Venturi tube application in high power test of the SRF module

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Abstract In the superconducting RF module, the dissipation power of the niobium cavity is an important parameter. In the Superconducting radio frequency (SRF) module's acceptance test at Shanghai Synchrotron Radiation Facility (SSRF), the Venturi tube is used to measure the quality factor of SRF cavity at 4.2 K. During the test, the venturi tube is be calibrated by increasing heat load with internal heater. In this paper, the horizontal test principle and venturi effect are briefly introduced. The authors find out a correct way to calibrate the venturi tubes, the calibration results are presented here. From the calibration results, one can deduce the static loss of each module, the source of static loss is also analyzed.

Key words RF superconductivity, Venturi, Horizontal test, Static loss

1 Introduction

Superconducting radio frequency (RF) cavities are used in many synchrotrons in the world, such as the Cornell Electron Storage Ring (CESR)[1], Diamond Light Source[2], Taiwan Light Source[3], KEK-B[4] in Japan, etc. In China, both Beijing Electron Positron Collider (BEPC-II)[5] and Shanghai Synchrotron Radiation Facility (SSRF)[6] have SRF cavities in the storage rings.

Three SRF modules for the SSRF storage ring were manufactured by ACCEL Instrument®, and the site acceptance test was completed in summer of 2008. The high power test (or the horizontal test as it is called) is an important part of the acceptance test. One of the control screens is shown in Fig. 1. In an SRF module, a cavity is dressed into a well vacuum-insulated helium vessel, and a certain level of the liquid helium in the vessel should be kept for submerging the cavity. The cryoplant provides liquid helium and brings back the heat produced in the cryomodule. The pressure of the helium vessel must be stable. The valve box is an integration of many cryogenic valves, including the ones controlling influx of liquid helium and liquid nitrogen, and the valves controlling cold return and warm return of gas helium. Some other instruments like the helium Venturi are also installed inside the box.

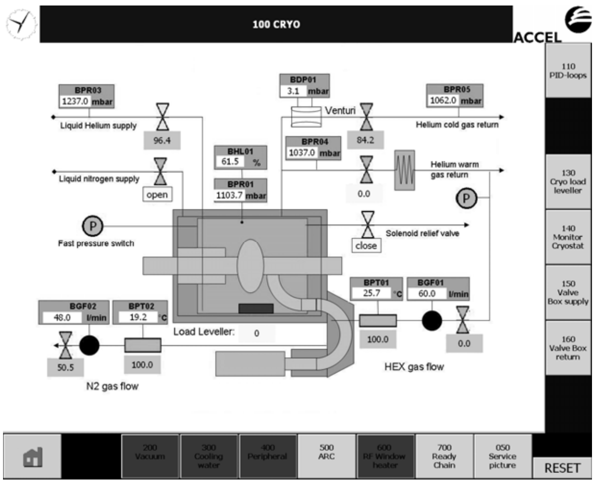

Fig. 1 A snapshot of screen of the SRF cavity control.

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2 Horizontal test

In the horizontal test, the cavity works at nearly full reflection state. The intrinsic quality factor Q_0, the cavity voltage V_c and acceleration gradient E_{acc} are the important parameters in the acceptance test of the SRF module. One of the methods of Q_0 measurement is using cryogenic loss,

$$Q_0 = \frac{V_c^2}{P_{diss} \cdot (R/Q)} \quad (1)$$

where P_{diss} is the cavities' dissipation power, R/Q is only decided by the cavity shape.

First, cavity voltage V_c is measured. The incident power is added through a waveguide coupler, its coupling coefficient β>>1. The dissipation power is much smaller than the incident power,

$$P_{diss} = \frac{4\beta}{(1+\beta)^2} P_{inc} \approx \frac{4}{\beta} P_{inc} \quad (2)$$

Also, $P_{diss} = V_c^2/R_{sh}$, $Q_e = Q_0/\beta$, $R_{sh} = (R/Q)Q_0$, where R_{sh} is the shunt impedance of the cavity, Q_e is the external quality factor. Then,

$$V_c^2 = P_{diss}(R/Q)Q_0 \approx 4(R/Q)P_{inc}Q_e \quad (3)$$

And the acceleration gradient shall be,

$$E_{acc} = \frac{\sqrt{4 \cdot (R/Q) \cdot P_{inc} \cdot Q_e}}{\lambda/2} \quad (4)$$

From the Eq. (1) and (3), one has

$$Q_0 = 4P_{inc}Q_e/P_{diss} \quad (5)$$

where Q_e is a constant, 1.78×10^5. P_{diss} is measured by the Venturi tube in the valve box. The pressure difference of the Venturi tube corresponds to the helium gas flow rate.

In the horizontal test, the Venturi tube plays an important role. The cryogenic loop during the experiment is shown in Fig. 2. The gas helium (GHe) goes into "cold box" and is changed to liquid helium (LHe) at the temperature of 4.5 K. The LHe is accumulated into a Dewar (Helium Main Dewar in Fig. 2) and the gas above the liquid level keeps pressure larger than 1.3 bar, so that the LHe is pressed into the transfer lines if the valves in "valve box" are open. Therefore LHe is transferred through the transfer lines into the superconducting RF modules, both in the test cave and tunnel. The return lines from the modules bring back the heating generated by the superconducting cavities working at high power. The highest voltage of each module can reach 2 MV. The Venturi locates on the cold return line.

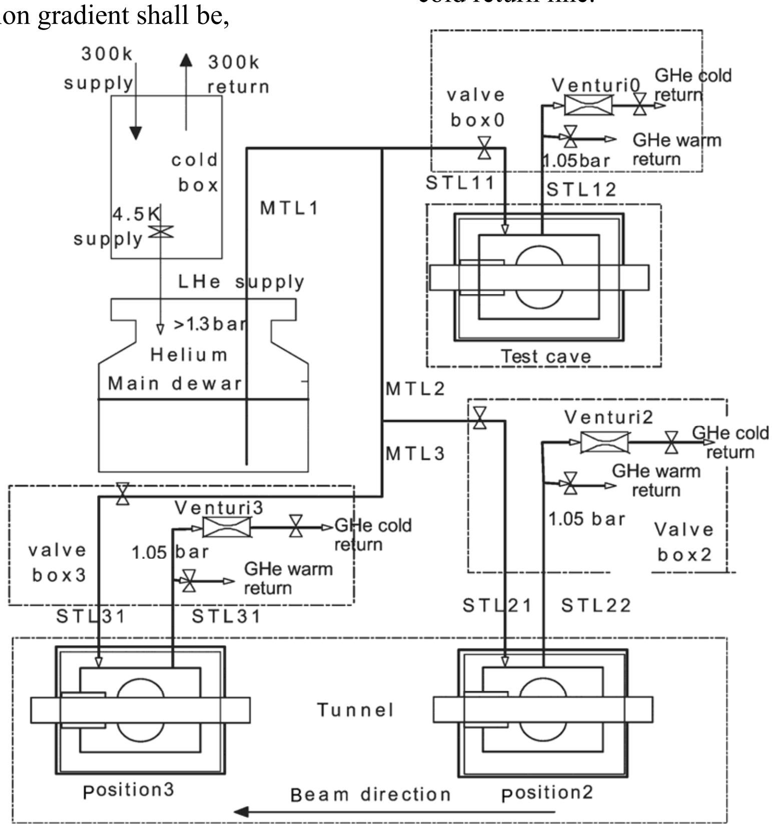

Fig. 2 The display of the cryogenic system for SRF cavities at SSRF.

When an incompressible fluid flows through a constricted section of the pipe, fluid pressures at different cross-sections are different, this is called Venturi effect. The Venturi effect can be used in cryogenic fluid measurements[7]. In a choked fluid pipe, there is pressure difference between the normal and the choked pipe, see Fig. 3. The pressure difference's square root is proportional to the flow rate in the pipe. From Bernoulli's principle, $\rho \times v^2/2 + P =$ constant.

As $\rho v_1^2/2 + P_1 = \rho v_2^2/2 + P_2$, so

$$\Delta P = P_1 - P_2 = \rho(v_2^2 - v_1^2)/2 \tag{6}$$

Since flow rate $Q = vA$, and the flow stays constant, so

$$\Delta P = \frac{\rho}{2}\left(\frac{Q^2}{A_2^2} - \frac{Q^2}{A_1^2}\right) \propto Q^2 \tag{7}$$

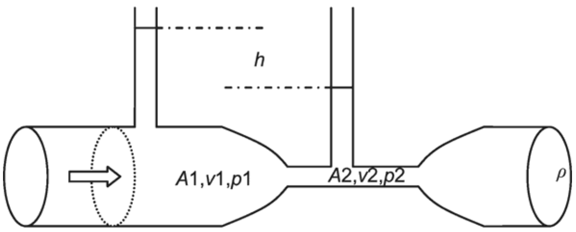

Fig. 3 Venturi diagram.

There is an electrical heater at the bottom of each module's helium vessel. It provides load for the cryogenic system without cavity dissipation power. In the SRF module, all the vaporized helium should be brought away from the cold return pipes, so that the helium vessel's pressure is kept stable. Liquid helium's latent heat vaporization is 21 J/g; If gas helium's density in the cold return pipe is D (mL/g), and the heater power of cryomodule, H (W), in order to keep the helium level constant, the flow rate of gas helium in the cold return route should be

$$Q = \frac{H(W)}{21(J/g)} \times D(mL/g) \propto H(W) \tag{8}$$

The helium flow rate is proportional to the module's heat power. Comparing Eqs.(7) and (8), one has

$$\Delta P\ (\text{mbar}) \propto H(\text{W})^2.\ \text{i.e.}\ (\Delta P)^{1/2} \propto H(\text{W}). \tag{9}$$

3 Venturi calibration

The heat power H (W) in the SRF module includes,

$$H(\text{W}) = P_{\text{diss}} + P_{\text{heater}} + P_{\text{static}}. \tag{10}$$

In the Venturi calibration experiment, no RF power is fed into the cavity, $P_{\text{diss}} = 0$, and the following steps were taken.

1) Use the Proportional Integral Derivative (PID) loop to keep the liquid helium level at certain level, for example 70%;
2) Turn the heater at the bottom of the helium vessel;
3) After each power value, the Venturi pressure is kept for at least half an hour;
4) Set the power at 0 W, 10 W, 20 W… 90 W and 100 W, and record the Venturi pressure after each valve is set for half an hour;
5) Make a chart of $(\Delta P)^{1/2}$ *v.s.* H(W).

In the chart of $(\Delta P)^{1/2}$ *vs.* H(W), the point where the proportional fitting line crosses the coordinate of the heater power, indicates the static loss of the cryomodule and transfer lines.

One of the calibration experiments was taken on July 30, 2008, when only modules 1 & 3 are in the tunnel while module 2 in the test cave hasn't been cooled down. We measured and processed the data of calibration, as shown in Fig.4. After the calibration, the heat power can be calculated by the Venturi differential pressure according to the (x, y) equations shown in Fig.4.

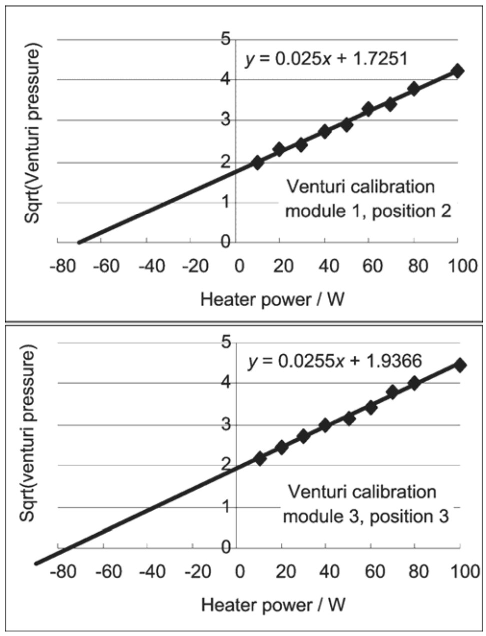

Fig.4 Results of the Venturi calibration.

4 Results and conclusion

From the results of the Venturi calibration, the total static losses of each module are deducted. But the static loss doesn't only include the module's static loss, but also the multi-transfer line (MTL) from the Dewar vessel to the cryomodule, and the single transfer lines (STL) from the cryomodule to the valve box. Details are shown in Table 1.

Table 1 Static loss of each test

Module	Position	Static loss / W	Static loss components
Module 1	Position2 in tunnel	70	MTL(1+2)+VB2+ STL(21+22)+Module1
Module 3	Position3 in tunnel	74	MTL(1+2+3)+VB3+ STL(31+32)+Module3

As estimation, each module's static loss is about 30 W, the MTL's loss is totally about 50 W, and the STL's loss is about 20 W for each module. Since module 2 has not been cooled down in the test cave, the total static loss is estimated as 30×2 + 20×2 +50 = 150W, while the measured result is 70 + 74 = 144 W. Because STL in the test cave are soft pipes, and most of the STL inside the tunnel are stiff pipes which are better insulated, the static loss in the test cave is larger than that in the tunnel. Further experiments are needed to measure different pipes' static loss. After the acceptance test, all of the Q_0 of the three SRF modules at 1.8 MV reached 1×10^9.

The Venturi calibrations were taken in the Site Acceptance Test (SAT) of superconducting modules. But previous SAT in other synchrotron facilities [2, 8] gives the SRF's static loss by data fitting after the Venturi calibration. The calibration results in Fig. 4 show only the sum of static loss by data fitting. Actually, however, it includes the static loss of valve boxes and transfer-lines, too. We found that fitting method in SRF module's SAT is incorrect, and the method in this paper is correct.

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References

1 Padamsee H, Barnes P, Chen C, *et al*. Particle Accelerators, 1992, **40**: 17-41.

2 Jensen M R F, Alex J, Pekeler M, *et al*. Status of the Diamond Storage Ring Radio Frequency System. Proceedings of the European Particle Accelerator Conference. Edinburgh, Scotland: 2006: 445-447.

3 Wang C, Chang L H, Lin M C. Commissioning Experience of Superconducting Radio Frequency Systems for the Taiwan Light Source. Proceedings of the Asian Particle Accelerator Conference. Indore, India: 2007: 549-551.

4 Akai K, Akasaka N, Ebihara K, *et al*. Nuclear Instruments and Methods in Physics Research Section A, 2003. **499**(1): 45-65.

5 WANG Guangwei, SHA Peng, PAN Weimin, *et al*. Chinese Physics C (in Chinese), 2008. 32 (Supplement I): 169-171.

6 DAI Zhimin, LIU Guimin, YIN Lixin, *et al*. Status of the SSRF Storage Ring. Proceedings of the European Particle Accelerator Conference. Genoa, Italy: 2008: 1998-2000.

7 Song Weirong, Bai Hongyu, Wang Juanjuan, Cryogenics and Superconductivity (in Chinese), 2001, **29**(2): 21-25.

8 Pekeler M, Dunkel K, Peiniger M, *et al*. RF Activities of ACCEL Instruments in ASIA-PACIFIC. Proceedings of the Asian Particle Accelerator Conference. Indore, India: 2007: 791-793.