STUDY OF ELECTROSTATIC SEPTUM BY LOW-Z MATERIAL FOR HIGH INTENSITY PROTON BEAM

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Abstract

We examined a feasibility of a low atomic number (low-Z) material as a septum part of an electrostatic septum device (ESS) in the slow extraction at a high intensity proton accelerator. We succeeded to fabricate robust wires from carbon fibers by applying a twisting technique. We produced a testing machine of the ESS using the carbon wires.

INTRODUCTION

A slowly extracted beam from the main ring (MR) of J-PARC is delivered to the hadron experimental facility, and used for experiments of nuclear physics or particle physics [1, 2, 3].

The slow extraction is a method to extract the beam continuously from a ring using resonance phenomena.

An electrostatic septum device (ESS) is one of the key components for the slow extraction. The ESS kicks out the beam by the electric field applied between a high voltage electrode and a septum attached on the ESS yoke surface. Fig. 1 shows a photograph of the ESS working in the J-PARC MR. The 30 μm thick and 1 mm wide tungsten ribbons are stretched on the yoke at 3 mm pitch [4].

The beam loss at the septum by a hitting cannot be theoretically avoided. In a high intensity beam, the beam losses cause a serious problem on the maintenance, and thereby limit the beam intensity. Damage and radioactivity of the apparatus generated by Therefore, in order to increase the extraction beam power, a reduction of the beam loss is a very important issue.

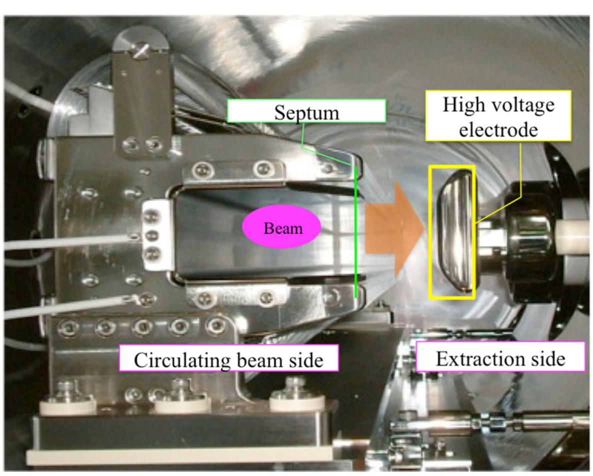

Figure 1: Present ESS for J-PARC MR.

As a new septum-anode material to reduce the beam loss, we chose carbon fibers, which has a low atomic number (low-Z). We developed a fiber-twisting technique and fabricated robust wires required for practical use. The wires were also assembled on an ESS experimental model and tested.

NEW MATERIAL FOR ESS

Present ESS uses tungsten with a large atomic number disadvantageous from the radiation point of view. As shown in Fig. 2, carbon with low-Z material is advantageous as the septum material, since angular spread by the multiple scattering and the beam loss by the nuclear reaction are small.

A carbon material has also better mechanical property and heat resistance. We decided to choose a graphite fiber (CF) from various existing forms of carbon (see Fig. 3).

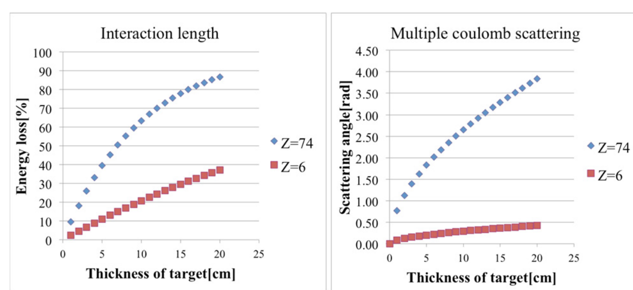

Figure 2: Beam losses and angular spread due to multiple scattering of tungsten and carbon as a function of thickness.

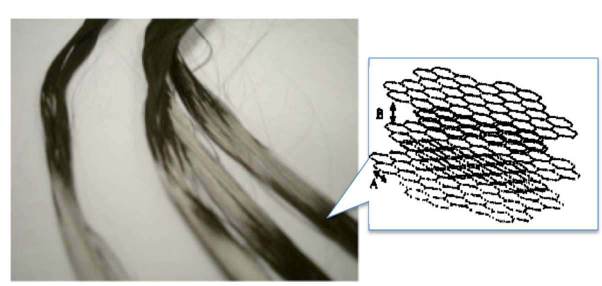

Figure 3: Carbon fiber.

FIBER-TWISTING TECHNIQUE

In order to oppose bending force caused by an electric field, it is necessary to apply a tension to the septum wires. However, since each fiber has only 5-7 micrometers in diameter and insufficient in tension strength. Then, we tried to fabricate robust wires with a diameter of about 100 micrometers by twisting many fibers.

We have established a carbon fiber (CF) twisting technique by solving various technical subjects. A manual fiber-twisting machine originally for a silk thread was applied to twist the carbon fibers (see Fig. 4).

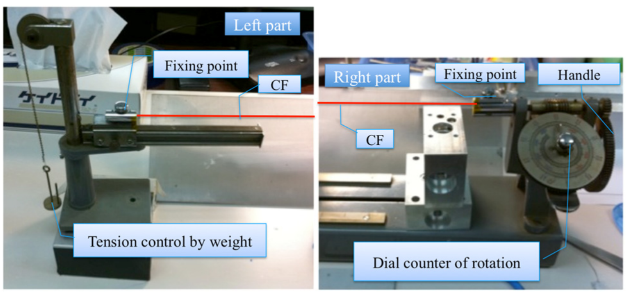

Figure 4: Fiber-twisting machine.

The fibers selected from a commercial CF bunch were twisted by the fiber-twisting machine. Then the two a wire or three twisted fibers are twisted each other again to obtain a wire (see fig.5). We call them two bundle or three bundle CF twisting.

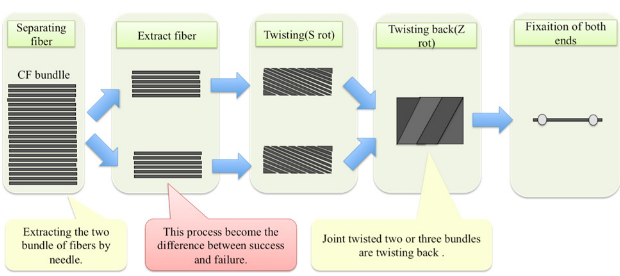

Figure 5: Process of fiber-twisting (in two bundles).

TEST OF CARBON WIRE

We examined basic characteristics of the fabricated CF wires. A surface condition and a cross-sectional size were inspected with a microscope. The average sizes were 69 to 253 μm for 48 samples. The average density of the twisted wire was obtained from the length, the average cross-sectional size and weight measured by an electronic balance scale. The maximum value of it was achieved to 72% for 2 bundles wire and 83% for 3 bundles wire, respectively.

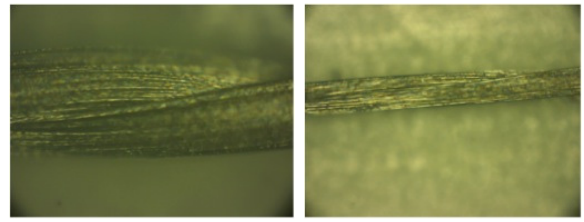

Figure 6: The twisted CF wires observed by a microscope.

The tension strength of the CF wires was measured with a spring balance scale. It was 229 kg/mm^2 on the condition of two-bundles fiber-twisting, which exceeds 180 kg/mm^2 of the tungsten wire. Also it exceeds 300 kg/mm^2 on the condition of the three bundles fiber-twisting.

The three bundles type is superior to the two bundles type as to the stress mitigation due to a smaller twist angle and a higher average density.

To study the thermal behavior when a particle beam hit the CF wire, we observed the temperature rise of the CF wire by conducting currents through it in a vacuum chamber.

In this experiment, although the maximum temperature

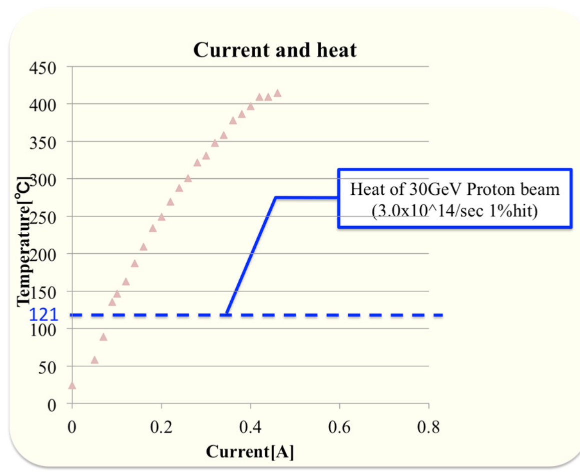

Figure 7: The heat-resistant examination of a wire.

of the CF wire reached over 400℃, which is higher than the temperature that is estimated when the actual beam hit the wire as shown in Fig. 7, any damage was not observed.

These examinations showed that the CF wire was promising as the septum-anode material.

EXPERIMENTAL MODEL

In order to use the CF wire for septum anode, the wire should be fixed to a yoke. The CF wire is weak against for the transverse stress due to an anisotropy of graphite. Therefore, when the wires are stretched on the yoke, the

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method for the present tungsten bending or looping cannot be adopted any more.

Edges of the wires were carefully held by developed clamps not to damage the wires.

The yoke surface touching the wires has a moderate curvature to suppress the transverse stress for the bend.

A Wire alignment error as well as a wire thickness affects the beam hit rate on the wires. The alignment error for the wires stretched on the model yoke is shown in Figure 8. It was measured by a laser displacement meter. The measured error was ±40 μm, which is in an acceptable level considering the wire thickness.

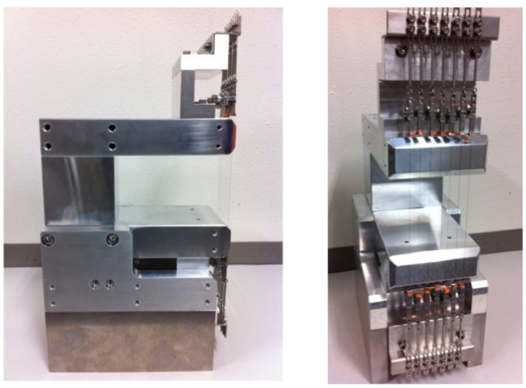

Figure 8: Photographs of the experimental model.

FUTURE PLAN

A future plans for the development of the ESS using the CF wires are as follows;

- Furthermore optimization the fiber-twisting conditions and fabricating thinner wires.
- The proof tension under a heat load will be examined.
- Simulation of a beam hit process on the CF wires, examine a temperature rise and a mechanical characteristics like stress, tension etc. by using the MARS and the ANSYS codes.
- Assembling an ESS model for vacuum use and applying a high voltage to examine an electric discharge behavior and damage by it.

SUMMARY

In order to solve serious radioactivity issues on the slow extraction with a high intensity beam, we examined a feasibility of low-Z material as a septum of the ESS.

Carbon is a promising candidate of the septum-anode material, since less nuclear reaction rate, small angular spread of the multiple scattering and low temperature rise.

We developed a fiber twisting technique to produce robust wires from a commercial CF bundle. The various characteristics of the fabricated wires were examined.

We assembled an ESS test model stretching the fabricated CF wires.

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