How ML, 3D printing revolutionise the LNF IARI infrastructures

Nano Rome, 18-22 September 2023 Innovation Conference & Exhibition

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INTRODUCTION

Applications of ML and 3D printing, and additive manufacturing are changing the paradigm in industry 4.0 as in other sectors as in the research.

An example of how an application of those technologies are transforming IARI infrastructures of the Laboratori Nazionali di Frascati of INFN will be provided.

3D printing and additive manufacturing are innovative technologies that enable the creation of complex three-dimensional objects by adding material layer by layer. These technologies offer several benefits that are particularly advantageous in research facilities:

- **Customization**: 3D printing allows for the creation of custom parts and components tailored to specific research needs. This flexibility is invaluable for experimental setups and research equipment, which often require specialized components that may not be readily available off-the-shelf.
- **Rapid Prototyping**: 3D printing enables researchers to quickly prototype and test their designs before committing to costly production methods. This iterative process helps save time and resources, ensuring that the final designs are optimized for their intended purpose.
- **Material Variety**: Additive manufacturing supports the use of various materials, including metals, polymers, ceramics, and even composites. This versatility allows researchers to select the most suitable material for the desired properties and functionality of their components.
- **Integration of Complex Features**: 3D printing can produce intricate geometries and internal structures that would be challenging or impossible to achieve through traditional manufacturing techniques. This capability opens up new possibilities for advanced research equipment and experimental setups.
- **On-Demand Manufacturing**: Having 3D printing capabilities in research facilities allows for on-site production, reducing the need for external suppliers and minimizing lead times for obtaining critical components.

Machine Learning (ML) is a subset of artificial intelligence that focuses on training algorithms to learn patterns and make predictions or decisions based on data. In the context of research facilities, ML can revolutionize various aspects of operation and experimentation:

- **Process Optimization**: ML algorithms can analyse experimental data and identify optimal conditions for specific experiments. This can lead to improved efficiency and better utilization of resources.
- **Predictive Maintenance**: In facilities like the vacuum furnace and magnet measurements labs, ML can monitor equipment performance and detect early signs of potential issues, allowing for proactive maintenance and reducing downtime.
- **Data Analysis and Pattern Recognition**: ML can analyse large datasets generated during experiments to identify patterns, correlations, and anomalies that might be difficult or time-consuming for researchers to discover manually.
- **Energy Efficiency**: In large facilities like LNF, ML algorithms can be employed to optimize energy usage and reduce operating costs.
- **Automation**: *ML-powered automation can streamline repetitive tasks, freeing up researchers' time to focus on more complex and creative aspects of their work.*

By ***combining 3D printing with Machine Learning***, researchers can **take advantage** of advanced design optimization techniques, autonomous fabrication processes, and real-time feedback from sensors to further enhance the **functionality and performance of research infrastructure** as the IARI infrastructure of Laboratory Nazionali di Frascati.

The Laboratori Nazionali di Frascati LNF-INFN IARI infrastructures

The Open Research Infrastructure (IARI) of LNF (LATINO)++ makes **advanced technologies** and expertise developed in the field of particle accelerators **available to companies** and the scientific community for research, medical, and industrial applications.

The infrastructure consists of four high-value-added laboratories: Radio Frequency, Magnetic Measurements, Vacuum, and Thermal Treatments.

The Magnetic Measurements laboratory

The magnetic measurement lab can fully characterize electromagnets such as dipoles, quadrupoles, steerers correctors and any kind of high order mode magnet. The characterization comprises field map, harmonic analysis, and integral field measurements. The lab is also equipped with a wide range of high stability power supplies, gauss meter and instrumentation of electrical measurement at high precision.

The 3D printing in the Magnetic Lab.

Thanks to the possibility to the innovative design of the 3D printing technique it was possible to realize a steerer magnets with 3D printed coils support as shown in figure 1.

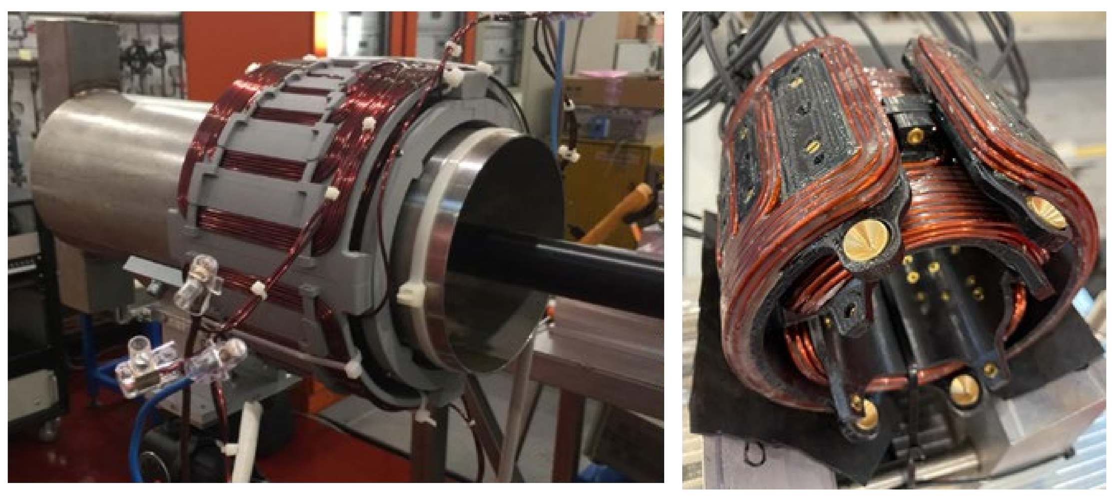

Fig 1 Steerer magnet with 3D printed coils support.

The Vacuum laboratory

The Vacuum lab can provide an outgassing measurement bench with a residual gas analyser (RGA) and a vacuum chamber for thermal treatment and UHV brazing systems.

The 3D printed Titanium spiral RF load outgassing measurement are shown in figure where the loads show only gaseous species typical for the treatments received and suitable for mounting in the vacuum system respect the CAMERA for the test

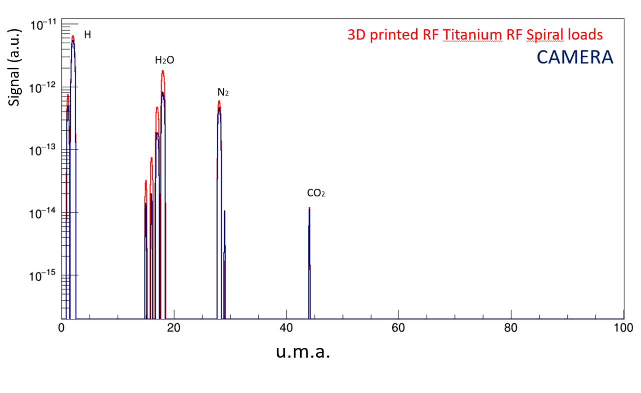

Fig 2 The 3D printed Titanium Spiral load RGA measurements on the right the 3D printed Titanium RF load.

++ Rome Technopole is the first multi-technology hub for education, research, and technology transfer in the fields of energy transition and sustainability, digital transformation, and the bio-pharmaceutical and health sectors. The project is part of the National Recovery and Resilience Plan (PNRR) and, for the first time, creates an innovation ecosystem.

Within the framework of Spoke 6 of Rome Technopole, the National Laboratories of Frascati of INFN are involved in the enhancement of the Open Research Infrastructure (IARI) through LATINO.

The RF measurement labs

An extremely complete and refined instrument laboratory for measuring the low-power frequency response (of the order of 1 W in continuous wave) of electronic components and devices up to 100 GHz, and for measuring signals in the time and frequency domain up to 20 GHz.

This lab allows to characterize the components as done with the 3D printed load that will be installed in the high-power test station.

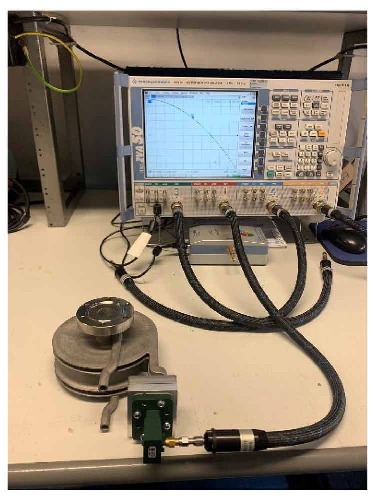

Figure 2: The 3D printed Titanium RF load low power test setup .

THE TEX (TEst stand for X-band) FACILITY

It's the high-power test-stand at ~12GHz (European X-Band) RF station. It could produce 1 μs RF pulse length with a peak power of 50 MW at 50Hz repetition rate[1-3].

Figure 4: The TEX facility subsystems.

The TEX Facility and 3D printing innovation

The use of 3D printing in the TEX facility, particularly for components like the 3D printed spiral load, offers numerous advantages, including customization, lightweight design, rapid prototyping, material selection, sensor integration, reduced lead time, cost-effectiveness, and flexibility for design modifications. These effects collectively contribute to enhancing the capabilities and efficiency of experiments conducted in the TEX facility, enabling researchers to achieve more accurate and insightful results in their studies of thermal expansion and related phenomena.

TEX is co-funded by Lazio region in the framework of the LATINO project (Laboratory in Advanced Technologies for INnOvation). The setup has been done in collaboration with CERN and it will be also used to test CLIC structures.

It provides all the challenges to build an accelerator with all the subsystems as shown in figure 3.

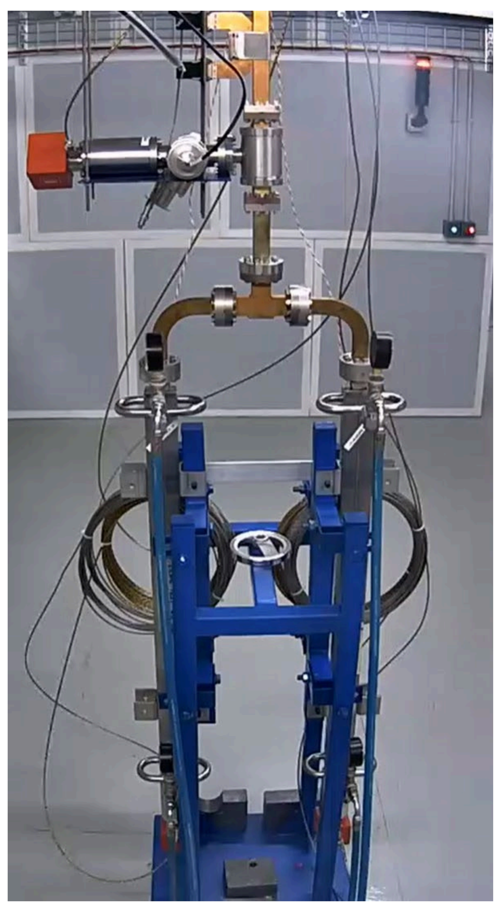

Figure 5: Stainless steel RF load.

Figure 6: The 3D printed Titanium RF load.

Thanks to the 3D printing it was possible to redefine the layout of the test of RF high power components reducing the supports necessary for the old standard RF welding load shown in figure 4 and 5 and the space need for them and the cooling request was different.

The TEX Facility and ML innovation

ML-powered automation can streamline repetitive tasks, freeing up researchers' time to focus on more complex and creative aspects of their work.

This is what happened at TEX where. A detailed description of the algorithm developed at TEX will be presented in the next conference of the accelerator control in October this year. Thanks to the ML the automation of the RF power conditioning of the 3D printed Titanium RF load was possible to reduce the manpower necessary for the operation

CONCLUSIONS

ML and 3D printing revolution in the Laboratori di Frascati IARI infrastructure is started. The knowledge for the next steps is in acquisition to improve the functionality and performance of research infrastructure.

REFERENCES

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