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DESIGN OF NEW BEAM INSTRUMENTATION FOR THE ISOLDE ISOTOPE SEPARATOR AT CERN

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Abstract

The ISOLDE radioactive ion beam separator facility at CERN produces beams of short-lived isotopes for experiments in physics, material and medical science. New requirements for more precise measurement of profile, position and intensity has pushed the CERN beam instrumentation group to start the study of a new generation of ISOLDE beam instrumentation dedicated to the specific needs of this facility.

This paper will describe the design and the development of a number of new ISOLDE instruments with the aim of achieving better performance, increased reliability and to facilitate maintenance in a radioactive environment.

It will explain how modern technologies such as magnetically coupled linear actuators and 3D additive machining have been used to make a modern, precise and reliable beam instrumentation design.

INTRODUCTION

The on-line isotope mass separator ISOLDE [1] is a facility dedicated to the production of a large variety of radioactive ion beams for a wide range of experiments in the fields of nuclear and atomic physics, solid-state physics, materials science and life sciences. The facility takes beam from the Proton-Synchrotron Booster (PSB) at CERN, the European Organization for Nuclear Research.

At ISOLDE, radioactive beams are produced in two fixed target areas, known as front-ends, and subsequently delivered to their respective isotope separators: the General Purpose Separator (GPS) and the High Resolution Separator (HRS). The GPS line has one mass separator magnet and the HRS line has two magnets. The extracted mass-separated beams are then delivered to different experimental lines.

BEAM DIAGNOSTIC REQUIREMENTS

Beam diagnostics in ISOLDE is comprised of wire Secondary Emission Monitor (SEM) grids, wire or needle scanners and Faraday cups in order to measure the properties of the beam during set-up and operation of the front-end and separators.

The SEM grids and scanners can be used to take beam profile measurements by moving them into the beam path. The charge depletion measured in the wires is proportional to the local beam density and thus allows for the reconstruction of the beam profile as a function of wire position. Faraday cups are used to take measurements of the beam intensity, however, in this paper the focus will be placed on SEM grids and needle scanners.

EXISTING SITUATION AND REASONS FOR CHANGE

The existing beam instrumentation was designed and built in the early 90's. The success of the ISOLDE facility, including a recent upgrade has meant that these instruments are operating far past their initial expected lifetime. Despite a surprising longevity, they are now showing their limits in terms of performance and reliability. New requirements for more precise measurement, more stringent vacuum acceptance constraints and a CERN-wide policy to reduce maintenance requirements in radioactive environments according to modern "As Low As Reasonably Achievable" (ALARA) guidelines has led to a project for the design, development and construction of a new generation of ISOLDE instrumentation.

USE OF NOVEL TECHNOLOGIES

The mechanisms that move a grid, wire or Faraday cup into the beam path do so using pneumatic actuators, lead-screws or pulleys. The current scanners use a system of in-vacuum motors and pulleys, which in turn rely on in-vacuum electronics and numerous small parts. These require frequent and costly maintenance in a hazardous area where there is a risk of radioactive contamination. Similarly, the combined scanner and Faraday cup instruments, which were recently redesigned, used pneumatic actuators coupled with edge welded bellows. Edge welded bellows allow a long movement for their nominal length, but are limited in fatigue life to some 10,000 cycles, are difficult to clean for ultra-high vacuum environments and are fragile, with the associated risk of leaks.

Magnetically coupled push-pull linear actuators (MPPL) were identified as a solution as they avoid these limitations. The MPPL is driven by a stepper motor and ball screw with a rated linear speed of 100 mm/s and a nominal linear resolution of 25 µm per half step of the stepper motor. The ball screw is connected to a thimble containing $SmCo_5$ magnets and running over a tube that creates the vacuum-air interface. The thimble is magnetically coupled to an in-vacuum shaft supported on a nose bearing. The MPPL is installed onto the instrument using a ConFlat® flange.

Existing MPPLs did not fully complying with CERN's requirements. A development was therefore made with a supplier to introduce some key modifications. Opto-couplers, which may fail under stray magnetic fields and radiation, have been replaced by micromechanical switches, and an over-travel hard stop has been incorporated to avoid damaging the push-pull. Finally, due to the rapid degradation of PTFE in a radioactive environment, the PTFE and

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bronze matrix bushing has been replaced by a PEEK bushing. This should have no impact on the lifetime and is approved for use in accelerator vacuum.

The cantilevered load applied will be 0.18 Nm with the maximum that can be applied to the MPPL being 0.5 Nm. The maximum deflection at the end of the shaft has been calculated to be 0.134 mm.

In addition to the MPPL development, several parts were designed and manufactured by Selective Laser Melting (SLM), including a metallic cable-carrying chain that was printed fully assembled. These parts were designed iteratively and optimized for additive manufacturing as outlined in another paper at this conference [2].

SCANNERS

The current scanners use a system of motors and pulleys to actuate metallic needles, which measure the current of the beam as a function of position, thus allowing for the reconstruction of the beam profile. The scanners were designed more than 20 years ago for a few thousand scans (see Fig. 1). As aforementioned, the instruments contain numerous small parts as well as in-vacuum electronics and resins, requiring frequent and complex maintenance.

Figure 1: Existing ISOLDE beam needle scanner.

The purpose of the consolidation project is to redesign three horizontal needle scanners with the aim of simplifying the mechanisms in use, improving the reliability and minimising the required maintenance. The needles should maintain their exiting coverage of the aperture and the instrument footprint should be minimised.

One scanner is situated on top of the GPS switchyard and the other two are installed on the HRS line. The three scanners have different specifications in order to meet the requirements at each location.

The GPS scanner has two needles which, when fully retracted (Fig. 2), are at opposite ends of the instrument, centred about the vacuum chamber. The reason for this is twofold: firstly, the total distance to be covered is larger than the maximum stroke of a single MPPL. Secondly, having two needles which overlap over a common area offers some redundancy in case of failure of one of the two needles. Each needle(Fig.3) has a stroke of 250 mm, 70 mm more per needle than in the current instrument. With respect to the current instrument, the total coverage has been increased from 300 to 350 mm and the overlap has been increased from 60 to 150 mm. The two needles move along parallel planes 2 mm apart from each other.

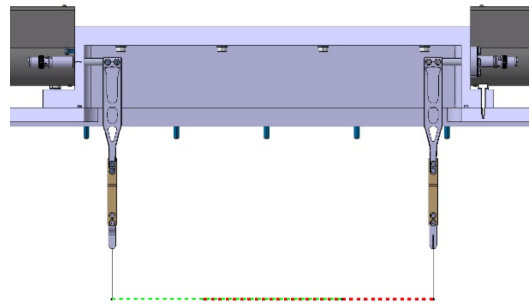

Figure 2: Section view of the scanner with both needles fully retracted.

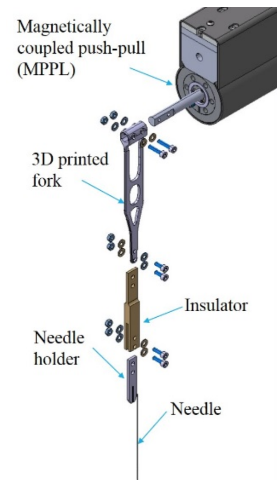

Figure 3: Push-pull to needle assembly.

Two HRS scanners have been redesigned. The first one will be installed before the separator magnets with an overall aperture to cover of 95 mm. The proposed instrument is shown in Fig. 4. The second scanner will be installed after the separator magnets, requiring a larger aperture of at least 180 mm, and having two needles for redundancy purposes. The instrument is shown in Fig. 5. Currently the needles run along parallel planes 10 mm apart from each other. For the new design, the needles have been brought closer together, running 2 mm apart from each other. This allows for the beam to be measured at almost the same transverse location regardless of the needle that is used.

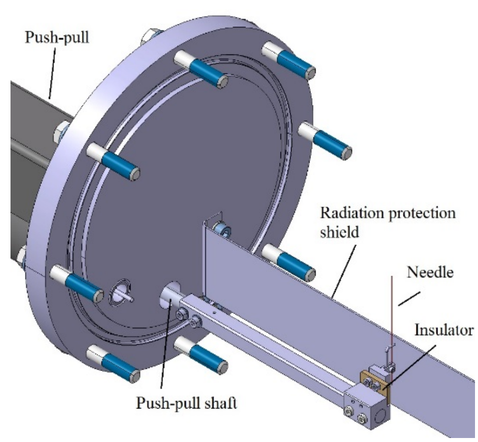

Figure 4: Cropped view of the single-needle HRS scanner.

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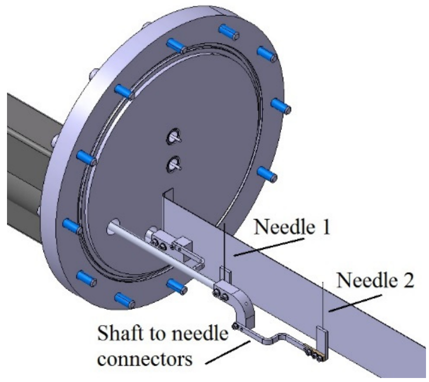

Figure 5: Double-needle HRS scanner with one needle fully retracted and one in the centre.

The motors as well as the electronics and resin currently used for the in-vacuum pre-amplifier will be removed and replaced by a new amplifier, located outside vacuum but having the same interface as the existing one. This in turn will also lead to an improved vacuum quality.

There are several advantages in undertaking this re-design. By using fewer parts and completely removing the need for bellows this system will offer much greater reliability than the pulley system, thus in turn reducing the maintenance required. When maintenance does have to be carried out, such interventions will be easier and therefore quicker, reducing the exposure of personnel to radiation and the risk of contamination. Furthermore, because of the removal of the pre-amplifier and the use of the MPPL actuators, the vacuum level will be improved. All of these changes and improvements will maintain the full functionality of the device and in some cases make the instrument even more versatile.

SEM GRID

The ISOLDE front-end areas are amongst the most radioactive areas at CERN and the existing SEM grid was rendered inoperable due to this radiation environment a few years ago. Considering this, the materials for the redesign have been limited to metal, glass, ceramic and Kapton®, a polyimide foil. The grid is made of two plates of ceramic Al_2O_3, installed one on the top of another with Macor® ceramic spacers. Wires are placed horizontally on the first plate and vertically on the second. This allows the beam density profiles in two directions to be read simultaneously. Each ceramic plate has 31 Tungsten wires installed at 2.5 mm intervals symmetrically about the beam centre. The wires are soldered to the copper circuits printed on the ceramic plates and connected with flexible circuits (FLEX, see Fig. 6 and Fig.7) to the D-Sub connector. FLEX is composed of two layers of polyimide foil with electro-deposited copper circuits between them. Formerly composed of 62 independent wires with a considerable risk of errors in the connections the new FLEX cable will improve the wiring phase and the outgassing rate. This significantly simplifies the assembly of the instruments. The D-Sub connectors are welded to a specially designed body, which acts as an interface between the vacuum inside the beamline and ambient atmosphere outside.

The SEM Grid can be mechanically moved in and out of the beam. This movement is achieved through a pneumatic actuator, specially designed to be free of rubber seals. Instead, a very precise machined piston without seals is used.

Figure 6: ISOLDE SEM grid FLEX cable.

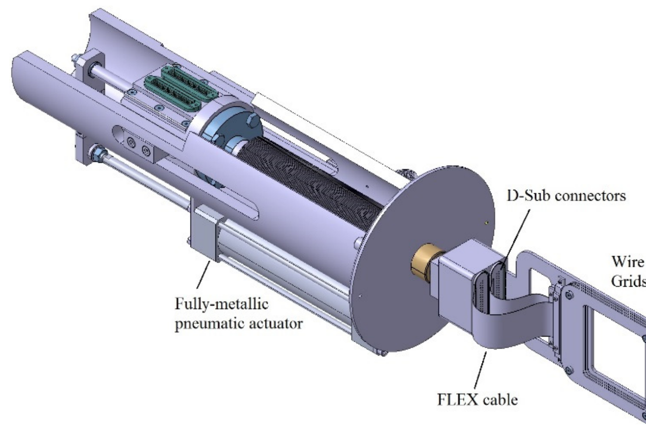

Figure 7: ISOLDE SEM grid.

CONCLUSIONS

Three new types of ISOLDE scanner and one ISOLDE SEM grid have been designed with a view to significantly increasing the reliability and maintainability of these devices.

A series of tests performed with the first prototype of the SEM grid have given good results and production of all instruments is now underway. The new design will allow for easier and faster assembly and maintenance with a significant reduction in the time spent in a hazardous area.

The installation is planned for the next ISOLDE long shutdown scheduled from January 2019 to July 2020.

REFERENCES

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