RF measurement in SHINE cavity and cryomodule test stands

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INTRODUCTION

The SC Linac of SHINE (Shanghai HIgh repetition rate XFEL aNd Extreme light facility) comprises 79 cryomodules housing 609 1.3 GHz TESLA type superconducting cavities(SCCs), and 16 3.9 GHz SCCs. These SCCs and cryomodules should be tested in ATH(cryomodule Assembly and Test Hall) at SSRF(Shanghai Synchrotron Radiation Facility) campus.
Four VTFs(SCC Vertical Test Facility) and four HTFs(Cryomodule Horizontal Test Facility) will undertake the vertical test of these SCCS and horizontal test of cryomodules.

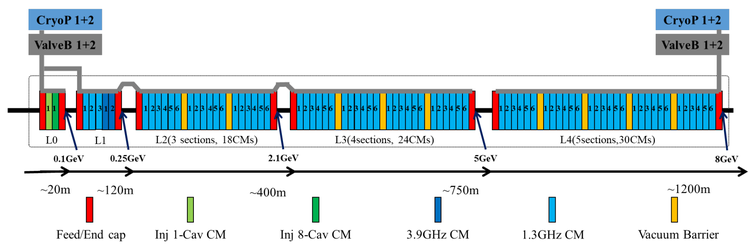

Fig.1 General layout of the SHINE superconducting Linac.

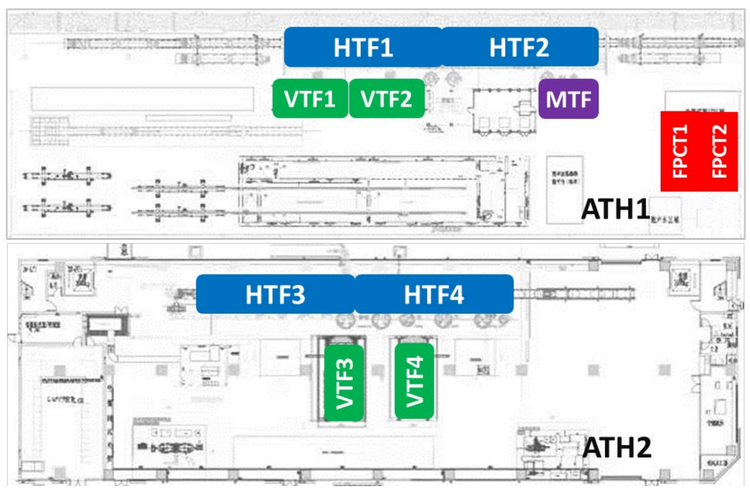

Fig.2 SCC and cryomodule test stands in ATH.

VTF

Every VTF(Vertical Test Facility) have an insert which can carry four(more for single cell cavity) 1.3G TESLA type cavities. RF switches are adopted to switch measurement among the four cavities and switch between calibration and measurement, which idea is from Euro-XFEL.

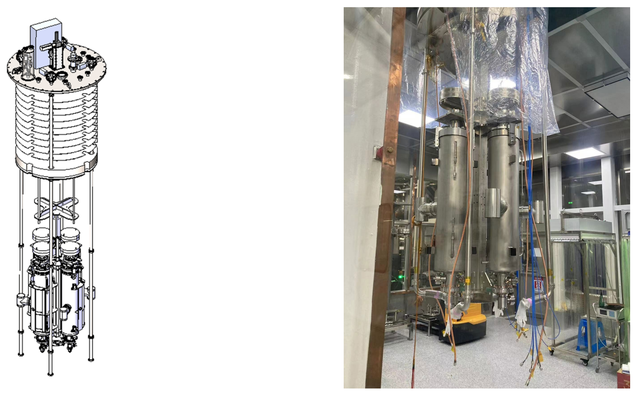

Fig.3 vertical test insert.

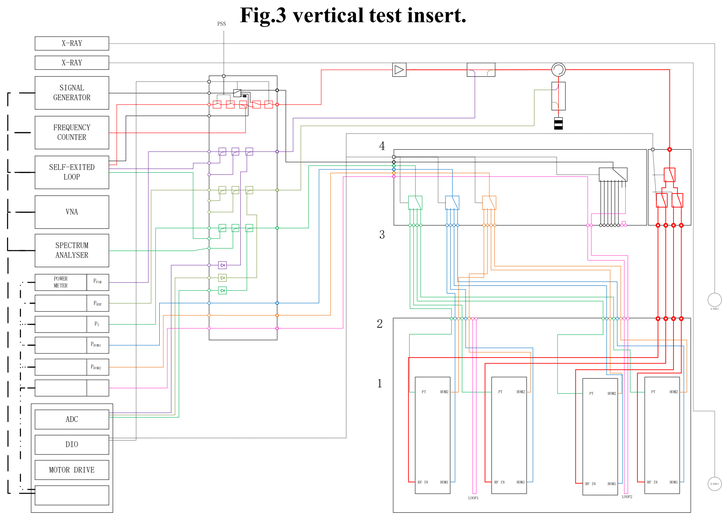

Fig.4 RF distribution of VTF.

The full formula of Q/E measurement in vertical test are shown below.

$$P = P_0 e^{\frac{-t}{\tau_L}} \quad Q_L = 2\pi f \tau_L$$

$$P_{diss} = P_{for} - P_{ref} - P_{tran} - P_{HOM1} - P_{HOM2}$$
$$\beta_t = \frac{P_{tran}}{P_{diss}} \quad \beta_{HOM1} = \frac{P_{HOM1}}{P_{diss}} \quad \beta_{HOM2} = \frac{P_{HOM2}}{P_{diss}}$$
$$\beta_i = \frac{1+\sqrt{P_r/P_f}}{1-\sqrt{P_r/P_f}} \quad \beta_i > 1 \qquad \beta_i = \frac{1-\sqrt{P_r/P_f}}{1+\sqrt{P_r/P_f}} \quad \beta_i < 1$$
$$Q_0 = (1+\beta_i(1+\beta_t+\beta_{HOM1}+\beta_{HOM2})+\beta_t+\beta_{HOM1}+\beta_{HOM2})Q_L$$

$$Q_t = Q_0/\beta_t \quad Q_{HOM1} = Q_0/\beta_{HOM1} \quad Q_{HOM2} = Q_0/\beta_{HOM2} \quad Q_e = Q_0/\beta_e$$

$$E_{acc} = \frac{1}{L_{eff}}\sqrt{\frac{r}{Q}Q_t P_{tran}} \qquad Q_0 = Q_t \cdot \frac{P_{tran}}{P_{diss}}$$

Fig.5 Formula of Q/E measurement in vertical test.

The key points for accurate RF measurement in VTF includes:
1.High accurate RF power meter(NRP8S, <0.56db);
2.Low input VSWR of the circulator from port 2(<1.05), which lead to measurement uncertainty of decay time;
3.High directional coupler for measuring forward power and reflected power(direction >40db), which makes the measurements more accurate;
4. High directional coupler before measurement unit((direction >30db) reduce influence from instrument plug and unplug to RF power meter measurement;
5.High mechanical stability (<5mdb) cable reduce difference of insert loss before and after calibration;
6. Torque spanner are used to reduce human uncertainty.

T-mapping

As a important method to find the defective point on the cavity surface, T-mapping has been developed based on the design from Kyoto University.

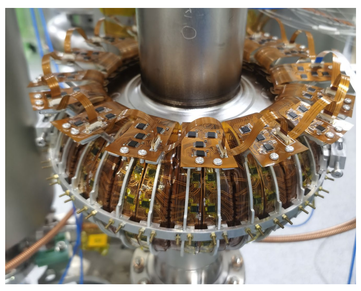

Fig.6a T-mapping on a single cell cavity

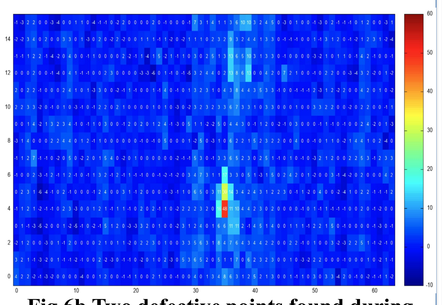

Fig.6b Two defective points found during vertical test

HTF

In the HTF, high direction waveguide directional couplers(>40db) are used to get accurate forward power. The circulator's port2 has a low VSWR(<1.05) to make the decay time measurement more accurate.
Because the high power heating of input coupler will make the Qe change, and it take long time to stabilize, we use Pt(pick-up power) to calculate the Eacc instead of using Pfor(forward power).
The Qt calibration will be done at low forward power(<100W).

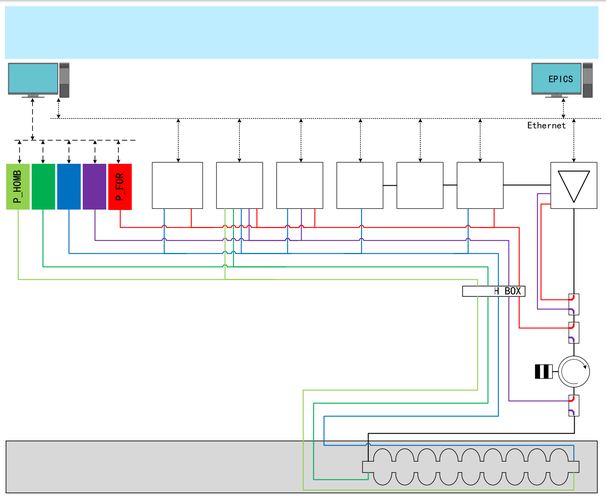

Fig.7 RF distribution of HTF.

$$P = P_0 e^{\frac{-t}{\tau_L}} \quad Q_L = 2\pi f \tau_L \quad Q_e \cong Q_L$$

$$E_{acc} = \frac{1}{L_{eff}}\sqrt{\frac{r}{Q}4Q_e P_{for}} \qquad Q_t = \frac{(E_{acc}L_{eff})^2}{\frac{r}{Q}P_{tran}}$$
$$Q_{homA} = \frac{(E_{acc}L_{eff})^2}{\frac{r}{Q}P_{homA}} \qquad Q_{homB} = \frac{(E_{acc}L_{eff})^2}{\frac{r}{Q}P_{homB}}$$

$$E_{acc} = \frac{1}{L_{eff}}\sqrt{\frac{r}{Q}Q_t P_{tran}} \qquad Q_0 = \frac{(E_{acc}L_{eff})^2}{\frac{r}{Q}P_{diss}}$$

Fig.8 Formula of Q/E measurement in Horizontal test.

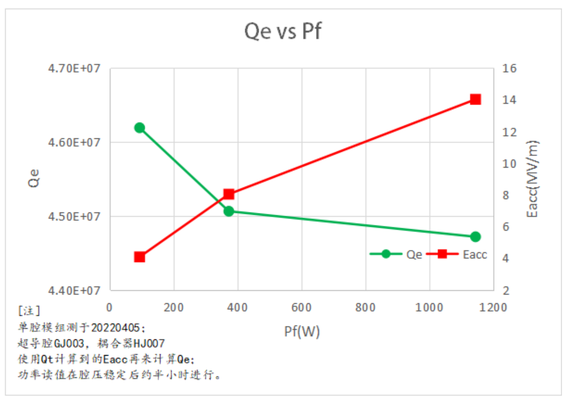

Fig.9 Qe vs Pf

A set of microphonics measurement unit based on PXI has been developed to measure the microphonics of cavities one by one. This unit is also used to measure the precision of the Piezo.

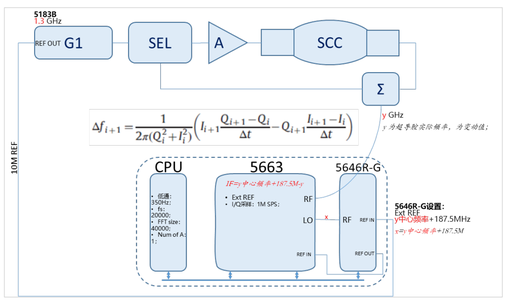

Fig.10 Microphonics measurement unit.

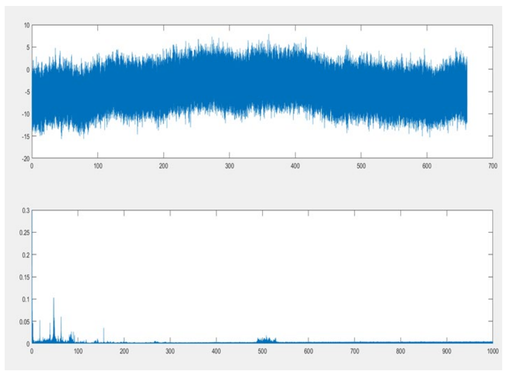

Fig.11 Microphonics measurement result.

CONCLUSIONS

- Two VTF have been built in SHINE to make accurate Q/E measurement during vertical test and over 100 cavities have been tested(some cavities more than one time).
- Two HTF have been built to test two 1.3G eight-cavity cryomodule (CM_BCP, CM_HQ) and one twin-input-coupler cryomodule housing a 1.3G cavity.
- Most test methods have been tried and proved feasible.
- The other two VTFs and two HTFs are under construction.
- Several development are ongoing to make the test more efficiently, changing the RF test and LLRF GUI from LabVIEW to EPICS, developing microphonics measurement and suppression in LLRF, test information system development , etc
- Test sequence will be fixed after a upgrade of the cryostat system for cryomodule test, which will be finished at the end of this month.

ACKNOWLEDGEMENT

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