SADM POTENTIOMETER ANOMALY INVESTIGATIONS

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ABSTRACT

During the last 3 years Contraves Space have been developing a Low Power (1-2kW) Solar Array Drive Mechanism (SADM) aimed at small series production.
The mechanism was subjected to two test programmes in order to qualify the SADM to acceptable levels.
During the two test programmes, anomalies were experienced with the Potentiometers provided by Eurofarad SA and joint investigations were undertaken to resolve why these anomalies had occurred.

This paper deals with the lessons learnt from the failure investigation on the two Eurofarad (rotary) Potentiometer anomaly.

The Rotary Potentiometers that were used were fully redundant; using two back to back mounted "plastic tracks". It is a pancake configuration mounted directly to the shaft of the Slip Ring Assembly at the extreme in-board end of the SADM. It has no internal bearings.

The anomaly initially manifested itself as a loss of performance in terms of linearity, which was first detected during Thermal Vacuum testing.
A subsequent anomaly manifested itself by the complete failure of the redundant potentiometer again during thermal vacuum testing.

This paper will follow and detail the chain of events following this anomaly and identifies corrective measures to be applied to the potentiometer design and assembly process.

1. INTRODUCTION

Contraves Space has developed a "Low Power SADM" for small series production. This development was described in detail in reference [1].
The SADM utilises a potentiometer to provide feedback to the electronics to identify the position of the solar array.

As part of the development, the SADM mechanism was subjected to a complete series of "qualification" tests to verify its performance against the specified requirements.
During this test programme, anomalies were experienced with two potentiometers that were part of the SADM assembly.
This paper describes the anomalies experienced with the potentiometer and the joint evaluation process that was undertaken to establish the cause of the failures.

2. TEST PROGRAMME

The SADM was subjected to two series of tests as part of the verification programme.
The test flow in both test programmes is shown on figure 1.

2.1 1st Test Series

Overview of Test Programme

The first test series was intended as the verification programme for the development of the SADM and SADE and included functional, vibration and thermal vacuum tests on both the SADM and the Solar Array Drive Electronics (SADE) assemblies.
Despite slightly under testing SADM in both the Vibration and TV tests, with the exception of the potentiometer, the environmental tests were completed successfully.

Potentiometer Anomaly 1

In this first series of tests, a "Plastic Track" potentiometer manufactured by Eurofarad, with 10 wire brushes per track were used. As shown in figure 2, the potentiometers (main and redundant) are phase shifted by 90° to each other.

During the TV test, anomalies with the accuracy and linearity of the Potentiometer were recorded. The accuracy of the Potentiometer continued to degrade, even after the completion of the TV Test. In order to

investigate this anomaly, with the agreement of Eurofarad, it was decided to measure the Static Contact Resistance and the Dynamic Contact Resistance (RCD) of the potentiometer.
Initially, it was not planned to measure the RCD at Contraves as a linearity measurement provides a good indication of the potentiometer performance. However, during the test programme, it was noticed that the linearity performance of the potentiometers was increasing. Additionally the static resistance measurement showed large deviations, i.e. with values between 200Ω and 2kΩ. Since the total resistance of the potentiometer is 10kΩ, this represents 20% of the total value.

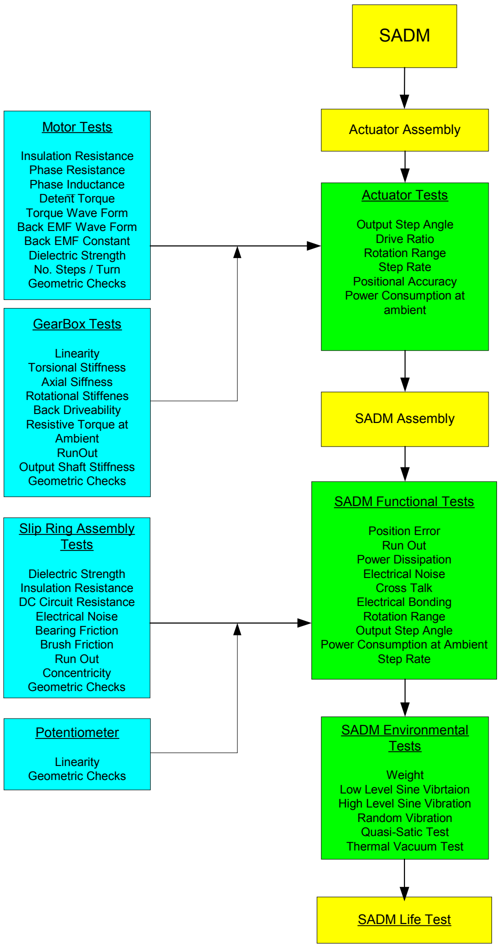

Figure 1: Flow for SADM Qualification Tests

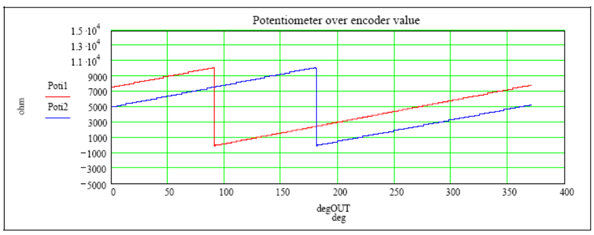

Figure 2: Potentiometer Phase shift

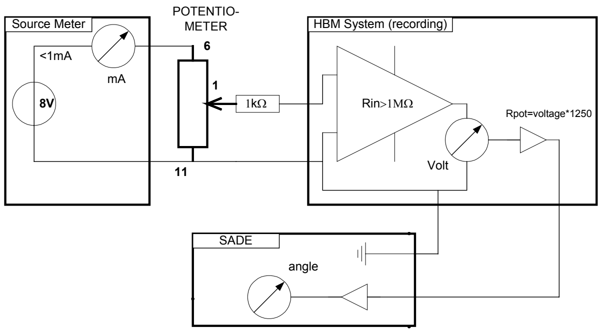

Figure 3: Sketch showing RCD measurement set-up

The measurement of the RCD is a good way of assessing the health of the potentiometer over the life. Although it is not advisable to use single measurements as proof of degradation, these measurements should be used in conjunction with others for comparison purposes.
Although the RCD measurement is performed y Eurofarad at delivery, this measurement is rarely performed by potentiometer users as the linearity measurement on the potentiometer can also be used to provide a coarse indicator of the health of the unit. The devices are primarily used for positional feedback.
Normally a linearity measurement on the potentiometer is used to provide a coarse indication of the health of a potentiometer.

RCD measurements can irreversibly damage the potentiometer if they are performed incorrectly. Indeed, to avoid this, Contraves had to invest significantly in special test equipment for the performance of this test. In support of the test, Eurofarad proposed a measurement set up to measure the Dynamic Contact Resistance using a constant 1mA current source. The set up finally selected is shown on figure 3.

Using the RCD method to evaluate the health of the potentiometer, values of 2.8kΩ for main and 1.8 kΩ for redundant potentiometer were measured when mounted to the SADM which is indicative that there was an anomaly with the contact within the potentiometer.

The potentiometer removed and was examined at Eurofarad where the static contact resistance values measured by Contraves were confirmed. The potentiometer was then checked on the Eurofarad Linearity and RCD standard test jig where no differences against the delivered state were noted.

It should be noted here that the standard test rig rotates relatively quickly during the initialisation phase and also in the start/stop measurement mode. This is fast in comparison to the operating speed on the SADM, which is at a maximum 0.3°/sec.

This approach taken by Eurofarad effectively cleans the track and brush interface.
After re-mounting the potentiometer onto the SADM (at Contraves), it was also possible to confirm the RCD measured on the Eurofarad measurement system.
This was an indication that something had changed on the potentiometer between the time after removal from the SADM and the measurement after re-integration.

The figures 4 & 5 show the linearity measurement traces of the potentiometer at the start of testing and after the TV test.
It can be clearly seen that the linearity of each of the potentiometers has degraded which leads to a higher inaccuracy of the position feedback from the potentiometer.

It was for this reason that the RCD measurement was made. Traces of the RCD measurements are shown on figure 6.

The two peaks at 170° and 270° are due to the movement of the brushes during the vibration test (where the mechanism was stationary) but do not represent a critical performance issue. There are two peaks because the potentiometer was moved once in between the vibration tests.
The vertical lines are due to the dead-band of the potentiometer.

The RCD measurements shown in this figure demonstrate acceptable performance and are in no way critical.

Figure 7 shows a RCD measurement on the redundant potentiometer where the RCD is degraded by a factor 2 when compared with the values presented on figure 6.
This is an indication of the worsening performance of the potentiometer sliding contacts.

NDI Evaluation at ESTEC

After the measurement of inconsistent results on the mechanism, it was decided that the potentiometer should be sent to ESTEC for an NDI evaluation.

The conclusion from this evaluation was that there were silicone deposits in many places including the track and the brush. This silicone was identified as coming from an amount of RTV silicone used to insulate the brushes and to hold the brushes, and provide damping against vibration.

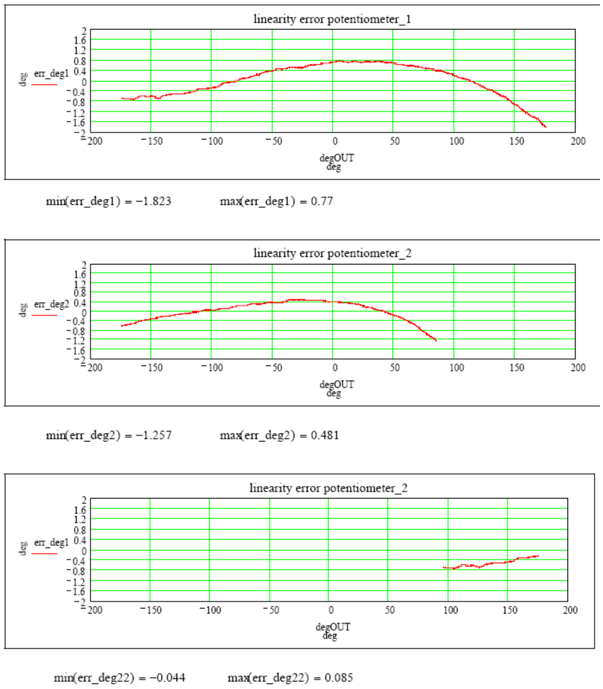

Figure 4: Start of Test Linearity Measurements (potentiometer 2 –split measurement)

Outcome from investigations

After discussions with Eurofarad, it was decided that the brush configuration within the potentiometer should be changed. Instead of wire brushes embedded in silicone, it was decided to change to a finger brush that is directly attached within the potentiometer.
Both of the potentiometer types have flight heritage, so in theory both should have been acceptable for this application.

2.2 2nd Test Series

Overview of Test programme

As a new potentiometer was being assembled onto the SADM the mechanism had to be re-qualified before the mechanism could be subjected to the life test. It was therefore decided to subject the SADM mechanism to a repetition of the environmental test programme as shown on table 1
With the exception of a further potentiometer anomaly, the test programme was completed successfully.

Potentiometer Anomaly 2

During the second TV test, two anomalies manifested themselves. The first anomaly that was identified was similar to that already witnessed during the first series of tests, namely with the change in the RCD and the linearity of the potentiometer.

The second anomaly was more serious, in so much that the potentiometer exhibited an electrical failure that manifested itself initially as an open circuit.

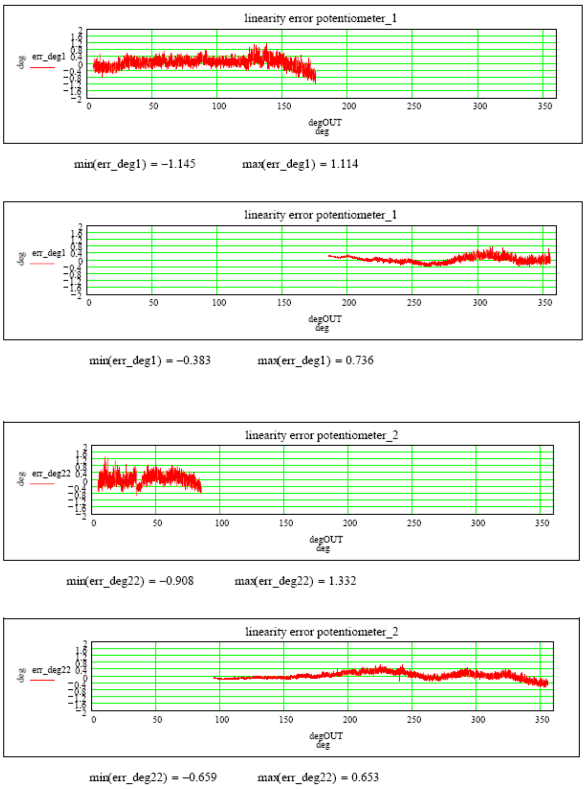

Figure 5: Linearity measurement after TV Test (split measurements)

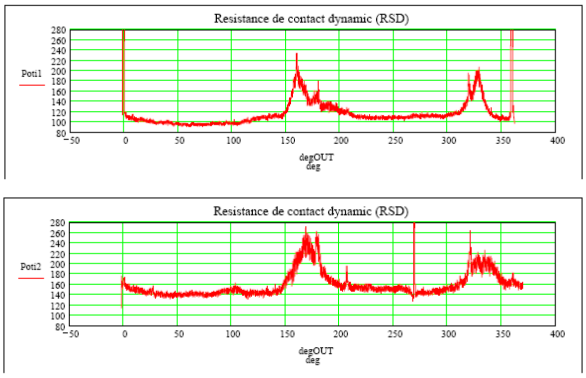

Figure 6: RCD measurement after TV Test

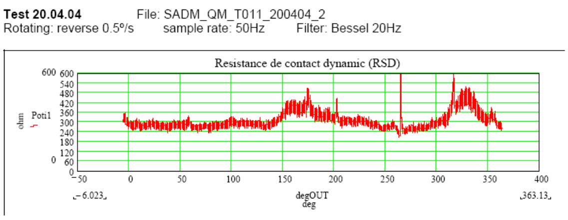

Figure 7: "Out of Spec" RCD measurement on redundant potentiometer

<u>Linearity and RCD anomaly</u>

In a similar manner to the measurements performed during the 1st test series, the new potentiometer used in the 2nd test series displayed a similar increase in the linearity and the RCD measurements.
For comparison, the initial linearity measurements are shown on figure 8.
After the completion of the test, the Linearity and RCD was measured again and compared against the measured values at the beginning of the test programme.
The traces for linearity provided on figure 9 show that the linearity has degraded but it should be noted that the difference is not as significant as in the first test series.

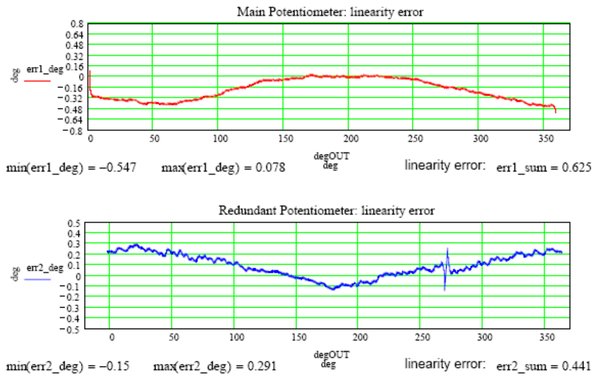

Figure 8: Initial Linearity measurements

Although the linearity results are measured at cold temperature, the changes resulting from the difference between ambient and cold are not significant.
The RCD measurements before the start of the test series are shown on figure 10, and the measurements after the completion of the test series, shown on figure 11. Again these end measurements are made at cold temperature but the difference between cold and ambient is negligible.

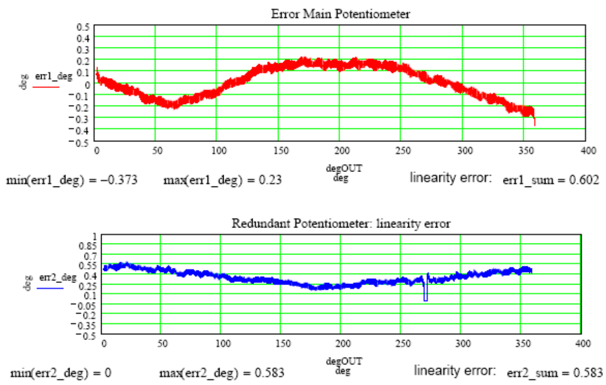

Figure 9: Linearity measurements at the completion of the test programme (obtained at cold temperature)

It can be seen from a comparison between the values on figure 10 and 11, that the RCD has not changed significantly.

<u>Electrical Anomaly with Potentiometer</u>

After a successful first cycle of the TV test, the redundant potentiometer exhibited an anomaly during the second hot cycle at +65°C. It was realised that it was not possible to measure the RCD on this Potentiometer, in fact a value of about 10kΩ was recorded. The main potentiometer continued to function in a correct manner.

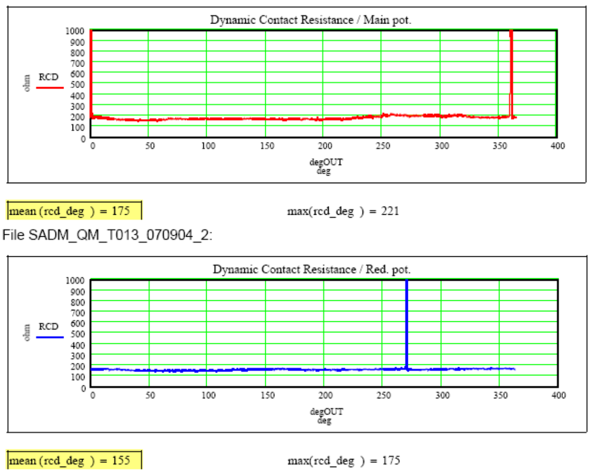

Figure 10: Initial RCD measurements

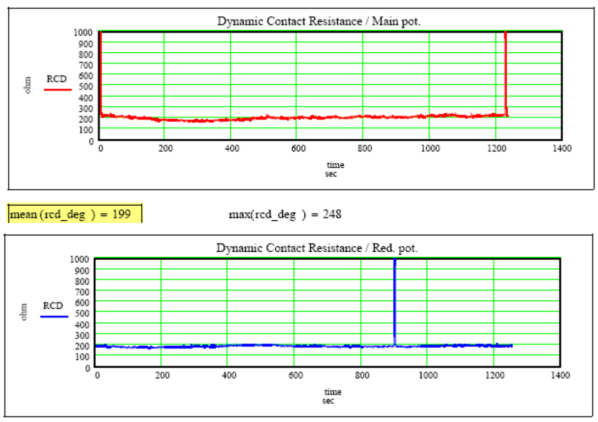

Figure 11: RCD measurement at the completion of the test programme (at cold temperature)

The measuring system was reconfigured to use the Potentiometer in the "normal" voltage divider configuration; this again yielded no plausible reading.

Since the anomaly seemed to be somewhere in the Wiper to Track circuit, the initial action was to check the complete EGSE/Instrumentation circuit.

After opening the vacuum chamber it was possible to show a complete continuity right up to the Potentiometer connector pins.

The next step was to see if any external influence was acting on the potentiometer such as movement of the slip ring with respect to the potentiometer rotor.
The Potentiometer was dismounted from the SADM and installed on its transportation fixture where it was statically measured again. The redundant side still exhibited the same behaviour as already witnessed, appearing to be open circuit. The main potentiometer was still functioning nominally. The potentiometer mounted on its transportation fixture was subjected to one thermal cycle to determine what happened.
At cold temperature, the potentiometer operated and at hot, there was no operation.
This indicated that the anomaly was with the potentiometer alone.
Since the removal of the potentiometer for further investigations would have meant that the complete test had to be interrupted, it was decided to continue with the TV test and to only monitor the redundant potentiometer and to measure the SADM position with the main unit.

During the second cold cycle (-55°C) on the SADM, the previous behaviour witnessed on the potentiometer alone was repeated, i.e. the redundant Potentiometer functionality had returned to nominal.
This was shown to be repeatable through out the TV test and established a trend where the potentiometer would function during the cold cycle but not during the warm cycles.
Due to the nature of the test programme it was not possible to log at fast enough rate (whilst fulfilling the other requirements) to determine a "switching" temperature but it certainly did not function above 0°C.

After the completion of the test it was decided to send the potentiometer to ESTEC for further evaluation.

<u>ESTEC Investigations</u>

Three investigations were undertaken at ESTEC. The first concentrated on the disassembly and X-ray inspection. It was during this inspection that a broken wire was discovered.
It was concluded during this inspection that the redundant side, the one with the broken wire was of no further use to the SADM test programme and could therefore be fully dismantled and subjected to destructive testing.

The next evaluation concentrated on a Scanning Electron beam Microscope (SEM) evaluation of the potentiometer. Here similar results were obtained to the previous evaluation conducted on the first potentiometer. Namely silicone compounds were found on the track and brush, and in other locations.
Since the assumed source of silicone contamination had been removed from the potentiometer design, this was a surprise. Upon further investigation, it was discovered that a silicone-based lubricant was used on the track of the potentiometer. The lubricant used has a high vapour pressure at higher temperatures and is therefore prone to outgassing.

The second test was conducted to determine what happened with the potentiometer at various temperatures. The results shown on figure 12 reinforced the results obtained during the SADM test programme and showed that the switching effect occurred at colder temperatures. The step in the performance of the main potentiometer is due to rotation during the test.

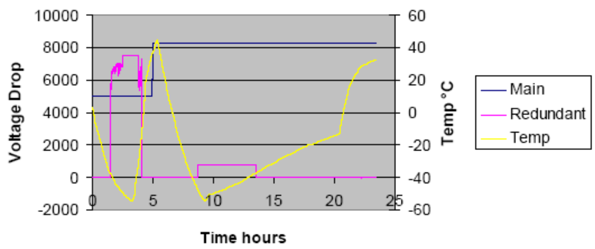

Figure 12: Elevated Temperature test on Potentiometer

Finally, the redundant potentiometer was subjected to a destructive inspection, which involved X-ray analysis and sectioning to establish how the wire had been laid into the track. This process involved polishing back a section of the track in 10µm increments and photographing the section under a microscope as shown in figure 14.

As shown on figure 13, the X-ray inspection identified a break in the internal wire connection to the collector track in the potentiometer.

Using the section analysis, it was possible to identify the reason for the wire break. What the analysis identified was that the wire had been incorrectly mounted at the collector track location.

The various sections through the collector track are shown on figure 15. The sections have been taken at low magnification and show in a series of steps how the three areas of wire connection to the collector and resistive track. The respective designations (A, B, and C) are depicted in Figure 14

Generally, the wires are guided through a hole into specific groove in the potentiometer track and are laid to the outer end. This means that the wire is embedded in the groove over a relatively short distance. The wire connections to the resistive track are continuous (B and C). In contrast to the resistive track, the connection to the collector track (A) appears to be interrupted. Section A is shown in figure 15 in larger magnification, where there is no evidence of continuous electrical contact into the groove.

It is also clear from the X-ray section shown on figure 16, that the wire to the collective track has been mounted incorrectly. This probably weakened the resistance of the connection when subjected to thermal stresses.

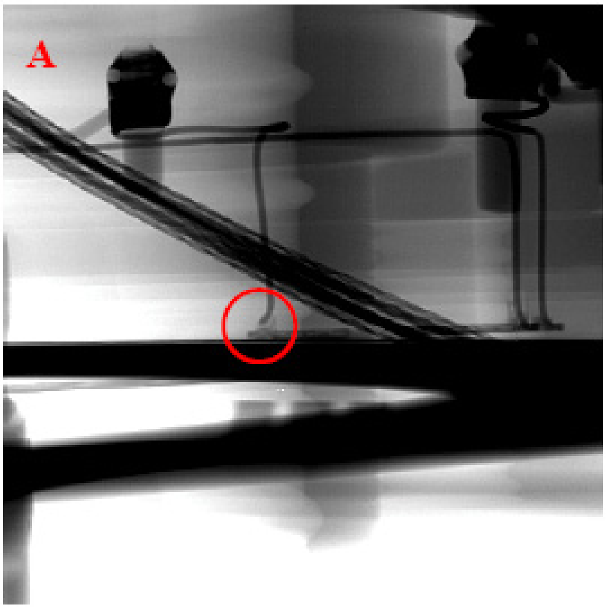

Figure 13: X-Ray Photograph showing wire break

3. SUMMARY

The two test programmes identified anomalies with the potentiometer that cost the programme a great deal of time and effort undertaking these investigations.

Although the potentiometer had been described as "qualified", in view of the experience gained during this test programme, any component can only be regarded as being "qualified" for an application when it has been tested in the same configuration and under the same conditions as the application in question.

3.1 <u>Silicone Oil</u>

Firstly, the silicone lubricant was not declared in the DMPL initially by issued by Eurofarad. This lead to a change in design of the potentiometer that may not have been necessary as RTV Silicone has already been used in space applications and has known outgassing characteristics.

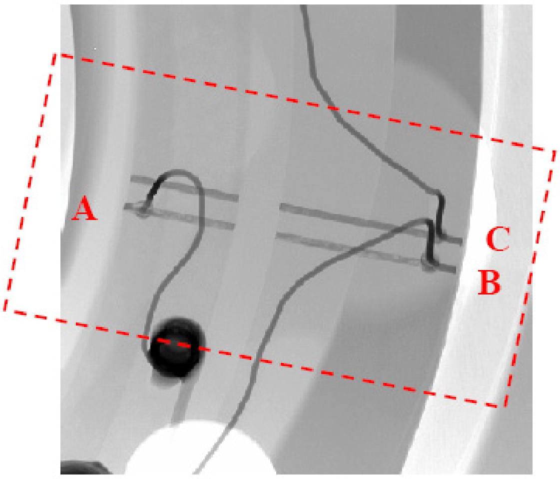

Figure 14: Definition of Section scheme

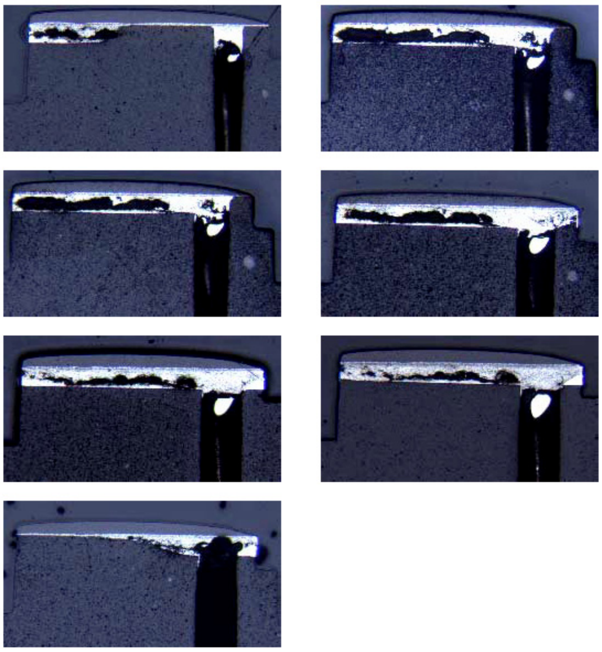

Figure 15: Sections through the Collector and Resistive Tracks

The lubricant however, is much more volatile and also has known polymerisation problems which can lead to deposits on the brushes/wipers.
The polymerisation effect leads to the build up of silicone deposits at the wiper/track interface leading to the increase in the RCD and linearity measurements on the potentiometer.
It is possible that after a short time in vacuum and at high temperature, the silicone-based lubricant has completely evaporated leaving only the plastic film to provide the lubrication. This may also lead to the increase in RCD and linearity increase.

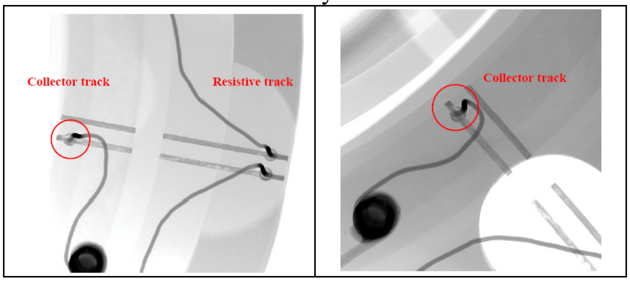

Figure 16: X-Ray of Wire Installation

The recommendation from this investigation is that the current lubricant has to be replaced with one with a lower vapour pressure, to ensure that the lubricant remains for the life of the potentiometer and to minimise the polymerisation affects.
Eurofarad have identified a potential candidate lubricant and will be conducting tests in the near future to demonstrate its suitability.

3.2 Wire Failure

The failure of the wire leads means that additional process controls need to be introduced and the collector and resistive tracks should be subjected to X-ray inspection prior to mounting in the potentiometer assembly. This will avoid such problems in the future.

4. CONCLUSIONS

Tests undertaken in this investigation identified problems with the design and assembly of the space range of potentiometers from Eurofarad.
Following exhaustive investigations, corrective actions have been identified that when implemented will lead to improvements in the performance of the space range of potentiometer products from Eurofarad.

5. REFERENCES

1. Wood, B., Sutter, G. Mrs. Hamze, N. *The development of a Low Power Solar Array Drive Mechanism.* 10th European Space Mechanisms and Tribology Symposium, ESA SP-524 September 2003

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