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AM-SLM process-driven redesign, manufacturing and testing of a slipring rotor for space applications

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Abstract
This paper proposes a novel design concept based on an Additive Manufacturing (AM) process, enabling the development of mechanical parts featuring built-in electrical wires and interfaces. The concept is successfully applied to re-design the rotor of a SlipRing Assembly (SRA) intended to space applications. The implementation of the concept leads to a significant simplification of the physical architecture of the product, with subsequent reduction of the manufacturing and assembly operations. The prototypes were manufactured and validated through a set of standardized functional and performance tests.

Additive Manufacturing, Selective Laser Melting, Slipring, design, space, aerospace, automotive, machine-tool

1. Introduction

SlipRing Assemblies (SRAs) are continuity devices whose function is to transfer electrical signals from a stationary member to a rotating member. In space, SRAs are part of many satellite sub-systems such as Solar Arrays Drive Mechanisms, Antenna Pointing Mechanisms, Control Momentum Gyroscopes and others [1]. The physical architecture of SRA rotors relies on a delicate manufacturing and assembly sequence involving many operations. Notably, each conductive ring is manually soldered to a cable (see Figure 1.), itself manually routed and connected to a terminal block. 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 exemple, 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.

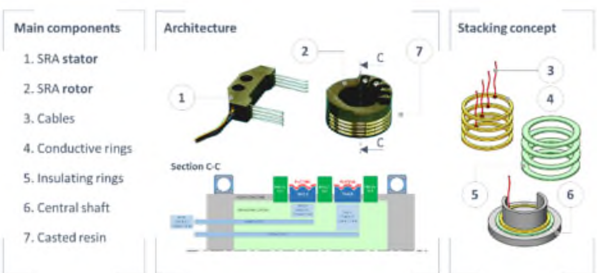

Figure 1. Standard architecture and assembly concept for SRA rotors

To avoid the use of cables and reduce the number of components, a novel design concept based on an Additive Manufacturing process is proposed and applied to the SRA use-case. The resulting design, the main results of the prototypes manufacturing and the results of the functional and performance validation tests are presented. The concept enables the design of metallic structural parts, whereas the current alternative concepts are limited to insulating polymer structures combined with conductive inks or polymers [2] offering lower power transmission capacities and reduced design flexibility for electrical interfaces.

2. General design and manufacturing concept

The design concept illustrated by Figure 2. relies on the AM production of a *monolithic* structure comprising a structural hull and a plurality of electrical wires, mechanically linked to the hull by means of sacrificial bridges. Various AM technologies can be applied depending on the application requirements, metallic powder-based processes being preferred. As a second step, the structure is filled with an insulating material. This 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 built-in electrical conductors. 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 step already mentioned, 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 step.

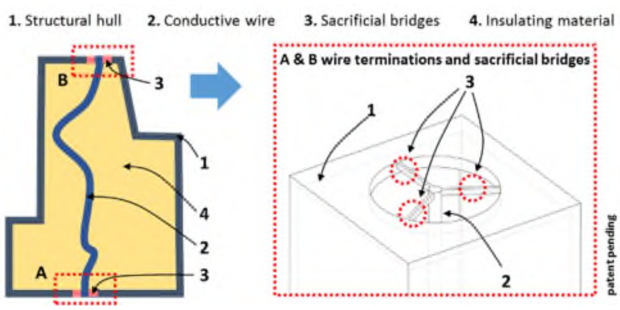

Figure 2. Schematic description of the concept of mechanical parts featuring built-in electrical wires (patent pending).

3. SRA rotor design, manufacturing and validation testing

The Figure 3. describes the new physical architecture of the SRA rotor in a simplified way, the built-in wires being all gathered within a 2D imaginary plane. The architecture includes V-groove shaped slip ring interfaces (tracks) on the wire termination "A" and soldering interfaces on the wire termination "B". As shown, the slip rings are intrinsically part of the monolithic structure built during the AM process. After casting and curing, a re-machining step is performed to remove the external hull and bridges and to machine the V-grooves on each individual ring. With standard CNC machining equipment, the overall V- groove track pitch deviation technically achievable is not more than a few microns, i.e. two orders of magnitude below that obtained with the architecture outlined in section 1.

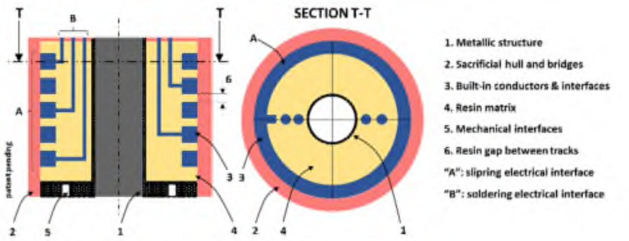

Figure 3. SRA rotor new architecture concept (patent pending)

The detail design illustrated by Figure 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 goes 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.

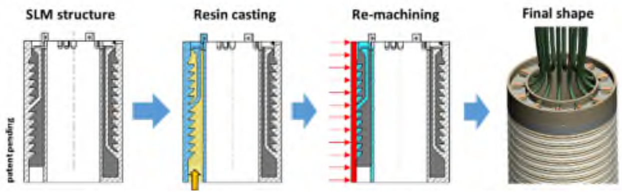

Figure 4. New SRA rotor manufacturing sequence (patent pending)

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. Especially, 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 to be readily available for SLM and much better suited for remachining. The raw material is also cheaper, a first order criteria to anticipate the costs optimization foreseen in the industrialization phase. The material used for the casting is a structural epoxy resin reinforced with a load of 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 Figure 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 parameters were not disclosed). 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 mesured at 21±4 µm, confirming the significant improvement on this parameter. The optimum resin gap between tracks is still under investigation.

3.3. Prototypes functional and performances 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, exluding vacuum. The success criteria – electrical noise below 10 mΩ during 2 million cycles – was achieved, thus validating the applicability of the concept.

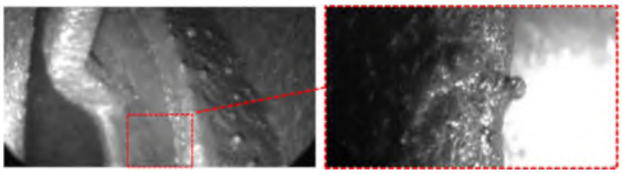

Figure 5. SRA rotor prototype surface defects i

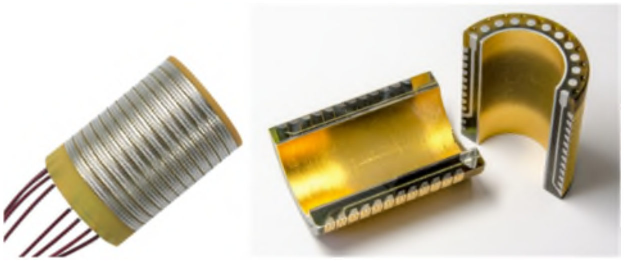

Figure 6. Two SLM-made SRA rotor prototype examples

4. Conclusions

The original design and manufacturing concept invented allowed developing and validating a cable-less SRA rotor intended to space applications. This concept can be advantageously applied to other electro-mechanical components and assemblies, with the same potential to simplify their architecture. Considering a rotor featuring 12 channels, the new architecture involves only *one* SLM-made structure instead of more than 30 high precision components. The SLM service sub-contracting model followed for the procurement turned out to be a significant impediment to the overall development, due to the limited transparency and reactivity of the sub-contractor. This model, de facto imposed to SMEs who are not owning their own AM facilities is seen as an additional obstacle for the adoption of AM at industrial level. In the upcoming months, efforts will be dedicated to define the safe value for the resin gap in order to maximize the compactness of the rotor. Then, a new rotor prototype will be procured, integrated to a complete SRA and fully qualified in terms of performance and environmental testing at system level. The tests specifications will be defined based on the applications foreseen.

[1] Conley P, 1998, Wiley, *Space vehicle mechanisms: elements of successful design*

[2] Espalin D, Danny W. Muse D, MacDonald E, B. Wicker R, 3D Printing multifunctionality: structures with electronics, Int. J. Adv. Manuf. Technol. **72** 963–978

[3] Sames W.J., List F. A., Pannala S., Dehoff R. R., Babu & S. S., The Metallurgy And Processing Science Of Metal Additive Manufacturing, 2016, International Materials Reviews, 1743-2804