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TATRA: a versatile high-vacuum tape transportation system for decay studies at radioactive-ion beam facilities

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ABSTRACT

A compact and versatile tape transport system for the collection and counting of radioactive samples from radioactive ion beam facilities has been developed. It uses an amorphous metallic tape for transportation of the activity. Because of this material, the system can hold very good vacuum, typically below 10^{-7} mbar.

1. Introduction

Further development of our understanding of the structure of atomic nuclei strongly depends on experimental data of the highest quality. Progress in radioactive-ion beam technology within the past decade has opened new possibilities for systematic decay studies, which could potentially reveal a rich spectrum of excited states of daughter isotopes. Isotopically pure samples can be created by deposition of mass-separated low-energy radioactive ion beams. Simultaneous measurements of γ rays and conversion electrons following the decay are of particular interest, since they allow the internal conversion coefficients to be deduced with high precision. This unambiguously establishes multipolarities of transitions. Moreover, transitions with electric monopole components, which is a model independent fingerprint [1,2] of nuclear shape coexistence [3], can be unambiguously identified.

A complication related to the study of isotopes far from stability, especially odd mass isotopes away from closed shells, is a large density of states at low excitation energy. Therefore, the best possible energy resolution for both γ rays and conversion electrons must be achieved. While germanium γ ray detectors typically have very good resolution, especially modern Broad Energy Germanium (BEGe) [4] or Small Anode Germanium (SAGe) detectors [5], the detection of conversion electrons is far more difficult. The best option is a windowless planar Si(Li) detector, operated at liquid nitrogen temperatures, inside the vacuum chamber [6]. Insufficient vacuum quality, which is a common problem of many tape transportation systems, causes frequent problems with such detectors.

Therefore, the presently described tape transportation system TATRA[1] (TApe TRAnsportation) was developed as a compact system providing high quality of the vacuum. The development was done at the Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia for the purpose of dedicated studies of shape coexistence [3] in odd-Au isotopes via the β^+/EC decay of Hg isotopes at the CERN-ISOLDE facility (experiment IS521). A need for regular ground transportation of the tape system from Bratislava to CERN (the distance is approximately 1400 km) was motivation for the development of a compact system with reasonably low weight.

The system was developed and tested at the Institute of Physics and successfully commissioned online during the IS521 experiment at the LA1 beam line of the CERN-ISOLDE facility in August 2014.

2. Construction and operating principle

The TATRA tape transportation system is constructed as a portable, standalone unit that can be easily connected to the beam

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[1] The Tatra Mountains is the highest mountain range in Slovakia.

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line of any low-energy radioactive-ion beam facility. The operating principle of the system is depicted in Fig. 1. Samples of radioactive isotope are produced by deposition of a radioactive-ion beam onto a metallic tape. After collection, the sample is transported into a measurement position, where the radiation (γ rays, conversion electrons, β particles, etc.) is detected. After the measurement, a new sample is created and the whole process is periodically repeated. Deposition and measurement times are selected according to the half life of the studied isotope and to the yield of the radioactive ion beam.

The system is based on the concept of an endless loop that originates from historical 8-track cartridges, used in the past for sound and video recording. Previously, this concept was widely and successfully used at the UNISOR facility at the Oak Ridge National Laboratory [7], where it produced many important results, see, e.g., [8–12] and references therein. The endless loop of the tape is carried by a single reel. The tape is pulled from the centre of the reel, passes into the system and winds back to the outside of the same reel. Original 8-track recording cartridges used plastic tape with coating of graphite to act as a lubricant. Lubrication was needed to ensure easy slipping between the layers of the tape in the reel that were moving with different linear velocities.

Unlike in the past at the UNISOR facility, in the TATRA system the original plastic tape was replaced by an amorphous metallic alloy. The metallic tape was prepared by rapid quenching (10^6 K/s) of a molten $Fe_{30}Ni_{46}Cr_2Mo_2Si_5B_{15}$ alloy on the surface of a highly polished and smooth copper wheel using a planar flow casting technique [13]. This produces amorphous metallic material, which has excellent mechanical properties for construction of the tape transportation system. The tape is radiation hard, does not stretch and it is difficult to break; typical tensile yield strength of this type of material exceeds that of high-strength steels. Its properties are very stable during operation, it does not undergo corrosion. It keeps metallic properties and can be used in a high vacuum environment. However it can be easily torn and thus needs to be manipulated very carefully. A reel carrying the endless loop was made of stainless steel instead of the plastic material used in original cartridges. The alloy, which was used for the tape production, ensured a slippery surface and thus graphite coating was not necessary.

The tape has a width of 6 mm and a total length of 25 m. A longer tape could not be used within the scope of the present concept, since the metallic tape is too heavy and inertia of the reel caused tearing of the tape. This is unlike in, e.g., the novel BEDO tape station [14] recently constructed within the TANDEM-ALTO project at CNRS Orsay, France, which can house a very long tape. This limitation needs to be taken into account when a specific experiment is considered.

The heart of the system is housed in a cylindrical vacuum chamber with a diameter of 425 mm and a height of 160 mm. Opening and closing of the chamber is done via the ISO 320 flange located on top of the cylinder. The tape is driven by means of a stainless steel capstan with two additional wheels made from Viton rubber. Wheels are pressed onto the tape and the capstan with a spring, see Fig. 1. The capstan is connected to an externally-mounted stepper motor via a feed-through that is hermetically sealed using Rigaku SuperSeal™ ferrofluid technology.

Vacuum in the system is generated with the HiPace300® turbomolecular pump with a nominal pumping speed of 300 l/s, which is connected directly to the chamber via a DN63 ConFlat® flange. The typical vacuum in the system is less than 10^{-7} mbar. The pump can be separated from the vacuum inside of the main chamber using the gate valve. To avoid transportation of vibrations from the vacuum pump to the system, a damper is placed between the turbo molecular pump and the gate valve.

The system is connected to the beam line of the radioactive-ion beam facility via the DN40 ConFlat® flange. To avoid possible ground loops, a ceramic insulator is attached to the entry flange. To suppress the transfer of vibrations from the beam line to the system, the hydraulically formed unbraided bellows is also connected to the entry flange. Maximal possible suppression of vibrations of the system of any origin is crucial, when Si(Li) detectors of conversion electrons are employed. Vibrations cause a microphonic effect of the detector and thus cause deterioration of the energy resolution.

Before implantation onto the tape, radioactive ions pass through a hole with a diameter of 5 mm in the four-fold segmented copper collimator. Each quadrant of the collimator is connected to a separate picoampermeter located outside of the vacuum chamber, allowing direct measurement of the beam current. In addition, the metallic tape is electrically insulated from the rest of the system and from the ground. It is connected also to an external picoampermeter. Such a system allows easy and precise beam tuning on the tape, which is a very important issue with travelling setups.

Insulation of the tape from inner installations of the system provides an excellent internal safety interlock system. In the case of any failure of the tape, e.g., rupture or loosening, the tape would touch the wall of the chamber, or plate on which the mechanics is mounted resulting in a short-circuit connection which is detected and triggers the alarm signal of the control system.

A balance lever, see Fig. 1, is used to suppress the shock wave in the tape during rapid start and stop of the motion of the tape. Without this, the inertia of the heavy reel plus the metallic tape might tear the tape at the exit of the reel. A string attached to the balance lever, see Figs. 1 and 2, is crucial to avoid slight back moving of the tape at the stop.

A photograph of the opened TATRA system connected to the LA1 beam line at the CERN-ISOLDE facility is given in Fig. 3.

3. Operating characteristics and versatility of the system

The goal of the IS521 experiment was to study the β^+/EC decay of $^{181-189}$Hg isotopes. The distance between the implantation point and the measurement position was approximately 67 cm. The minimum transportation time was approximately 0.8 s which did not limit any of the performed measurements. For studies of very exotic isotopes with half lives significantly below 1 s, the versatility of the system easily permits reconfiguration into a collect-measure-move mode. In that case, the beam line would be connected directly to the measurement position.

The capstan is 32 mm in diameter and the driver of the stepper motor was configured to operate at 200 steps per revolution. This gives 0.5 mm per step. However, the stepper motor and driver employed allow a micro-stepping mode with 3200 micro-steps per revolution. This gives 0.03 mm per micro-step. During the experiment, the transport over 67 cm was shown to be reproducible within ± 1 mm.

The P70530-SDN stepper motor controller, which allows precision motion with encoderless stall detection, antiresonance filtering, and dynamic smoothing, is connected to a computer via the serial port. The same computer controlled also the data acquisition system and synchronised the motion of the tape with the opening and closing of the beam gate of the ISOLDE facility. This makes the instrumentation of the whole system very simple and in principle everything can be controlled by one computer only and no NIM logics was needed.

In total, during 4 days of experiment, the tape carried out 7820 collection-measurement cycles and travelled approximately 5.23 km.