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KATRIN NEG pumping concept investigation

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Abstract

The Karlsruhe Tritium Neutrino experiment (KATRIN) is going to use a very large electro-static tandem spectrometer to measure the electron spectrum from the tritium beta decay, where several kilometers of non-evaporable getter (NEG) strips (type ST707) are to be used to achieve the UHV requirements. Different geometrical configurations of the NEG strips have been studied by Monte Carlo simulations. It is shown that the resulting pumping speed of the getter pumps will allow to get a pressure below 10^{-11} mbar in the huge vessel with a volume of $1400\,m^3$. By systematic assessment of the statistics of the pumping surfaces, it could be demonstrated that the design is sound.

Keywords: Non-evaporable getter (NEG); Monte Carlo simulation; Pumping speed

1. Introduction

Though the evidence of non-zero neutrino mass has been revealed by experiment, its mass value is still an open question and of great significance to fundamental particle physics, astrophysics and cosmology [1,2]. The Karlsruhe Tritium Neutrino experiment (KATRIN) is an ambitious experiment to determine the electron neutrino mass with a sensitivity of 0.2 eV. Because the neutrino mass will be derived by measuring the shape of the electron spectrum from the tritium beta decay close to the energetic endpoint at 18.6 keV, KATRIN will be a direct and theoretic model independent experiment [3].

The overall length of the KATRIN setup is about 70 m, comprising an intensive windowless gaseous tritium source, a differential pumping and transport section, an electrostatic tandem spectrometer and a silicon pixel detector. In order to achieve the unprecedented sensitivity, the spectrometer section, consisting of a pre-spectrometer (3.4 m long and 1.7 m in diameter) and a main spectrometer (24 m long and 10 m in diameter), requires a very low background rate in the order of 10 mHz, corresponding to a total pressure below 10^{-11} mbar. The huge size of the main spectrometer vessel ($1400\,m^3$) and special requirements with regard to the maximum-allowed tritium background present a great challenge for the vacuum task. State-of-the-art techniques for surface treatment are employed during manufacturing and conditioning of the vessel, minimizing the outgassing rates of the inner surfaces. However, the large surfaces (more than $650\,m^2$) still require a huge pumping speed. The pumping scheme combines cascaded turbo-molecular pumps and several kilometers of non-evaporable getter (NEG) strips (type ST707). Different geometrical configurations of the NEG strips have been systematically studied by Monte Carlo simulations. The obtained results will be presented and discussed in this paper.

2. The pre-spectrometer: UHV measurement and results

The pre-spectrometer plays a major role both in the R&D phase for the experiment and in the final tritium beta decay measurement. In the R&D phase it serves as a prototype for the main spectrometer, to verify the UHV concept, test the operation modes of the heating/cooling system and investigate properties of new electro-magnetic design. During the spectrum measurement of the beta particles it will be operated as a pre-filter by working at a fixed retarding energy of approximately 300 eV below the endpoint.

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After industrial manufacturing and initial vacuum tests, the pre-spectrometer vessel was delivered to Forschungszentrum Karlsruhe (FZK) in autumn 2003. Since then, a very careful vacuum test programme has been performed. Here we just summarize the main ideas and results. The detailed preparation techniques of surfaces, the proper design and reliable handling of large vacuum flanges and vacuum test programs and results will be reported separately [4].

The pre-spectrometer vessel (Fig. 1) is a cylindrical tank with a length of 3.38 m and an inner diameter of 1.68 m. The walls of the vessel are made of 10 mm thick 1.4429 (316 LN) stainless steel. The inner volume is 8.5 m^3 and inner surface is 25 m^2. At one end of the cylindrical section a large DN1680 flange with a differentially pumped all-metal double sealing allows installation of the inner electrode system. Close to the other end two cylindrical pump ports with a diameter of 500 mm and a length of 1 m are perpendicularly welded to the vessel. In the current test setup, the horizontal pumping port is equipped with two DN200CF all-metal valves and two turbomolecular pumps. The pumping port, pointing upwards at an angle of 45°, is equipped with a tailor-made NEG pump cartridge to provide the necessary pumping speed. In this cartridge 90 ST707 NEG strips, each 1 m long, are circularly mounted in one layer (Fig. 2) close to the wall of the pumping port.

After baking the system at 230 °C for 48 h, the outgassing rate of the vessel for different wall temperatures was determined by the pressure rise method. For 20, 0 and −20 °C, the values were 5.3×10^{-13}, 1.3×10^{-13} and 0.7×10^{-13} mbar l s^{-1} cm^{-2}, respectively. Local electrical heating around the pump port was used to activate the NEG strips at 350 °C for 24 h. The ultimate pressure after cooling down the walls to 20 °C was measured less than 10^{-11} mbar with an inverted magnetron gauge (MKS). The total pumping speed of the NEG pump is estimated as 25 000 l s^{-1}, taking into account the gas loads from outgassing of the walls, vacuum gauges and turbopumps.

Fig. 1. KATRIN pre-spectrometer vessel.

Fig. 2. NEG pump cartridge.

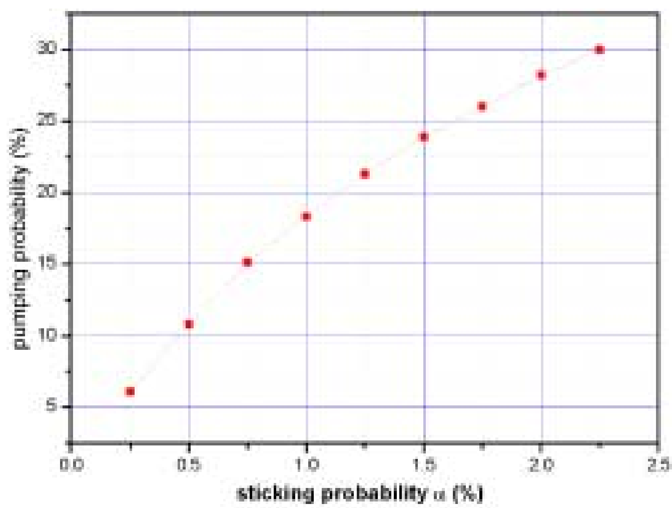

Fig. 3. Pumping probability of the pre-spectrometer NEG pump.

One important parameter which determines the pumping speed of the NEG pump is the sticking probability α of the NEG strip. It is the key parameter when it comes to do a new geometrical design, as it is needed for the main spectrometer. In order to derive this parameter, the NEG pump was simulated with Monte Carlo method by the code MOVAK3D, Vers. 6.06, 2004, which is a visual, versatile and variable (command language integrated) programme code [5]. The opening of the pumping port was considered as a circle, where 100 000 particles were generated into the pumping port according to Maxwellian distribution. Both sides of active NEG strips were simulated for various sticking probabilities and the walls of the pumping port were treated as diffuse reflectors. The pumping probability w which denotes the ratio of the number of the particles captured by the NEG strips to the number of the particles going into the NEG pump was simulated and the result is plotted in Fig. 3. The pumping speed of the NEG pump can be calculated by

$$S=\frac{1}{4}v(M,T)Aw, \quad (1)$$