Beam trip diagnostic system at SSRF

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Abstract In this paper we report the design and realization of beam trip diagnostic system at Shanghai Synchrotron Radiation Facility (SSRF). The system can find out the first fault signal in the key operation signals related to the RF system by analyzing the time sequence, also it can decide which trips occurs first among the three superconducting RF stations. All the states of monitored signals in a time period ahead and behind beam trip are recorded. The results are compared with those from other diagnostic tools at SSRF. The work is of help in improving reliability of the superconducting RF system and stability of the storage ring operation.

Key words Trip, Shanghai Synchrotron Radiation Facility (SSRF), Radiation frequency (RF)

1 Introduction

Superconducting RF modules are adopted in the storage ring of Shanghai Synchrotron Radiation Facility (SSRF)[1]. A beam with excessive drift in position will trip off the RF system, and the beam trip problem in each RF system must be monitored by identifying which is the first fault signal and judging which system the fault signal comes from. It is important to identify a fault signal related to the RF system when beam trip happens[2]. Key signals of beam current, quench detector, machine protection signal etc, are monitored and recorded by the beam trip diagnostic system.

For beam trip diagnostics, the system should be able to (1) distinguish the first fault signal correctly and quickly and display directly to operator; (2) trace and indicate various causes of beam trip clearly; (3) record as much as possible information of fault signals and other monitored signals; and (4) record and save status of key signals for a period of time overlapping the beam trip, so as to improve the system reliability. In this paper, we report beam trip diagnostic tools for the superconducting RF (SRF) modules of SSRF.

2 Design of the beam trip diagnostic system

2.1 Recorder selection

The monitoring signals are of different time resolutions, from ms vacuum signal to μs quench protection signal. Therefore, the recorder must be selected properly, with storage device, of multi-channels and fast sampling rate, working in trigger mode or continuous mode. The Dimension 4i recorder[3] has the following specifications that satisfy requirement for the RF system:

(1) Maximum sampling rate, 200 kS/s, which is enough to analyze the ms signals. Two sampling rates can be set for signals of different time resolution.

(2) Continuous mode or trigger mode. It performs continuous recording until the hard disk is full or starting record by the multi-trigger. This is convenient during the beam test and operation, without the need of restarting the recorder software until the multi-trigger value is reached.

(3) Analysis on-line and off-line. The data analysis can be done while recording, and post-process

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software (Perception) is provided for off-line data analysis.

(4) A maximum of 16 channels, which is enough at present for one superconducting RF station.

2.2 Monitored signals selection

The interlock of SSRF is to shut off the RF power on occurrence of a beam trip wherever it is caused For monitoring the superconducting RF systems, the key signals include:

(1) Bean current I_b, which is introduced from a BPM (beam position monitor) and transformed into voltage signal for recording. It is used as the trigger signal for all recorders on one time base. The first fault signal, and the fault RF system, is judged by the time ahead or behind the trigger.

(2) RF pick-up power P_t, which is related to the cavity voltage and indicates status of the cavity.

(3) Forward RF power P_f from the waveguide coupler, and it indicates status of the amplifier.

(4) Reflected RF power P_r, to show tuning status of the cavity.

(5) Quench protection signal V_{quench}. A quench signal is sent by the quench detector when quench conditions are fulfilled.

(6) Analog and protection signal of RF window pressure P_{pob}, which indicates status of the high power RF window.

(7) Helium vessel pressure P_{he}, which indicates the power dissipated in the superconducting cavity. If real quench happens, the pressure will increase.

(8) SRF cavity arc signal *ARC*, to indicate an arc at the waveguide input coupler, so as to avoid an RF vacuum window break down by discharges.

(9) Beam orbit interlock *Orbit*, which indicates the beam position fault.

(10) Round beam tube pressure P_{rbt}, vacuum of the superconducting cavity will be worsening if it is hit by the beam bunches or synchrotron radiation.

(11) SRF module ready signal *readychain*, to indicate that the superconducting modules are ready for applying RF power.

(12) Machine protect signal *MPS*, which is composed of several hundreds of signals from other systems and input to the power source. It indicates the beam trip caused by other systems.

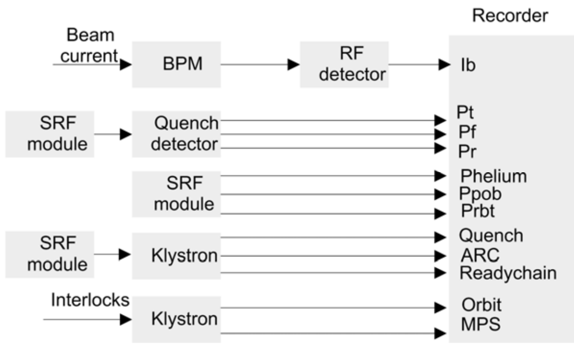

Fig.1 Design scheme: layout of monitored signals and recorder.

2.3 Design and realization

The monitored signals can be divided into analogy signals and digital protection signals obtained from the interlock klystron system. Fig.1 shows the design scheme. The recorder is set to work at trigger mode, and time period is selected about several seconds ahead and behind the trigger, the sampling rate is set to maximum and the trigger number is set to above ten. The trigger pulse has a rising edge and trigger level is set related to the beam current voltage. The hysteresis is used to avoid the error trigger brought by the measurement errors at several mVs.

2.4 Other diagnostic tools at SSRF

In addition to the fast speed recorder, we have two more diagnostic tools: the interlock system of the Thomson amplifier and the RF PLC interlock system.

The Thomson amplifier makes the RF signal and output RF power high enough for diagnosis of the beam. There are some spare channels for interlock signals such as MPS, Orbit and 5 fast interlock signals from SRF module to shut off RF power. The first fault signal is indicated by a red blinking LED on the panel or by the alarm handler. The Thomson amplifier finds a first fault signal easily, but it provides no information about the time when beam trip happens, and it cannot distinguish which SRF station trips first.

The RF PLC interlock system controls and protects equipments other than the SRF modules, e.g. the gate valves on both sides of SRF module, and operation mode of SRF module. It spots the first trip SRF station, but does not judge the fault signal, or save the signal and beam information.

3 Operation results

The beam trip diagnostics system has been in operation for over a year, and its diagnostic results, have agreed with the other two diagnostic tools. Although it cannot tell the first fault signal without analyzing the signal time sequence, it saves and provides lots of information of the signals and beam when the trip happens. Some operation results of typical trip causes are reported below.

3.1 Beam trip by RF window vacuum

Fig.2 shows the beam trip happens when beam current is about 200 mA when the RF window vacuum became worse. It can be seen clearly that the first fault signal is Ppob of Cav1 and first trip SRF station is Cav1 by analyzing the time sequence. The time ahead of the trigger is 364 μs, 251 μs and 244 μs for Cav1, Cav2, and Cav3, respectively, while the same result that the first fault is Ppob is given from the other two diagnostic tools. The waveform indicates that when Cav1 tripped, the other two stations tripped, too, by quench signal that is shown as first fault signal in the Thomson interlock system. The RF interlock system shows Cav1 is the first trip SRF station.

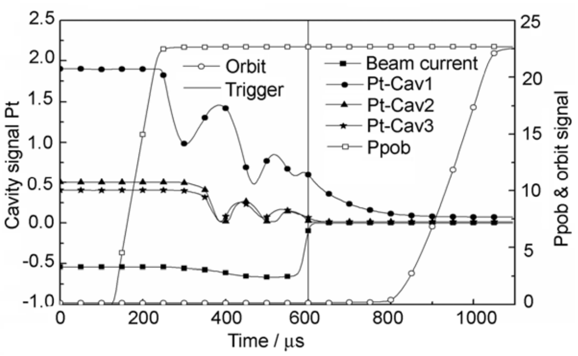

Fig.2 Beam trip by RF window vacuum of first SRF station.

3.2 Beam trip by Orbit interlock

Fig.3 shows beam trip caused by Orbit interlock signal. Analysis of the signal time sequence shows the RF powers are lost at respectively about 4.83 ms, 4.58 ms, and 4.79 ms behind the beam trip and the state of Orbit interlock changed before the RF power signals. Thus the Station 2 SRF tripped first and the first fault signal is Orbit interlock signal. The same result is obtained from the other diagnostic tools. It can be found that the RF power signal waveforms are different from the case tripped by RF window vacuum.

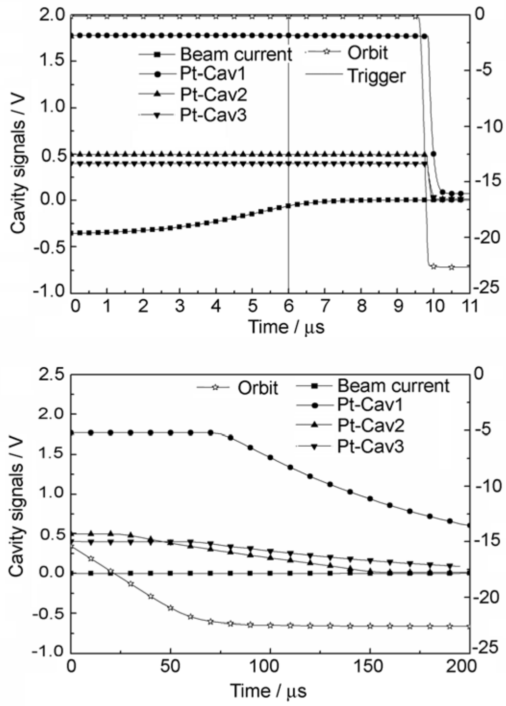

Fig.3 Beam trip by orbit interlock signal. Right side is the signals in detail behind trigger.

3.3 Beam trip by machine protection signals

There are hundreds of signals for machine protection needs of kicking the beam off, such as temperature of the beam absorber, insertion devices, vacuum chamber in the storage ring, etc. Finally only the sum signal and machine protection signals are input to the interlock system of the Thomson amplifier. Fig.4 shows this beam trip event. The MPS signal changes states at 474 μs before the trigger, and the three SRF stations trigger at 300 μs, 290 μs, and 276 μs. Thus the first tripped SRF station is Cav1 and first fault signal is MPS. These agree with the outcome of the other two diagnostic tools.

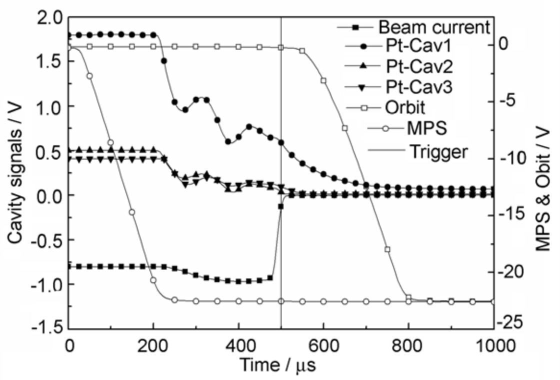

Fig.4 Beam trip by machine protection signal.

3.4 Beam trip by cavity quench signal

Fig.5 shows beam trip by cavity quench signal. The time stamps ahead of trigger are 297 μs, 284 μs and 220 μs, respectively, thus the first fault signal is quench and the first trip station is Cav1. However, there was no temperature increment on niobium cavity or pressure increment in helium vessel observed. It can be seen that the voltages of pick up and forward power and reflected power of all three cavities had fluctuation before cavity quench. Therefore, the quench should be caused only by this fluctuation until it fulfilled the condition of quench detector rather than a real quench.

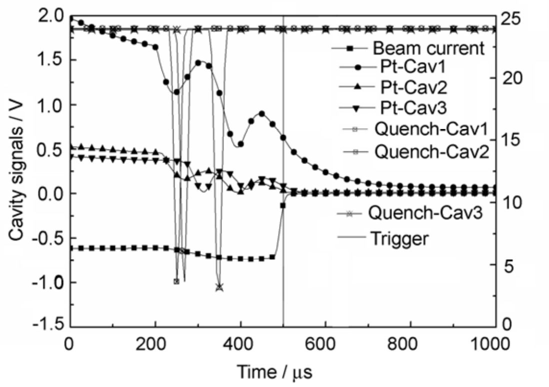

Fig.5 Beam trip by cavity quench signal.

4 Conclusion

The beam trip diagnostic system has been designed, realized and operated well at SSRF. It can identify the first fault signal and first tripped SRF station. Also, it can provide lots of information of beam and monitored signals. It can be a help of improving the reliability of superconducting RF system and the stability of beam operation.

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