ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-THPF055

STATUS OF THE SUPERCONDUCTING CAVITY DEVELOPMENT AT IHEP FOR THE CADS LINAC*

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Abstract

IHEP (Institute of High Energy Physics) is developing a CW 10MeV proton injector and part of the 25MeV main linac for the CADS project. 14 SRF (superconducting radio frequency) spoke-012 cavities for the injector, as well as 6 SRF spoke-021 cavities for the main linac are to be beam commissioned before middle of 2016; meanwhile, VT (vertical test) of two more types of prototype cavities are to be finished with 2015, for the future phases of the project. In this paper, the VT statistics of 10 spoke012 cavities, 4 spoke021 cavities, and a 5-cell β0.82 elliptical cavity are reported; the cavity performance during beam commissioning of the TCM (test cryomodule) is reported as well.

INSTRUCTION

The C-ADS project is a strategic plan to help solve the nuclear waste problem and the resource problem for nuclear power plants in China [1]. For the first phase, the project goal is to build a CW proton linac of 25 MeV and 10 mA by about 2016. IHEP is developing one of the two 10-MeV injectors for the project, which is called Injector-I. The TCM, which contains two spoke-012 cavities, is under beam commissioning now. 8 more spoke0-12 cavities reached Ep of 60MV/m and Bp of 90 mT during VT, and 7 of them are being assembled to the CM1, which is the upstream cryomodule for the injector. 3 prototype spoke-021 cavities went through VT in 2014, and one more spoke-021 cavity for the cryomodule at the end of the 25MeV main linac reach specification during VT. Two spoke-040 cavities and two HMB cavities, which are 5cell β0.82 elliptical cavities, were fabricated, while one of the HMB cavities went through VT and reached specification. 8 more spoke-012 cavities and 7 more spoke-021 cavities are under fabrication now to catch up with the project schedule.

DESIGN AND FABRICATION OF THE CAVITIES

The Injector-I uses spoke012 cavities, which are 325MHz, β_0 of 0.14, single-spoke cavies. The main linac contains two types of 325MHz single-spoke cavities, i.e. spoke021 and spoke040, and two types of 650MHz multi-cell elliptical cavities, i.e. MB063 and HMB082. All types of cavities except for the MB063 have been designed and prototyped at IHEP, while three of them have reached the design specification during VT. The key parameters of these cavities are listed in Table 1.Note the effective length is defined as Leff = $\beta_0 \times \lambda$.for single-cell spoke cavities, while β_G is used for elliptical cavity instead of β_0.

*Work supported by Chinese Academy of Science strategic Priority Research Program-Future Advanced Nuclear Fission Energy
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Table 1: RF Parameters of the ADS SRF Cavities at IHEP

RF Parameters	Spoke -012	Spoke -021	Spoke -040	HMB 082
Frequency-MHz	325	325	325	650
β_0	0.14	0.24	0.46	0.82
Aperture-mm	35	40	50	100
Ep/Eacc	5.0	4.4	3.9	2.1
Bp/Eacc-mT/(MV/m)^2	6.9	9.4	9.2	4.1
G-Ω	60	71	104	236
R/Q-Ω	150	191	265	515
df/dp-Hz/mbar	+40	+0.6	+0.7	
df/dF-Hz/N	60	94	N/A	N/A
Leff -mm	129	221	424	945

The RF design of the spoke012 cavity was biased towards eliminating MP (multipacting); while stiffening rings and the helium vessel were designed to reduce pressure sensitivity. The spoke021 cavity was shaped to facilitate the fabrication, and the designed pressure sensitivity was significantly reduced by adopting a different helium vessel and tuner design. The spoke040 cavity is in the early phase of prototyping, and the RF properties are not fully optimized yet. The HMB082 cavity was designed to minimize surface field and to avoid MP. HOM (higher order modes) are not a concern for any type of these cavities.

The spoke012 cavities are in mass production phase now. The first two prototype spoke012 cavities were fabricated in 2012, and were VT in 2013. During the fabrication of the second batch of 4 cavities for TCM, the frequency errors of 2-4 MHz induced by inaccuracy in deep-drawing and machining were well understood and compensated by trimming the height of outer conductor. Though, a frequency scattering of 1.6 MHz induced by EBW were observed during the mass production of the third batch of 7 cavities for CM1 (see Fig. 1); since then the process flow of fabrication was adjusted to reduce the frequency error. The fourth batch of 8 cavities will be delivered from two vendors by September; they will be VT qualified after the He vessels are welded, and is

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supposed to be ready for cavity-string assembly before December.

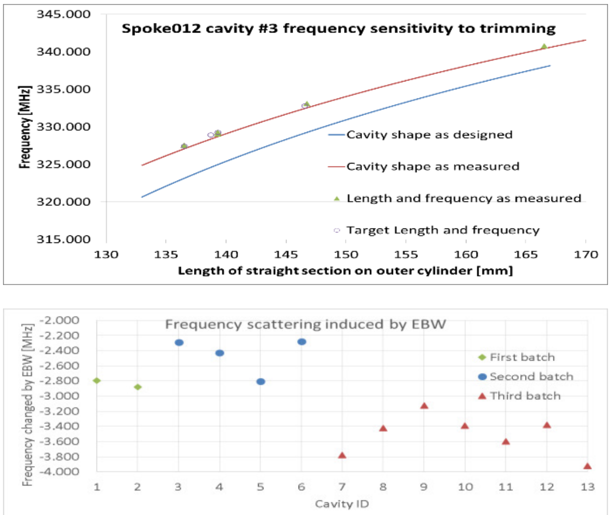

Figure 1: Frequency error caused by fabrication and EBW.

The first two prototype spoke021 cavities were fabricated and VT in 2013. A third cavity with improved fabrication scheme was finished in 2014. The fourth cavity was VT in Apr. 2015, which qualified a new vendor for this type of cavity. The horizontal test with He vessel and tuner is planned in Mid-May. Another 7 spoke021 cavities will be ready to assemble within 2015.

Two prototype spoke040 cavities were developed in March, and will go through VT before June. Two prototype HMB082 cavities were also developed, following the well-known methods to control the frequency of elliptical cavities; one HMB082 cavity were VT and reached the design specification.

Two new types of low-beta cavities were also developed as alternative to spoke012 and spoke021 cavities at IHEP. One is 325MHz HWR (half wave resonator) of β0 0.145, the other is 325MHz spoke cavity of β0 0.243. These two cavities are optimized with much lower surface field. One of the spoke cavity has went through VT, and the VT to HWR is planned in mid-May.

VT STATICS OF THE CAVITIES

Recipe of Post-Processing

A post-processing facility was built in 2014 with cooperation between IHEP and OSTEC (Ningxia Orient Superconductor Technology Co., Ltd). Cavities were delivered from OSTEC to IHEP after BCP and rinsing, and then went through HPR and cleanroom assembly. Standard recipe is adopted for the ADS cavities as listed below:.

- Ultrasonic cleaning with micro90 at 50 ^{O}C
- Ultrasonic cleaning with deionized water
- BCP 120 μm with 1:1:2 acid at 15 ^{O}C
- High baking 750 ^{O}C x 3hrs / 650 ^{O}C x 2hrs
- Ultrasonic cleaning with and w/o micro90
- Light BCP 30 μm
- Deliver to IHEP
- HPR and clean assembly
- (Optional) low baking at 120 ^{O}C

VT Results of the Spoke-012 Cavities

The first two prototype cavities were VT in 2013, while the gradients were limited by FE (field emission) due to pour cleanness during HPR and assembly. The recipe was improved then for the 10 cavities in the second and third batch, and they statistically reached Ep of 60 MV/m and Bp of 90 mT. Generally it took one hour or so to process low-field MP (below 7MV/m), then gradient jumped to about 12-14 MV/m, as shown in Fig. 2. It is confirmed that the cavity performance was limited by thermal effect for most tests at 4K. We only had chance to do 2K test to one cavity since the 2K dewar is to be finished in middle 2015, but unfortunately it was the only cavity that was limited by strong FE starting 7MV/m..

One phenomenon we haven't understood yet is the scattering of Q_0, and thus Rs. There are twice difference in Q_0 between cavities, whose history are generally the same. Some cavities were low baked for 7-28 hours, which should have no effects on BCPed cavities. The cooling down curve of the cavities are being analysed now.

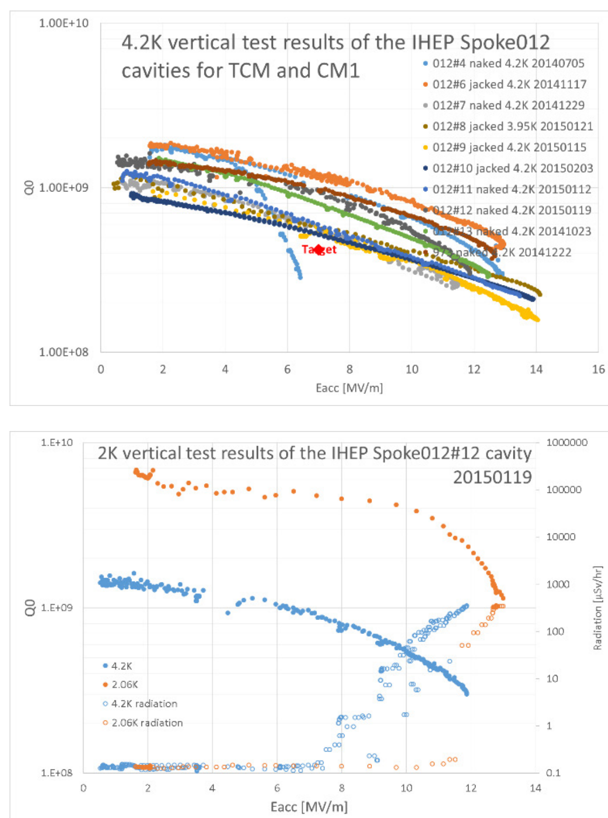

Figure 2: VT results of the spoke012 cavities.

VT Results of the Spoke-021 Cavities

As mentioned in previous section, there is a major improvement on how the inner conductor was made from the first two prototype cavities to the third one. The fourth

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cavity was made by a new vendor following similar arts, and it went through the standard post-processing recipe before VT. The cavity #3&4 reached Ep of about 50MV/m, and Bp of about 105mT. The low-field Q indicate Rres (residual resistance) of merely 3nΩ. The entire Q-E curve is in Fig. 3.

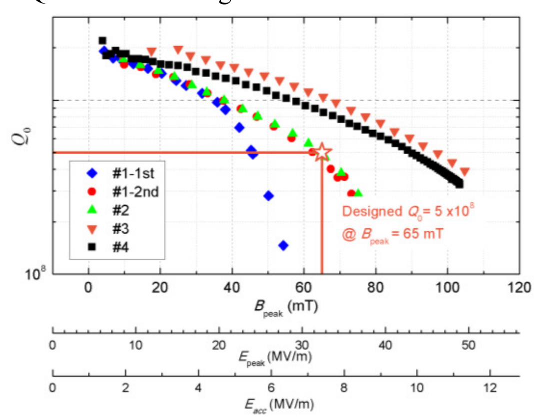

Figure 3: VT results of the spoke021 cavities.

VT Result of the HMB082 Cavity

Two HMB082 cavities with coupler port was developed in 2013, and we got a chance to VT one of them in Jan. 2015. It reached 9MV/m at Q_0 of 1e9, which exceed the design target of 8MV/m at Q_0 of 3e8 at 4.2K, as shown in Fig. 4; the temperature didn't reached 2K because we went out of liquid helium.

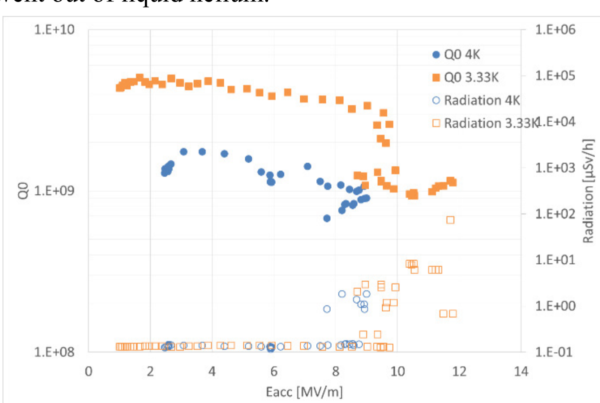

Figure 4: VT results of the HMB082 cavity.

CAVITY PERFORMANCE DURING BEAM OPERATION WITH TCM

Two spoke012 cavities (#4 and #6) were used in the TCM, and they reached 6MV/m and 7MV/m, respectively, after conditioning of about 3 days. There were significant FE, which was possibly because the dirt introduced during coupler assembly outside the class-100 cleanroom. As a preliminary result, energy gain of 0.55 MeV was reached for proton beam pass through two cavities. The pressure sensitivity, frequency deviation induced by microphonics, and the Lorentz force detuning factor was measured as 175 Hz/mbar, about 40Hz, and -11 Hz/(MV/m)^2, respectively.

CONCLUSION

It is close to the end of the first phase of C-ADS project, and good progress have been achieved on SRF cavities at IHEP. We are in the mass production and beam commissioning phase, i.e. we will finish all the cavities VT qualification within 2015, and are working hard on beam operation on the whole Injector-I no later than early 2016.

ACKNOWLEDGMENT

We would like to thank people at OSTEC for their help on building the post-processing facility, and their efforts on the surface treatment to the cavities.

We would also appreciate Tom Powers at JLab for his great help on helping us reducing the microphonics level of the cavities, as well as for the help on the LLRF system which ensures the stable operation of the TCM.

REFERENCES

[1] Edited by Jingyu Tang, Zhihui Li, "Conceptual Physics Design on the C-ADS Accelerators", (2012).