An H- Surface Plasma Source for the ESS Storage Ring

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INTRODUCTION

H- charge exchange (stripping) injection into the European Spallation neutron Source (ESS) Storage Ring requires ~80 mA H- ion source that delivers 2.9 ms pulses at 14 Hz repetition rate (duty factor ~4%) that can be extended to 28 Hz (df 8%). This can be achieved with a magnetron surface plasma H- source (SPS) with active cathode and anode cooling. The Brookhaven National Laboratory (BNL) magnetron SPS can produce an H- beam current of 100 mA with about 2 kW discharge power and can operate up to ~1 % duty factor (average power 14 W, energy efficiency up to 67 mA/kW) without active cooling. An RF SPS in SNS have energy efficiency ~ 1 mA/kW. We describe how active cathode and anode cooling can be applied to the magnetron SPS increase the average discharge power up to 60 W (df 4%) and up to 140 W (df 8%) to satisfy the needs of the ESS. We also describe the use of a short electrostatic LEBT as is used at the Oak Ridge National Laboratory Spallation Neutron Source to improve the beam delivery to the RFQ.

ADVANCED DESIGN OF MAGNETRON SPS

An advanced design of magnetron SPS with the spherical focusing of emitted negative ions and forced cathode and anode cooling is shown in Fig. 1. This new magnetron SPS is capable for DC operation with high average negative ion current generation.

Cross sections of new magnetron are shown in Fig. 1.

A disc shape cathode (1) has 18 mm diameter D and 12 mm thickness H. A surrounded anode (2) is separated from the cathode by AlN insulators (3). A vacuum gap between cathode and anode is d~1 mm. Cathode is cooled by liquid or gas flux flowing through the cooling tube (5) with OD~4 mm. The magnetron is compressed by ferromagnetic poles (4).

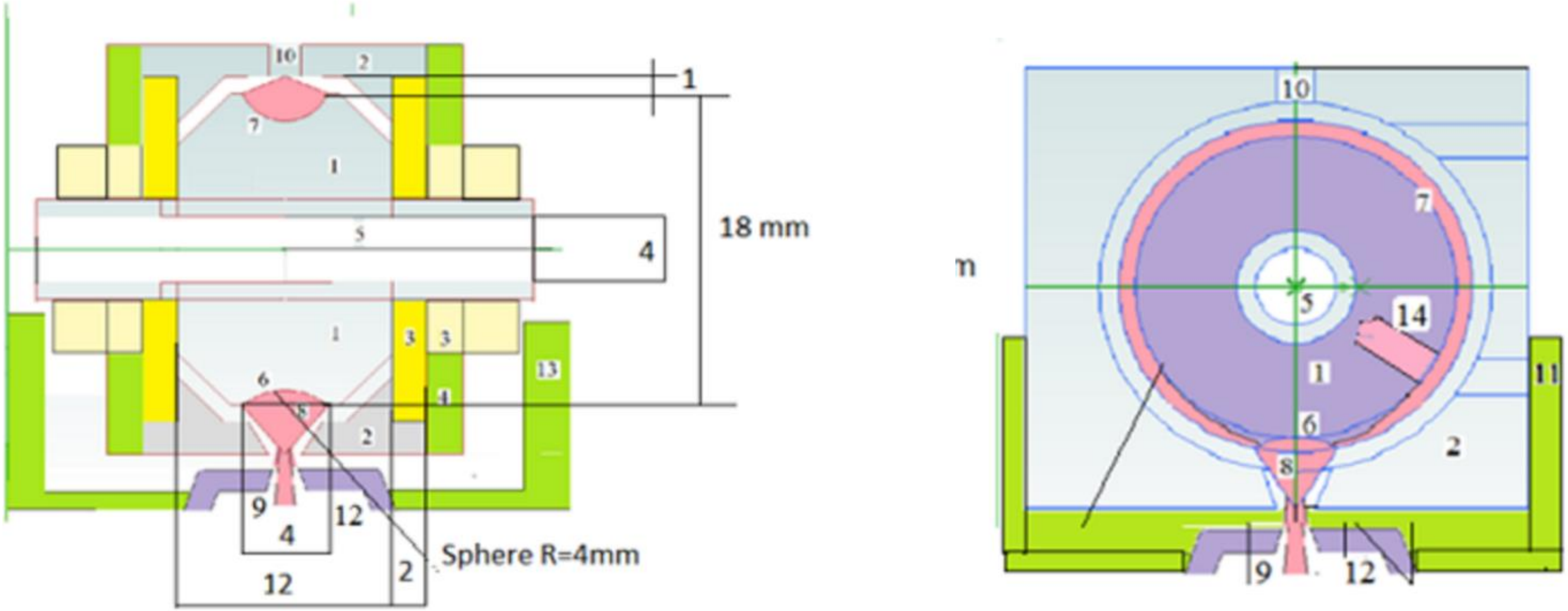


Fig. 1

The discharge in the crossed ExB fields is localized in the cylindrical grove (7) as in the semiplanotrons SPS. The cylindrical grove focus emitted negative ions to the anode surface and fast particles keep anode surface clean by sputtering the flakes and deposit. A plasma drift in the discharge can be closed around the cathode perimeter or ca be bracket by shallow cylindrical grove. For beam formation are used negative ions emitted from the spherical dimple (6), geometrically focused to the emission aperture made in anode (2). These ions are extracted by electric field applied between anode (2) and extractor (12).

The spherical dimple with a curvature radius R~4 mm has a working surface S~12 mm^2. For the emission current H- of 0.1 A it is necessary to have the emission current density on the cathode surface Je~ 1A/cm^2, which is acceptable for pulsed operation. The emission current density of H- ~0.1 A/ cm^2 necessary for 10 mA extraction is acceptable for DC operation. Anode (2) is cooled by gas or liquid flow flowing through the cooling tube attached to the anode front. Material of cathode and anode for H- beam production is Molybdenum. The surface of spherical dimple should by mirror smooth for efficient negative ion emission and sharp focusing into the emission aperture.

Photographs of cathode and anode of magnetron SPS with active cooling is shown in Fig. 2.

Fig. 2 Photograph of cathode and anode of modified magnetron SPS

Two stage extraction/acceleration is preferable for operation with high average beam current for collection of co-extracted electrons to the electrode with low potential.

Proposed ESS H- beam injector

A schematic of proposed ESS injector is shown in Fig.3. It consist from surface plasma negative ion source with magnetron configuration comprising of cathode 1 and anode 2 with emission aperture, extractor electrode 3 and magnetic pole 4. Extracted ion beam is accelerated to grounded electrode 6. Coextracted electrons collected by electron damp 5. The accelerated beam is focused by electrostatic Einzel lens 1 (7) and lens 2 (9) into RFQ wall aperture 10 and focused by RFQ vanes 11. A joint of beams from two ion sources is presented in ref. [4]. But it more practical to have two separate RFQ for protons and for H- and joint both beams after RFQ.

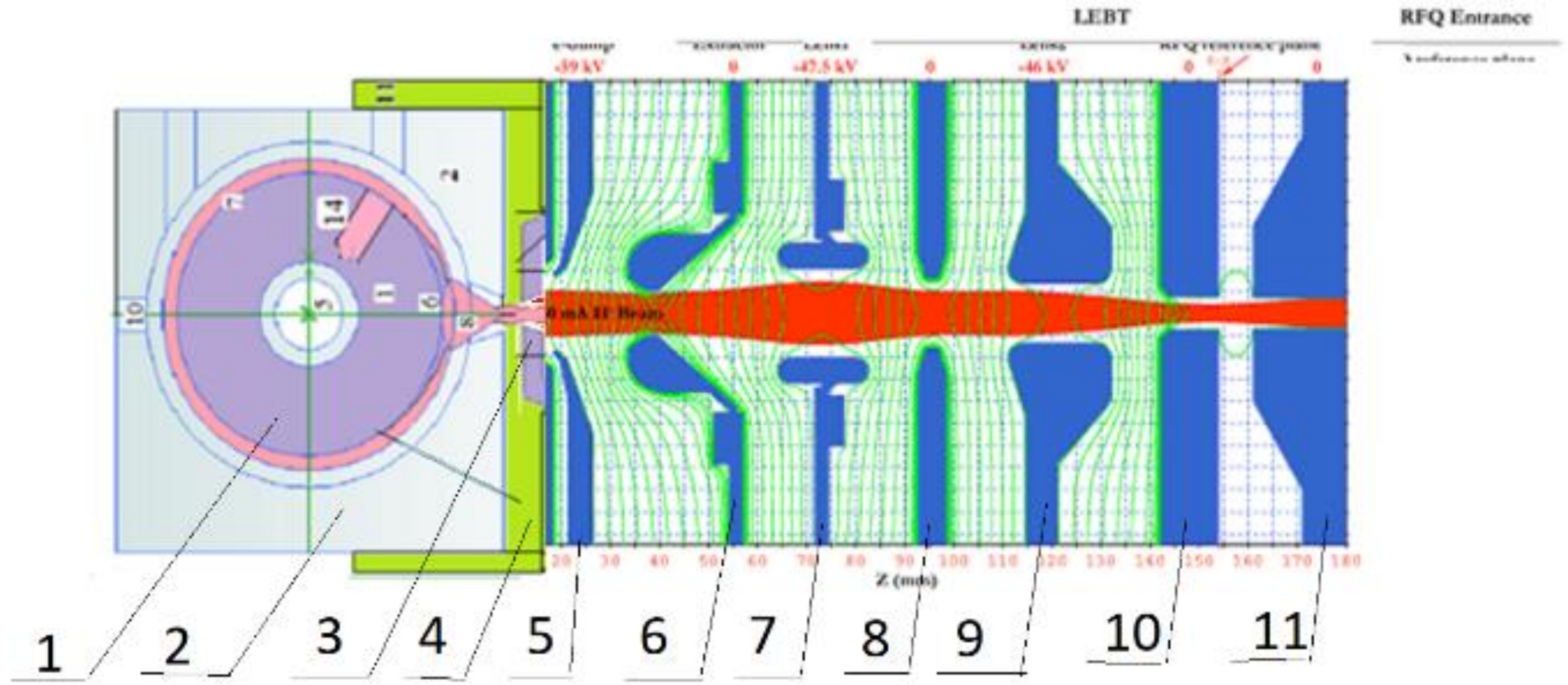
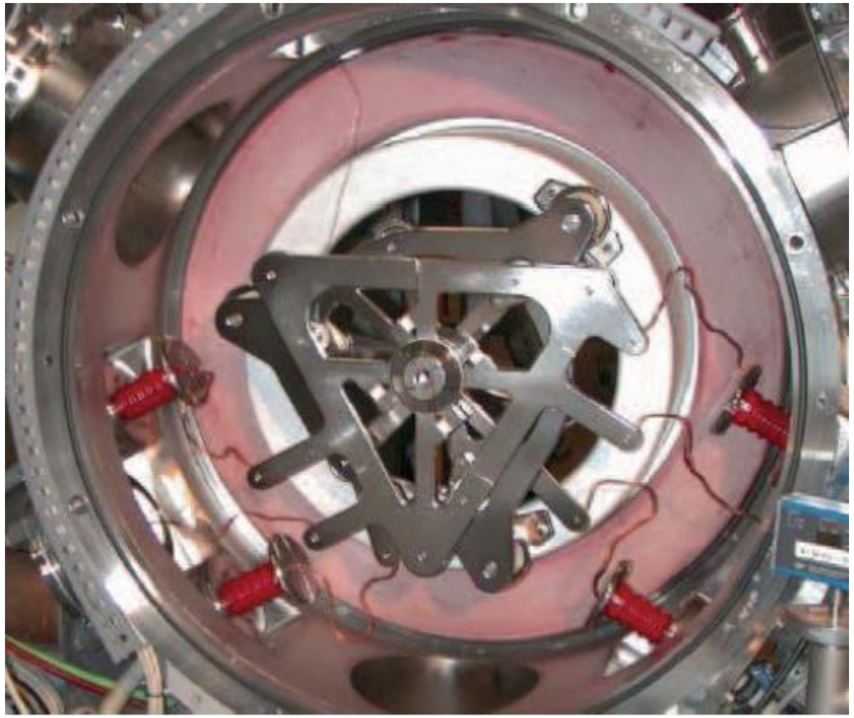


Fig. 3 A schematic of proposed ESS injector.
1-cathode, 2-anode, 3-extractor, 4-magnetic pole, 5-electron damp, 6-grounded electrode, 7-lense 1, 8-grounded electrode, 9-lense 2, corrector, 10-RFQ wall, 11-RFQ van

Construction of the LEBT for transporting the H⁻ beam in RF SPS for SNS to the RFQ is shown in Fig. 4.



It operate well with H- beam current 60 mA at 65 kV with df up to 10%.

Figure 4. Construction of the LEBT for transporting the H⁻ beam in RF SPS for SNS to the RFQ.

Alekoue, E. Baussano , N. Blaskovic Kraljevici, et al.," The European Spallation Source neutrino Super Beam", arXiv:2203.08803v1 [physics.acc-ph] 15 Mar 2022

V. Dudnikov and G. Dudnikova, "Compact surface plasma H⁻ ion source with geometrical focusing", Review of Scientific Instruments 87, 02B101 (2016);

Figure 5 shows the erosion of material on a BNL magnetron SPS that successfully operated for 2 years: the cathode has a hole of 1.8 mm^2 close to the center of its spherical focusing dimple and the anode cover plate shows marks in the vicinity of the extraction hole spread in an area of 6.2 mm^2.which is don’t influent for magnetron operation. This damage is produced a back accelerated positive ions of Cs^+ and H_2^+. It is possible to have lifetime ~ 6 month for df 4% and 3 month for df 8 %. Estimation of sputtering of cathode and anode magnetron SPS was presented in [4].

[4] H. Pereira , J. Lettry , J. Alessi and T. Kalvas, “Estimation of Sputtering Damages on a Magnetron H- Ion Source Induced by Cs+ and H+ Ions”, AIP Conf. Proc. 1515, 81 (2013); doi: 10.1063/1.4792773

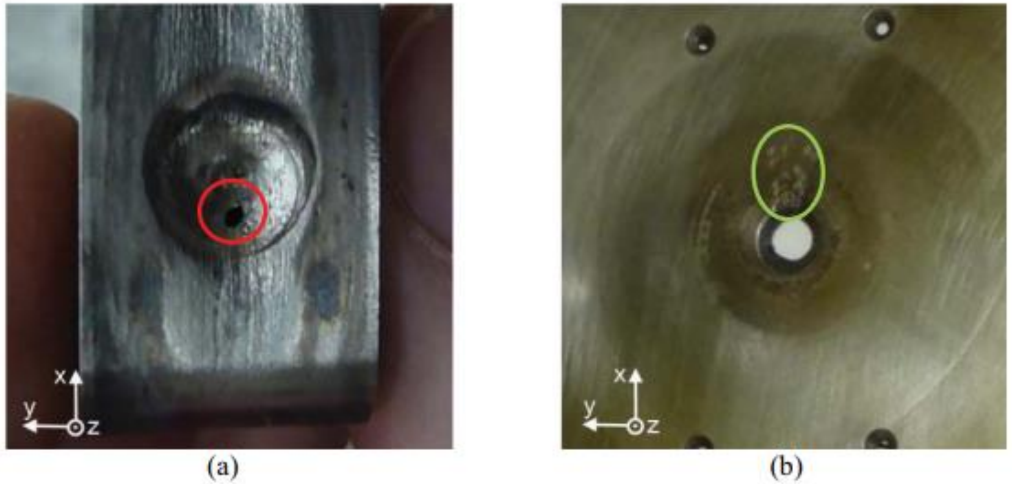


Figure 5. Wear traces on the (a) cathode and (b) the anode cover plate of BNL’s magnetron. The location of the traces on the cathode and anode cover plate is indicated by a circle and an ellipse (red and green), respectively

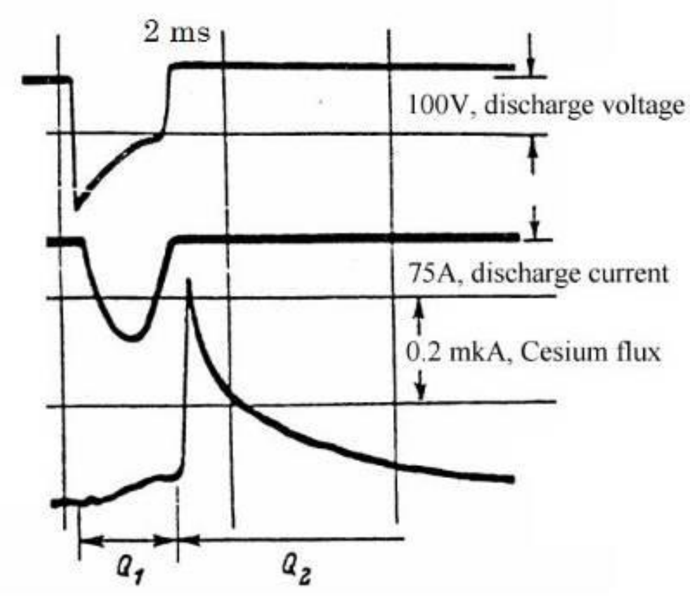


Figure 6. Characteristic oscillogram of cesium ion current from mass spectrometer collector, illustrating the time variation of cesium atoms flux from a planotron SPS at high cathode temperature (~1000 K); also showing oscillograms of discharge current I_d and discharge voltage U_d.

But estimation of Cesium density was incorrect, because during discharge Cesium is strongly ionized and cannot escape the discharge chamber as shown in Fig. 6 from [5]. Fig. 6 shows a typical oscillogram of the cesium ion current from the collector of the mass spectrometer, illustrating changes in the cesium atoms flux from the source in time at a high (~1000 K) planotron cathode temperature, in conjunction with oscillograms of discharge current I_p and discharge voltage U_d. One can see that cesium atoms leave the source mainly after the end of the discharge pulse. Cesium release during the pulse is small, since cesium is highly ionized and the extraction voltage blocks the escape of cesium ions.

[5] Yu. Belchenko, V. I. Davydenko, G. E. Derevyankin, A. F. Dorogov, V. G. Dudnikov, Sov. Tech. Phys. Lett. **3**, 282 (1977).

Conclusion

Proposed H- beam injector can delivered H- beam with parameter necessary for ESS storage ring during months of continues operation.