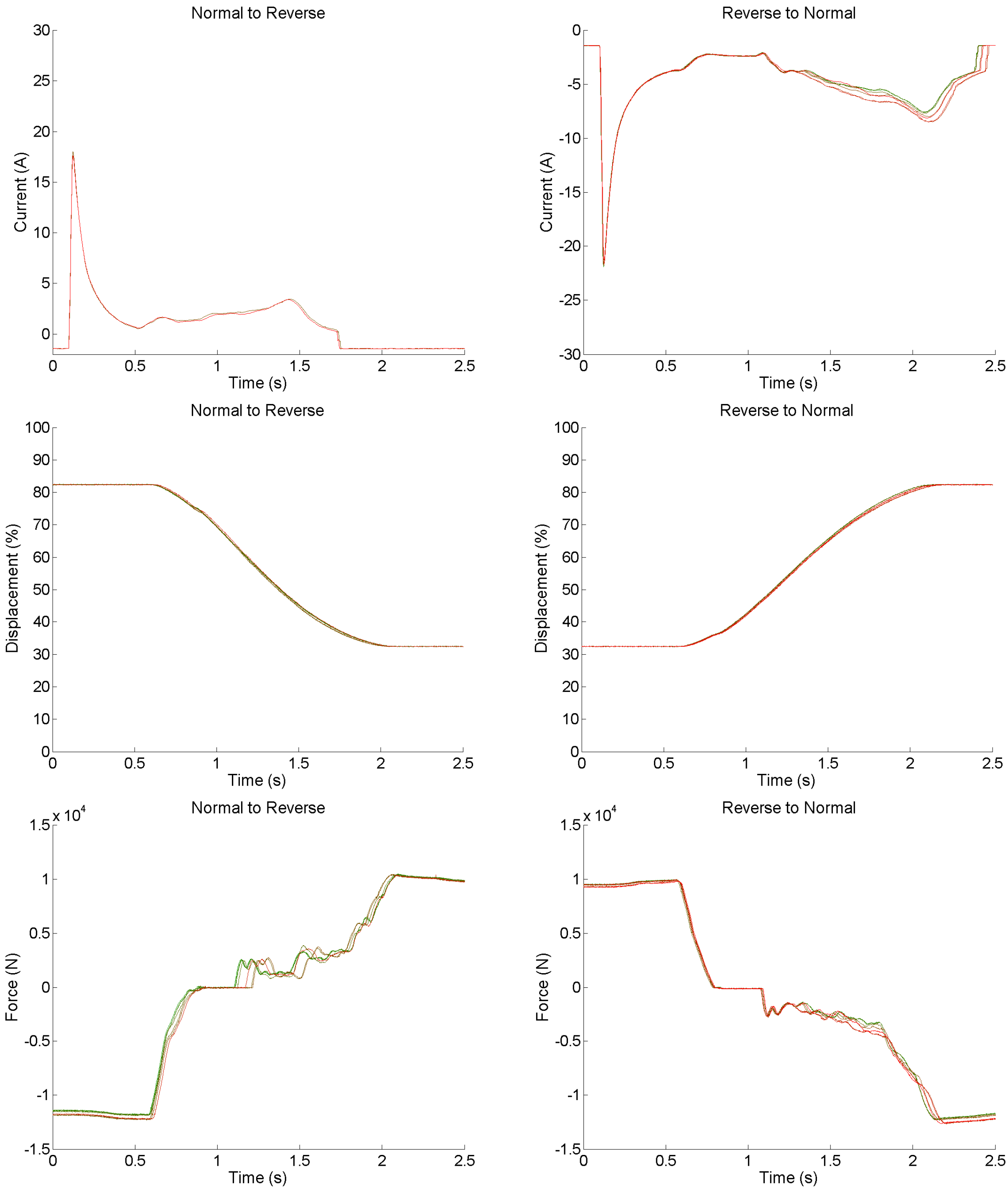


Figure 17 - Results of shim insertion between switch and stock rails

The shims were inserted in the normal side of the switch; an increase in current can clearly be seen on the reverse-normal waveform as the actuator pushes against the obstruction to lock the switch.

I (n-r)	I (r-n)	F (n-r)	F (r-n)	s (n-r)	s (r-n)	t (n-r)	t (r-n)
0	++	+	+	+	0	0	+

Table 9 - Effects on the measured variables of shim insertion

3.4.7 Motor brush damage

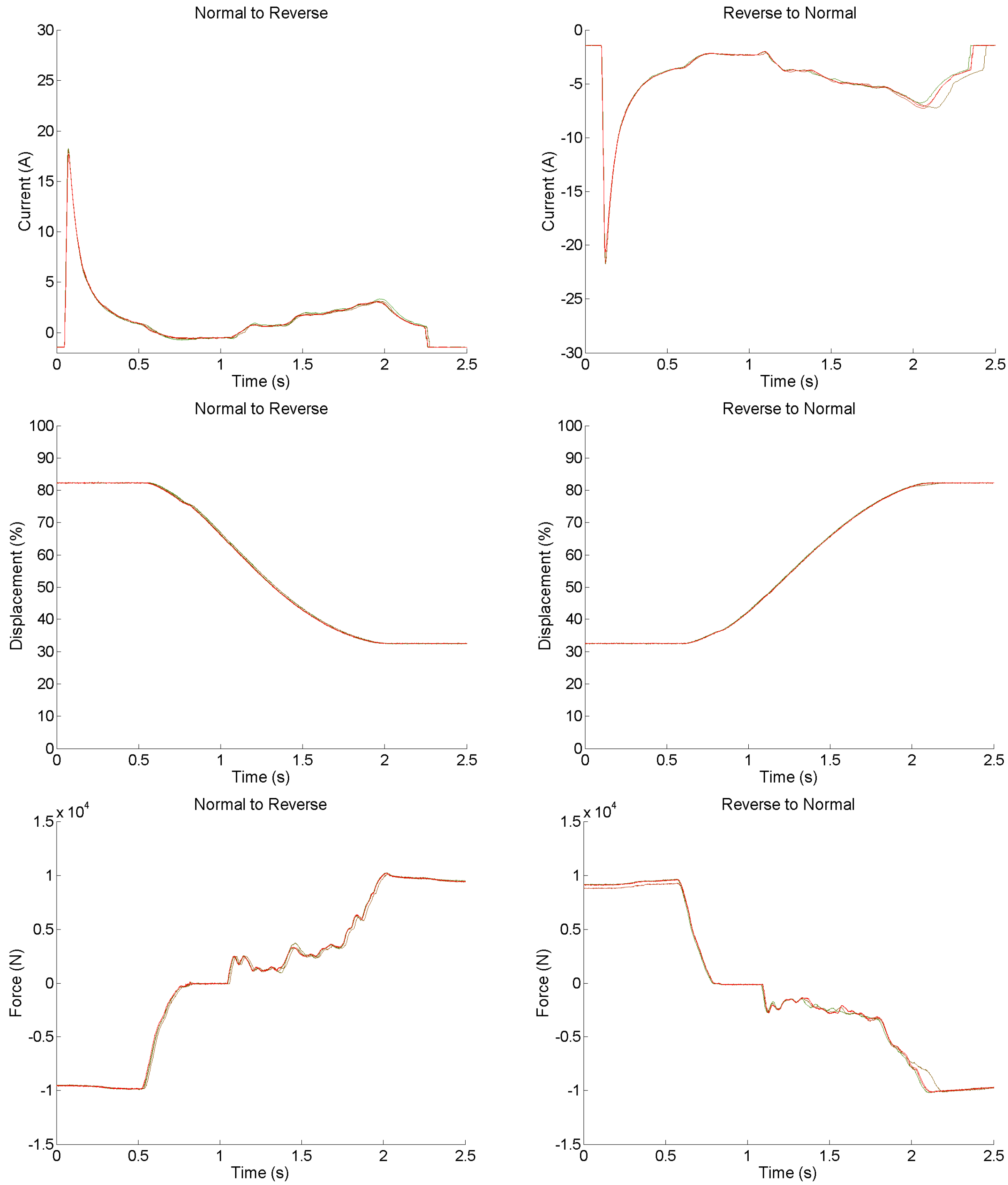


Figure 18 - Results of damage to the motor brushes

Damage to the motor brushes had minimal effect on all three variables.

I (n-r)	I (r-n)	F (n-r)	F (r-n)	s (n-r)	s (r-n)	t (n-r)	t (r-n)
0	0	0	0	0	0	0	0

Table 10 - Effects on the measured variables of damaged brushes

4. Conclusions

Table 11 shows a summary of the qualitative effects observed in the measured variables as each fault was simulated, along with the proportion of failures which correspond to these faults in the FRAME data previously analysed.

The results show that force and current are the parameters most affected by the introduction of incipient faults, but that the faults also have smaller magnitude effects on the displacement profile and the time to throw.

These findings are significant because they allow a comparison of the benefits of installing sensors to measure different variables. It is possible to detect the onset of some faults simply by measuring the time to throw the switch, but without measurement of parameters such as force, current or displacement, it is not possible to determine which fault is causing the changes. Given that actuators are overspecified for the switches they control, they are capable of overcoming faults which increase their load, sometimes without any change in throw time right up until they fail.

If the aim of condition monitoring is to gain early warning of incipient faults, then it must not only detect that the actuator is not performing correctly, but also diagnose what the problem is. Without this information, human intervention will lack the necessary information to target maintenance effectively.

Each of the three sensors used in these experiments is relatively cheap and would be easy to install as part of a suitably robust condition monitoring system. These sensors could also be included in future actuator designs with minimal difficulty, which would save expense compared with the retrofitting of a separate system. The sensors do not interfere in any way with the safe and effective operation of the switch, although the position of the displacement sensor would probably not be practical in an operational environment. There are, however, several other locations on the actuator where the displacement sensor could be placed and work more effectively.

Failure Mode Group	N-R I	R-N I	N-R F	R-N F	N-R d	R-N D	N-R t	R-N t	% of Faults
Overdriving towards normal	0	+	++	++	+	0	+	+	15.49%
Overdriving towards reverse	++	+	++	++	0	+	0	0	
Overdriving the backdrive	+	+	++	++	+	+	+	+	
Underdriving the backdrive	+	+	++	++	0	0	+	+	
Change in fulcrum point	0	++	+	+	+	0	0	+	23.3%
HR in Motor Circuit	0	0	0	0	0	0	0	0	5.89%

Table 11 - Summary of effects on measured variables

5. Bibliography

[1] Advantage Technical Consulting, Technical Report 25017-04-rep-01, "Review of the reliability of point motors and track circuits", 2002.

6. Annexes

6.1 Clamp Lock experiments

6.1.1 Instrumentation

The newly approved Smiths Hydraulic Clamp Lock Points with condition monitoring transducers together with an additional current transducer were used to take measurements from the system. The transducers were connected to a high speed National Instruments data acquisition card operating at 500Hz which allowed sampling times of up to 200µs. This high speed logging enabled the optimum logging speed to be calculated by applying filtering once the data had been collected.

6.1.2 Failure Modes Simulated

A brief study of the failure modes of the Clamp Lock was carried out. The study concentrated on those faults that would degrade the operation of the point machine, but not cause sudden failure. Information regarding the failure modes was collected from railway personnel, FRAME data and existing RCM analyses detailed in Railtrack Line Specification. The table below gives a summary of those faults considered.

Fault Number	Component	Description
1	Back Drive	Broken Back Drive
2	Back Drive	Maladjusted Back Drive
3	Clamp Lock	Tight Lock 3.2mm
4	Clamp Lock	Tight Lock 3.8mm
5	Clamp Lock	Tight Lock 4.4mm
6	Clamp Lock	Tight Lock 5.0mm
7	Clamp Lock	Tight Lock 5.9mm
8	Detection	Out of Adjustment
9	Hydraulic System	Leak on Normal Ram
10	Hydraulic System	Oil Reduced 1
11	Hydraulic System	Oil Reduced 2
12	Hydraulic System	Oil Reduced 3
13	Pump Motor	Brush Missing
14	Pump Motor	Worn Brush
15	Slide Chairs	Dry Slide Chairs
16	Slide Chairs	Highly Greased Slide Chairs
17	Slide Chairs	Increased Friction on Slide Chairs
18	Stretcher Bar	Lose Front Stretcher Bar
19	Stretcher Bar	Lose Second Stretcher Bar

Table 12 - Faults simulated on the Clamp Lock switch actuator

6.1.3 Results

Due to the design of the hydraulic circuitry the differences between signals in 'healthy' and 'fault' modes are subtle. However, the signals acquired proved to be highly repeatable, making the detection and diagnosis task more straightforward. Due to the subtle changes between 'healthy' and 'fault' modes it was concluded that it would be necessary to acquire data at least at 20ms (ideally at 5-10ms). The following pages show graphs of the obtained results.

6.1.4 Control measurements

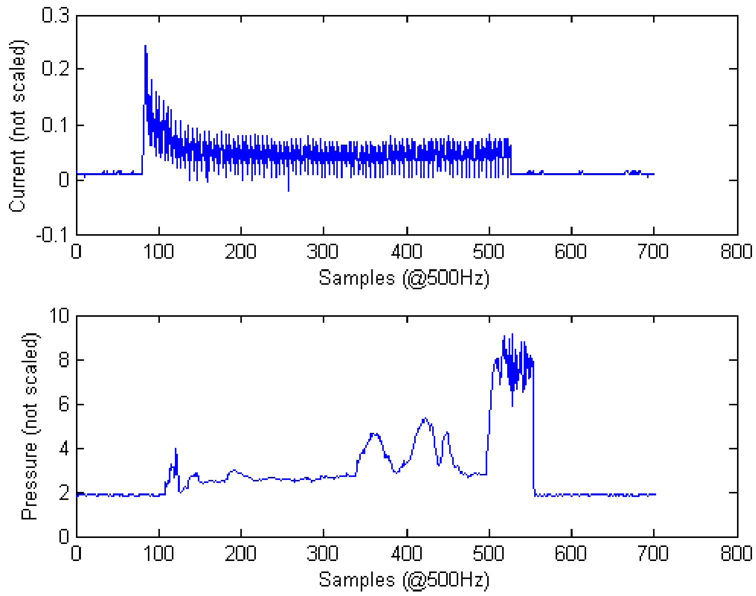


Figure 19 - Clamp Lock control measurements, normal-reverse throw

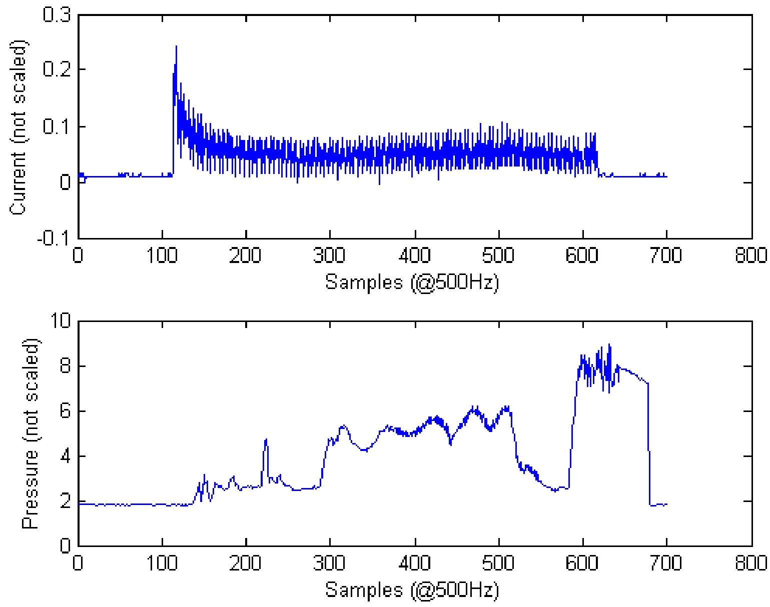


Figure 20 - Clamp Lock control measurements, reverse-normal throw

6.1.5 Broken backdrive

Subtle changes on both the Normal and Reverse throws at around 500 samples.
The fault is likely to be detectable but further investigation is necessary for diagnosis.

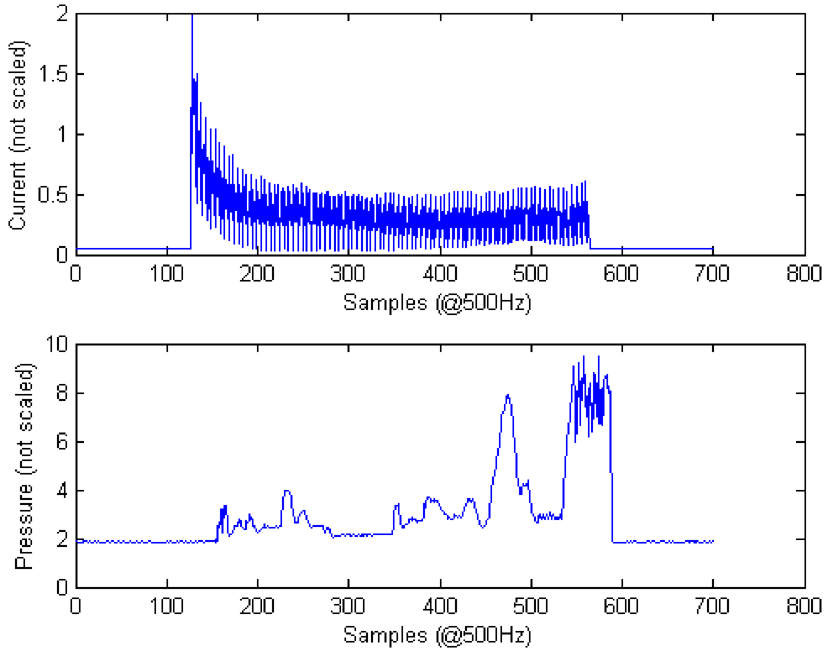


Figure 21 - Clamp Lock with broken backdrive, normal-reverse throw

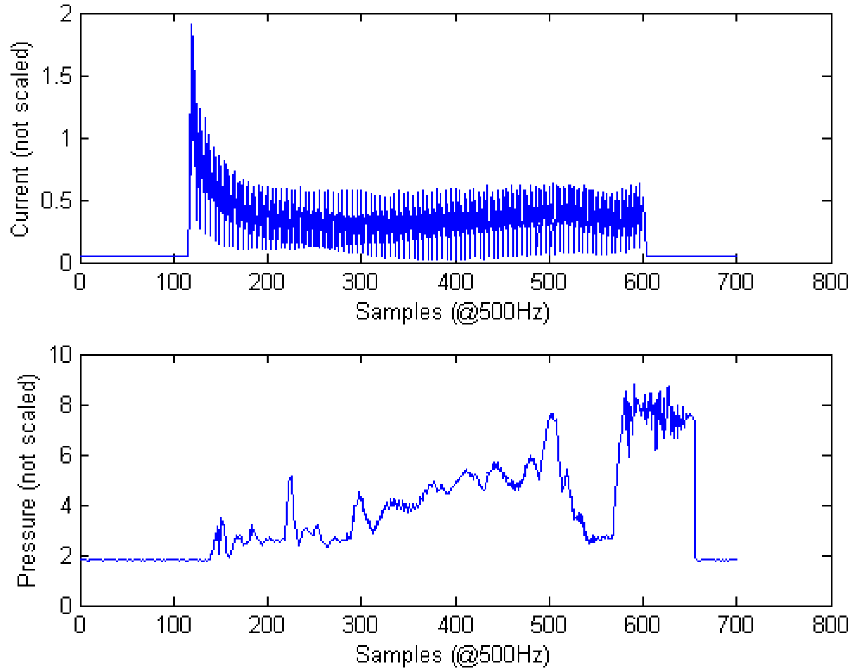


Figure 22 - Clamp Lock with broken backdrive - reverse-normal throw

6.1.6 Maladjusted Back Drive

Changes on both the Normal and Reverse throws can be observed.
The fault is detectable and can be diagnosed.

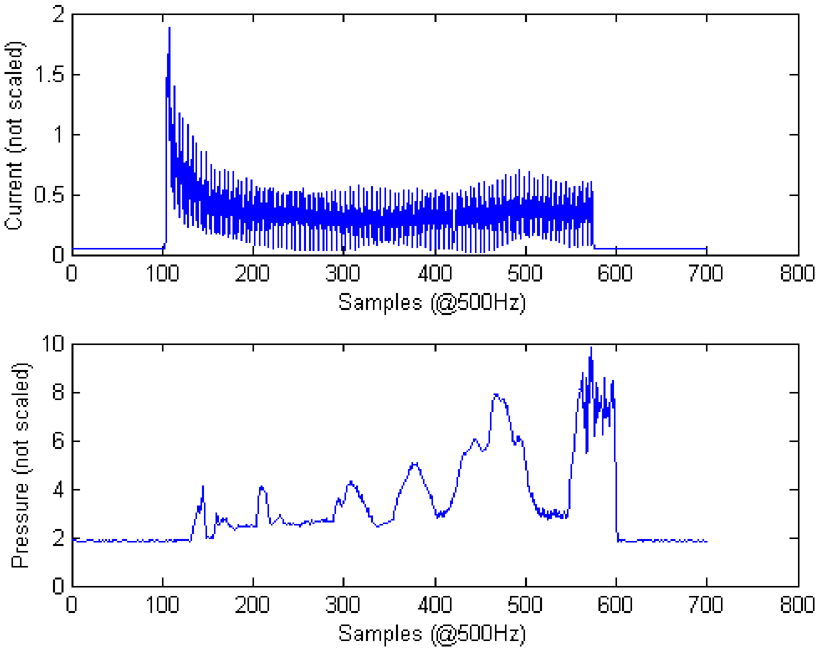


Figure 23 - Clamp Lock with maladjusted backdrive, normal-reverse throw

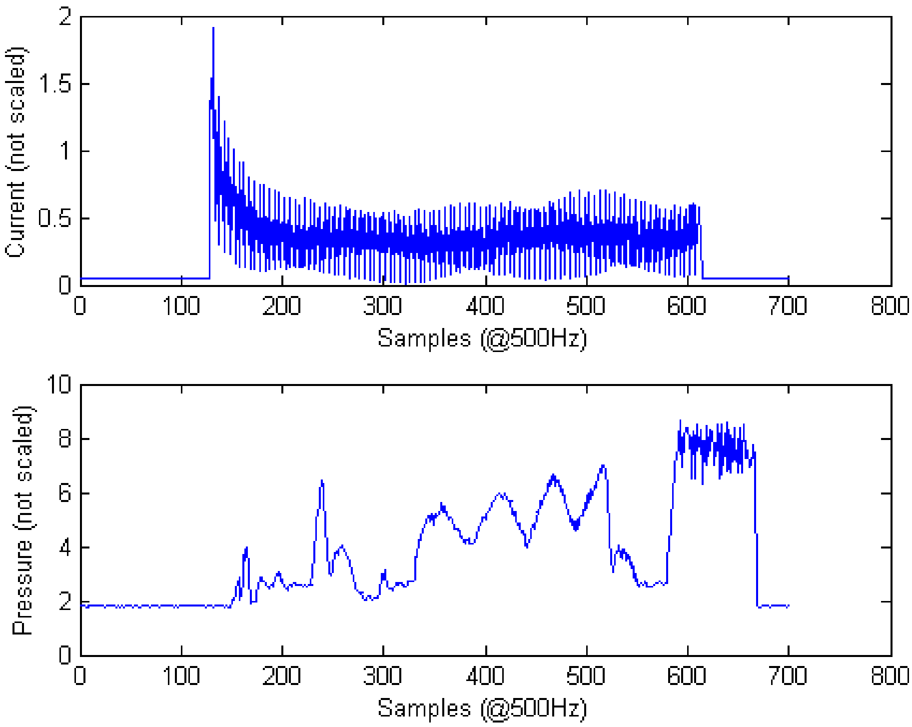


Figure 24 - Clamp Lock with maladjusted backdrive, reverse-normal throw

6.1.7 Tight Lock 3.8mm

Spike at time of locking on Normal throw. However, this is very high frequency.
Further investigation is necessary for detection.

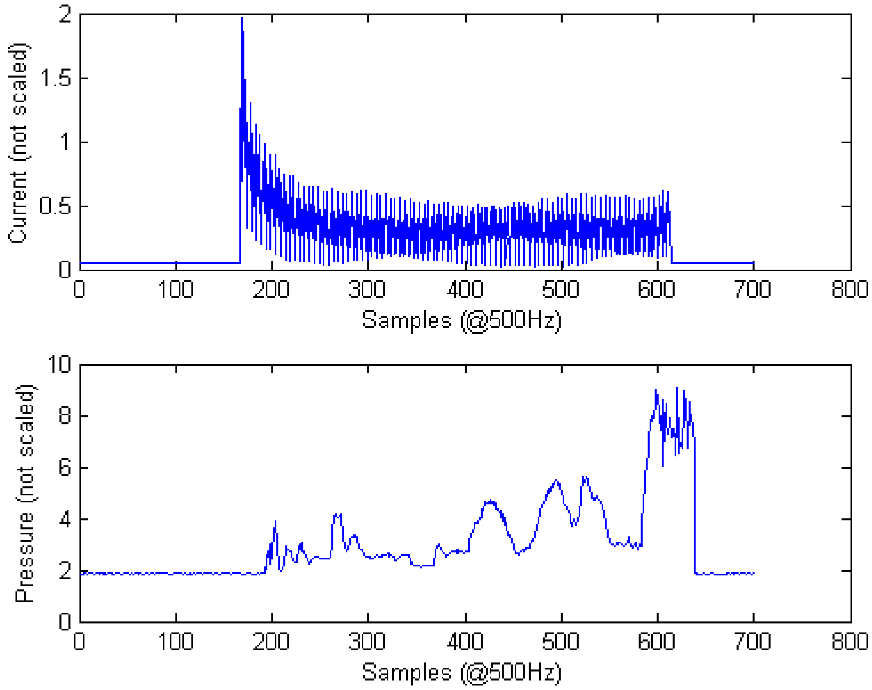


Figure 25 - Clamp Lock with 3.8 mm tight lock, normal-reverse throw

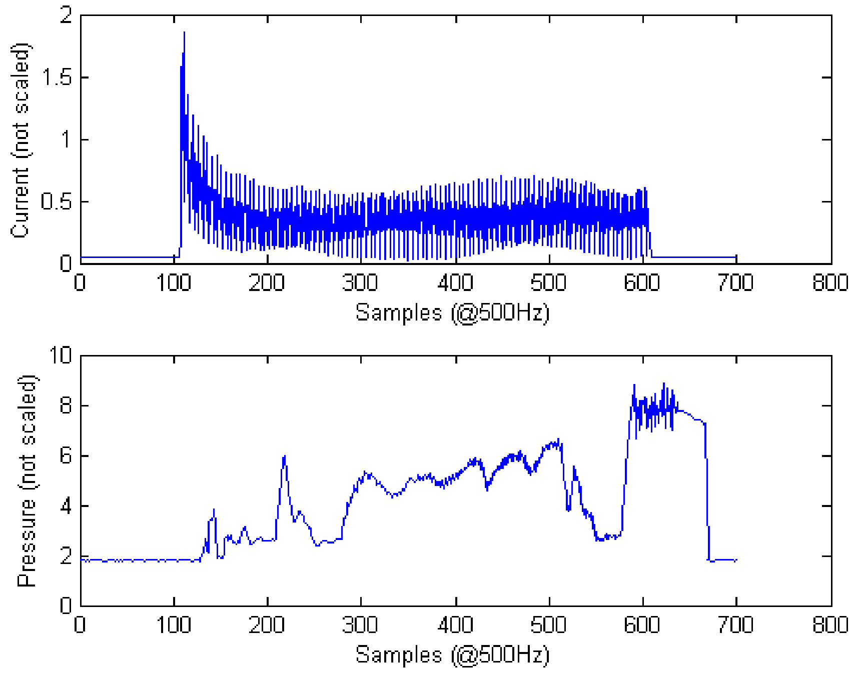


Figure 26 - Clamp Lock with 3.8 mm tight lock, reverse-normal throw

6.1.8 Normal Leak

Subtle changes on both the Normal throws at from 300-500 samples.
Further investigation is necessary for detection.

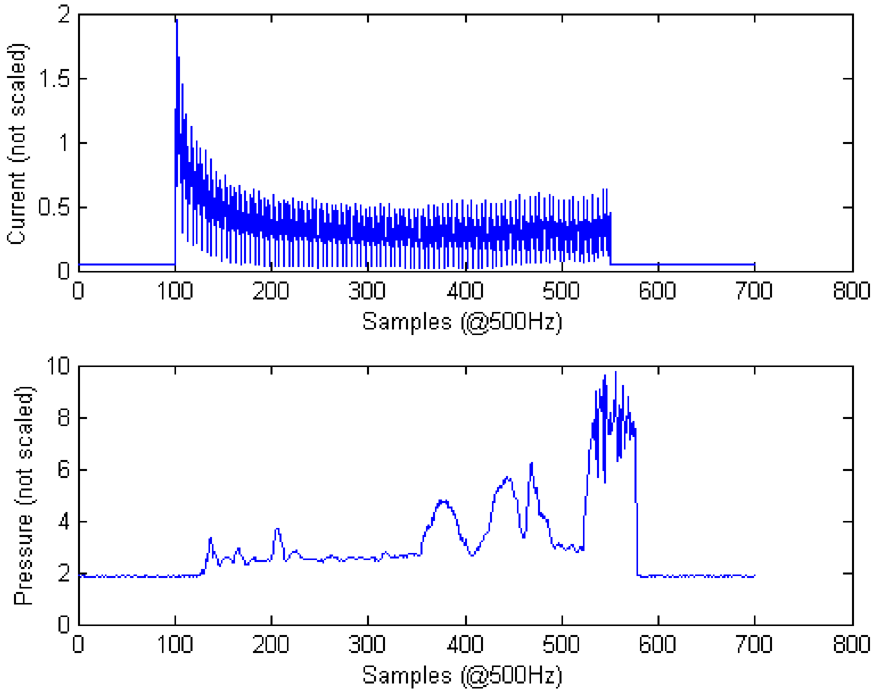


Figure 27 - Clamp Lock with normal side oil leak, normal to reverse throw

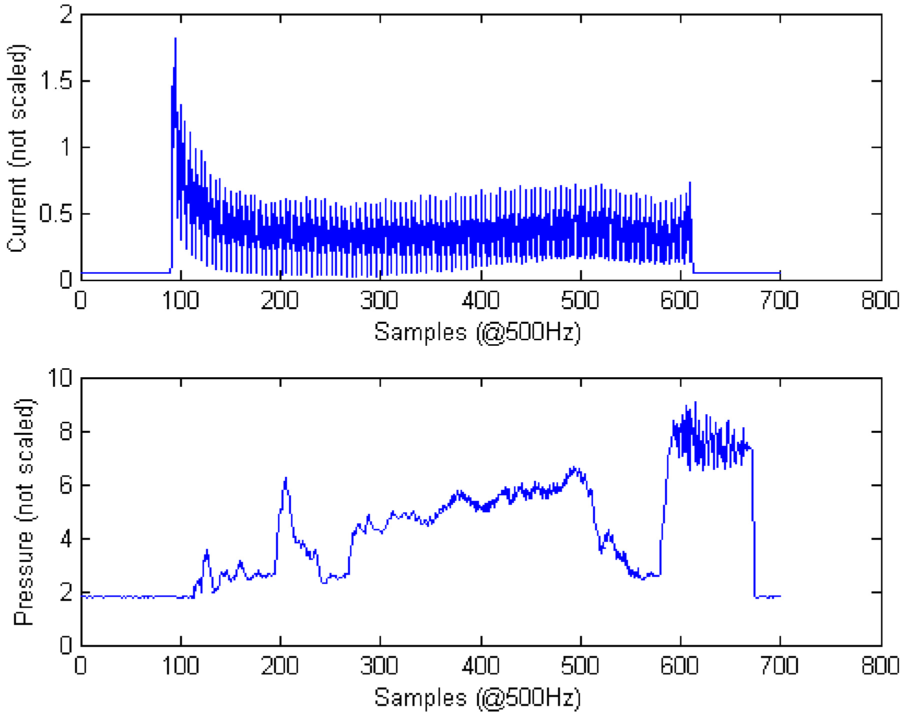


Figure 28 - Clamp Lock with normal side oil leak, reverse-normal throw

6.1.9 Brush Missing/Worn

Can be clearly seen through the time of operation.
Therefore detectable and diagnosable.

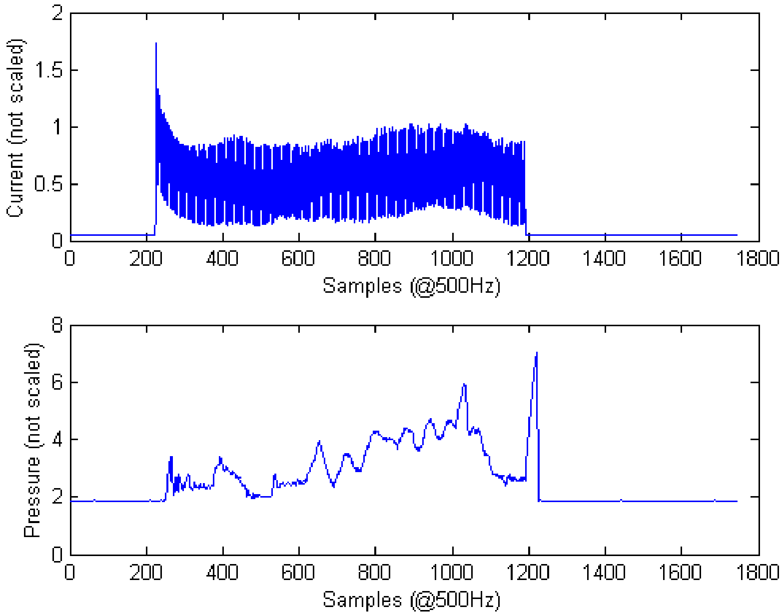


Figure 29 - Clamp Lock with missing motor brush, normal to reverse throw

6.1.10 Friction on Slide Chairs

Subtle change on both the Normal and Reverse throws at around 400-500 samples.
Further investigation necessary.

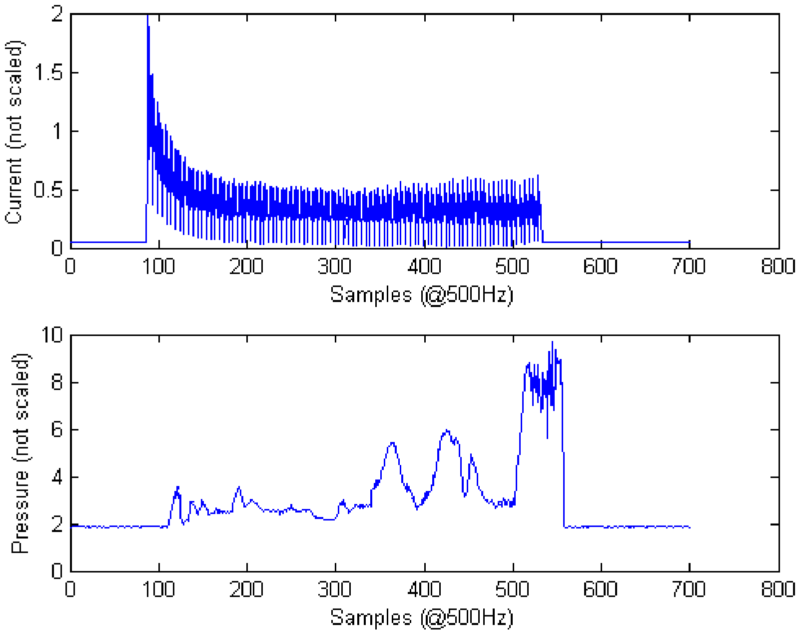


Figure 30 - Clamp Lock with friction on slide chairs, normal-reverse throw

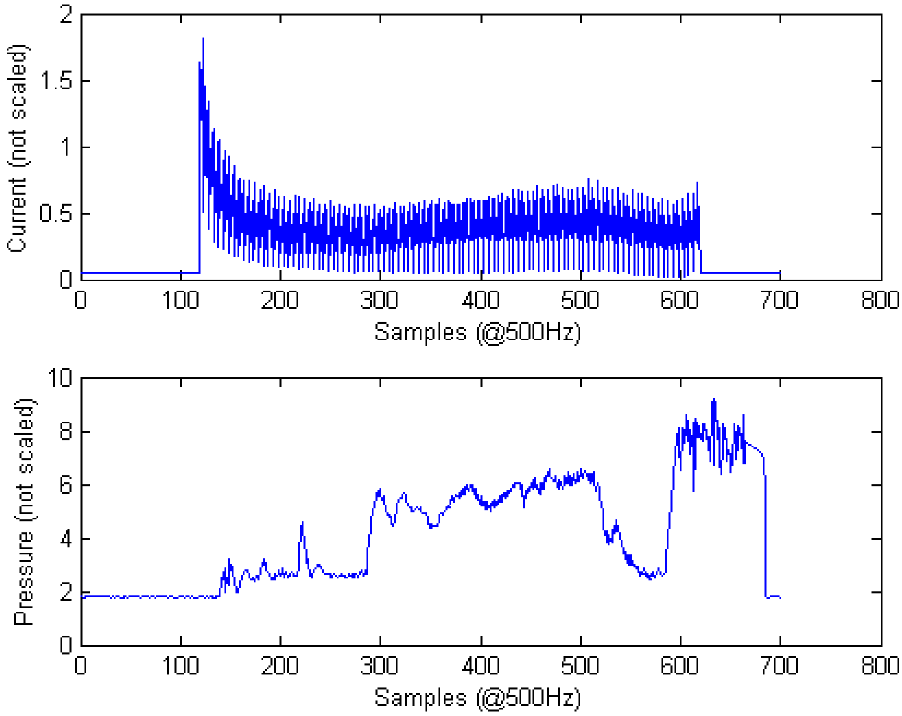


Figure 31 - Clamp Lock with friction on slide chairs, reverse-normal throw