ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB031

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SRF TRIP CAUSED BY THE TUNER IN BEPCII*

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Abstract

The stability and reliability of the Superconducting RF system (SRF) is generally a key issue in a large scale accelerator such as Beijing Electron Positron Collider II (BEPCII). In the past several years, SRF is one of the main factors limiting the availability of BEPCII, and many efforts have been made to fix the SRF troubles. This paper focuses on the details of the SRF trip caused by the tuner, which is one of the most persistent troubles and figured out till the summer of 2018.

INTRODUCTION

With the advantages of higher accelerating gradient, larger beam pipe and lower RF power consumption, a Superconducting RF system (SRF) has been used in Beijing Electron Positron Collider II (BEPCII) and worked successfully for more than ten years [1]. Yet, the stability and reliability of SRF is not so high and the downtime caused by SRF is one of the main factors limiting the availability of BEPCII [2]. As an example, Figure 1 shows the downtime distribution of BEPCII in the run of collider mode from November 2017 to June 2018. It may be seen that about one-quarter of the downtime is due to the SRF trips [3].

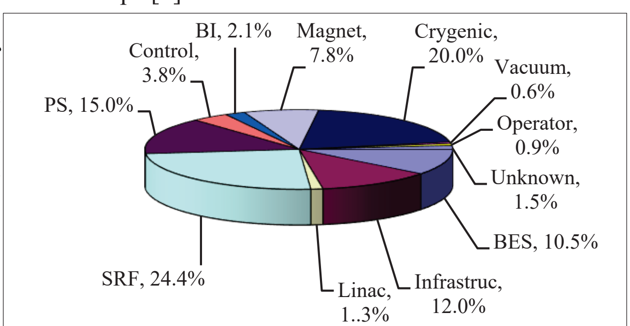

Figure 1: Downtime distribution of BEPCII from November 2017 to June 2018.

The SRF system of BEPCII is a very complicated system, and its trips may come from the beam loss, the failure of the high power RF parts, the outgassing and/or the arc of the SC cavities, the oscillation of the LLRF loops, the interlock of the cooling water and/or air, and so on. To analyse the SRF trips and then reduce the trip rate, the appropriate detection, record and even specialized experiments are needed.

Three types of equipment are of equipment are routinely used to detect and record the SRF trips in BEPCII. One is the control system of the 250kW power transmitter. This system is well developed by THALES and may record most of the trip causes, especially those come from the high power parts, the outgassing and/or the arc of the SC cavities and the interlock of the cooling water and/or air.

The second one is a 16-channel oscilloscope manufactured by YOKOKAWA. This oscilloscope may record at most 16 signals such as the beam current, the accelerating voltage, the loading angle, the forward and reflected RF powers, et al. And, with the trigger function, the oscilloscope can record and show graphically the micro-second scale variations of these signals. By observing the time sequence of the variations of the beam current and the accelerating voltage, it could be distinguished preliminarily which one is the cause of the beam trip, the SRF trouble or the beam loss.

The third one is a bunch-by-bunch BPM system built by BI group. With this system, the cause of the beam trip can be clarified further. Many beam trips have been analysed using the second and third equipment, and the results agree well with each other.

Among the SRF trips, one kind of trip caused by the tuner is the most persistent trouble, and the details will be discussed in the following sections.

TUNER OF BEPCII SRF SYSTEM

The tuning system is an essential part of SRF system to adjust the cavity resonant frequency to the RF frequency during beam operation so as to have a perfect transmission of RF power to the beam. It usually consists of a tuner and tuning loop.

BEPCII adopts a KEKB-type tuner, stretching the cavity to adjust its resonant frequency. Figure 2 is the schematic diagram of the BEPCII tuner [4, 5].

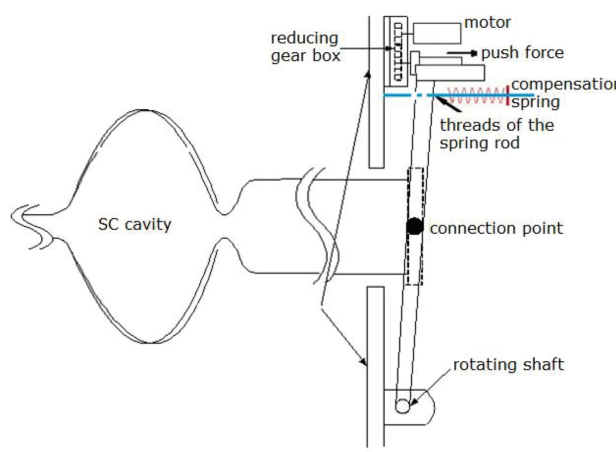

Figure 2: The schematic diagram of the BEPCII tuner.

In practice, the cavity is tuned on the basis of the measured loading angle Ψ_L, between the klystron current and the cavity voltage.

* Work supported by Natural Science Foundation of China (11575216)
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The related equations of the loading angle Ψ_L, the resonant frequency of the cavity f_C, the loaded Q factor Q_L, the shunt impedance R_L, the cavity voltage V_C, the forward power P_f, the beam current I_b and synchrotron phase Φ_S are as follows [6,7,8,9].

$$\tan\Psi_L = \frac{\tan\Psi + Y\cdot\sin\Phi_S}{1+Y\cdot\cos\Phi_S} \tag{1}$$

Where Ψ is the detuning angle of the cavity.

$$\tan\Psi = 2Q_L\cdot\frac{f_C - f_{rf}}{f_{rf}} \tag{2}$$

Y is beam loading factor

$$Y=\frac{I_b\cdot R_L}{V_C} \tag{3}$$

$$P_f=\frac{V_C^2}{4R_L}\cdot\left\{\left(1+Y\cos\Phi_S\right)^2\cdot\left[1+\left(\tan\Psi_L\right)^2\right]\right\} \tag{4}$$

The Robinson beam current limit is

$$I_{b\max}=\frac{V_C\cdot\sin\Phi_S}{R_L\cdot|\sin 2\Psi|} \tag{5}$$

The main parameters of BEPCII SRF system are shown in Table1.

Table 1: Main Parameters of BEPCII SRF System

Parameters	Unit	Colliding Mode
Energy, E	GeV	1.89
Circumference, C	m	240
Energy loss U_0	keV	123
RF freq., Frf	MHz	499.8
Beam current, I	mA	910
Beam power, P_b	kW	112
Gap voltage, Vc	MV	1.5
Impedance R_L	MΩ	19

Controlled by the tuning system, the loading angle of the cavity will maintain a constant value, that is, set value, during beam operation in normal case. Yet, sometimes, the loading angle may be out of control caused by the beam loss, or cavity environment instabilities like pressure fluctuations of helium bath, Lorentz forces and microphonics, or other factors, and then the SRF system will trip.

SRF TRIP CAUSED BY THE TUNER

The SRF trip caused by beam loss is the most common and well understood at BEPCII. Figure 3 shows a typical trip caused by beam loss.

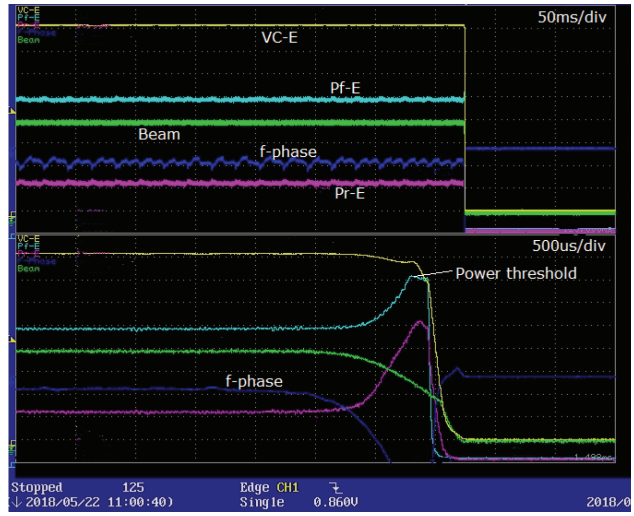

Figure 3: A typical SRF trip caused by beam loss.

This figure was collected and recorded by the 16-channel oscilloscope. In the figure, "VC-E" is the amplitude of the gap voltage of the east cavity (namely the superconducting cavity on the negative electron ring), "Pf-E" is the forward power, "Pr-E" is the reflected power, "f-phase" is the loading angle, and "Beam" is the amplitude of electron beam. The top part of the figure shows a longer trip history, 50ms/div, while the bottom part zooms in the trip history with more details, 500us/div

From Fig. 3 and Eq. (1) ~ (4), we may see that when the beam was lost very fast ("Beam" goes down in Fig. 3), the tuner could not adjust accordingly the resonant frequency of the cavity, so the tuning angle became much smaller ("f-phase" goes down) and the forward power needed became much larger ("Pf-E" goes up), as shown in Fig. 4, then the SRF system tripped when the forward power approached the interlock threshold.

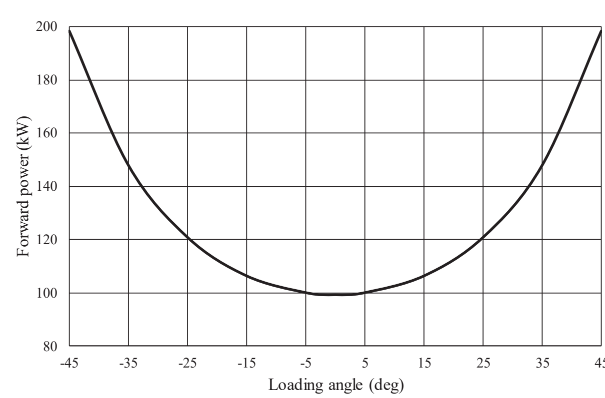

Figure 4: The forward power vs. loading angle of BEPCII @ beam current of 800mA.

Another kind of SRF trip was also occasionally observed and bothered RF people for a long time. In this

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10th Int. Particle Accelerator Conf. IPAC2019, Melbourne, Australia JACoW Publishing
ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB031

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case, the loading angle jumped from the set point of about -5 degree to 0 or positive value, and then the beam was lost and the cavity tripped, as shown in Fig. 5.

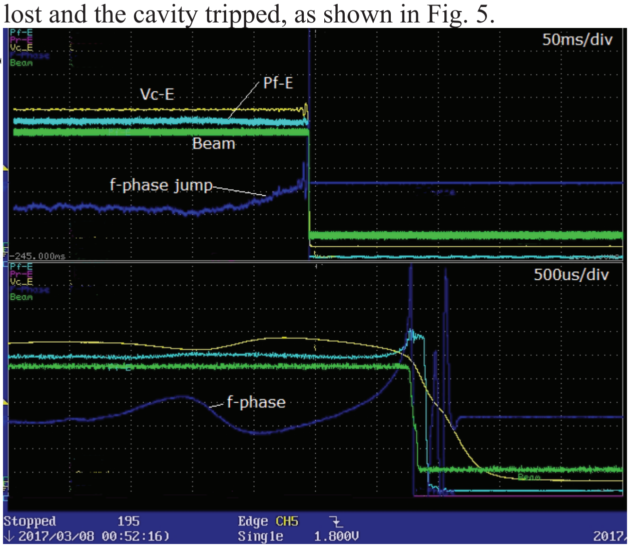

Figure 5: A typical SRF trip with the loading angle jump.

Since Robinson beam current limit drops rapidly for positive loading angle, as shown in Fig. 6, it is easy to understand that the beam will be lost when the loading angle becomes positive. Yet, why the loading angle jumps is a puzzle.

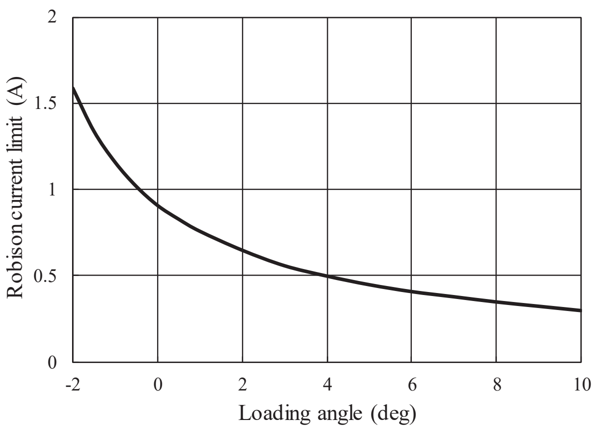

Figure 6: Robinson current limit vs. loading angle of BEPCII @ Vc of 1.5MV and beam energy of 1.89GeV.

At the beginning, the beam phase was doubted to be the cause of this kind of trip. But, the beam current and phase were monitored and founded to be stable before the loading angle jumped, as shown in Fig. 7, i.e. this trip should not be caused by the beam.

Then, after long-term observation and several dedicated experiments, the cavity environment instabilities were cleared of suspicions, and the mechanical part of the tuner became most suspected. In the summer of 2018, the thread of the spring rod was located as the cause of loading angle jump, and the spring rod was changed with a new designed one covered with a Teflon sleeve.

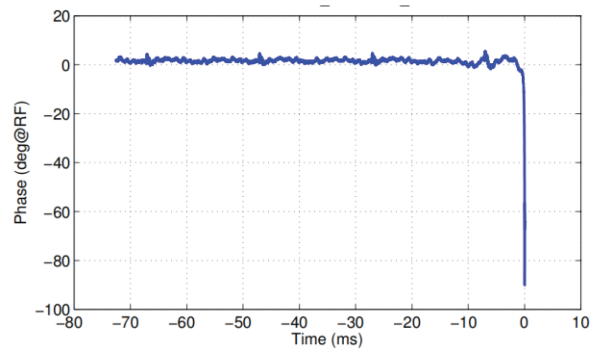

Figure 7: Beam phase monitored to be stable before the loading angle jumped and the SRF tripped.

After the improvement, the tuner arm moves smoothly and none of this kind of SRF trip has been observed till now.

CONCLSIONS

The SRF trips in BEPCII have been analysed and summarized in this paper. Among them, the details of the most persistent SRF trip caused by the mechanical part of the tuner were presented. After the improvements of the tuner, the down time of BCPCII caused by SRF system is expected to reduce remarkably.

REFERENCES

[1] G.W. Wang *et al.,* "Construction of the BEPCII RF System", *Chinese Physics C*, 2008, 32, pp. 169-171

[2] T.M. Huang *et al.,* "Some experiences with BEPCII SRF system operation", *Chinese Physics C*, 2016, 40 (6): 067001.

[3] J.P. Dai, "2017-2018 annual operating summary of RF system of BEPCII", 2018 annual report of BEPC.

[4] Z.H .Mi *et al.,* "A tuning system for BEPCII", *Chinese Physics C*, 2013, 37 (8): 087003.

[5] Z. H. Mi *et al.,* "Review on the operation of 500 MHz superconducting cavity made in china in BEPCII", *High Power Laser and Particle Beams*, 30 (8): 085103, 2018.

[6] P.B. Wilson, "High energy electron linacs: applications to storage ring RF systems and linear colliders", SLAC-PUB-2884 February 1982 (A).

[7] P. Krejcik *et al.,* "RF feedback for beam loading compensation in the SLC damping rings", in *Proc. 1993 Particle Accelerator Conference (PAC1993)*, Washington, D.C, USA, pp. 2370-2372.

[8] F. Pedersen, "Beam Loading Effects in the CERN PS Booster", *IEEE Trans. Nucl. Sci.* NS- 22, No.3, June 1975, pp. 1906-1909.

[9] K.W. Robinson, "Stability of beams in radiofrequency systems", CEAL-1010, Feb. 1964.