LESSONS LEARNED FROM QUALIFICATION TESTING OF A POTENTIOMETER BY USE OF COTS'S TECHNOLOGY

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ABSTRACT

During the finalized project, a potentiometer using COTS (Commercial of-the shelf) technology based on the requirement specification for RUAG mechanism has been developed, manufactured, and successfully tested. According to the given requirements the developed potentiometer provides full redundancy with a mass smaller than 50 g without harness.

The potentiometer did undergo different qualification tests and analysis, especially environmental tests (thermal vacuum cycling, vibration), functional and life tests. Currently, the potentiometer is able to deliver the full performance in a speed range between 0.004 °/sec and 6 °/sec in an operational temperature range between -55°C and +95°C for at least 100'000 revolutions in vacuum. On top, this potentiometer applicable for a wide range of space missions is free of International Traffic in Arms Regulations (ITAR) or Export Administration Regulations (EAR).

The paper provides details of the requirements specification, the design, the results of qualification tests, including life test and the lessons learned. The paper will close with an outlook on the future developments of the potentiometer e.g., in orbit demonstration.

INTRODUCTION

Potentiometers are very commonly used and reliable components to measure the rotary position of a device. RUAG's heritage in Solar Array Drive Mechanism (SADM) results in a deep understanding of potentiometers and their applications. Therefore, a development activity was started to enlarge the position sensor portfolio of RUAG Space Germany (RSG) by a hollow shaft potentiometer The goal is to assemble them into and improve RUAG's SADM's performance and potential use in other mechanisms.

In this paper we present a hollow shaft potentiometer based on a COTS potentiometer kit. In order to be independent of non-European suppliers, RSG developed a fully European potentiometer following the ECSS design rules and margins. The result is a hollow shaft potentiometer based on a proven principle which is able to provide equal or higher performances than equivalent non-European potentiometers available on the market for space applications.

Qualification models of the hollow shaft potentiometer were built and their qualification tested according to the specified requirements. The main characteristics of the hollow shaft potentiometer and the results of the qualification test campaign with focus on environmental testing as well as lessons learned are presented hereafter.

REQUIREMENTS

A dedicated target application was selected, based on a customer survey and the requirements were derived. A selection of the key requirements which have driven the development and qualification effort is given in Tab. 1.

Table 1: Key requirements for the potentiometer

Requirement	Value
Electrical resistance	10 kΩ ±10%
Electrical range	356,5°
Mechanical range	360° (no end stop)
Friction Torque	<5·10-3 Nm
Mass	≤ 60 g
Life	100'000 revolutions in vacuum
Op. temperature range	-55°C / +95°C
Non-op. temperature range	-105°C / +110°C

Another major design requirement was to avoid major design changes of RUAG's SADMs. RUAG decided to use the mechanical and electrical interface requirements given by the existing mechanisms. A further major design requirement addressed the parts, materials, and processes. The approach at RSG was to design a potentiometer which is in line with ECSS design rules and margins.

POTENTIOMETER DESIGN

According to the requirements the designed potentiometer provides full redundancy. The potentiometer design is divided into nominal and redundant independent single potentiometers. Basically, both potentiometers (nominal and redundant) consist of a potentiometer housing, potentiometer cover, the conductive track with connection wires and a wiper support with wipers. The single difference between nominal and redundant is a different design of the PCB cover to assure mounting both potentiometers to each other. An overall view of the design is shown in Fig. 1.

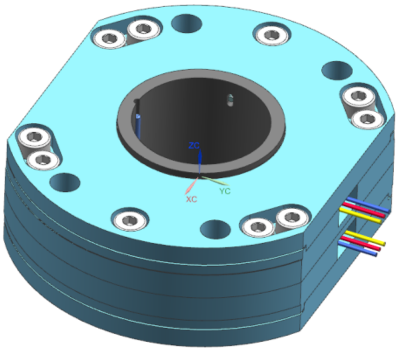

Figure 1: Potentiometer CAD design

The wiper support is glidingly mounted and guided in the potentiometer housing and cover as well. The problem of over constraining of the fixation in axial direction was solved by sufficient dimensioning of manufacturing tolerances. These tolerances will also provide the required distance of 1 ± 0,05 mm between conductive track surface and wiper mounting surface. In case manufacturing tolerances do not allow sufficient clearance, shims are used between cover and housing to provide a smooth rotation of the wiper support. Cylindrical pins are used as rotation lock between wiper support and hollow shaft as external interface. [1]
The mechanical interface is defined by an outer diameter of 45 mm and a hollow shaft diameter of 16H6. Several details are described within the interface drawing. The electrical interface consists of three ESCC/3901/012/02 wires AWG28 with coloured and / or numbered heat shrink tube. [1]

QUALIFICATION TESTING

A qualification test campaign for the potentiometer has been executed to qualify the developed device for space applications. The qualification test campaign started with performance testing focused on verifying functionality and reliability. Further tests were sine and random vibration, shock susceptibility, thermal vacuum cycling including functional tests at temperature extremes and life test. The major results are presented in the following section.

Functional Test

Figure 2: Potentiometer test configuration

Fig. 2 shows one of the qualification models of the potentiometer after assembly and integration. The resulting hardware are photographically documented, and all functional and test steps are recorded at the potentiometer as run procedures.
The performance and functional tests started after successfully performing the physical properties tests with mass, mechanical interface, and electrical parameter measurement. For functional tests, a potentiometer test setup at RSG was used, which consists of a mechanical fixture to accommodate one potentiometer, adapting parts for fitting and adjusting the device on the setup, a motor with reduction gear for actuation, an optical encoder, and a data acquisition board. After successful verification of the potentiometer functionality the nominal and redundant potentiometer outputs were recorded.

Vibration and Shock Test

Subsequently to the functional test the environmental tests were performed. The vibration and shock test were run within a complete mechanism. Fig. 3 shows the setup used for the vibration tests. These tests were realized using a dedicated shaker with a slip table. The vibration test was done axis by axis in the sequence sine sweep, sine vibration, sine sweep, random vibration, sine sweep.

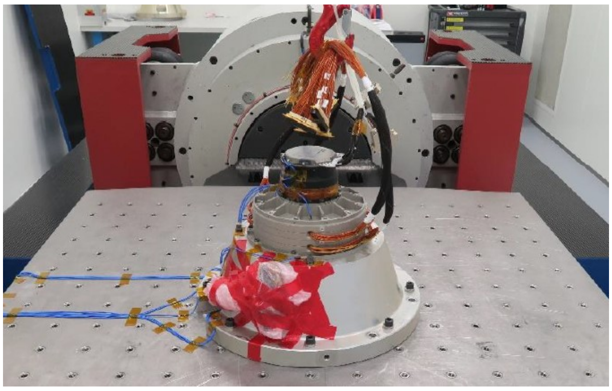

Figure 3: Vibration test setup

During sweep the natural frequencies were determined and compared to the test prediction values. The functional integrity of the mechanism including potentiometer were tested by means of electrical tests in between, before and after every vibration direction. The vibration test was finalized successfully. No difference between pre and post vibration test states of the potentiometer was observed.
Following the vibration test, the shock test was conducted for the three orthogonal axes of the potentiometer with defined levels. As result the tested potentiometer passed the shock test. No visible changes or damages and no changes in resonance behaviour greater than 5% were observed. Functional tests were performed successfully after the pyro-shock test.

Thermal Cycling and Life Test

A miniature thermal vacuum (TV) chamber was used for testing thermal vacuum and life test. The potentiometer was verified and inspected prior assembly and after disassembly inside the chamber (Fig. 4). Functional and physical properties tests were carried out prior thermal testing. In total 10 thermal vacuum cycles were performed, divided in one non-operation cycle between -80°C and 115°C as well as 9 operational cycles between -60°C and 100°C. The potentiometer exhibited excellent functional behaviour throughout the test campaign. Successful revolutions were obtained before and after the TV cycling test. In addition, there were no visible changes before and after the TV cycling test.

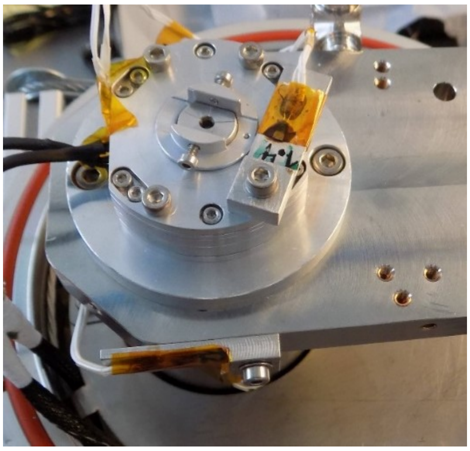

Figure 4: Potentiometer mounted on the heating/cooling stage for test inside TV chamber

For the life test a total of 202'060 revolutions was performed. One half of the revolutions was done under vacuum conditions, the other half was completed under ambient pressure conditions. Before and after the total environmental test campaign a number of functional tests were conducted. Fig. 5 shows the position error over the whole range of 360 degrees. The given graph has only been generated from clockwise rotation, since no difference between forward and backward rotation could be found.

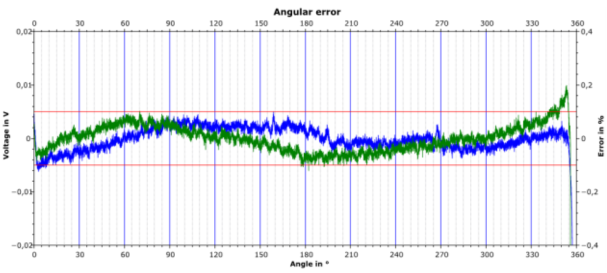

Figure 5: Error on the potentiometer outputs from functional testing, nominal output shown in blue and redundant output in green

A final inspection followed by disassembly took place after the life test and the functional performance checks. Near the gap between potentiometer body and rotor wear generation was although it was not present before the thermal vacuum and life test. Beyond the wear on the tracks no visible damage could be found on any other component.

QUALIFICATION RESULTS

Finally, all requirements that have been verified during the tests were listed in the verification control document with a conformance statement and with remarks on compliance status. The following table summarizes some of the achieved results from the hollow shaft potentiometer qualification.

Table 2: Potentiometer performance summary

Requirement	Value
Electrical resistance	10 kΩ ±10%
Electrical range	356°
Mechanical range	360° (no end stop)
Friction Torque	<5·10-3 Nm
Mass	≤ 50 g
Life	100'000 revolutions in vacuum
Op. temperature range	-55°C / +95°C
Non-op. temperature range	-80°C / +110°C

Appropriate conclusions could be drawn for the requirements that were only partially fulfilled. For example, the electrical range could not be achieved due to the selected technology for the potentiometer kit manufacturing. However, a reliable position detection is given.

LESSONS LEARNED

A problematic error was the non-operational temperature range. Due to limitations at the test equipment, the required non-operational temperature of -105°C could not reached. However, the non- operational temperature of -80°C was judged to be sufficient. If lower non-op compatibility has to be confirmed by test, an adequate testing facility must be used to repeat the thermal test.

As described at the beginning a 3.5° dead band is seen as a very ambitious goal and it was known that this goal could not be reached according to the conductive track supplier's drawings and data. The gap width between track start and track end is limited by the fabrication technology. If a smaller dead band than 4° is needed the diameter of the potentiometer would have to be increased.

In terms of wear generation, a more detailed investigation has been performed in the frame of a non-conformance report. Disassembly and detailed inspection confirmed the wear generation originating from the conductive tracks of the potentiometer. The manufacturer has been contacted regarding this wear effect and confirmed this to be normal after a large number of revolutions due to the manufacturing process. A run-in process in the final potentiometer configuration will reduce this effect. As a countermeasure a run-in during the assembly and integration phase of the potentiometer (suggested number of cycles: 10’000) followed by cleaning is introduced.

SUMMARY AND OUTLOOK

RUAG Space Germany successfully developed and tested a new hollow shaft potentiometer for space application. Three potentiometers were assembled and finally one was tested for qualification. The test campaign has been successful performed and the potentiometer has demonstrated its capability as a rotary encoder for space applications. As defined by the requirements, the interface allows to assemble the potentiometer into RUAG’s SADMs and potential use in other mechanisms.
After final closure of the qualification campaign review further potentiometers will be assembled and integrated. Due to the qualification for continuous rotation, it is planned to perform a life test with discontinuous rotation profile to be applicable for further mechanisms. As the potentiometer is currently qualified up to TRL8, it is planned to perform an in-orbit demonstration.

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