Cryogenic Settings for Testing of the Fully Equipped ESS’ High $\beta$
Cavity ESS086-P01

(Part II)

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1 Background

This report gives the details for this run with ESS’ high beta elliptical cavity ESS086-P01, from the 28th of June to the 11th of September 2018.

The reason to have warmed up after run 10 was because there was no contact to the stepper motor. Two of the phases could be found but not the other two. After checking the connector and the cables on the air side of the feedthrough it was clear that the problem laid inside the cryostat and so HNOSS had to be warmed up and opened. Once it was opened it could be seen that by moving the lemo connector that attaches the motor to the cable inside HNOSS the signal was coming and going even though kapton tape had been used to keep the two parts of the connector together, thus the problem was found to be this connector. Since there was no other lemo connector of the same size available it was decided, prior agreement with CEA Saclay, to directly solder the cables together.

Since nothing else has been changed inside HNOSS, this means that all other connections have remained the same as in run 10, so this report is a copy of [1] and is a continuation of those tests.

2 Modifications

The modifications done for this run are (Figure 1):

a) The scaling factors for FT301 and FT302 have been corrected and now show units in mg/s

b) A new pressure sensor, PT103, has been installed in paralell to PT102. This reading is only available in EPICS.

c) The steps in pressure given by PT102 when calculating heat loads via the pressure rise method in past runs has now been fixed

d) TT146A and TT146B are connected but they are not attached to any surface. These are to check the temperature inside HNOSS when the system is under vacuum and cold. TT146A is sitting on the ceiling of HNOSS on cavity 1’s side and TT146B is sitting close to the VB opening on cavity 2’s side.
e) There are two new valves, FV562 and FV563, placed after the reheater and before PT550 and PT551/PT552. These valves can only be commanded (and seen) via EPICS. These valves are needed to isolate HNOSS for when the cryomodules are tested.

f) The LHe probe connection (VCR type) from last run has been modified by shortening it and adding a CF16 flange (Section 3).

g) The cavity is placed on top of a small table (Section 4)

i) This table is actively cooled with 4K LHe.

ii) The outlet of this table is connected to an independent circuit with its own reheater (EH131) and flowmeter (FT131) [2], only available in EPICS.

h) The cavity heaters EH103A and EH103B (Section 5) are disconnected from the control cabinet. They can be connected to an external power supply and both heaters have two extra wires each to be able to measure the voltage directly at the heater for when calibrating the RF power with heat, each of these extra pairs are connected to EH104A and EH104B.

i) TT04x to TT06x are connected to the CTS, see Section 6.

j) Regarding the FPC (Section 7)

i) The ScHe circuit for coupler 1 has both inlet and outlet inside HNOSS.

ii) TT01x, TT02x and TT03x are connected along its length, together with TT147 and EH107.

iii) There are eight thin film heaters (5 W each) connected in parallel and placed on the grooves of the FPC vacuum side to avoid condensation on this flange and are regulated by EH108 and controlled by TT148. TT144C gives the temperature but does not regulate the heaters while TT144A and TT144B give the temperature on the air-side and the vacuum side of the FPC, respectively.

iv) A fan blowing on the air side of the FPC’s flange has been added to avoid water condensation.

v) A forced flow of warm air has been added to the ceramic’s cooling circuit.

k) As done for last run and have remained the same:

i) The sensors for cavity 2 have also been used for cavity 1 in the same positions as shown.

ii) The ScHe pipes’ input and output for Cavity 2 are directly connected to each other but in between there is a heater glued to a copper plate and inside the pipe there is a copper braid to increase the flow resistance. The heater glued on the ScHe pipe has its output in the control cabinet (cables marked EH(HX)) but are not connected to any power supply.

iii) FT550 is operational and is a Brooks thermal flowmeter with capacity 60 m$^3$/h but the data is only available through EPICS.

iv) CV102 and CV103 have been merged together into one pipe.

v) TT129 is connected at the branch between the 2K tank and SV101.

vi) Since the burnt heaters in the 4K tank have not been changed to new ones EH100AD are disconnected in the control cabinet but the sensors TT140AD are in place.
3 Cavity’s Cryogenic Connections

Only the High $\beta$ elliptical cavity is inside HNOSS for this run, placed to the east (cavity 1) and on a table cooled by 4K LHe as shown in Figure 2(a). The connection to the tee sitting below the 2K tank is, starting at the cavity, first via a bellow with a tailor-made flange on the side that connects to the cavity and a CF63 on the other. Afterwards, a long L-shape pipe with CF63 flanges on both ends and a bellow on the side of the 2K tank connects on one side to the bellow mentioned before and on the other side to the 2K tank tee. To avoid movement during cooldown, pumping or pressurizing that could put stress on the FPC, two clamps with three rods each have been attached to the bellows and tightened to keep the cavity’s position as fixed as possible. The other side of the tee (used to connect to cavity 2) is blinded in steps: the 2K tank’s CF63 flange is connected to a CF63-CF40 adapter which in turn is connected to a CF40-CF16 adapter, this last one blinded with a CF16 flange.

Figure 2. Setup inside HNOSS for this run with a) detail on the connection of the cavity to the 2K tank and b) a sketch of the cooling and LHe probe connections, all CF16 components (drawing not to scale).

The connections to the LHe probe and the cooling line are done via a CF16 flange placed below the cavity, on the FPC side, and are schematically drawn in Figure 2(b). Below this flange, a tee connecting on one side to an extension piece, a 90° bend, a 500 mm long below and an extra extension piece and on the other side to a 500 mm long below (all CF16 sizes) has been added. The first tee extension described meets the VCR-CF pipe for the LHe probe and the second extension connects to the cooling line coming from CV102 and CV103.

The connector sitting on the LHe probe inside HNOSS has been changed from last run: the initial pipe had a VCR connector on the bottom and was made in one piece where it connected to the cavity. Since this pipe was used in runs #8 [3] and #9 [4] and spikes in the level when working at 4K were observed, it was thought this behaviour came from a bending on this pipe so it was decided to modify it. The existing pipe was then cut shorter and a CF16 flange added, thus removing the pipe that was originally connected to it and that had a smaller diameter than a DN16 pipe. The reason not to have used the tee connector that was in place for all runs prior to run#8 and that did not give any problems was due to lack of space.
4 Table Sensors

The table is cooled via a pipe welded on to the table’s profile with 4K LHe coming from the 4K tank, thus it needs to have the usual instrumentation to avoid extra heating and to check the cooling performance. The sensor positions for the table are given in Figure 3(a) [20171205_Table sensors]. For checking the flow there are two dedicated Cernox sensors TT106 for the inlet and TT107 for the outlet while for checking the cooling TT108 and TT109, also Cernox and placed on the short sides of the table, are used. The inlet and outlet of the table are connected to their respective pipes inside HNOSS via 1 500 mm long flexible pipes.

![Figure 3: a) Overview of the location of the instrumentation placed on the table and b) detail of a thin film heater glued on a preformed copper plate together with its corresponding temperature sensor.](image)

For the heating the table has two heaters EH105A and EH105B with their corresponding temperature sensors TT145A and TT145B. Both are thin film heaters that have been glued to copper plates preformed to the shape of the table (Figure 3(b)) and placed on the long sides via screws and tape. The temperature sensors are attached via Apiezon N next to the heaters.

5 Cavity Sensors

The installed temperature sensors are shown in Figure 4 [20171204_Cavity sensors]. All Cernox sensors pertaining to the cavity itself are doubled (the double ones come from cavity 2) and are screwed onto copper blocks that have been glued onto the cavity’s helium tank.

There are also three heaters placed 120° apart that are glued onto preformed copper plates and kept in place via three stainless steel straps. Two of these heaters (EH103A and EH103B) have two extra wires in parallel with the power wires to be able to measure the voltage at the
heater itself more accurately. These extra wires are connected to the wires of EH104A and EH104B, respectively, coming from HNOSS into the control cabinet. This will be necessary when calibrating the applied RF power with electrical heat. As usual, the corresponding Pt100 temperature sensors are fixed in place via Apiezon N and kapton tape close to these heaters.

Figure 4: Temperature sensor positions on the cavity’s a) left, b) right, c) top and d) below when looked at from HNOSS’ door.
6 CTS Sensors

There are three Cernox sensors placed in the CTS, as shown in Figure 5 [20171204_Cavity sensors]. The one on the horizontal top bar is AA type so it is inserted in a copper block glued to this bar; another one (CD type) is directly screwed on the horizontal lower bar and the last one (also CD type) is directly taped to the motor. The original motor cables AWG 26 that go to HNOSS’ feedthrough have been exchanged for teflon insulated wire cables AWG 22, procured by CEA Saclay, as the current through the motor is four times higher (2.4 A) than for Romea (0.6 A). These cables have been taped to the thermal shield to improve their cooling and attach to the stepper motor via a lemo contact, also provided by CEA Saclay.

![Figure 5: Overview of the location of the temperature sensors placed on the CTS.](image)

Compared to Romea’s CTS, the number of sensors in this case is much less due to the fact that, after discussions with CEA Saclay, it was mentioned extra sensors were not needed and most importantly, none could be placed on the piezos themselves.

7 FPC Sensors

The installed temperature sensors in the FPC are shown in Figure 6 [20171204_Cavity sensors]. There are three Cernox sensors (from TT04x to TT06x) in the FPC body. These Cernox sensors (AA type) are inserted into copper blocks that have been glued to the surface. Also in the body of the FPC there is a heater EH107 glued onto a preformed copper plate with its corresponding Pt100 sensor TT147, held all in place by kapton tape.

There are two extra Cernox sensors for the ScHe cooling circuit: one at the inlet (TT303) and one at the outlet (TT305) as shown in Figure 7. Because of the outlet being so low inside HNOSS, a 90° bend has been added to avoid being in contact with the thermal shield. Both pipes connecting inlet and outlet to their corresponding pipes inside HNOSS are 1 500 mm long flexible pipes.
To avoid condensation on the FPC’s flange, CEA Saclay used four heaters KHLV-0502/10 rated at 10 W/28 V each connected in parallel. At the time of purchase only 5 W heaters with the same dimensions were available, so the number of heaters was increased to eight. These heaters have been joined in parallel and glued on the walls of the grooves the FPC has (Figure 8(a)) and are connected to the EH108 connector inside HNOSS and to an external power supply in the control cabinet. In the FPC’s flange two rings can be distinguished, thus two temperature sensors TT144C and TT148, located close to the heaters with a low resistance value, give the temperature reading but only TT148 is used for regulation. In order to have an idea of the general temperature of the coupler inside and outside HNOSS two Pt100 temperature sensors of the ceramic type have been used: TT144B is inside HNOSS while TT144A is on the air side (Figure 8(b)).

Figure 6: Temperature sensor positions on the FPC’s a) left, b) right and c) back when looked at from HNOSS’ door.
Figure 7. Temperature sensor positions on the FPC’s a) inlet TT303 and b) outlet TT305 to regulate the ScHe circuit for the cooling of the FPC.

To further avoid condensation on the FPC’s ceramic window, a home-made forced air flow with heated air has been connected to the inlet of the ceramic cooling circuit (Figure 8(b) and 9). This circuit has a copper pipe section with a copper wire mesh inside that is connected to an external power supply. For the same reason a standard air fan to blow on the air side of the FPC’s flange has been added.

Figure 8. a) Detail of the heaters glued on the FPC’s flange indicating the resistance and the temperature sensor’s location inside HNOSS (TT144B, TT144C and TT148) and b) TT144A outside HNOSS as well as the inlet to the ceramic cooling circuit.
8 Helium Level Probe Distances

The measured heights between the different parts inside HNOSS are shown in Figure 10, where also given are the estimated levels for the LHe probe LT101. These levels are calculated for an active length of 1536 mm for the probe.

Figure 10: Distances for the LHe probe and some estimated levels for LT101 (drawing not to scale).
9 Beam Vacuum Gauges and Connections

Because the high $\beta$ elliptical cavity has only a penning gauge IKR070 attached to the FPC to control the pressure, it was decided to use an existing pirani gauge TPR018, placed close to the cavity, as a relay for switching to the penning. This pirani gauge is sitting on the beam vacuum pumping group before the gate valve and, for its use together with the penning gauge, the card in TPG300-4 unit CP300 C10 has been exchanged for a CP300 T11. The details of all vacuum gauges and their connections are given in Figure 11.

As the pumping port for the beam vacuum sitting on the cavity is on the VB opening side, two 1000 mm long bellows, a 90° bend and another 1000 mm long bellow are connected to the pumping group. For conditioning purposes, it is of interest to estimate the effective pumping speed at the cavity side. This calculation gives an effective pumping speed of less than 1.7 l/s at the cavity taking into account a pumping speed of 67 l/s for the turbopump (see Appendix A). After discussions with CEA Saclay it was mentioned that this might not pose a problem during conditioning: they tested a bigger FPC with yet a smaller pumping speed and they saw no complications.

Figure 11: TPG300 connections for run #10 with changes marked in purple.
References


A Conductance Calculations

For the calculation of the effective pumping speed at the cavity, the layout of the equipment, diameters and lengths must be known. Figure 12 schematically gives these details. Since all components are connected in series, the effective pumping speed $S_{eff}$ can be calculated as

$$\frac{1}{S_{eff}} = \sum_i \frac{1}{C_i} + \frac{1}{S_{TMP}} \tag{1}$$

where $C_i$ is the conductance of the different components and $S_{TMP}$ the pumping speed of the turbopump, rated at 67 l/s for molecular flow.

Figure 12: Schematic of the equipment and piping connected to the beam vacuum for cavity 1. Marked in red are the components for which the conductance has been calculated.

This equation applied to the system has the following terms

$$\frac{1}{S_{eff}} = \frac{1}{C_{VAT\ 54035}} + \frac{3}{C_{CF\ 40\ pipe\ 1m}} + \frac{1}{C_{CF\ 90^{\circ} bend}} + \frac{1}{C_{CF\ 63\ pipe\ 0.12m}} + \frac{1}{C_{VAT\ 48236}} + \frac{1}{C_{CF\ 63\ Cross}} + \frac{1}{C_{VAT\ 57036}} + \frac{1}{C_{CF\ 63\ pipe\ 0.205m}} + \frac{1}{S_{TMP}} \tag{2}$$

For air at 20° and in the molecular flow regime, the conductance for a long pipe is

$$C_{pipe\ long} = 12.1 \frac{D^3}{L} \ [l/s] \quad [D, L] = cm \tag{3}$$

Where $L$ and $D$ are the length and diameter of the pipe, respectively, and the length of the pipe satisfies $L \geq 10 \ D$.

Under the same conditions, the conductance for a short pipe is

$$C_{pipe\ short} = C_{pipe\ long} \times \Psi = 12.1 \frac{D^3}{L} \times \left(1 + \frac{4D}{3L}\right)^{-1} \ [l/s] \quad [D, L] = cm \tag{4}$$
While for other type of piping that has an angle \( \theta \) the equations are the same as above but with a correction for the length \( L_{eff} \)

\[
L_{eff} = L_{axial} + 1.33 \frac{\theta}{180^\circ} D \quad [l/s] \quad [D, L] = cm; \quad [\theta] = \text{degrees}
\] (5)

The conductance values for the valves are taken from the manufacturer’s specifications. Considering the different components along the pumping line, the aforementioned equations can then be used to calculate individual conductances. Table 1 gives the conductance values following the same order as in Eq. 2. If all these values are plugged in Eq. 2 the effective pumping speed \( S_{eff} \) is then

\[
\frac{1}{S_{eff}} = 0.58 \ (l/s)^{-1} \rightarrow S_{eff} = 1.71 \ l/s
\] (6)

Table 1: Calculated conductances for the different components given in Eq. 2 and schematically shown in Figure 12.

<table>
<thead>
<tr>
<th>Component ( C^VAT )</th>
<th>( L ) [cm]</th>
<th>( D ) [cm]</th>
<th>( \theta )</th>
<th>( C ) [l/s]</th>
<th>Eq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C^{CF40}_{pipe \ 1m} )</td>
<td>100.0</td>
<td>3.7</td>
<td>-</td>
<td>6.13</td>
<td>3</td>
</tr>
<tr>
<td>( C^{CF40}_{90^\circ \ bend} )</td>
<td>12.6*</td>
<td>3.7</td>
<td>( 90^\circ )</td>
<td>30.65</td>
<td>4, 5</td>
</tr>
<tr>
<td>( C^{CF63}_{pipe \ 0.12m} )</td>
<td>12.0</td>
<td>6.6</td>
<td>-</td>
<td>167.25</td>
<td>4</td>
</tr>
<tr>
<td>( C^{VAT}_{48236} )</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>400.00</td>
<td>-</td>
</tr>
<tr>
<td>( C^{CF63}_{Cross} )</td>
<td>22.0*</td>
<td>6.6</td>
<td>( 90^\circ )</td>
<td>98.83</td>
<td>4, 5</td>
</tr>
<tr>
<td>( C^{VAT}_{57036} )</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>125.00</td>
<td>-</td>
</tr>
<tr>
<td>( C^{CF63}_{pipe \ 0.205m} )</td>
<td>20.5</td>
<td>6.6</td>
<td>-</td>
<td>118.72</td>
<td>4</td>
</tr>
</tbody>
</table>

* Axial length \( L_{axial} \)