Description and Procedure for RF Conditioning and High Power Tests of HINS Room Temperature Cavity RT-CH-1

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July 16, 2007

Introduction and System Description

<u>Cavity assembling.</u>

Cavity vacuum assembly takes part in a class 100 clean room. All parts are washed with alcohol and blown off with dry nitrogen before assembling. A care is taken to minimize the ingress of dust and contaminants inside the cavity. All cavity openings are flanged off or covered with vacuum grade, oil free clean aluminum foil unless otherwise required for assembly. The tuners, power coupler, pick-up antenna in the cavity, pick-up loop in the power coupler, the beam-pipe blank flanges are all fitted at this stage.

The complete sealed assembly is leak-check with helium before moving to the cavity test cave.

<u>The cavity test cave.</u>

The cavity assembly is then made ready for high-power testing by fitting the water pipes, vacuum pump, vacuum gauge, control and tuner actuators wiring in cavity test cave. The high power RF connection is made after cavity tuning is done, because the power coupler will be used to connect the cavity to network analyzer.

The cavity test cave is an area designated for high power RF tests in HINS R&D Facility in Meson Detector building. The cave meets safety requirements such as interlocks, search/secure and LOTO procedures, to prevent possible exposure of personnel to radiation during processing and operation at high fields.

<u>RF power system.</u>

The high power RF system consists of klystron, circulator, waveguide components, loads and couplers (see Figure 1). RF power is supplied by 325 MHz, 2.5 MW klystron (Toshiba E3740A). A 2.5 MW circulator is used to protect the klystron against high reflected power. Reflected power is dissipated in full power dummy load.

In order to generate the nominal effective voltage of 0.14 MV in RT CH1 cavity, a dissipated pulsed power of about 2 kW is needed with maximum duty factor of <1.5% at 4.5 msec pulse length and repetition rate of 2.5 Hz. However, RT CH1 was initially designed to hold effective voltage of 0.23 MV and peak surface field of about 30 MV/m. The remaining 15 RT CH cavities have been designed for the same peak surface field as well. So, it makes sense to condition and test the cavity at 2x nominal voltage to check overall RT CH RF design, surface and manufacturing quality. Therefore 8 kW of pulsed RF power is required to test the cavity.

The RF power from the klystron is divided into two legs (25 kW and 250 kW) just before the test cave. The leg with lower power of 25 kW can be used for the test.

Initially, the cavity will be driven with fixed RF frequency. The RF source is a general laboratory RF generator that can be easily set manually to the required frequency if needed. A frequency tracking loop can be implemented with reasonable effort should this prove useful.

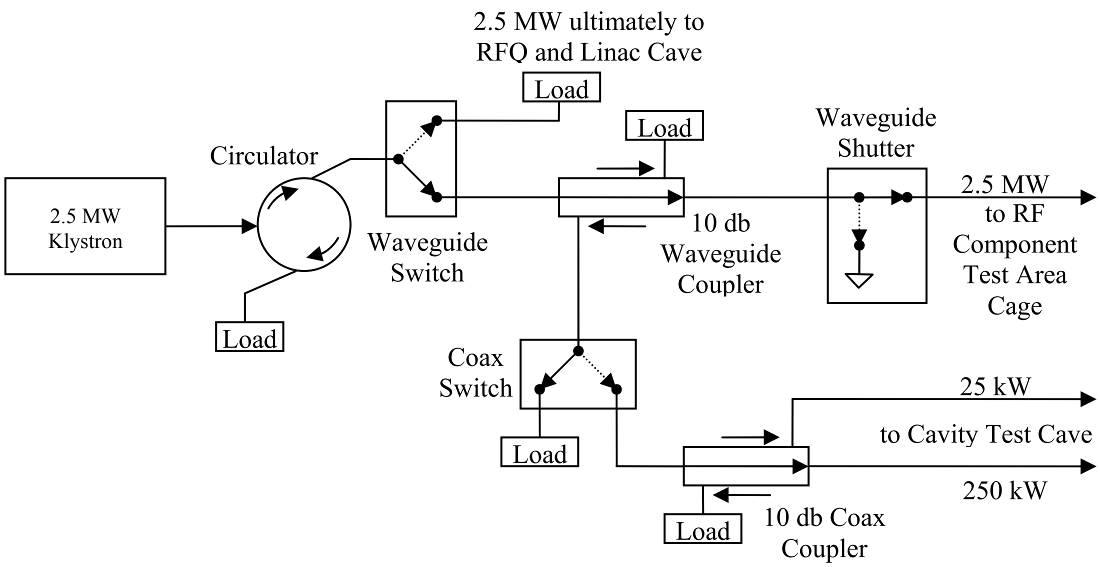

Figure 1. RF Power and Distribution System Diagram

Cooling system.

The cavity is cooled by low conductivity water. The flow of cooling water is about 1 gallon per minute and the inlet temperature is 90° F. Presently the inlet water temperature is not stable and varies about ±2° F with about 30 minute period. The average cavity temperature will be non-stable by the same amount. At a temperature sensitivity of ≈ 3 kHz/° F due to the simple thermal expansion of copper, the water temperature variation would give ±6 kHz cavity frequency change. This is relatively small compared to the cavity bandwidth of 72 kHz.

A result of non-uniform temperature distribution over the cavity is less predictable. The temperature gradient along spokes from base to drift tube depends on RF power level. The temperature rise of the water along the cooling channels from the inlet to the outlet is estimated to be about 1'F for average losses of 120W and water flow of 1Gal/min. It is very difficult to simulate a frequency shift due to this non-uniform heating, so an attempt to measure this thermal detuning experimentally will be made.

The system shall include a water flow switch that will inhibit RF power if water is not flowing through the cavity cooling circuit.

Vacuum system.

A turbo molecular pump is attached to the cavity for pump-down, after which an ion pump alone maintains cavity vacuum. An ionization vacuum gauge and a measure of the ion pump current provide monitors of the vacuum pressure. It would be useful to install a mass filter to measure residual gas spectrum during RF conditioning. Knowledge of the dominant component of the out-gassing from the cavity walls may give us a hint what pre-test surface treatment may be additionally needed (in-situ baking, for example).

A base pressure of $2*10^{-7}$ Torr before application of RF power is acceptable for beginning power tests. The system shall include a cavity vacuum pressure interlock to inhibit RF power.

Monitors and interlocks.

Fast interlocks for vacuum pressure and reflected power from the cavity are integral to the test stand system. These are in addition to the personnel protection interlocks and those interlocks required to protect the RF system itself.

The power reflected from the cavity ends up in RF distribution system loads and does not harm the klystron. However, the reflected power may indicate serious problems such as strong breakdown in the cavity or the cavity going off resonance due to temperature rise etc. The reflected power can double the voltage in the coupler and RF transmission line and can initiate the breakdowns there. A reflected power interlock, monitoring the signal from a directional coupler immediately upstream of the cavity input coupler, shuts off the RF power in such dangerous conditions. The reflected power interlock circuit is active during a time window set by control system timer card channels; these timing channels must be set appropriately to protect the cavity during the 'flattop' RF pulse. The timer must be re-set for each RF pulse length!

The vacuum interlock should be set to inhibit the RF at $5x10^{-7}$ to prevent operation at high power with bad vacuum, which may be hazardous for the cavity surface, coupler and coupler window. If, at the beginning of RF conditioning, trips occur too frequently, the interlock threshold can be raised to $1x10^{-6}$ Torr to start with lower voltage and/or short pulse length. The goal is to condition the cavity to operate at $<5x10^{-7}$ at full power because of the increased power available in case of breakdown.

The parameters that should be monitored during conditioning are RF drive level to the klystron, cavity vacuum, residual gas spectrum (if RGA is available), signal from the cavity, forward and reflected power, the signal from the cavity drive coupler, and cavity body temperature or inlet-outlet water temperature. These parameters will be controlled and periodically recorded with the HINS EPICs control system.

Probably it would be more useful to install a photo-diode detector in the coupler instead of simple pick-up loop to detect low power persistent arcs or glowing at the ceramic window that may indicate defective or contaminated window.

The cavity resonant frequency tuning.

The high power conditioning of RT CH1 will be performed at fixed klystron frequency; water flow rate and inlet water temperature will not be regulated. A phase detector circuit (mixer and low-pass filter) comparing the phase of the cavity drive forward power signal to that of the cavity field probe signal shall be installed and tuned to provide a monitor of the cavity resonant frequency. This circuit shall be in place, operational, and calibrated before power commissioning commences. Initially, it provides monitoring capability only; at some point, it may provide a feedback signal to an automatic frequency tracking loop or resonance control loop. A thermal detuning of the cavity and any other possible detuning will be compensated by the tuning plungers. At the first stage the tuning will be done manually, later a tuner feedback loop will be developed to keep a cavity under test on resonance. The step motors that drive the tuning plungers can be controlled remotely, so there will no interruption in RF conditioning.

Conditioning Procedure

All cavity conditioning and commissioning activities in the HINS 325 MHz Cavity Test Cave shall be conducted according to operational procedures defined in the document "HINS 325 MHz Cavity Test Cave Operations."

The specific goal of the RF conditioning of cavity RT-CH-1 is to achieve 8 kW pulsed input power at 3.5 msec pulse length and repetition rate of 2.5 Hz. The RF conditioning will be controlled manually by an operator.

A general strategy of RF conditioning is maintaining a low intensity and frequency of arcing in a cavity, while avoiding at the same time hard breakdowns and long shutdowns caused by RF trips due to the vacuum and reverse power interlocks. Arcing is a normal part of RF conditioning at high electric fields as small surface imperfections or dust particles are burned off and the frequency of arcs should decrease with processing. Then RF power level may be slowly ramped up while keeping the vacuum pressure below a pre-set threshold because a lot of outgassing occurs when cavity sparks. If the vacuum goes above the threshold, the RF power must be turned down and the vacuum should quickly recover. Once the pressure is good again the operator resumes.

Along with low starting RF power level, a shorter pulse length and a lower repetition rate help to get more controlled outgassing the cavity during initial conditioning. For shorter pulse length, gas is typically evolved in smaller bursts, and larger time between pulses is used to scrub out residual gas. A suitable combination of RF level, pulse length and repetition rate can usually keep vacuum surge below the trip level. This delicate choice depends on skill and experience of operator. Occasionally a larger gas burst or hard breakdowns will trip off the klystron and this just must be manually reset by operator.

The procedure of RF testing and conditioning of RT CH1 shall be as follows:

1. ____ Verify that the operating level of vacuum of $<5*10^{-7}$ Torr is established in the cavity and that the cavity cooling water is flowing.
2. ____ After the cavity temperature is stable, verify the cavity resonant frequency is near to the operating frequency of 325 MHz using a network analyzer connected to the cavity through the drive loop. Frequency adjustment will be made using the tuning plungers if necessary.
3. ____ Verify phase detector circuit operation and calibration.
4. ____ The high power RF connection should be made.
5. ____ The conditioning will be started with an input power of ~500 watt at a pulse length of 10 µsec and repetition rate of 1 Hz or slower.
6. ____ Monitor the cavity vacuum pressure and check reflected power for signs of sparking.
7. ____ Slowly increase power level to 4 kW with the 10 µsec pulse length. If vacuum pressure deteriorates to $1*10^{-6}$ Torr or sparking becomes evident the power level should be reduced by ~10% until the vacuum improves and the sparking rate is reduced to <1 per 10 pulses. If vacuum does not improve or

sparking continues at high rate, experts must evaluate the situation and determine how to proceed.

8. ____ When 4 kW is achieved at 10 μsec RF pulse length, increase RF pulse length in sequence below, **adjusting reflected power interlock timer settings accordingly at each pulse width**. Verify that acceptable vacuum pressure and spark rate can be achieved at each step before proceeding to next. Monitor phase detector circuit to assure that RF heating of the cavity does not push the cavity resonance too far from the drive frequency; if phase exceeds +-15 degrees, adjust RF generator frequency in 1 kHz steps to return phase to nominal. Anytime vacuum does not improve or sparking continues at high rate, experts must evaluate the situation and determine how to proceed.

    ____ 20 μsec at $< 1*10^{-6}$ Torr, < 1/10 spark rate and phase <±15 degrees

    ____ 50 μsec at $< 1*10^{-6}$ Torr, < 1/10 spark rate and phase <±15 degrees

    ____ 100 μsec at $< 1*10^{-6}$ Torr, < 1/10 spark rate and phase <±15 degrees

    ____ 200 μsec at $< 1*10^{-6}$ Torr, < 1/10 spark rate and phase <±15 degrees

    ____ 500 μsec at $< 1*10^{-6}$ Torr, < 1/10 spark rate and phase <±15 degrees

    ____ 1 msec at $< 1*10^{-6}$ Torr, < 1/10 spark rate and phase <±15 degrees

    ____ 2 msec at $< 1*10^{-6}$ Torr, < 1/10 spark rate and phase <±15 degrees

    ____3.5 msec at $< 1*10^{-6}$ Torr, < 1/10 spark rate and phase <±15 degrees

9. ____ Reduce pulse to 10 μsec and slowly increase power level up to 8 kW and repeat pulse length increase as in Step 7 above. If vaccum pressure or sparking is problematic at 8 kW, proceed through Step 7 at intermediate power level as an additional stage for approaching 8 kW.

10. ____ Once full power of 8 kW at 3.5 msec pulse length and repetition rate of 2.5 Hz (or lower if limited by modulator charging power supply capacity) is achieved, operate the cavity at this level for 8 hours to verify that the vacuum improves to $< 2*10^{-7}$ Torr and that the cavity can run for this extended period without tripping.

Subsequent Operating Procedure

After the RF conditioning goals are achieved, it is permissible to operate the cavity at any power level within the achieved conditioning range for additional cavity performance and sensitivity measurements or for low level RF and cavity resonance control system development purposes.