PhD course of National Interest in Technologies for Fundamental Research in Physics and Astrophysics

Annual report

Name and surname: Giacomo Voltan
Cycle and a.a.: XL – 2024/2025
Supervisor: Mattia Manzolaro
Co-Supervisor: Michele Ballan

• Research activity carried out during the year

The aim of the PhD project is to design and develop components dedicated to nuclear physics research, exploiting the advantages offered by Additive Manufacturing (AM) techniques, in particular Laser Powder Bed Fusion (LPBF). The project is carried out within the framework of the SPES project at the Legnaro National Laboratories, with a specific focus on ion sources and their related components, and is developed around two main topics: the first concerns the Legnaro ECR Ion Source, while the second addresses the FEBIAD Ion Source used in the SPES ISOL facility.

For the FEBIAD Ion Source, the project aims to investigate the influence of several factors on its performances, exploiting the advantages of Additive Manufacturing, particularly LPBF. The research is divided into three main branches: the first concerns the study of innovative anode–cathode interface geometries. The second involves the design and development of a new plane FEBIAD geometry, with the goal of improving both performance and assembly. The third addresses how different parameters, such as cathode surface finish, anode grid geometry, and component materials (for ex. using a TaW alloy instead of pure Ta), affect Ion Source performance. During the first year, several of these aspects were developed: a conical anode–cathode interface was designed with extensive use of Finite Element simulations, aiming at reproducing planar Ion Source characteristics. Components were then successfully produced by LPBF and will soon be tested at high temperature. In parallel, a study of anode grid transparency was started, in order to evaluate its effect on the electron flux going through the grid. Three new grid geometries with different transparency levels were designed, manufactured, and tested at high temperature using a dedicated setup. Finally, a study on the effect of cathode surface finish on thermionic emission was initiated, comparing three types of finish: turned, sandblasted, and polished. High-temperature tests have started with the turned cathodes, combined with pre- and post-test surface analyses using an optical profilometer, to identify which surface features enhance thermionic emission.

For the ECR Ion Source, the main focus is a system designed to produce Ion Beams from solid elements. This system is one of the key techniques employed in the source, and its proper operation is crucial to ensure stable and reliable injection of neutral species, to be subsequently ionized. Currently, the system allows to produce Ion Beams of several elements, such as Mg, Ca, and Zn, as well as some refractory metals like Mo and W, making use of their oxides. However, it shows some stability issues during operation, resulting in a not strict control of the resulting Ion Beam; furthermore, its performance is limited by the maximum operating temperature, which restricts the range of elements that can be evaporated. During the first year of the PhD, the work focused on studying and characterizing this device, with the goal of developing a model to better understand the processes occurring inside the oven. Special attention was given to the alumina crucible, where the solid material

to be evaporated is placed; indeed, knowing the crucible's temperature profile during operation is essential to assess which elements can be effectively evaporated. For this reason, extensive Finite Element simulations were carried out using ANSYS® Mechanical APDL, eventually producing a model capable of reproducing the thermo-electric behaviour of the system. To validate this model, high-temperature experimental tests were performed on a dedicated test bench equipped with the oven and its heating and cooling systems. Three experimental campaigns were conducted, measuring the crucible temperature with an infrared pyrometer. The model was successfully validated, especially in the high-temperature range; the experimental tests also confirmed the stability issues of the oven, showing strong power and temperature oscillations. In addition, the model revealed that the crucible temperature distribution is not homogeneous, with significant cold and hot spots that limit evaporation efficiency.

- **List of attended courses and passed exams**
  - Vacuum Technologies
  - Physics, Technology and Applications of Linear Accelerators (ongoing, exam end of Oct.)
- **List of attended conferences, workshops and schools, with mention of the presented talks**

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- **List of published papers/proceedings**

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- **Thesis title (even temporary)**

  Development, design and testing of metallic components for high-temperature nuclear physics applications produced using additive manufacturing technologies

Date, 15/09/25 **Signature**

Seen, the supervisor