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DESIGN AND COMMISIONING OF KEK NEW VACUUM FURNACE FOR SRF CAVITY DEVELOPEMENT*

K. Umemori†[1,2], M. Egi[1], E. Kako[1,2], T. Konomi[1,2], S. Michizono[1,2], H. Sakai[1,2]
[1]KEK/[2]SOKENDAI, 305-0801, Tsukuba, Ibaraki, Japan

Abstract

Recently new techniques such as Nitrogen-doping (N-doping) and Nitrogen-infusion (N-infusion) have been developed to improve performance of SRF (Superconducting RF) cavities. We purchased a new vacuum furnace, which is key to realize these techniques. Cleanness of the furnace is most important issue. The furnace has a cryopump and whole of vacuum system is oil-free system. Target vacuum level after cooling down is 1e-6 Pa. Heater, reflectors and support table were made from Molybdenum to avoid contamination during heat treatment. Metal gaskets are used for all vacuum seals, except big doors. Maximum operation temperature is 1150 degrees. Size is around 1 m diameter and 2m long for a 1.3 GHz 9-cell cavity. Entrance of furnace is covered by a clean booth. The furnace was fabricated, assembled at KEK COI building and commissioned. After several burning runs, target vacuum pressure was achieved after cooling down to room temperature (RT). Design and current status of the furnace is presented.

REQUIREMENT FOR FURNACE

N-doping and N-infusion technique are well known to improve SRF cavity performance [1]. KEK also had carried out R&D studies. Throughout our studies, it was realized that cleanness of furnace is very important issue. In the case of N-doping using a diffusion pump, Q-values always decreased even after removing surface by EP [2]. N-infusion studies using J-PARC furnace, with a cryopump, were much better, but still sometimes we were suffered from Q-degradation due to contaminations from the furnace [3].

“Clean” furnace is essential for current SRF development. What “clean” means are excellent available vacuum pressure and less contaminations, especially from carbons. Pumping system of furnace should be oil-free system. Powerful cryopump is desirable. To achieve good vacuum condition and less contaminant circumference, metallic vacuum seals are basically used and usage of SUS at high temperature region is avoided.

Furthermore, furnace should be surrounded by a clean booth to keep cavity handling clean. Operation of furnace is also important to keep cleanness of furnace, including selection of materials to apply heat treatment.

DESIGN AND CONSTRUCTION

Table 1 shows main design parameters for our new furnace. Size of the furnace is fit to install a L-band 9-cell cavity. Molybdenum was used for the heaters, reflectors and a support table. Heating zones are separated to three divisions. Maximum operating temperature is 1150 degrees. Main vacuum pump is a cryopump with 10000 L/sec for Nitrogen.

Table 1: Design Parameters

Parameters	Design values
Inner size of chamber	ϕ950 x L=2080 mm
Effective heating zone	370 x 370 x 1500 mm
Normal operating temperature	~1100 degree
Maximum temperature	1150 degree
Cryopump (CRYO-U20H)	10000 L/sec (N_2)
Drypump (CR300B)	5000 L/min
Heater	Mo heater
Reflector	6 layers of Mo reflector
Target vacuum pressure	RT: 1e-6 Pa 600 degrees: 1e-5 Pa 1000 degrees: 1e-4 Pa

Figure 1: Construction of the furnace.

Figure 2: (top left) Water-cooled baffle, gate-valve and cryopump. (top right) Inside furnace. (bottom) Completed furnace with clean booth.

† kensei.umemori@kek.jp

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Figure 1 and 2 show construction of the furnace and completed furnace with class-10000 clean booth. The cryopump is located bottom of the furnace. Construction work had performed at FY2017.

COMMISSIONING OF FURNACE

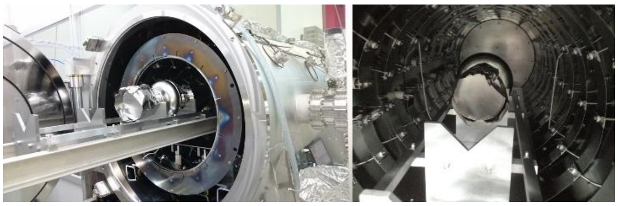

Figure 3: (left) Installing cavity using a lifter. (right) Cavity on a supporting tool inside the furnace.

Several commissioning runs were carried out. Figure 3 shows installation of a single-cell cavity into the furnace using a lifter made of SUS. A cavity supporting tool on the table is also made of Molybdenum.

Figure 4 shows typical 800 degrees x 3 hours commissioning run; log of temperature and vacuum and RGA spectrums. Main components shown in RGA spectrums are H_2, H_2O, N_2/CO, CO_2.

During commissioning runs, reachable vacuum pressures were as following; RT: 1.0e-6 Pa, 600 degrees: 4.4e-6 Pa, 1000 degrees: 7.5e-5 Pa(@955 degree) or 5.4e-6 Pa (with TMP). Target vacuum pressures were almost satisfied.

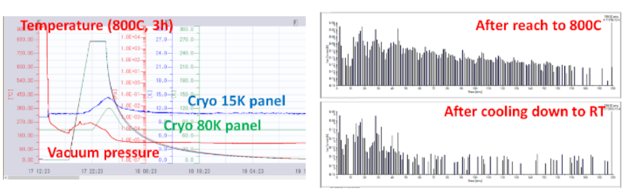

Figure 4: (left) Typical 800 degrees x 3h run. (right) RGA spectrums just after reaching 800 degrees and after cooling down to RT.

Figure 5: (left) TMP used during Nitrogen-injection. (right) Nitrogen-injection system.

Background purity during Nitrogen-injection (N-injection) is also important to realize good performance of SRF cavities. Figure 5 shows N-injection system. A TMP with 700 L/sec pumping speed was used with 90 % rotation speed, while the cryopump is turned off, during N-injection.

G1 grade Nitrogen bombes, 99.9999% purity, are used for Nitrogen treatment. N-injection line is leak-tight and baked. A mass-flow controller is used to precisely control Nitrogen pressure inside the furnace. A capacitance gauge is used to measure the pressure during N-injection.

TEMPERATURE RISE ON CRYOPUMP

Top-left of Fig. 2 is a picture around the cryopump. The cryopump is located bottom of the furnace. An water-cooled baffle is mounted just above a gate-valve to suppress heat input to the cryopump.

Temperature rise on the cryopump, however, became problem during the commissioning runs. We could not even keep 800 degrees. During commissioning runs, sometimes the TMP helped to pump the furnace, instead of the cryopump.

As mentioned above, the water-cooled baffle is used to suppress heat input to the cryopump, but thermal design seemed to be not enough. We decided to add additional reflectors above the cryopump port. Left of Fig. 6 shows 3 layers of SUS plates. They were installed between Mo reflectors and the cryopump port, as shown in right of Fig. 6.

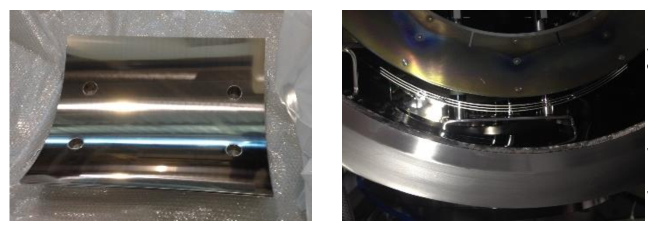

Figure 6: (left) Additional 3 layers of SUS plates. (right) Installed SUS plates between reflectors and a cryopump port.

Figure 7 shows temperature of 15K (left figure) and 80 K (right figure) cryo-panel after installing additional SUS plates. Furnace operation was tested for different temperatures; 800, 850, 900 and 950 degrees. We could keep the furnace at 800 and 850 degrees, 3 hours. But, as shown in Fig. 7, temperature raised up for 900 and 950 degrees operation and it was not possible to continue the cryopump operation.

We are discussing further improvement. One idea is more efficient cooling of the water-cooled baffle using a dedicated chiller. Another possibility is to prepare direct water-cooling line for the added outer SUS plate.

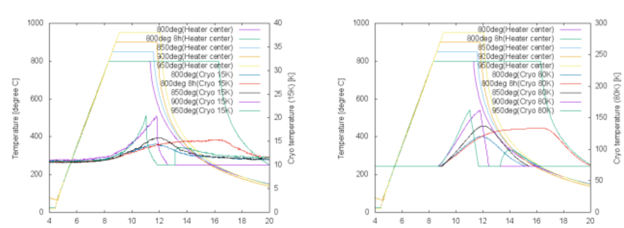

Figure 7: Temperatures of (left) 15K and (right) 80K cryo-panel during operations.

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FIRST N-INFUSION TRYAL

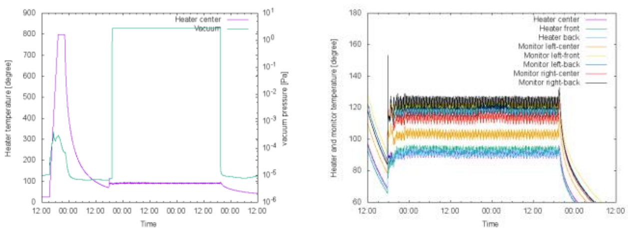

Figure 8: (left) Temperature and vacuum history during N-infusion. (right) Temperatures during N-injection.

First trial of N-infusion at KEK new furnace was applied for an L-band single-cell cavity made from FG material. Before installing into the furnace, HPR was applied to the cavity. Then, the cavity was packed inside cleanroom and transferred to the clean booth of the furnace. The cavity was installed into the furnace with Nb caps and foils, as shown in Fig. 3.

Left of Fig. 8 shows temperature and vacuum history of Furnace during N-infusion process. After 800 degrees, 3 hours heat treatment, the furnace was cooled down to 120 degrees, then 3.3 Pa Nitrogen was introduced and the condition of 120 degrees with 3.3 Pa Nitrogen was kept 48 hours. It is noted that temperature adjustment of the furnace was little bit difficult. As shown in right of Fig. 8, measured temperatures were different between the ones for furnace control and the ones for monitoring temperature around cavities.

Again, the cavity was packed inside the clean booth and transferred back to HPR area. After HPR, the cavity was assembled with vertical test flanges.

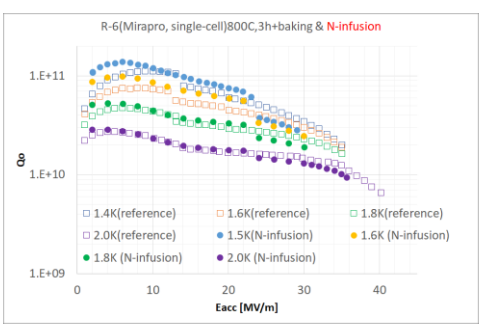

Figure 9: Vertical test results of first N-infusion trial at KEK new furnace, applied for an L-band single-cell cavity. Coloured circles and blank squares are for N-infusion and reference (standard) treatment, respectively.

Vertical test was carried out at KEK-STF. Magnetic field of the vertical test dewar was cancelled by a solenoid coil and remaining magnetic flux was expelled by thermal gradient during cooldown.

Figure 9 shows the results of vertical tests. Coloured circles in the figures are for the data of N-infusion and blank squares are for standard surface treatment, EP + 120 degrees, 48 hours baking. Q-drops around 23 MV/m is known phenomena for this cavity, due to a defect.

First of all, most important message from these results is that no Q-degradation due to contaminations was observed. Cleanness of the furnace was confirmed. Cavity performance was not perfect as a N-infused cavity. There was small improvement of Q-value at low field region, but accelerator gradient decreased.

Systematic study on N-infusion will be carried out and Nitrogen and furnace parameters will be optimized in a future.

SUMMARY

New clean furnace was designed and constructed at KEK. Its pumping system is oil-free system and main pump is a cryopump. Nitrogen injection line is also prepared. Instead of the cryopump, a TMP is used during Nitrogen injection. A mass-flow controller is used to control Nitrogen pressure. Commissioning runs were conducted, and target pressure level was achieved. Temperature rise on cryopump was problem. It was solved partially, not perfect, and normal operation of 800 degrees heat treatment and N-infusion runs were already started. Systematic studies and realization of N-infusion technique is main target for near future studies.

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