FIRST BEAM TEST OF A VOLUME PRODUCTION H^- ION SOURCE WITH A LEBT

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Abstract

A volume production H^- ion source (VPIS) with a low energy beam transport (LEBT), which will be used as the pre-injector of the KEK/JAERI Joint Project for high-intensity proton accelerator facility, was developed at KEK. The design beam current, extraction hole diameter of the VPIS, in which no cesium is used, are 36 mA and 7 mm, respectively. The 0.54 m long LEBT is composed of two short strong solenoid electromagnets (SM's). At the first operation, an H^- beam of 7 mA with a 4-times rms normalized emittance of 0.42π*mm*mrad was produced and transported to the entrance position of the following radio-frequency quadrupole (RFQ) linac.

1 INTRODUCTION

On 1997, we started to construct a volume production H^- ion source (VPIS) with a low energy beam transport (LEBT) as the pre-injector of the Japan Hadoron Facility (JHF) project [1,2] at KEK. The VPIS was designed to produce a 36-mA, 50-keV H^- beam with a 3% (600 μsx50 Hz) duty factor based upon the experience of a VPIS [3,4] development for the Japanese Hadron Project (JHP). The JHP-VPIS produced a 16-mA H^- beam with a 4-times rms normalized emittance of 0.4π*mm*mrad, in which no cesium was used. However, the beam pulse width was limited to 200 μs due to the thermal problem of the pulse arc power supply. Furthermore, the lifetime of the used LaB_6 filament was short. Because of an unknown reason, the arc impedance increased and the beam current decreased for the same filament current by about two weeks operation. Therefore, several modifications (new plasma confinement and filter magnetic field design, a pulse DC arc power supply with an inductor energy storage system, a pulse rf arc power supply, the rf antenna developed at LBNL [5] and so on) are tried toward the design beam current, duty-factor and lifetime (more than one month). Since the LEBT developed for the JHP succeeded to transport the 16-mA H^- beam with negligibly small emittance growth, almost the same design with the JHP-LEBT was adopted in the LEBT. In the solenoid electromagnet (SM) for the JHP-LEBT, an the asymmetric magnetic field due to one turn current around the beam axis was produced by an inappropriate current feed. The current feed of the SM was improved. The preliminary results of the beam test of the VPIS with the LEBT are described in this paper.

Since the JHF will be amalgamated with a JAERI's neutron science center project into the KEK/JAERI Joint Project for high-intensity proton accelerator facility, the VPIS with the LEBT will be used as the pre-injector of the facility [6,7].

2 EXPERIMENTAL SETUP

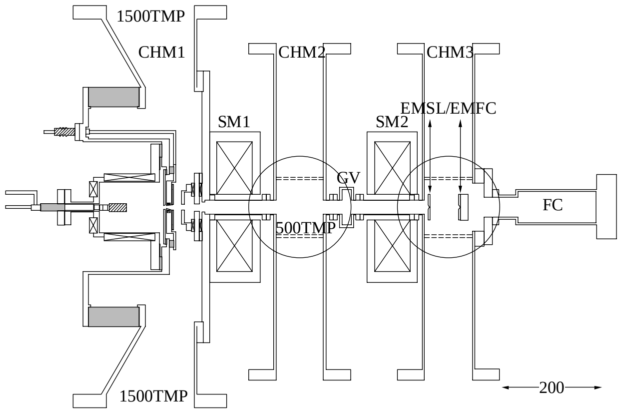
A schematic drawing of the experimental setup viewed from the upper position is shown in Fig.1. The vacuum chamber (CHM1) just after the VPIS is pumped out with two 1500 l/s turbo-molecular pumps (1500TMPs). The first solenoid electromagnet (SM1) is located 90 mm downstream from the plasma electrode of the VPIS. In the space of 215 mm between SM1 and the second solenoid electromagnet (SM2), the vacuum chamber for the beam diagnostic (CHM2) and the gate valve (GV) are located. SM1 and SM2 have the same shape with a length of 100 mm, an outer diameter of 300 mm and a bore diameter of 50 mm. A 500 l/s turbo molecular pump (500TMP) pumps out CHM2. By moving the movable slit (EMSLH) and the Faraday-cup with the slit (EMFCH) horizontally step by step, the horizontal emittance can be measured. The vertical emittance is measured by using EMSLV and EMFCLV. Each slit used in EMSL or EMFC is made of molybdenum plates with a tip-thickness of 0.05 mm and a gap of 0.2 mm. The distance between the slit of EMSL and that of EMFC is 61 mm. Since the alignment error of each slit is less than ±0.1 mm, which is the error of the real space of the emittance phase space, the error of xp or yp space was calculated to be ±1.6 mrad. The beam current was measured with the Faraday-cup (FC). By terminating the output of the FC with a 50 Ω-terminator, the beam current was measured as a voltage with a conversion coefficient of 1 mA/50 mV. A voltage of -1.5 kV was fed to each bias electrode of the EMFC or FC in order to suppress any secondary electrons form each Faraday-cup. EMSL is located at almost the same position as the entrance of the following radio-frequency quadrupole (RFQ) linac when the LEBT is connected to the RFQ.

In the following beam test, the pulse DC arc power supply, in which the energy to produce the plasma is stored in an inductor and the energy is supplied with a constant current mode, was used. The maximum magnetic field on the beam axis in the SM's is 1.1 Tesla for the maximum coil current of 800 A, which corresponds to a magnetomotive force of 72 kAT.

3 RESULTS OF THE BEAM TEST

We experienced much shorter lifetime of a LaB_6 filament than all of the previous operations at KEK, when only the arc plasma was produced, without any beam extraction and acceleration. The arc impedance increased drastically within half a day. During the operation, there were much more frequent unusual discharges, in which the arc voltage were very low (less than one-tenth) compared with the usual arc discharge. After the operation, the entire surface (including the surface of the LaB6 filament) inside of the arc chamber seemed to be coated by a dark-gray material.

The coating on the filament was analyzed to be Mo, Ta and Re. All of these materials are used to support the LaB_6 filament. Based upon these results, we comprehended that the unusual discharge was the discharge from one local point of the filament support to the arc chamber surface. The temperature of the support point speculated to exceed the melting points of the material (Mo:2610°C, Ta:2996°C, Re:3180°C). The liquid material in the vacuum easily vaporizes and makes a coating on the lower temperature surface than the melting point. Thus, the surface of the LaB_6 filament speculated to be coated and the arc impedance was increased , since the operating temperature of LaB_6 filaments (1500°C) is much lower than these melting points. In order to avoid the local discharge from the filament support, an alumina ceramics cover, which was expected to obstruct the discharges, was installed around the support. With the cover, the rate of the unusual discharge was significantly decreased. The VPIS with the cover was operated only a few days. We will continue the operation after LINAC2000 in order to examine the lifetime of the LaB_6 filament.



CHM:vacuum chamber, SM:solenoid electromagnet, GV:gate valve, FC:Faraday-cup
EMSL:movable slit for emittance measurement, TMP:1500or500l/s turbo molecular pump
EMFC:movable Faraday-cup with slit for emittance measurement

Figure 1: Schematic drawing of the experimental setup viewed from the upper position.

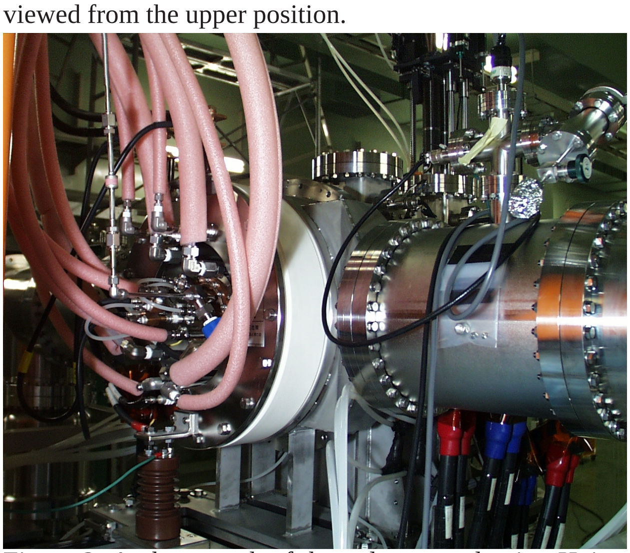


Figure 2: A photograph of the volume production H^- ion source.

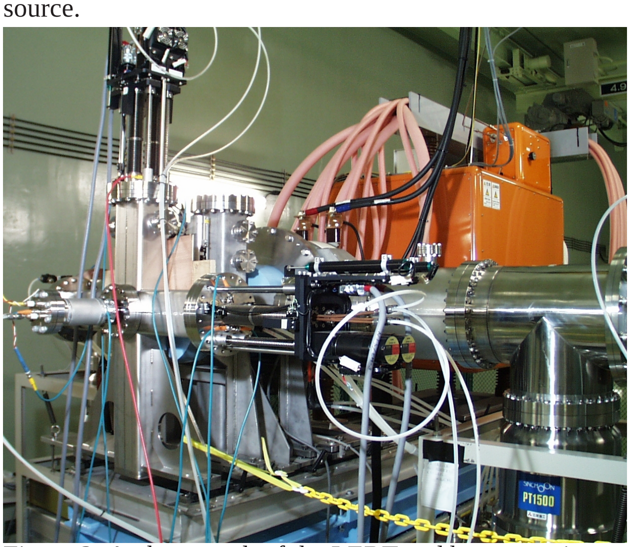


Figure 3: A photograph of the LEBT and beam monitors.

In addition to the coating problem of the filament, there were several vacuum problems (impurities at the welding point of the vacuum valves and so on) were occurred and are not settled completely.

The operating parameters of the VPIS and LEBT are summarized in Table 1. The measured waveforms of beam current, arc current and arc voltage are shown in Fig. 2. The measured beam current is about 7 mA for the arc current of 150 A and the arc voltage of 160 V, which corresponds to a arc power of 24 kW. Although one of the possible causes of the lower beam current than the JHP-VPIS is the modified plasma confinement and filter magnetic field, we have to settle the vacuum problem completely before the final judgment on it.

In Fig. 5, the measured particle distributions in the emittance phase plane are shown (top plot: horizontal and 3rd plot: vertical). The relationships between the normalized emittance and the beam fraction contained in the distributions are shown as the 2nd plot (horizontal) and the bottom plot (vertical) of Fig. 5. The ellipses with the rms values of the measured distribution's alpha and beta and a normalized emittance of 1.5 π*mm*mrad (the design acceptance of the RFQ) are shown in the top plot and the 3rd plot.

The measured 4-times rms normalized emittances of 0.43 (horizontal) and 0.41 (vertical) π*mm*mrad are almost the same with those measured for the JHP-VPIS. The larger filamentations than them were probably produced by the insufficient extraction voltage due to the insufficient conditioning of the extraction gap, since the extraction voltage could not increased due to the sparking in the gap. The averaged centers of the distributions are shifted slightly (xav=-0.55 mm, xpav=-6.8 mrad, yav=-0.88 mm and ypav=1.7 mrad). These errors will be compensated into negligible level with the steering electromagnet located just after the ground electrode (65 mm downstream from the plasma electrode). It is possible to steer the beam ±13.5 mrad in vertical plane and ±2.7 mrad in horizontal plane.

4 CONCLUSIONS

The first beam test of the volume production H^- ion source with the LEBT composed with two short strong SM's were performed. The reason of the short lifetime (the increase of arc impedance within less than two weeks) of a LaB_6 filament was comprehended as the coating of the high melting point materials used as the support of the filament, which was speculated to be caused by the local discharge from the support. The alumina ceramics cover around the support worked well to repress the discharge. The lifetime of the filament with the cover will be examined by continuing the operation. The produced beam current of 7 mA was rather low and the measured particle distributions had rather large filamentation due to insufficient conditioning and so on.

In order to produce the design beam current of 36 mA, we will continue to make efforts such as the rf arc plasma method by using the rf antenna developed at LBNL, the other plasma confinement and filter magnetic field pattern and so on.

Acknowledgment

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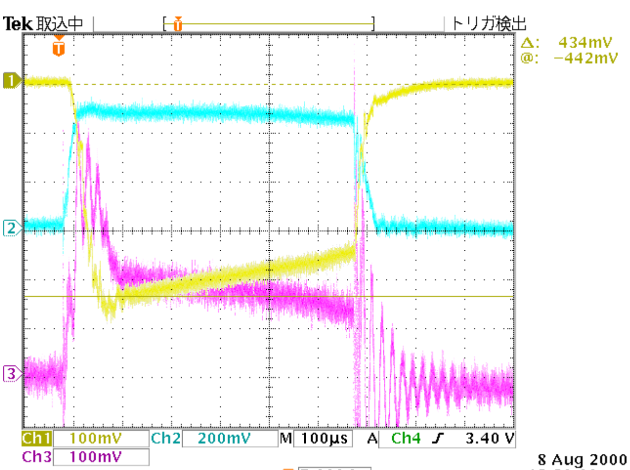

Figure 4: Preliminarily measured waveforms of beam current (top trace:2mA/div. ∴~7mA), arc current (middle trace 60A/div. ∴~150A) and arc voltage (bottom trace:80V/div. ∴~160V).

Table 1: Operating parameters of VPIS and LEBT.

Flow rate of H2 gas:Q_{H2}=16.4 SCCM
Filament Voltage & Current:Vf=6.5 V & If=55 A
Bias Voltage:V_{bias}=25 V
Extraction Voltage:V_{ext}=6 kV
Acceleration Voltage:V_{acc}=44 kV
Coil current of SM1: I_{SM1}=610A ∴H=54.9kAT, B_{axis}=0.86Tesla
Coil current of SM2:I_{SM2}=500A ∴H=145kAT, B_{axis}=0.71Tesla

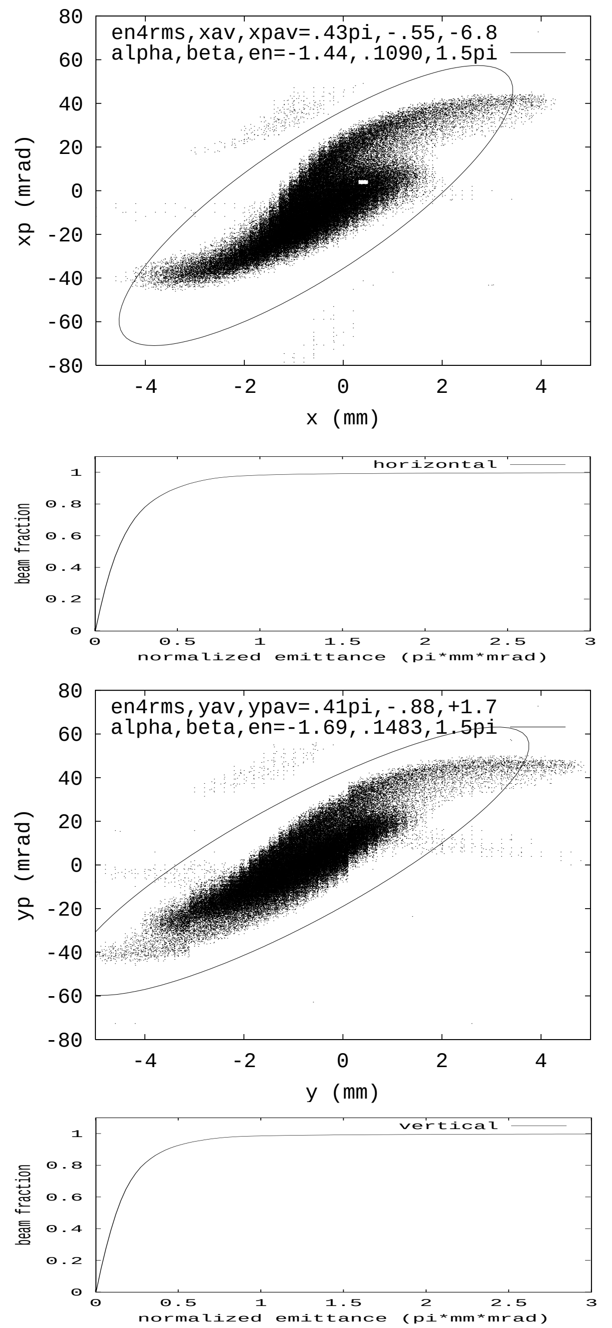

Figure 5: Measured particle distributions in the emittance phase plane (top plot: horizontal and 3rd plot: vertical) and the relationships between the normalized emittance and the beam fraction contained in it (2nd plot: horizontal and bottom plot: vertical). The ellipses with the rms values of the measured distribution's alpha and beta and a normalized emittance of 1.5 π*mm*mrad (the design acceptance of the RFQ) are shown in the top plot and the 3rd plot.