PERFORMANCE OF THE SRRC/TLS STORAGE RING RF SYSTEM

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Abstract

The 1.3 GeV TLS storage ring rf system is a 500 MHz system consists of two single cell cavities. It provides a total rf power of 120 kW at 800 kV gap voltage for acceleration and compensation of radiation loss. Since the first operation in March 1993, it has an accumulated operation time of more than 10,000 hours. In the first two years of operation, the system had been running smoothly. However, occasional crowbar fires in one transmitter had occurred. The cause of this problem has been found out and was eliminated recently. It is due to resonances between klystron electron gun and the output circuit of high voltage power supply. In order to reduce the strengths of possible multibunch instabilities, damping antennae were installed in the cavities. However, multibunch instabilities were still significant. Observed longitudinal coupled-bunch instabilities have in general a threshold current of only a few milliamperes. Highest beam current ever achieved is 500 mA at 800 kV gap voltage.

1. INTRODUCTION

The 1.3 GeV TLS storage ring rf system has two single cell cavities driven by their own rf power plants. It provides a total gap voltage of 800 kV for acceleration and to compensate beam radiation loss at a nominal beam current of 200 mA. Major design parameters are listed in Table 1.

Nominal frequency	499.654 MHz
Harmonic number	200
Number of cavities	2
Effective shunt impedance per cavity	3 MΩ
Transit time factor	0.587
Unloaded quality factor	37000
Maximum power per cavity	50 kW
Maximum gap voltage at zero beam current (2 cavities)	1100 kV
Operating gap voltage (2 cavities)	800 kV
RF power installed (each station)	60 kW
Klystron power supply (each klystron)	130 kW
Synchrotron phase angle @ 800 kV	5.2 degrees
Synchrotron tune @ 800 kV	1.15×10^{-2}
Quantum lifetime	> 1000 hours

Table 1. Major parameters of the TLS RF System.

2. RF SYSTEM PERFORMANCE

The storage ring rf system consists of two identical 60 kW rf stations. The cavities, transmitters, low level rf systems, high power transmission systems and cooling units in both stations are identical but independently controlled and operated. The main advantage of two independent rf stations for the storage ring is that one system can still be operated in case of the other system is in failure. Also, there is no need for a power splitter, thus eliminating the risk of cross talk of high order modes of the cavities via the waveguide system. Phasing between the two cavities can be done with a low power phase shifter. Therefore, distance of separation between the cavities can be arbitrary. Instead of WR1800 waveguides, EIA 6-1/8″ coaxial lines are used for the high power rf transmission system. They are much cheaper and also easier to work with. Since the system is limited to 60 kW, commercial TV klystrons can be used as the rf power source. The voltage to drive the klystron can be limited to below 30 kV, which is space economic and easier to build. Layout of the system is shown in Figure 1 in next page.

2.1 RF Cavities

Doris cavities with damping antennae are used in the rf system to reduce the Qs of some high order modes [1]. These cavity bodies and damping antennae were bought from DESY. According to the original designs, components such as pick-up loops, tuners and rf windows (couplers) were fabricated by ITRI/ERSO in Taiwan under the guidance of the rf group staff. With resistive part of beam loading is taken into account, the coupling ratio of each rf window was adjusted to 1.23. Both cavities had been baked to 250°C in laboratory and to 150°C after installation in the tunnel. Both cavities had been conditioned to 50 kW CW before use. The pressure after long term operation is $\sim6\times10^{-10}$ torr. RF system trips off due to bad vacuum condition inside the cavities are seldom occurred. However, significant outgassing can still be observed from ion gauge when the cavities are operated near the multipacting thresholds at 500 W and 20 kW. In case we need to operate near these thresholds, rf trips due to vacuum over pressure can be avoided by slow processing at these power levels for a few minutes.

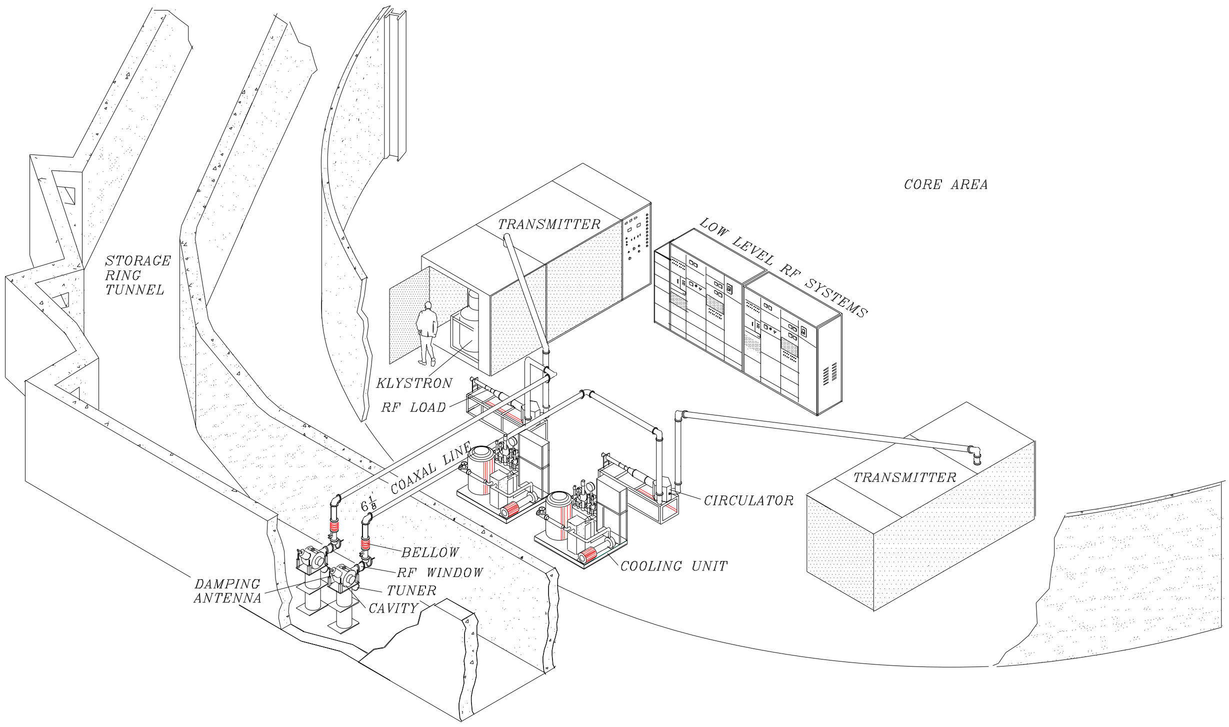

Figure 1. Layout of the SRRC/TLS RF System

2.2 RF Power Systems

RF power from the klystrons are transferred to the cavities in the tunnel through 6-1/8″ coaxial lines. ANT 75 kW circulators, with 80 kW load resistors connected, were added to ensure good matching as seen by the klystrons under all cavity tuning conditions. Reverse powers from cavities can be absorbed by the loads. Transmitters were built by Dr. Larry Barnett of Mountain Technology. Since the power of each transmitter is limited to 60 kW CW, commercial TV klystrons can be used. The Varian VKP-7953S integral five-cavity klystrons (a modified version of VKP-7553S TV klystron) are used. The klystron 25 kV high voltage DC power supply is a 12 pulses transformer/rectifier that allows an output filter capacitor with minimum stored energy of about 500 Joules as well as surge limiting. This design adds safety and reliability to the power supply and klystron. The output regulation is done by controlling saturable reactors at the three phases of power line. Excellent regulation demonstrated by varying klystron current from one to five Amperes and observing that the output voltage depresses less than 0.04% that is the resolution limit of the metering circuit. Measured high voltage ripple level at klystron cathode is 2 to 5 volts peak-to-peak. It consists of components at 60, 120 Hz etc.. The measured cavity voltage spectrum shows the sidebands are all below –60 dBc (Figure 2).

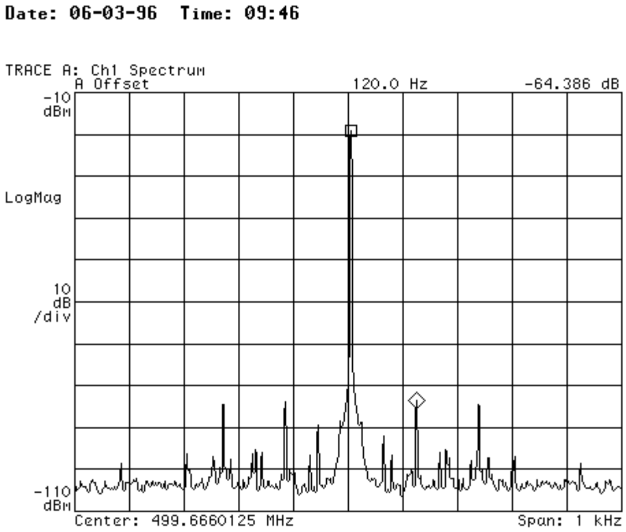

Figure 2. Spectrum of rf signal picked up from cavity

Fast crowbar units were installed in parallel with the power supply output to protect klystrons from damages due to overvoltages or klystron internal instabilities.

Crowbar test circuit activated and observed with a high voltage probe and storage scope. The voltage decrease rate, as measured at the klystron cathode, was observed to be very fast, less than 100 nsec. which is the limit of the measurement. After two years normal operation, one of the transmitter had excessive crowbar fires (three to four times per week on average) triggered by klystron cathode and body overcurrent monitoring circuits. These problems were finally traced back to resonances between the klystron electron gun and the output circuit of power supply at about 1 MHz and 50 MHz. It has been corrected recently by putting ferrite beads on the anode leads and replacing one of the high voltage resistor in the power supply that have different parasitic inductance.

2.3 Low Level RF Systems

The low level rf systems were designed and constructed by SLAC Microwave Engineering Group. Each of these systems provides the following functions:

1. regulation of gap voltage amplitudes
2. phase control of cavity voltages
3. cavity tuning control.
4. damping synchrotron oscillations during injection.
5. rf system monitoring and protection.

In order to avoid interactions of beam coherent synchrotron oscillations with these feedback loops, the gap voltage amplitude and phase control loop have unity gain bandwidths of 7 kHz and 2 kHz respectively. Since cavity tuning control loop has mechanical component (cavity tuner) involved, it has a unity gain bandwidth of 1 Hz. An offset of cavity tuning angle can be set for Robinson damping. In user shifts, the offset is set at zero since beam loading of the cavities at 200 mA is not heavy. Although the synchrotron oscillation feedback loop was installed, it is not in use because energy oscillation due to injection energy mismatch is, in general, not so large.

3. MULTIBUNCH INSTABILITIES

Although cavities are equipped with damping antennae to reduce the Q values of some high order modes, both longitudinal and transverse coupled-bunch instabilities are still significant. In normal operation condition, transverse instabilities are damped by the transverse feedback system [2]. Previous studies of longitudinal coupled-bunch instabilities [3] show that a 740 MHz signal was observed from the reverse power of one cavity. It is the TM_{011}-like cavity mode excited by the bunched beam. Longitudinal coupled-bunch modes with frequencies in the vicinity of this cavity mode were found ~20 dB higher than the others. Measured threshold currents of these troublesome modes are about a few milliamperes. The most significant mode has a maximum saturated amplitudes of ~20 dB in compare with the rf carriers. It corresponds to a phase modulation of 6° to the rf carrier. The total effects of these modes is ~12°. Also, it was found that the amplitudes of these modes change with time at a period of about several milliseconds. As a result, the brightness of synchrotron radiation emitted by electron beam in the nonzero dispersion region also has the same slow temporal variation.

With transverse feedback turned on, the highest beam current ever achieved is 500 mA at 800 kV gap voltage. Although vacuum condition became poor, further increase of beam current was still possible and was not limited by longitudinal coupled-bunch or beam loading instabilities.

4. UPGRADE ISSUES

For higher beam stability, damping antenna will be replaced by a second cavity tuner. Besides controlling cavity water temperatures, this auxiliary tuner adds another degree of freedom for shifting resonant frequencies of cavity high order modes. This approach will be tested in the near future. Longitudinal feedback is also under studies and considered to be the ultimate way to damp longitudinal rigid bunch dipole motions.

To increase beam lifetime, adding a 1.0 or 1.5 GHz passive Landau cavity to the rf system is also under study.

5. REFERENCES

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