ABSTRACT
A novel design concept has been developed based on an Additive Manufacturing (AM) process, enabling the re-design of the rotor of a cylindrical Slipring Assembly (SRA) intended for space applications. The implementation of the concept leads to a significant simplification of the physical architecture of the subsystem, with subsequent reduction of the manufacturing and assembly operations.

The prototypes manufactured and tested show electrical and lifetime performances which are compatible with Solar Array Drive Mechanism (SADMs) LEO and GEO applications. The first phase of this development was funded by the Swiss Space Office and reached a TRL 4 [1]. The partnership between RUAG Slip Rings SA (RSSR) and CSEM SA continues to optimize the design of the AM-based SRA rotor and to perform a detailed qualification at SRA level. In parallel, a conventionally produced SRA rotor will be procured and qualified for benchmarking purposes, following the same qualification flow. At the same time, several innovative features pertaining to the SRA stator will be qualified. At the end of this phase, the new SRA will reach a TRL 7.

1 INTRODUCTION
SRAs are electrical continuity devices intended to transfer electrical signals from a stationary member to a rotating member. In space applications, SRAs are recurrent devices present in many satellite sub-systems such as Solar Arrays Drive Mechanisms (SADMs), Antenna Pointing Mechanisms, Control Momentum Gyroscopes and other instruments [2]. RUAG Slip Rings SA (RSSR) has a 20 years expertise in the field of SRAs design, manufacturing and testing for the space industry. The transition currently ongoing towards Industry 4.0 is drastically changing the supply chain dynamics and the space market is no exception. To respond to this new paradigm, RSSR is developing new ranges of SRAs whose objectives are driven by customer’s specific requirements on LEO/MEO/GEO markets. Those objectives are to guarantee short lead times, high throughput production and cost savings whilst keeping the highest reliability level. RSSR ongoing developments also seek at proposing highly optimized modular & configurable SRAs to precisely match the customer’s needs. As a central part of the SRA, the re-design of the rotor was a key pre-requisite to reach those objectives.

In its current state-of-the-art physical architecture. The rotor of a cylindrical SRA consists of a stacking of high-precision insulating and conductive rings, each conductive ring being manually soldered to an electrical wire, itself routed to the extremity of the rotor. The stack is interfaced to a structural central shaft, and the whole assembly is mechanically stabilized by a matrix of casted resin (see Fig. 1).

Figure 1. Traditional architecture of a cylindrical SRA and picture an SRA (stator left side, rotor right side).

The physical architecture of SRA rotors relies on a delicate manufacturing and assembly sequence involving many operations. As a rule of thumb, the number of components increases with the number of electrical channels to be included in the rotor, following a multiplication factor of 3. In other words, each channel to be achieved involves three components: an insulating ring, a conductive ring and an electrical wire. Unsurprisingly, the manufacturing and assembly efforts tend to increase accordingly, as well as the probability of reliability issues. Furthermore, stacking conductive and insulating rings implies a long tolerance chain which makes it mandatory to achieve high dimensional precision for each component. As an example, a 30 channels SRA rotor involves the stacking of 60 rings.
Considering a ring thickness tolerance of ±10 μm, the overall track pitch deviation increases to ±600 μm, causing obvious design, machining and assembly issues.

To avoid the use of cables and reduce the number of components, a novel design concept based on an Additive Manufacturing process has been proposed and applied to the SRA rotor.

2 NEW SRA ROTOR CONCEPT

The new rotor concept illustrated by Fig.2, consists of an AM-based monolithic structure, which includes the two essential features of the rotor: conductive rings and electrical wires. As a second step, the structure is filled with an insulating material. The insulating material is cured and finally, the sacrificial bridges are removed by means of a conventional subtractive process. The resulting component is a mechanical part featuring a built-in electrical conductor. The termination of the wires can take various shapes to achieve the function of electrical connection interfaces, such as pin, crimping, spring or slip ring contact. The shape of the wire terminations “A” and “B” can be directly achieved during the AM fabrication step or re-shaped during the post-AM re-machining, when high precision is requested. The structural hull may comprise additional features such as mechanical interfaces, reference surfaces, flexure elements, lattice structure and many others, all of them being achieved “by design” during the AM fabrication or during the post-AM re-machining.

The detail design illustrated by Fig.4 comprises a total of 12 annular slip ring interfaces with an equal amount of built-in wires, spread all around the periphery of the rotor. Depending on the prototype versions, the diameter of the wires varies from 0.5 to 1 mm. The external diameter of the rotor after final machining is a cylinder of 33 mm diameter and 44 mm height. The design was elaborated so that the use of support material could be completely avoided.

3 MANUFACTURING

The final design was manufactured by means of Selective Laser Melting (SLM), using AlSi10Mg aluminium alloy. After the SLM fabrication, the usual post-processing steps of stress relief annealing, part separation and precision cleaning were executed. The part was then filled with an epoxy resin, cured and re-machined in order to remove the external shell of the structural hull and the sacrificial bridges. After re-machining, a gold layer was selectively applied to the surface of the slip rings in order to improve the tribological and electrical performance of the SRA rotor during operation. At the end of the sequence, cables were soldered to the final part which was then mounted on a performance test bench.

3.1 Material and process selection

Selective Laser Melting (SLM) was selected for its availability at industrial level and ability to achieve the key geometries requested. Particularly, the ultimate surface roughness is lower compared to other powder-bed fusion processes such as Electron Beam Melting [3].
which is a key criteria to optimize the compactness of the SRA rotor. Because it offers the best compromise between electrical conductivity and mechanical properties, AlSi10Mg was chosen as a first priority material. Copper alloys are a possible alternative but AlSi10Mg has the advantage of being readily available for SLM. The raw material is also cheaper, which is an important criteria to anticipate the costs optimization foreseen in the industrialization phase. The material used for the casting is a structural epoxy resin reinforced with glass beads.

3.2 Prototypes manufacturing

The SLM made structures were successfully procured from two suppliers. For both, similar surface defects up to 350 μm were observed (see Fig. 5). The presence of such nodules increases the risk of electrical short-circuit between the tracks, since the resin gap is set to 400 μm. To reduce this risk, the selected supplier performed some fine tuning of the SLM parameters and implemented a post-SLM chemical etching step which successfully removed the residual defects. The SLM was followed by stress relief annealing, prior to removing the parts from the building platform and to performing the chemical etching treatment. The raw parts were then filled with the epoxy resin, cured and re-machined. The V-groove track pitch deviation was measured at 21±4 μm, confirming the significant improvement on this parameter.

Based on the inspection of several prototypes, it was defined that the main challenge is to reduce the resin gap between the electrical tracks of the SRA rotor in order to increase the track density. Another challenge is consolidate the process towards production criteria to ensure that no local defects such as those illustrated by Figure 5 will remain.

4 FUNCTIONAL AND PERFORMANCE VALIDATION TESTING

Electrical continuity, insulation resistance and dielectric strength tests were performed on three prototypes with successful results. To measure the electrical performances, two dedicated prototypes were integrated on a test bench simulating the standard operating conditions, excluding vacuum. The success criteria – electrical noise below 10 mΩ during 2 million cycles – was achieved, thus validating the applicability of the concept. The current performances are compatible with the SADMs LEO (Low Earth Orbit) and GEO (Geostationary Orbit) applications.

5 WORK IN PROGRESS

The development recently entered in its second phase and currently focuses on the improvement of the track density of the rotor, which is an essential parameter for the AM based SRA rotor if it is to be competitive with respect to the traditional manufacturing and procurement flow. Improving the track density implies reducing the width of the gap between two adjacent geometries (i.e. the SRA rotor tracks), which is a well-known limitation of all Additive Manufacturing technologies. This minimum width depends on several parameters, including the specific geometries but also the material and AM process combination, including all the manufacturing parameters.
To find the most appropriate process, several alternative combinations to the one presented in this paper were selected based on preliminary manufacturing tests (see Fig. 7 and 8).

![Sample manufactured by SLM with copper as an alternative material to aluminium.](image)

The key outcome of these initial tests is that the main weakness of each combination could be clearly identified. Copper processed by SLM shows significantly better surface quality than aluminium but requires specific post-AM heat treatments to reach satisfying material properties. Moreover, the 45° overhang limitation related to SLM could limit the scope of possibilities in a longer term perspective. Binder jetting enables designs with no overhang limitations but the geometrical accuracy of the parts was affected by the sintering and bronze infiltration process. As for Binder Jetting, the parts manufactured by investment casting offer an unlimited design freedom but the first parts revealed design limitations related to the flowability of the alloy.

6 CONCLUSION

The original design and manufacturing concept invented during the first development phase has allowed the validation of a cable-less SRA rotor intended for SADMs LEO and GEO applications. This concept can be advantageously applied to other electro-mechanical components and assemblies, with the same potential to simplify their architecture. The new SRA rotor concept allows significant mass reduction, since the central shaft of the rotor can be removed or optimized thanks to advanced design tools (topology optimization, lattice structures). Considering a number of twelve channels, the new design allows the reduction of the number of parts from more than thirty to only one single part, inducing a drastic decrease of the time required to assemble the rotor and a significant increase in reliability. The overall production costs are impacted accordingly: the preliminary analysis indicates that the objective of 40% costs reduction is realistic. Thanks to this digitalized design, the modularity and configurability become significantly more accessible compared to the traditional SRA rotor.

In the second phase currently ongoing, new rotor designs will be elaborated for each specific process and material combination. The manufacturability of the critical geometries and the compatibility with critical post-processes such as re-machining, casting and gold plating will be compared through in-depth experimental evaluation. The results will allow to perform a final material and process selection for the production of an SRA rotor Qualification Model (QM). This QM produced by AM will be qualified at SRA level in parallel to a conventionally produced SRA rotor QM to be equally qualified at SRA level. The results of this double qualification shall allow to confirm the advantages of the new rotor concept based on Additive Manufacturing and validate the adoption of this innovative technology for the future ranges of product developed by RSSR.

REFERENCES