Description and Procedure for RF Conditioning and High Power Tests of HINS Room Temperature CH Cavities

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Introduction and System Description

The Cavity Test Cave

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

The completed cavity assembly is leak-checked with helium after moving to the cavity test cave. The cavity assembly is then made ready for high-power testing by connecting water, vacuum pumps and gauges, tuner control wiring, the high power RF directional coupler and cable, and low-level RF signal cables.

RF Power System

The high power RF system consists of klystron, circulator, waveguide components, loads and couplers as shown in Figure 1. RF power is supplied by a 325 MHz, 2.5 MW, Toshiba E3740A klystron. A 2.5 MW circulator protects the klystron from high reflected power. Reflected power is dissipated in a full power dummy load.

The RF power from the klystron is divided into two legs (25 kW and 250 kW) just before the test cave. The leg with the lower power of 25 kW shall be used for all the RT-CH cavities for which that power is sufficient. Cavities #12-16, whose nominal operating power exceeds 25kW, might require testing using the 250 kW line.

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

Cooling System

The cavity under test is cooled by low conductivity water at a flow of about 1 gallon per minute and inlet temperature of approximately 90° F. The nominal LCW system water temperature varies about ±2° F with a period of approximately 30 minutes. Without additional water temperature regulation the average cavity temperature will vary accordingly. A temperature sensitivity of ~3 kHz/°F, due to the thermal expansion of copper, would yield a ±6 kHz cavity frequency change for this water temperature variation. This range is relatively small compared to the cavity bandwidth of ~75 kHz. A water heater and water temperature sensor are mounted near the cavity water inlet and can be implemented as elements of a local inlet temperature regulation loop as needed.

Resonant frequency variation as a result of non-uniform temperature distribution from RF heating in the cavity is difficult to simulate and predict. A temperature gradient will exist along the spokes from drift tube to spoke base. The resonant frequency sensitivity to RF power will be measured as part of the RF power testing. The cooling water

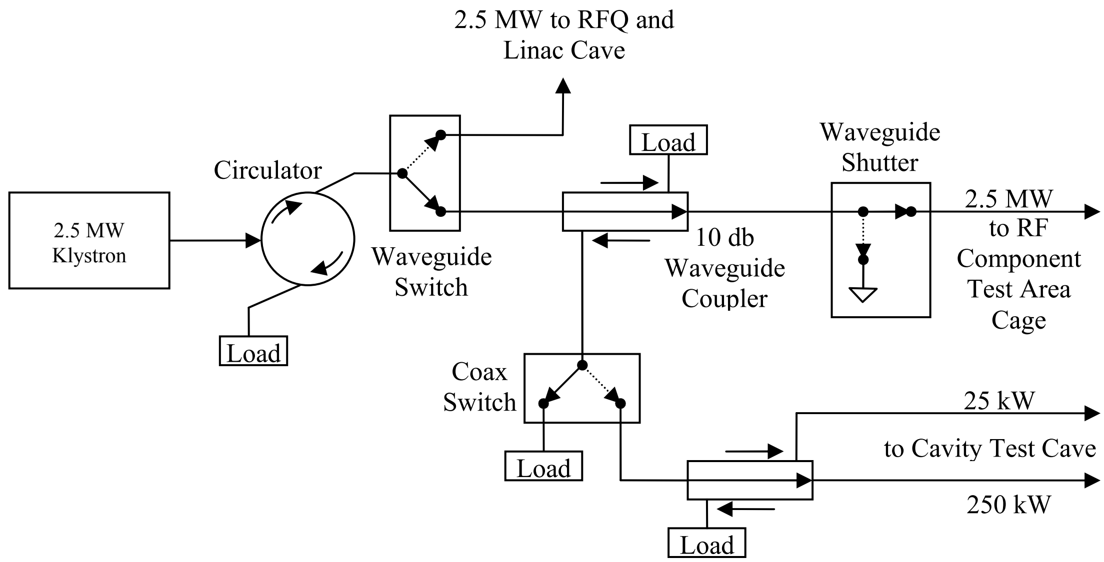

Figure 1. RF Power and Distribution System Diagram

temperature rise between inlet and outlet at the cavity is estimated to be about 1°F for a flow of 1Gal/min at an average RF power loss of 120W.

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 can maintain cavity vacuum. An ionization vacuum gauge and 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 capable of inhibiting 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 protecting the RF power system itself.

Any 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 electrical breakdown in the cavity or the cavity going off resonance. The reflected power potentially doubles the voltage in the coupler and RF transmission line and might initiate 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 potentially damaging 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, as this can 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.

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

The Cavity Resonant Frequency Tuning

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 high-power commissioning commences. Initially, it provides monitoring capability only; at some point, it might provide a feedback signal to an automatic frequency tracking loop or resonance control loop. Detuning of the cavity can be compensated by the mechanical 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 stepper motors that drive the tuning plungers can be controlled remotely.

General Conditioning Procedure Conditions

Prior to the start of RF conditioning for each cavity, a signed approval to commence must be obtained from the HINS program manager or his designee. That approval shall also assign a person who is responsible for execution of this commissioning procedure for the respective cavity. A sample form is provided at end of this document. The signed approval and assignment form shall be placed in the HINS Operating Procedures Book in the Meson Detector Building.

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 each cavity RT-CH cavity is to achieve pulsed operation at a 120% of its unique nominal operating power for a 3.5 msec RF pulse length and a repetition rate of 2.5 Hz. Table 1 specifies the unique nominal operating power for each RT-CH cavity. The RF conditioning process will be accomplished manually by a human operator who is physically present at all times, not by an automatic programmed conditioning routine.

A general strategy of RF conditioning is to maintain a low intensity and frequency of electrical breakdown or arcing in a cavity, while avoiding long interruptions caused by RF trips due to the vacuum and reverse power interlocks. Vacuum activity and even arcing are a normal part of RF conditioning at high electric fields; the rate of breakdowns should decrease with processing as small surface imperfections or dust particles are burned off. RF power is slowly increased while keeping the vacuum pressure below a pre-set threshold. If the vacuum goes above threshold, the RF power must be turned down. As vacuum recovers and the pressure is good again the operation resumes.

Along with low initial RF power level, a shortened pulse length and lowered repetition rate help to control outgassing in the cavity during conditioning. 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.

RT-CH Cavity Number	RT-CH design type	Pcopper kW
1	1	3.1
2	2	6.2
3	3	7.1
4	4	9.6
5	5	8.9
6	5	11.1
7	8	18.8
8	8	18.8
9	8	20.8
10	11	24.9
11	11	24.9
12	11	29.9
13	14	39.1
14	14	35.6
15	16	37.7
16	16	41.4

Table 1. Nominal Operating Power Level for Each RT-CH Cavity

Specific Conditioning Procedure Steps

The procedure for RF testing and conditioning each RT-CH cavity is as follows:

1. ____ Notify the Accelerator Division Radiation Safety Officer that power testing of a new cavity is ready to begin. In general, he will require that a radiation safety technician be present to perform radiation measurements at some stage(s) of the commissioning. Proceed only according to RSO’s instructions.
2. ____ Verify, at nominal cavity temperature, using a network analyzer connected to the cavity drive input, that the cavity resonant frequency is 325 ± 0.020 MHz. Adjust the resonant frequency with the tuning plungers as necessary.
3. ____ Connect the high power RF transmission line to the cavity.
4. ____ Verify calibration of RF power monitors.
5. ____ Verify proper operation of vacuum and reverse power interlocks.
6. ____ Verify that the cavity vacuum is $<2*10^{-7}$ Torr and that the cavity cooling water is flowing.
7. ____ Verify phase detector circuit operation and calibration.

8. ____ Start conditioning with an input power of ~500 watt at a RF pulse length of 10 μsec and repetition rate of 1 Hz or slower.
9. ____ Monitor the cavity vacuum pressure and check reflected power for signs of sparking.
10. ____ Increase RF power slowly, maintaining the 10 μsec pulse length, up to 50% of the nominal operating power specified for the particular cavity under test. 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.
11. ____ When 50% power 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
12. ____ Reduce pulse length to 10 μsec and slowly increase power level up to the specified nominal operating power for the cavity under test. Then repeat the pulse length increase sequence as in Step 11 above. If vaccum pressure or sparking is problematic, iterate at intermediate power levels to achieve full nominal cavity power operation.
13. ____ Repeat above steps to condition cavity up to 120% of its nominal operating power.
14. ____ Once full nominal cavity operating power is achieved 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 for a cavity, it is permissible to operate that 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.

HINS RT-CH Cavity RF Conditioning Approval and Responsibility Assignment

Approval to proceed with RF power conditioning of HINS RT-CH cavity #____ according to the prescribed procedure is granted.

_____________________ is assigned as the person responsible for executing the prescribed conditioning procedure for this cavity.

________________________________ ____________________________

HINS Program Manager or Designee Date