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DEVELOPMENT AND EVALUATION OF STF-TYPE POWER COUPLER FOR COST REDUCTION AT THE HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

Yasuchika Yamamoto†, Shinichiro Michizono, Toshihiro Matsumoto
High Energy Accelerator Research Organization, Tsukuba, Japan

Abstract

At the High Energy Accelerator Research Organization, cost reduction study for STF-type input power coupler used in the STF-2 accelerator has been attempted since FY2015. In FY2019, one cold coupler was fabricated by some cost-effective and non-conventional methods including different alumina-ceramic material, copper plating and TiN coating. In high power RF test at room temperature, this coupler achieved 1 MW at 900 µsec/5 Hz, and 935 kW at 1.65 msec/5 Hz. After that, this coupler experienced 10 thermal cycle tests from room temperature to liquid nitrogen temperature without vacuum leakage. In this report, the detailed results will be presented.

INTRODUCTION

Since 2017, the High Energy Accelerator Research Organization (KEK) has been conducting a new research and development project to reduce the cost of superconducting cavities under the Japan-U.S. Science and Technology Cooperation. The main goal of this project is to find the best surface treatment for the cavities, on the other hand it also includes R&D on ancillaries such as input couplers, etc. The input couplers used in the STF cryomodules are of the STF type with two disc-washer ceramic pieces on the cold and warm sides. In order to reduce the cost of this input coupler, a new input power coupler was manufactured by changing the titanium nitride (TiN) coating applied to the ceramic and copper plating, and its performance was evaluated on a test bench at STF. At the same time, we selected ceramic materials because the ceramic manufacturer that had been used at KEK withdrew from the market a few years ago, and it became necessary to find a new manufacturer. In the following sections, each process will be described in detail. The previous studies on the STF-type power coupler are described in [1-3].

PRODUCTION OF STF-TYPE POWER COUPLER FOR COST REDUCTION

Mock-up Study for Copper Sulfate Plating

In this production, we decided to change the copper plating from pyrophosphate copper plating to copper sulfate plating. In our previous research, we had found that copper sulfate plating had a better yield and a higher RRR at low temperature. However, this was the first time copper sulfate plating had been applied to the STF-type input couplers, therefore a mock-up was manufactured first, and a damage test was conducted after heat treatment and ultrasonic cleaning. The results were satisfactory, and we were able to proceed with the manufacturing of the real cold power coupler without any problems. Figure 1 shows this mock-up of the STF-type cold power coupler.

Figure 1: Mock-up of STF-type cold power coupler for the study of copper sulfate plating.

Titanium-Nitride Coating on Ceramics

In this production, the ceramic material was also changed from the conventional material. This is because the ceramics long used at KEK are no longer available due to the withdrawal of the manufacturer. Therefore, AL300 (Morgan Advanced Materials), which has been also used in E-XFEL, was selected as good candidate. The side planes (inner/outer) are metalized for brazing as shown in Figure 2.

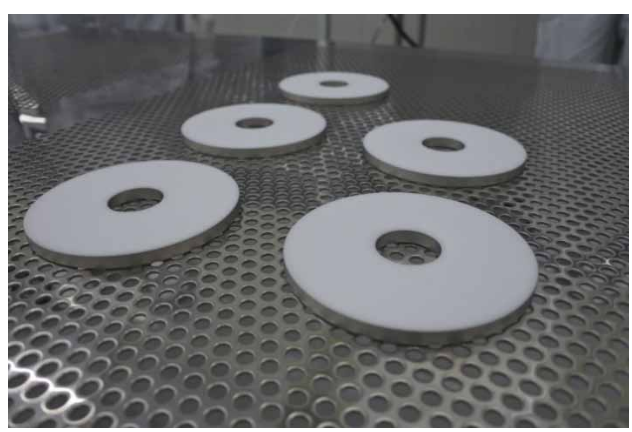

Figure 2: Five metalized disk-washer type ceramics for RF window.

† yasuchika.yamamoto@kek.jp

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The ceramic window used in STF-type input couplers is a disk washer type, with Titanium-Nitride (TiN) coating on both sides on the cold side and on one side on the warm side. During manufacturing, each piece is placed in a coating chamber and TiN coating is applied to one side at a time. In this production, this process was changed to a method where two pieces are coated with TiN coating on both sides at the same time. This allows TiN coating to be performed with four times the efficiency of the conventional method. Naturally, we have already practiced TiN coating on samples in advance and confirmed that it can be done without any problems. The coating could be performed without any problem on the actual ceramics. The coating thickness is 10 nm as target, actually 11 nm as measured value using some samples. This result is acceptable for the specification.

Copper Sulfate Plating

The next step is to copper sulfate plating the inner and outer conductors of the input coupler. The actual process would be divided into several steps including rinsing and drying processes. This process was finally successfully completed. After this, all parts including the ceramic with TiN coating are sent to the manufacturer for brazing. All necessary parts include some spare parts to recover from unexpected trouble.

Brazing

The last process is brazing. First, the ceramic window part is brazed at 1000°C, and then the remaining parts are joined by brazing at 800°C to complete the input coupler. After completion, leakage tests are conducted to confirm that there are no problems, and the product is packaged and nitrogen-filled before shipping. Figure 3 shows the cost-effective STF-type cold power coupler.

Figure 3: Cost-effective STF-type cold power coupler.

PREPARATION AND ASSEMBLY FOR HIGH POWER TEST

After delivery at KEK, the input coupler is checked externally and brought to the clean room. In the clean room, the input coupler is first placed in a water bath with neutral detergent and ultrasonically cleaned. They are rinsed with ultrapure water and dried in the ISO 4 room. After drying, the test stands are assembled into two sets of input power couplers. After leak check, the test stands are baked at 120°C for 48 hours.

After baking, for the RF coupling, the insertion depth of the inner conductor is adjusted to about -20 to -30 dB at S11. Finally, the test stand is connected to the resonant ring system to complete the preparation for the high power test. Figure 4 shows the sequence of work described above.

HIGH POWER TEST

High power testing of the input coupler was performed on the resonant ring system in the STF. The system consists of an 800 kW klystron and a MARX modulator, the RF output of which is circulated in a ring-shaped waveguide to generate higher power. Typical coupling is around 10 dB. The monitoring system consists of transmitted and reflected power from directional couplers located upstream and downstream of the input coupler test stand, vacuum on the cold and warm sides, arc outputs mounted near the warm side window, and electron probes mounted near the cold side window. The vacuum interlock is $1x10^{-4}$ Pa. The RF pulse width starts at 10 µs and gradually increases in width until it finally reaches 1.65 ms. The repetition rate is 5 Hz. The max. achieved power shows Table 1.

Surprisingly, no significant signals were ever observed from the electron probe during the high power test. It is believed that the ultrasonic cleaning was effective. Similarly, the arc output signal was also small. Discharges in the waveguide often triggered interlocks, especially around doorknob. The interlock level was loosened to $4x10^{-4}$ Pa at 1.65 ms because the vacuum level also increased due to the heating by higher duty factor. The maximum achievable RF power at each pulse is as follows. Figure 5 shows the trend of RF power, and the both vacuum during RF conditioning.

Table 1: Summary of Max. achieved power

RF condition	Max. achieved power
10 µsec/ 5Hz	1.18 MW
30 µsec/5 Hz	1.2 MW
100 µsec/5 Hz	1.2 MW
500 µsec/5 Hz	1.05 MW
900 µsec/5 Hz	1.0 MW
1.65 msec/5 Hz	935 kW

THERMAL CYCLE TEST

After the high power test, the test stand is dismantled and only the cold power coupler developed at this time is subjected to thermal cycling tests. This is because the cold couplers installed into cryomodule need to be operated in an environment of about 70 K. Usually, the cold coupler is submerged in a container of liquid nitrogen, and the test is repeated about 10 times to make sure there are no leaks as shown in Figure 5. In this case, a new ceramic was used, and there were no problems.

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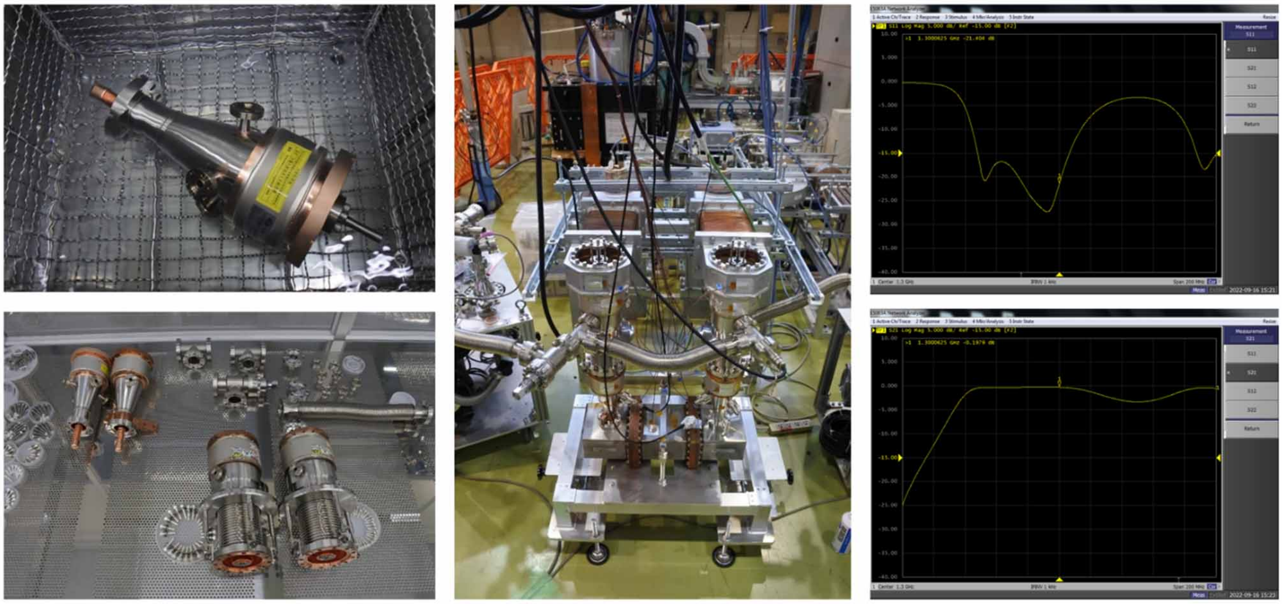

Figure 4: Process of preparation and assembly work for test stand (left, center), and measurement of s-parameters (right).

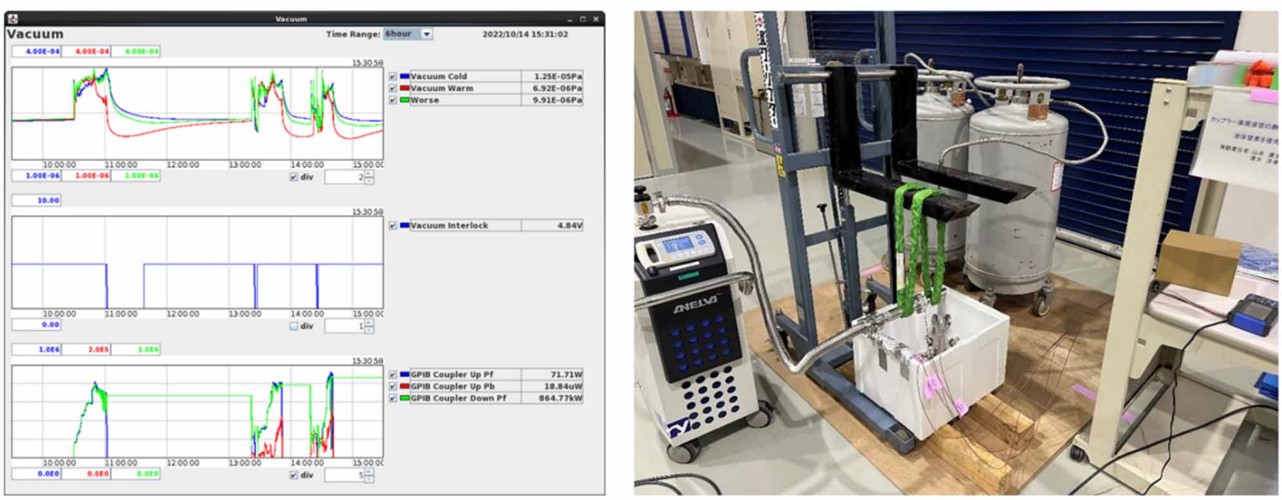

Figure 5: Trend of RF power, and the both vacuum during RF conditioning (left), and thermal cycle test (right).

Since all the necessary tests were passed, we can conclude that we have completed the production and the test for this cost-effective STF-type cold power coupler that can be operated in a cryomodule.

SUMMARY

KEK has developed the cost-effective STF-type input power coupler as one of the cost reduction R&D for SRF since 2017. The cost reduction was successfully achieved through copper plating and titanium nitride (TiN) coating processes. In addition, we used a type of ceramic that has never been used in STF. A cold power coupler was fabricated by combining these materials, and high power tests were conducted at the resonant ring. Subsequently, a thermal cycle test was conducted assuming operation in a low-temperature environment. These results were satisfactory, indicating that the cost-effective STF-type cold power coupler can be used without any problems in the future.

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