ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUPO071

STUDY ON NITROGEN INFUSION FOR 1.3 GHz SRF CAVITIES USING J-PARC FURNACE*

K. Umemori†[1,3], T. Dohmae[1], M. Egi[1], Y. Hori[1,3], E. Kako[1,3], T. Konomi[1,3], S. Michizono[1,3], T. Saeki[1,3], H. Sakai[1,3], Y. Yamamoto[1,3], [1]KEK, 305-0801, Tsukuba, Ibaraki, Japan
S. Kurosawa[2], K. Takeichi[2], J. Kamiya[2], [2]JAEA, 319-1195, Tokai, Naka, Ibaraki, Japan
T. Okada[3], [3]SOKENDAI, 305-0801, Tsukuba, Ibaraki, Japan

Abstract

Nitrogen infusion (N-infusion) is new surface treatment technique for niobium SRF (Superconducting RF) cavities. After cooling down from 800 degrees heat treatment, a vacuum furnace and cavities are kept 120 degrees, 48 hours with about 3 Pa Nitrogen. Improvement of Q-value and accelerating gradient is expected. We used J-PARC furnace, since N-infusion procedure requires clean vacuum furnace. It has a cryo-pump and turbo molecular pumps and its vacuum system is oil-free system. Six times of N-infusion tests were carried out, while changing vacuum condition, N-infusion temperature, Nitrogen pressure, niobium material and so on. Niobium caps were mounted on cavities to avoid contaminations on inner surfaces. Some of trials were successful and vertical test results showed improvement of Q-values and accelerating gradient. However, some of them were not. Most of failed cases showed degradation of Q-values above 5 MV/m. Details of heat treatment procedure including N-infusion and vertical test results are shown in this presentation.

J-PARC FURNACE

N-infusion technique is recently developed to improve SRF cavity performance for both Eacc (accelerating gradient) and Q-values [1]. KEK also had carried out R&D studies to realize high gradient SRF operations.

Throughout N-doping studies we recognized that cleanness of furnace is most important for Nitrogen treatment [2, 3]. Especially, in case of N-infusion, cleanness of furnace could directly affect to cavity performance, since final EP can not apply to the cavity surface.

Figure 1: J-PARC vacuum furnace.

Therefore, we selected J-PARC furnace for N-infusion studies in Japan. Figure 1 shows the J-PARC furnace. This furnace has oil-free and powerful pumping systems. Right and left of Fig. 1 shows a cryopump with 10000 L/sec and three TMPs with 3000 L/sec (x 3), respectively. Vacuum pressure can be reached to around 1e-6 Pa.

One weak point is that this furnace is not dedicated to SRF cavities, but normally used for degassing of beam-duct and components, made of SUS, Cu, ceramic and so on.

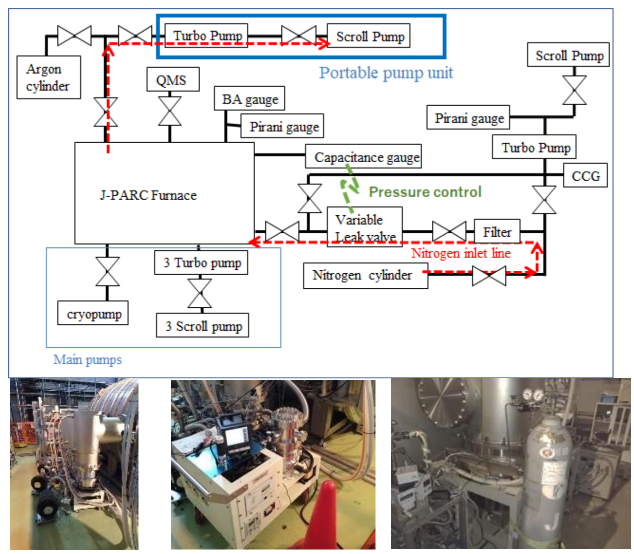

Figure 2: (top) Diagram for N-injection system. (left-bottom) TMPs and scroll pumps. (center-bottom) Portable pumping unit. (right-bottom) N-injection line.

Figure 2 shows Nitrogen-injection (N-injection) system constructed on the J-PARC furnace for the N-infusion study. Nitrogen gas is fed from G1 grade, 99.9999% purity, Nitrogen bombe. Nitrogen pressure in the furnace is controlled by a variable leak valve (right-bottom of Fig. 2). During injection of Nitrogen, the furnace is pumped by pumping system.

At the beginning, a small portable pumping unit (center-bottom of Fig. 2) was used. But we could not maintain clean background condition. Background pressure was estimated to be around 2e-2Pa. After that, we changed to use TMPs with reduced pumping speed. This could improve background pressure to level of 1e-5 Pa.

N-INFUSION PROCEDURE

In order to maintain the furnace as clean as possible, most of case, 950 degrees, 3hours burning runs were carried out, just before N-infusion runs.

Before installing to the furnace, cavities were washed by HPR (High Pressure Rinsing), dried in a cleanroom

† kensei.umemori@kek.jp

ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUPO071

and packed in a clean bag, at KEK. Then they were transported from KEK to J-PARC furnace. They were unpacked at J-PARC and installed into the J-PARC furnace.

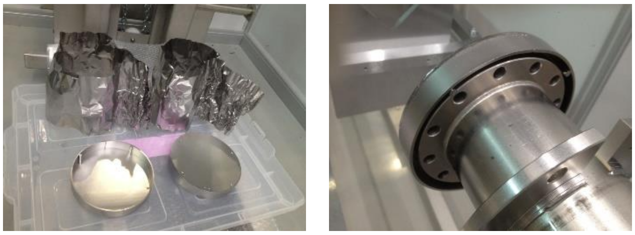

Figure 3: (left) Nb caps and foils to cover flanges. (right) Cavity flange covered with Nb cap.

As shown in Fig. 3, cavity flanges were covered by Nb caps and surrounded by Nb foils. There is enough space, more than several mm, as Nitrogen passage between cavity flanges and Nb caps. These Nb caps and foils are cleaned by CP and ultra-sonic rinsing with detergent, every time. Cavities were supported by Nb jigs and set on Inconel table of the furnace, as shown in top of Fig. 8.

Figure 4 shows typical N-infusion process. (1) The cavity is heat treated at 800 degrees, 3hours, (2) cooled down to 120 degrees, (3) kept at 120 degrees with 3.3 Pa Nitrogen, 48 hours and (4) cooled down to RT. Total of 6 times of N-infusions were applied to total of 8 L-band cavities. It is summarized at Table 1. Right of Fig. 4 shows RGA spectrum of background condition during N-injection. Red (blue) lines are the case using the portable pump unit (TMPs with 50% rotation speed), respectively. These data were taken without Nitrogen. Background condition was clearly improved by using TMPs with reduced speed.

For the 5th and 6th N-infusion runs, two cavities were installed to the furnace at the same time.

After N-infusion, cavities were packed at J-PARC and transferred back to KEK. After HPR, cavities were dried and assembled for vertical tests.

Vertical tests were carried out at KEK-STF. Magnetic field inside dewar was cancelled by a solenoid coil. Typically, remaining field is around 1 mG or less. Thermal gradient on the cavity surface was made by a heater during cool-down for better flux expulsions [4].

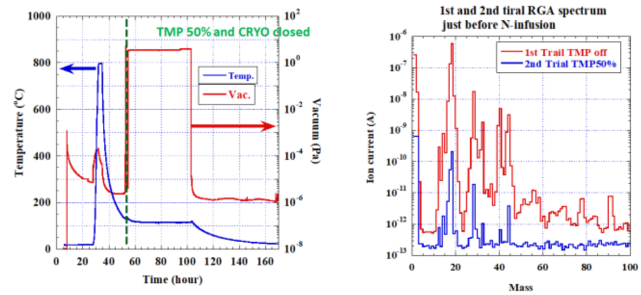

Figure 4: (left) Temperature and vacuum history of typical N-infusion. (right) RGA spectrum of background condition during N-injection. Data was taken without Nitrogen.

VERTICAL TEST RESULTS

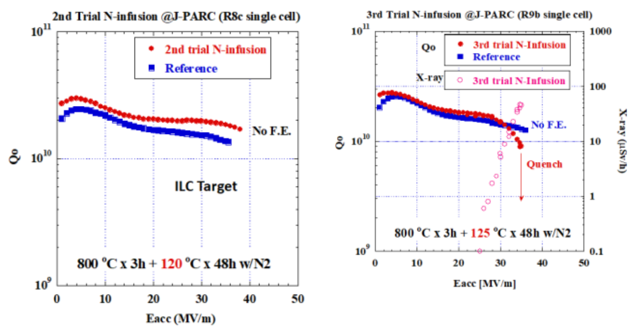

Figure 5: Vertical test results for (left) 2nd N-infusion and (right) 3rd N-infusion.

Figure 5 shows two vertical test results of successful N-infusions. Left and right figure shows results for 2nd and 3rd N-infusion, respectively. In the figures, red and blue points are for N-infusion and reference, which is so called standard treatment; EP + 120 degrees, 48h baking. First of all, Q-degradation or HFQS (High Field Q-Slope) are not observed. In the table 1, "success" of N-infusion is defined as the case for no Q-degradation. Slight improvement of Q-value and Eacc was observed for 2nd N-infusion results. It is noted that N-infusion and reference data were taken at 1.97 K and 2.00 K, respectively. Better Q-values of N-infusion includes temperature effect too. The results for 3rd N-infusion was not so different from reference data. Both data were taken at 1.99 K.

Table 1: Conditions of N-infusion

No.	Date	Cavity name	No. of cells	Nb material	N-infusion process	Pumping system	Results
1	2017.4	R-2	Single	FG (TD)	800C, 3h + 120C, 48h w/ 3.3Pa N_2	Portable	Fail
2	2017.11	R-8c	Single	FG (TD)	800C, 3h + 120C, 48h w/ 3.3Pa N_2	TMP 50%	Success
3	2018.1	R-9b	Single	FG (TD)	800C, 3h + 125C, 48h w/ 3.3Pa N_2	TMP 50%	Success
4	2018.2	R-2	Single	FG (TD)	800C, 3h + 160C, 48h w/ 3.3Pa N_2	TMP 50%	Fail
5	2018.3	R-9	Single	FG (TD)	800C, 3h + 120C, 48h w/ 3.3Pa N_2	TMP 50%	Fail
		R-10b	3-cell	LG (CBMM)			Success
6	2018.4	R-2	Single	FG (TD)	800C, 3h + 120C, 48h w/ 3.3Pa N_2	TMP 50%	Fail
		R-9b	Single	FG (TD)			Fail

ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUPO071

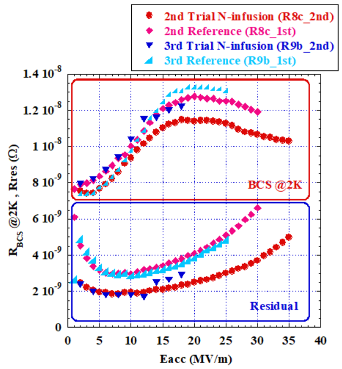

Figure 6: Deconvoluted BCS resistance and residual resistance for 2nd and 3rd N-infusion.

Vertical test results of 2nd and 3rd N-infusion were analysed and deconvoluted to BCS resistance and residual resistance. Figure 6 shows deconvoluted results. Considering temperature effect, mentioned above, BCS resistance for N-infusion and standard treatment does not show clear difference. There is a tendency that residual resistance is smaller for N-infusion case. Up to now, significant improvement of cavity performance can not be observed from N-infusion studies performed using J-PARC furnace.

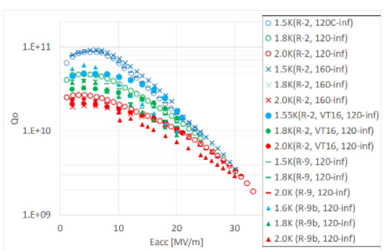

Figure 7: Vertical test results for failed N-infusion. 1st, 4th ,5th (R-9) and 6th (R-2&R-9b) N-infusion results are plotted.

As shown in Table 1, sometimes N-infusion was failed, and Q-degradation was observed. Figure 7 shows vertical test results for failed cases. Results from total of 5 cavities are included; 1st, 4th, 5th (R-9) and 6th(R-2&R-9b). It is interesting that all results show rather similar degradation curves, even the case for different N-infusion conditions. Q-degradation always starts above 5 MV/m and make exponentially degraded Q-slope. It is considered that Q-degradation is caused by contaminations from the furnace. Normal conducting materials might become the source of heating.

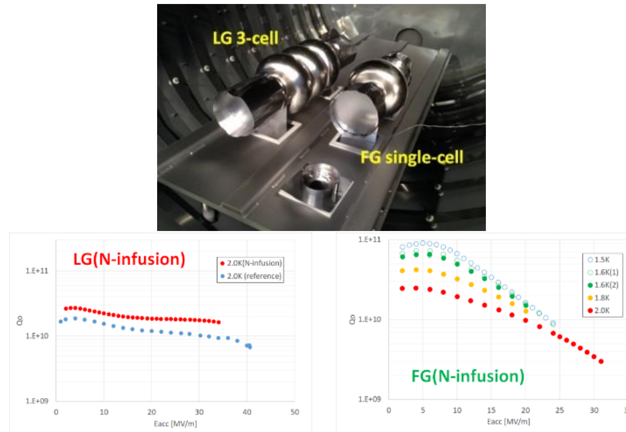

Figure 8: (Top) LG 3-cell and FG single-cell cavities installed to the Furnace. Vertical test results for LG 3-cell (left-bottom) at 2.0K and FG single-cell (right-bottom).

5th N-infusion showed interesting results. LG 3-cell cavity and FG single-cell cavity were installed into the furnace at the same time, as shown in top of Fig. 8. Bottom-left figure shows N-infusion results (red points) compared with standard treatment (blue points) at 2.0K for LG 3-cell cavity. Since magnetic conditions are different between these measurements, Q-values are not compared. Unfortunately, Eacc decreased compared with standard treatment. Bottom-right figure shows N-infusion results for FG single-cell cavity. Q-degradation is clearly observed. These results might indicate dependence on materials.

DISCUSSION

We had carried out series of N-infusion studies using J-PARC furnace. However, we could not reproduce good performance of cavities as expected.

One reason still come from cleanness of furnace. The J-PARC furnace is not dedicated to Nb cavities. Many beamline components have been heat treated. Surface analysis of Nb samples were also investigated to understand the reason of degradations [5]. It is still not clear, but Carbon component might be one of candidate.

Different results for LG and FG cavities are interesting. To understand well, however, more statistics are required.

SUMMARY

KEK had carried out N-infusion study using J-PARC oil-free furnace with the cryopump. The furnace and N-injection line were tried to maintain as clean as possible. TMPs are also used to achieve better background condition during N-injection. There were some successful results, but it was not well reproduced. We often suffered from Q-degradation of cavity caused by furnace contaminations. We will continue N-infusion study to realize high gradient performance using newly constructed KEK furnace [6].

ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUPO071

REFERENCES

[1] A. Grassellino *et al.*, "Unprecedented Quality Factors at Accelerating Gradients up to 45 MV/m in Niobium Superconducting Resonators via Low Temperature Nitrogen Infusion", *Supercond. Sci. Technol.* 30 (2017) 094004 (10pp)

[2] K. Umemori et al., "Vertical Test Results of Nitrogen Doped SRF Cavities at KEK", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, paper WEPMB016, pp. 2154-2157. doi:10.18429/JACoW-IPAC2016-WEPMB016

[3] T. Konomi *et al.*, "Trial of Nitrogen Infusion and Nitrogen Doping by Using J-PARC Furnace", in *Proc. 18th Int. Conf. on RF Superconductivity (SRF'17)*, Lanzhou, China, July 2017, paper THPB021, pp. 775-778. doi:10.18429/JACoW-SRF2017-THPB021

[4] K. Umemori *et al.*, "Improvement of Magnetic Condition for KEK-STF Vertical Test Facility Toward High-Q Study", in *Proc. 18th Int. Conf. on RF Superconductivity (SRF'17)*, Lanzhou, China, July 2017, paper TUPB028, pp. 444-447. doi:10.18429/JACoW-SRF2017-TUPB028

[5] T. Konomi *et al*., "Niobium Sample Analysis for Nitrogen Infusion and Doping", presented at 29th Linear Accelerator Conf. (LINAC'18), Beijing, China, Sept. 2018, paper TUPO073, this conference.

[6] K. Umemori *et al*., "Design and Commissioning of KEK New Furnace for SRF Cavity Development", presented at 29th Linear Accelerator Conf. (LINAC'18), Beijing, China, Sept. 2018, paper TUPO070, this conference.