Recent Cooling Tests on the Pixel Staves and Real Scale Circuits

Prepared by Vic Vacek

with thanks to

M. Bosteels' lab Team, Ph. Bouvier, G. Hallewell, M. Olcese

Agenda:

- **Pixel stave prototype measurements on the Evaporative Cooling System with the first prototype of the heat exchanger**
- **Monophase cooling test [backup solution]**
- **Real scale circuits and coming tests and measurements**

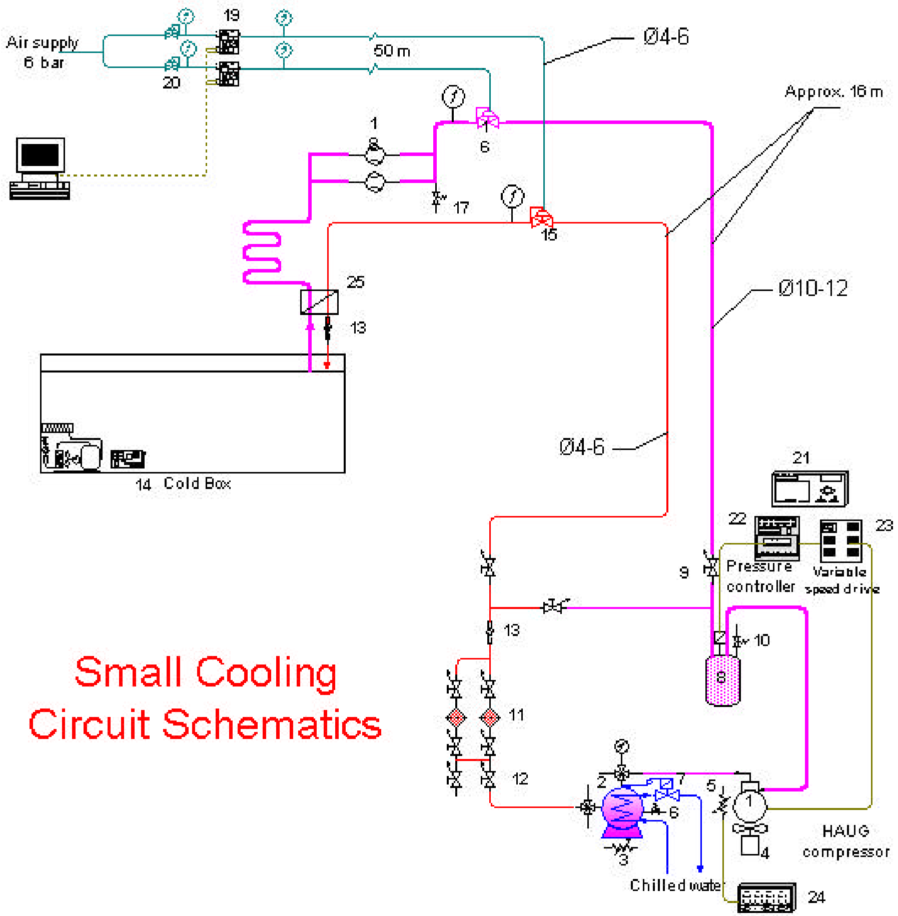
• Additional Pixel Stave Prototype Measurements

The Small Evaporative Cooling System with the first prototype of the heat exchanger implemented into the circuit was used for test together with Prague mobile DAQ system

Main modification of the cooling system *[worked satisfactory prior to changes]:*

1. Implementation of the heat exchanger made of inlet and outlet copper tubes, which were soldered together along the length, upon design suggested by D. Cragg *[the first prototype]*
2. Inlet and outlet pipes (between pressure regulators and staves) with lengths and diameter sequence consistent with the present layout of the ATLAS detector were used
3. Capillary designed for max. power dissipation, i.e. 134 W [approx. 6 – 8 bars as the inlet condition before the capillary]
4. Additional sensors were added to monitor technological parameters of the Cooling system and heat exchanger [see following Figs.]

- **Short tests were performed at the end of December 1999 [after the thermal tests of the two Genova staves in series finished in November/December]**

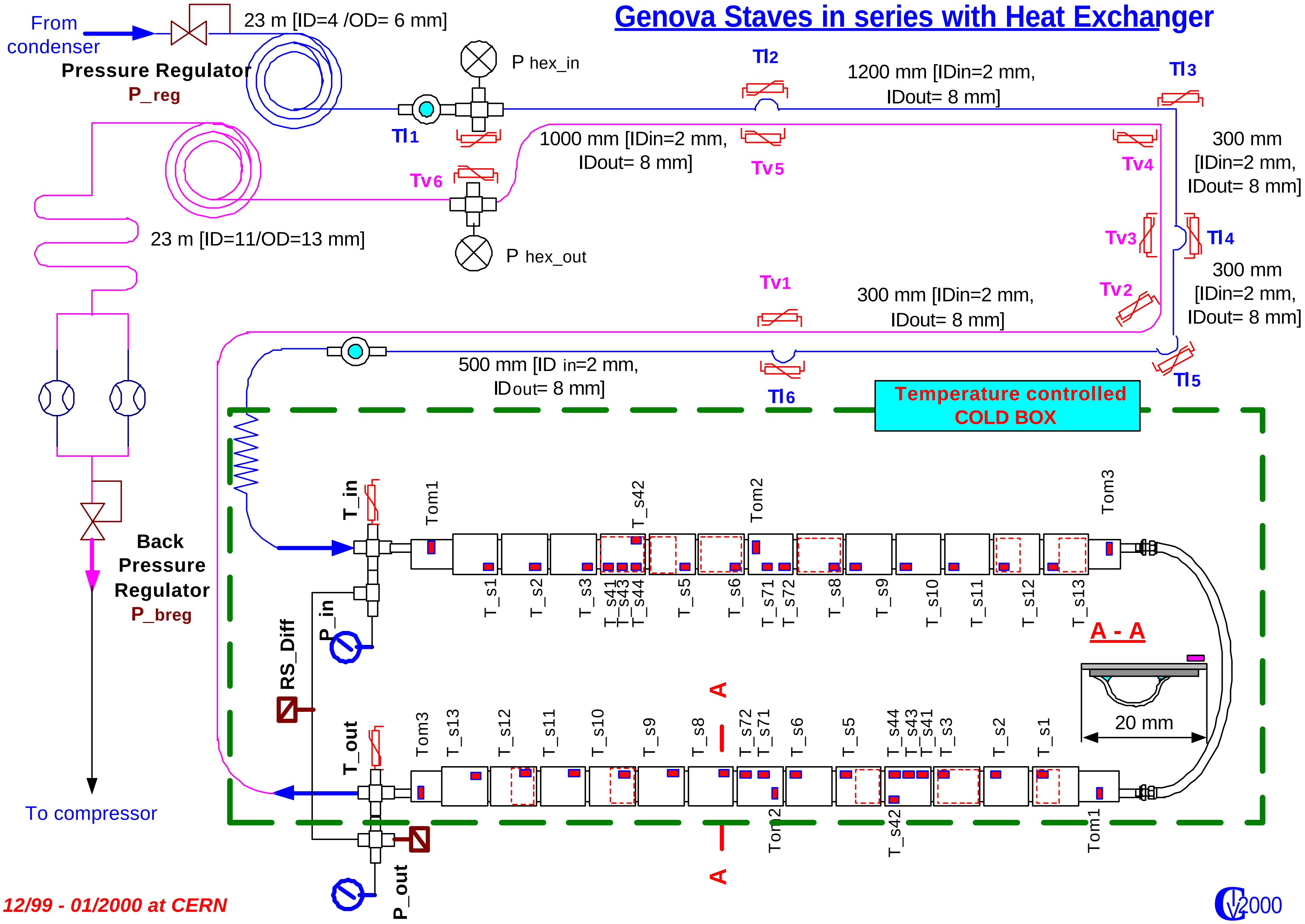


Small Cooling Circuit Schematics

Scope of the test:

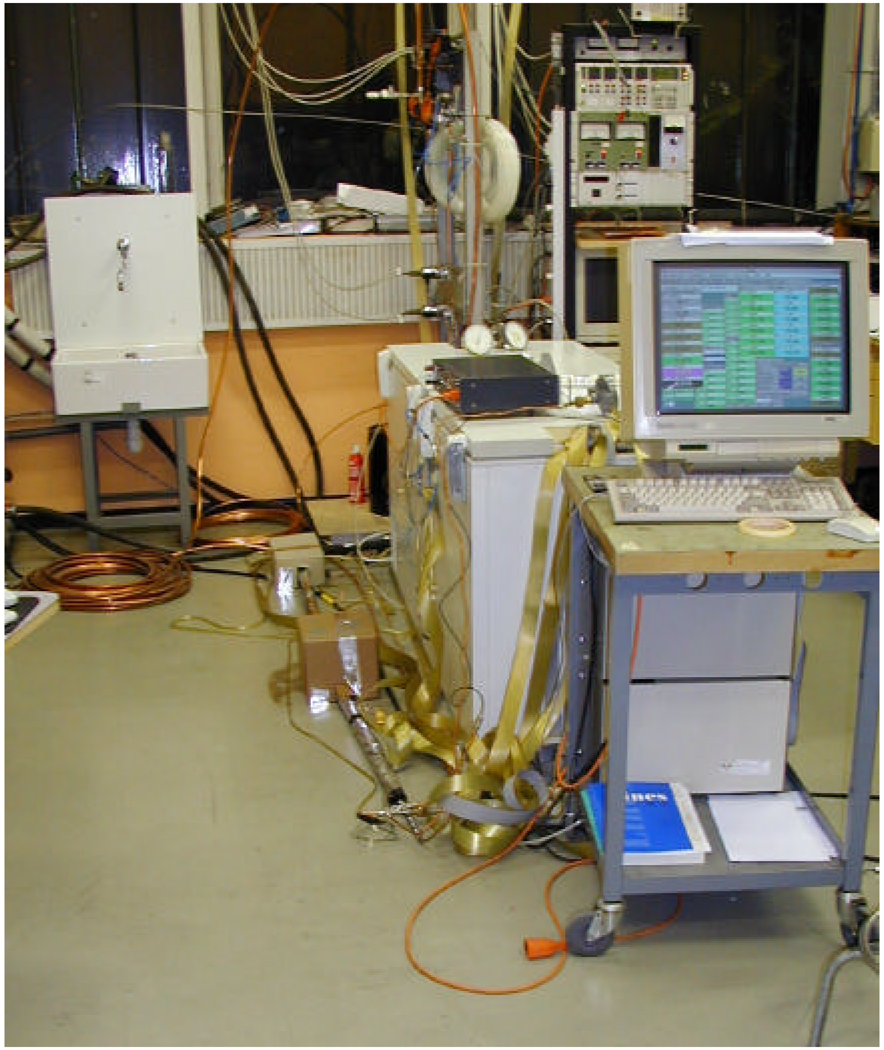
- Test of the existing cooling setup that has been modified in such manner to be as close as possible to the final arrangement of the cooling system in real detector
- Behavior and performance test of the implemented heat exchanger prototype

Genova Staves in series with Heat Exchanger

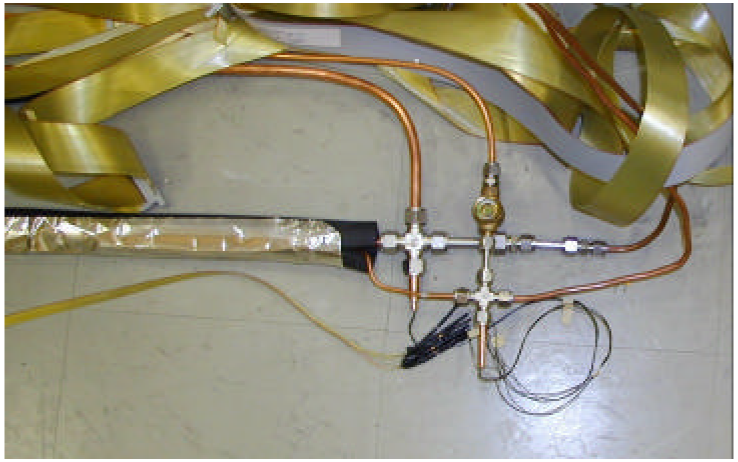


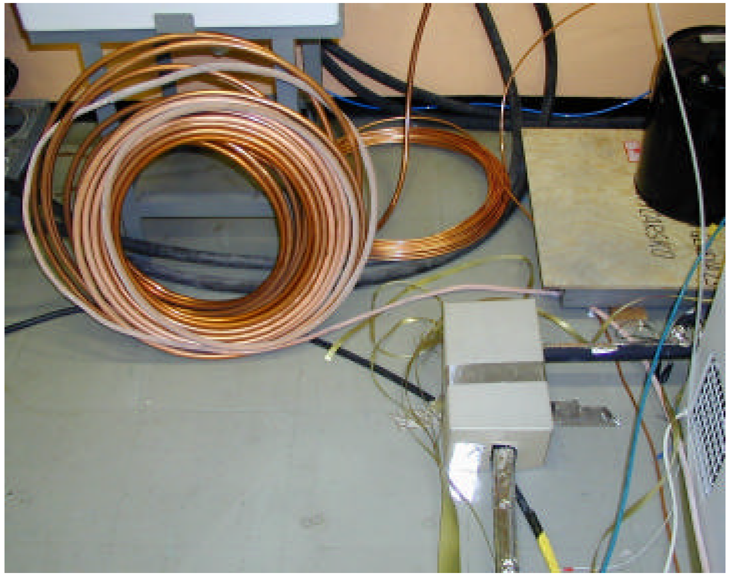
12/99 - 01/2000 at CERN

Situation in the lab during the test



Heat Exchanger was insulated and placed around the cold box; inlet and exhaust tubes simulating the real lengths inside the detector were kept at room temperature





Detail of the inlet into the heat exchanger [left up]

Exhaust pipe detail – filled with the excess liquid during the 0 W power load run [left down]

Test Description:

1. Test run with no power [0W on the staves]: we were trying to establish so-called standby conditions.
2. Test run with 50 W on both staves to check the stability at these conditions [i.e. search for minimum flow].
3. Test run with 107 W on both staves to check the stability at these conditions [i.e. search for minimum flow]. This power is the design power for layer one and layer two.
4. Test run with maximum projected power, i.e. 134 W on both staves [design power for B-layer] to check the behavior at these conditions [i.e. search for minimum flow].
5. Long term test after the 134 W on one or both staves were switched off while the input conditions [pressure] were kept the same.

Results and Observations:

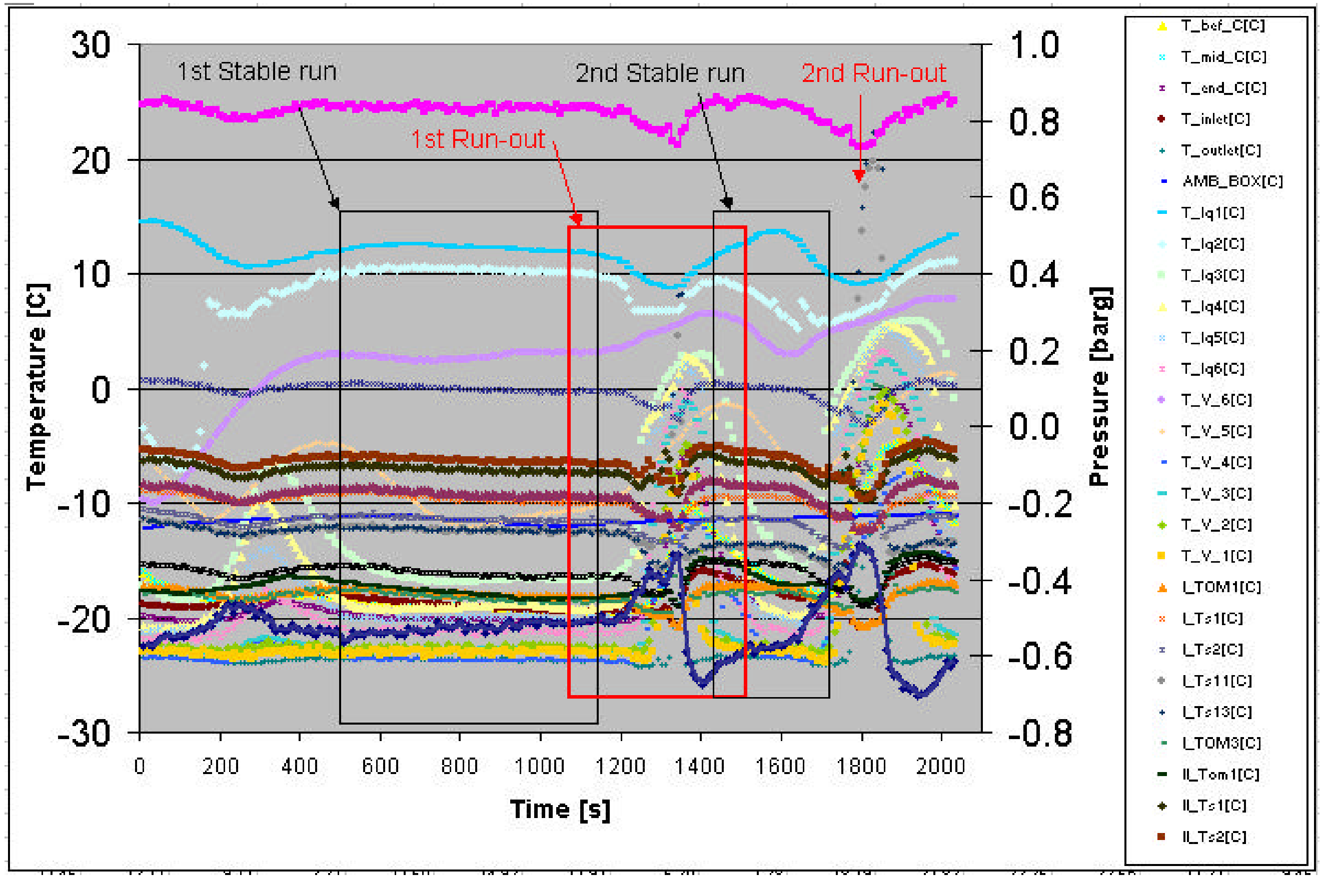
Two time dependant parameters were found to be relevant for description of the system behavior in transient conditions. The first observed parameter **Dt1** is time needed by the system to react when the set parameter change is introduced [changes of pressure after the pressure regulator]. The second parameter **Dt2** is time needed by the system to recover from so called dry out conditions.

Standby condition **ad 1.**:

At low flow conditions [i.e. low inlet pressure, let us say below 5 bar, which also means to be below s.v.p.], it is very difficult to achieve stable run. We were not able to maintain this mode stable [correction free] with the tested arrangement of the cooling system [the heat exchanger and current control system].

Test with 50W power dissipation per stave **ad 2.**:

It seems that introduced power load makes the system a bit more stable in operation but not stable enough to maintain the ultimate control of the system easily at the current tested arrangement [seeking minimum mass flow – “WATCH” – low inlet pressure conditions].



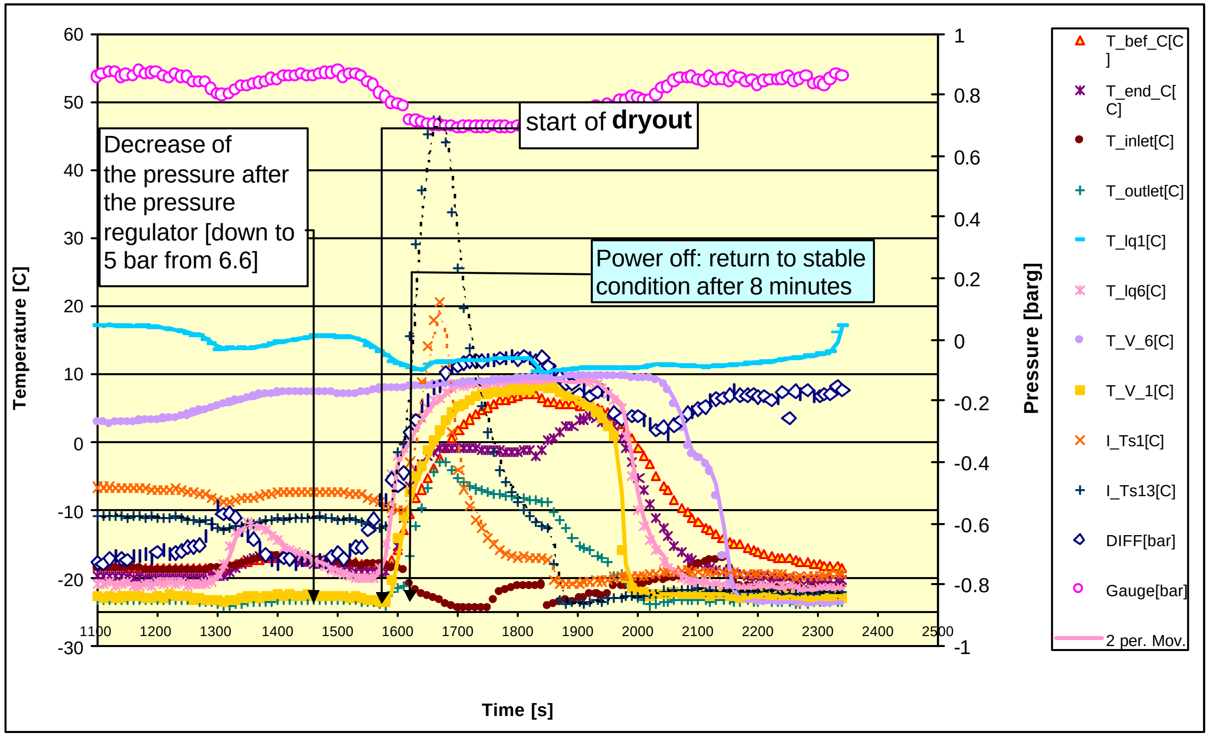
Overall scan of the run with nominal power 107 W per stave

Tests with nominal power 107 W per stave ad 3.:

This run displayed stable conditions during operation [see Fig.]. We have observed that heat exchanger worked at this power as expected, i.e. we can heat up fluid in return line above 0 C and incoming liquid is sub-cooled up to –20°C and with DT~30 °C [from+12 °C to –20 °C].

Tests with maximum power 134 W per stave **ad 4.:**

In the case of the 134 W runs the system did not display too different behavior from the runs at 107 W. System looked stable to sudden changes of the power (switch on and off). We could also determine time constant Dt1 = 2 min and Dt2 = 8 min in average. During the stable part of the run – see end part of the Fig. - we observed the filling of the exhaust lines with liquid refrigerant.



Decrease of the pressure after the pressure regulator [down to 5 bar from 6.6]

start of **dryout**

Power off: return to stable condition after 8 minutes

Selected scan of the run at 134 W: stable part of the run, dry out and system recovery due to the power cut off are displayed

Preliminary Conclusions

Summary:

- Present design of the added heat exchanger makes difficult to operate system at standby conditions and at low power [50W power dissipation per stave was tested for this purpose]
- At nominal power (layer 1&2) and maximum power (B-layer) we could maintain the stable conditions of the runs and we could handle even the transient conditions (power switch on and off)
- Response time of the cooling system to the changes of technological parameters was evaluated based upon the two characteristics **Dt1** and **Dt2**.
  Typical values are 2-3 minutes for **Dt1** and 7-10 minutes for **Dt2**

It is evident that current design of the heat exchanger and its implementation into the cooling circuit has limitations (restricted operating range) and difficulties to cope with all requirements for easy operational system [push button system]. Next improvements are under way [see following presentation by G.H.]. More C.S. tests are planed.

• Monophase Cooling Test [backup solution]

- Tests were performed with two Genova staves in series at the end of December 1999
- Monophase Cooling Unit from the Geneva University was used with C_6F_{14} as the cooling liquid

Modification of the Set up:

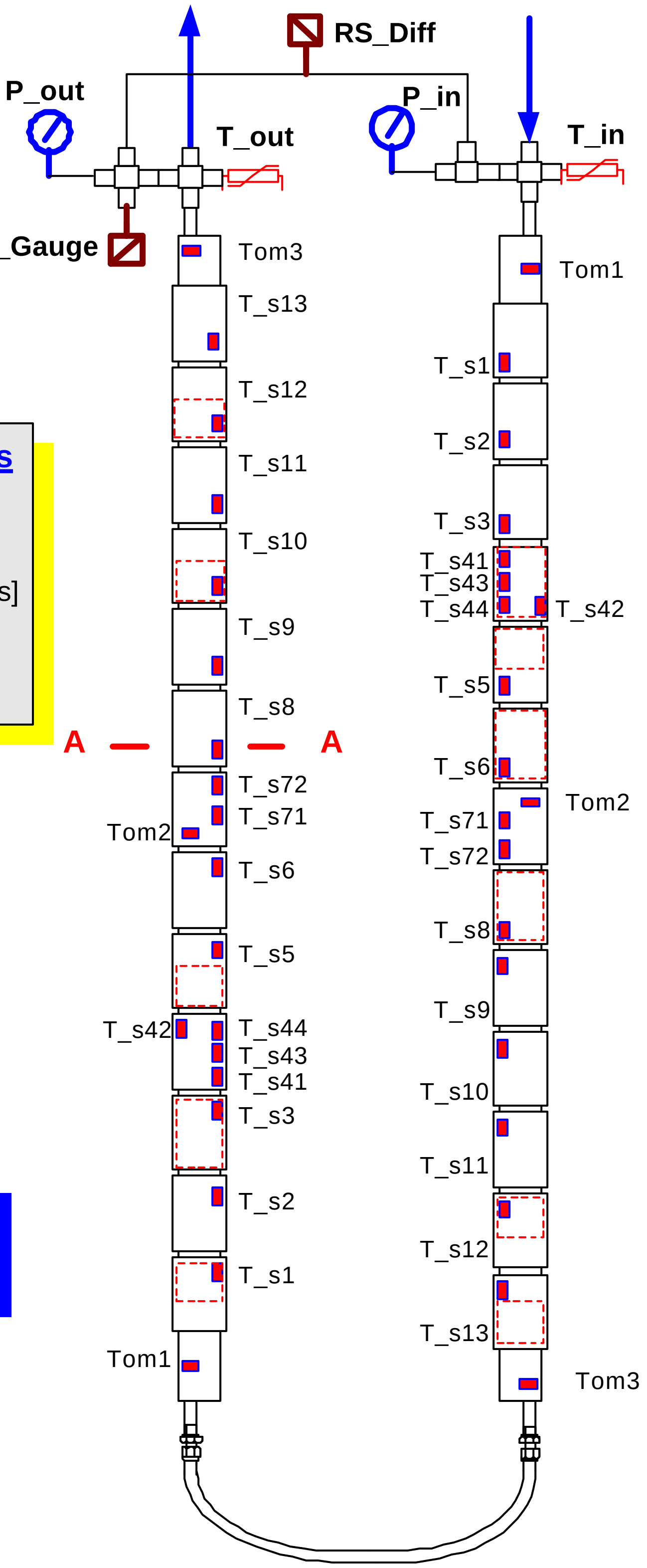
- Pipes of the evaporative circuit were disconnected at the inlet and outlet of the staves and liquid coolant circuit was connected instead

- Temperature and pressure sensors were kept in the same manner as in the original layout during the tests with evaporative cooling system

- The Prague mobile DAQ system was used to monitor temperatures and pressures [calibrated RS pressure sensors were used to monitor pressures within the stave loop and pressures were also read by analog pressure gauges at the same positions]

Two Genova Staves in series

Arrangement for Monophase Cooling - C_6F_{14}



TILE	Sensor position [mm]
TOM1	30
T_s1	100
T_s2	160
T_s3	225
T_s41	240
T_s42	285
T_s43	280
T_s44	285
T_s5	345
T_s6	400
TOM2	415
T_s71	430
T_s72	460
T_s8	475
T_s9	530
T_s10	595
T_s11	655
T_s12	710
T_s13	775
TOM3	835

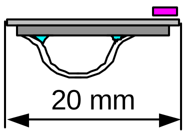
Stave parameters

ID_h = 3.4 mm

L_{tiles} = 783 mm [Tiles]

$L_{tot\_C\_C}$ = 870 mm

A - A



U tube connection

ID = 4.0 mm

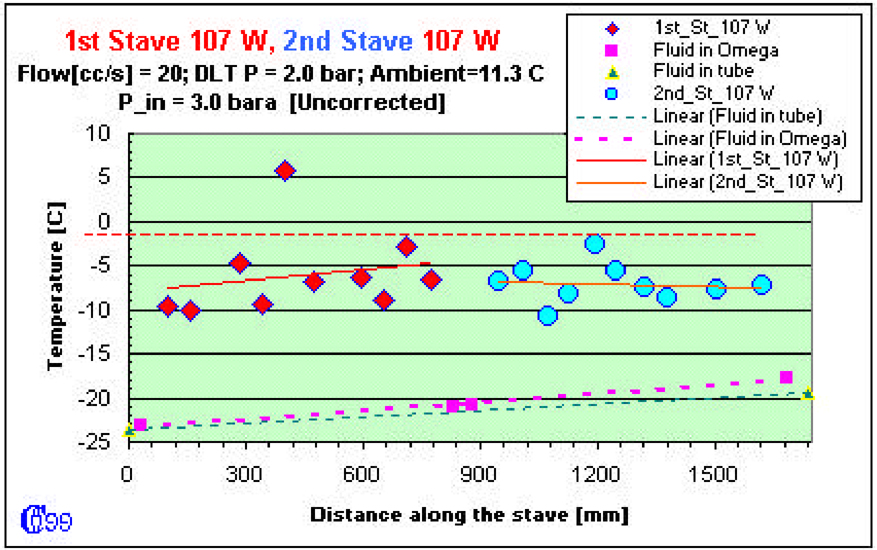
L = 700 mm

2nd in line
[Stave No.1]
BFG

1st in line
[Stave No.2]
SGL

Hot Spot Tile

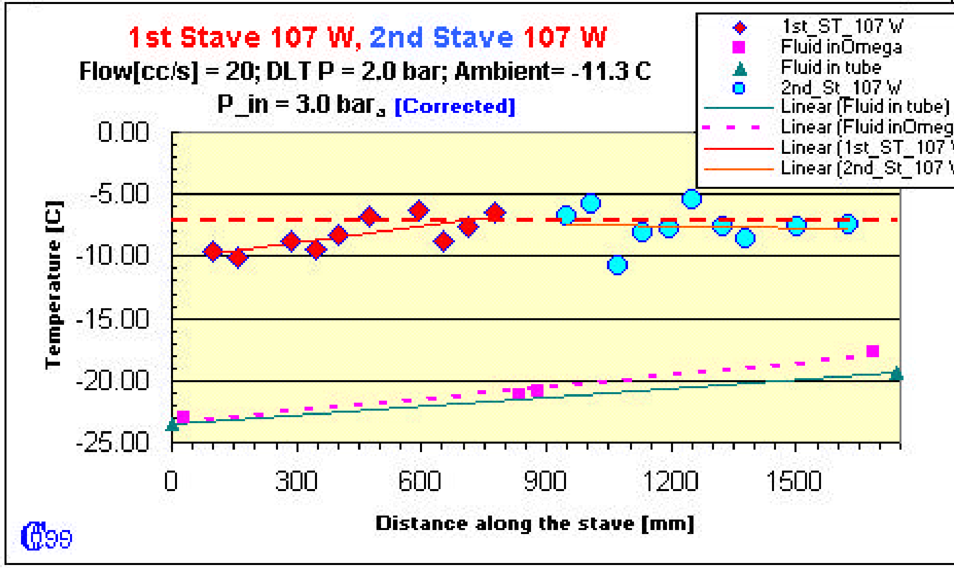
Results for the Nominal Power 107 W runs



1st Stave 107 W, 2nd Stave 107 W

Flow[cc/s] = 20; DLT P = 2.0 bar; Ambient=11.3 C

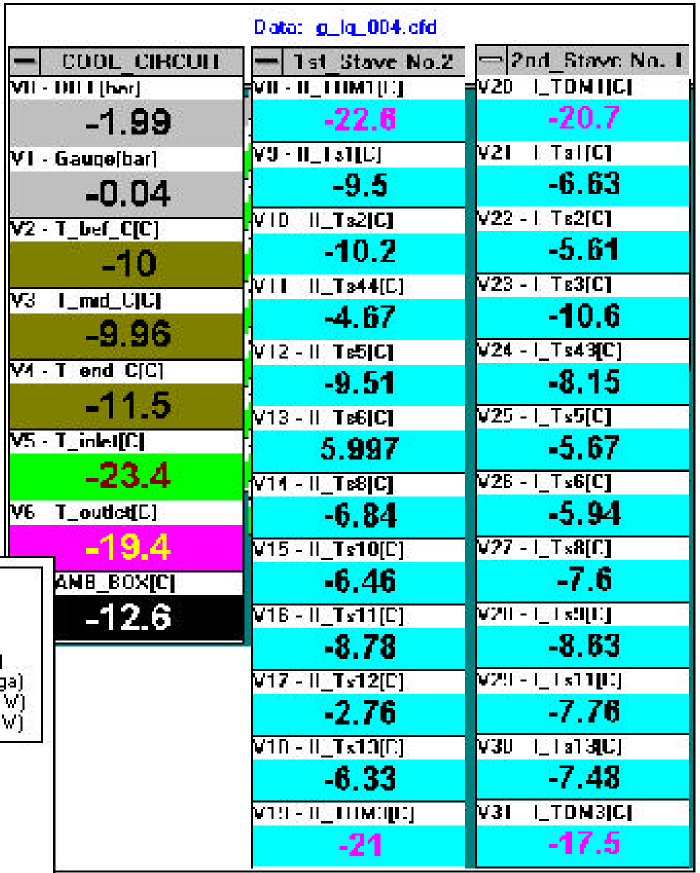
P_in = 3.0 bara [Uncorrected]



1st Stave 107 W, 2nd Stave 107 W

Flow[cc/s] = 20; DLT P = 2.0 bar; Ambient= -11.3 C

P_in = 3.0 bar$_a$ [Corrected]



Data: g_lq_004.cfd

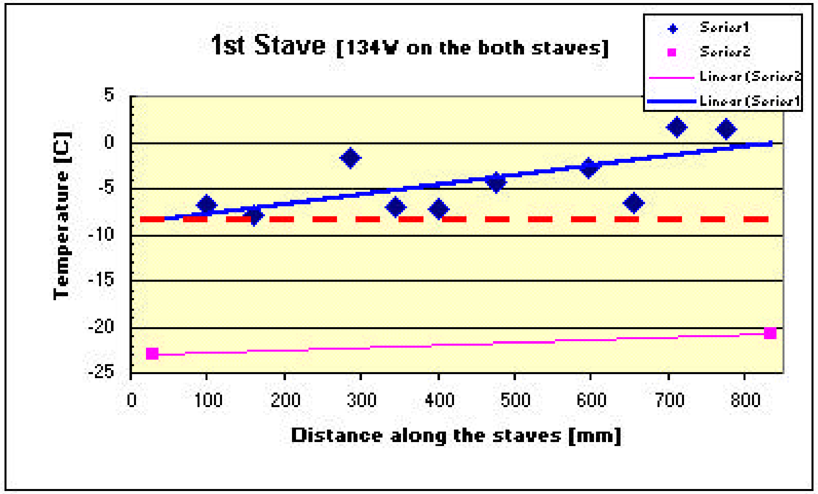
COOL_CIRCUIT	
V0 - DIFF[bar]	-1.99
V1 - Gauge[bar]	-0.04
V2 - T_bef_C[C]	-10
V3 - T_mid_C[C]	-9.96
V4 - T_end_C[C]	-11.5
V5 - T_inlet[C]	-23.4
V6 - T_outlet[C]	-19.4
AMB_BOX[C]	-12.6

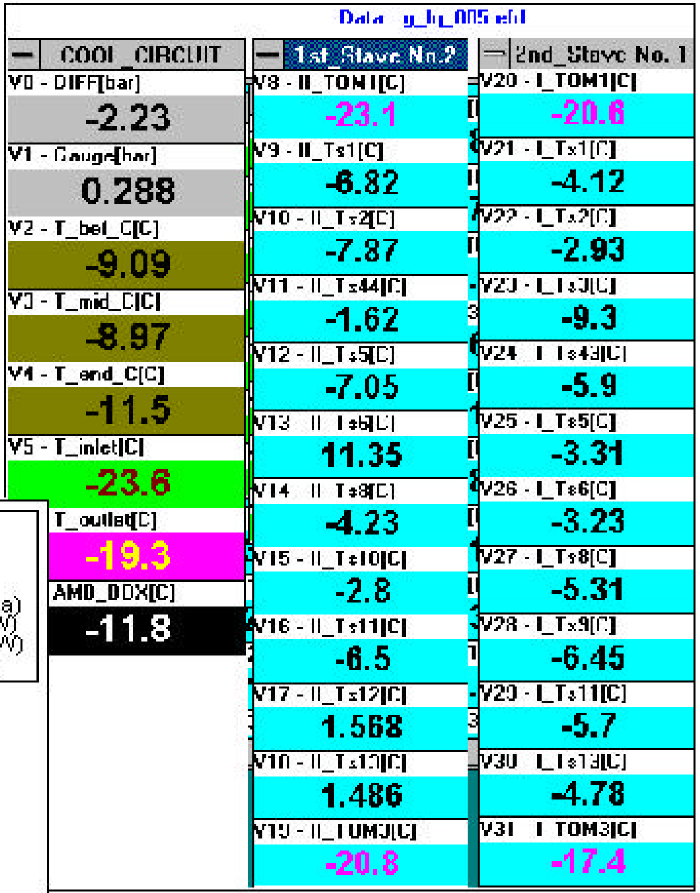
1st_Stave No.2	
V8 - II_TDM1[C]	-22.6
V9 - II_Ts1[C]	-9.5
V10 - II_Ts2[C]	-10.2
V11 - II_Ts44[C]	-4.67
V12 - II_Ts5[C]	-9.51
V13 - II_Ts6[C]	5.997
V14 - II_Ts8[C]	-6.84
V15 - II_Ts10[C]	-6.46
V16 - II_Ts11[C]	-8.78
V17 - II_Ts12[C]	-2.76
V18 - II_Ts13[C]	-6.33
V19 - II_TDM2[C]	-21

2nd_Stave No. 1	
V20 - I_TDM1[C]	-20.7
V21 - I_Ts1[C]	-6.63
V22 - I_Ts2[C]	-5.61
V23 - I_Ts3[C]	-10.6
V24 - I_Ts43[C]	-8.15
V25 - I_Ts5[C]	-5.67
V26 - I_Ts6[C]	-5.94
V27 - I_Ts8[C]	-7.6
V28 - I_Ts9[C]	-8.63
V29 - I_Ts11[C]	-7.76
V30 - I_Ts13[C]	-7.48
V31 - I_TDM3[C]	-17.5

Monophase test performed
with Genova Stave
Prototypes - Fluid C_6F_{14}

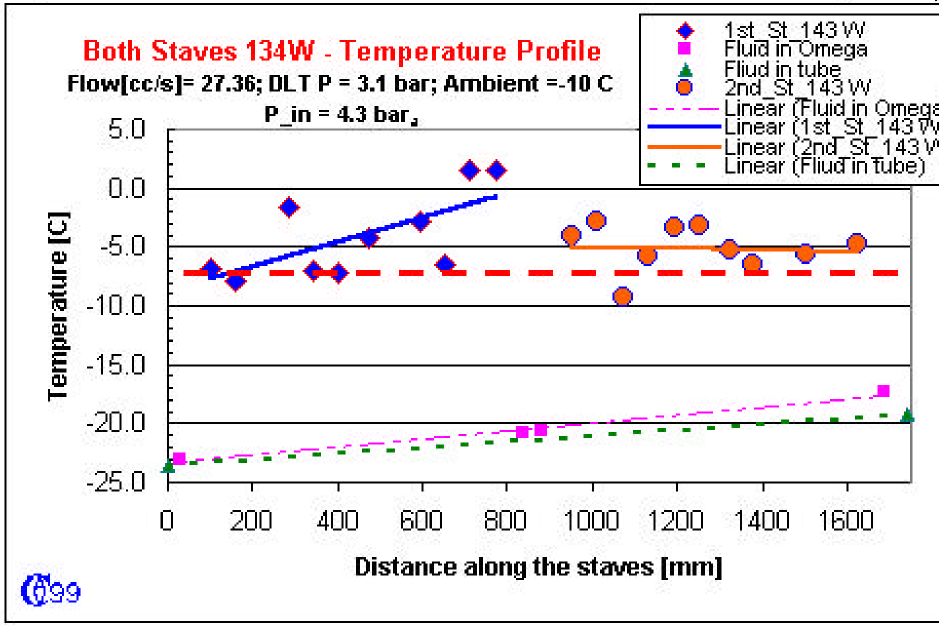
Results for the Maximal Power 134 W runs





Data g_hj_005.efd

COOL_CIRCUIT	1st_Stave No.2	2nd_Stave No. 1
V0 - DIFF[bar] -2.23	V8 - II_TOM1[C] -23.1	V20 - I_TOM1[C] -20.6
V1 - Gauge[bar] 0.288	V9 - II_Ts1[C] -6.82	V21 - I_Tx1[C] -4.12
V2 - T_bel_C[C] -9.09	V10 - II_Ts2[C] -7.87	V22 - I_Tx2[C] -2.93
V3 - T_mid_C[C] -8.97	V11 - II_Ts4[C] -1.62	V23 - I_Ts3[C] -9.3
V4 - T_end_C[C] -11.5	V12 - II_Ts5[C] -7.05	V24 - I_Ts4[C] -5.9
V5 - T_inlet[C] -23.6	V13 - II_Ts6[C] 11.35	V25 - I_Ts5[C] -3.31
T_outlet[C] -19.3	V14 - II_Ts8[C] -4.23	V26 - I_Ts6[C] -3.23
AMD_DDX[C] -11.8	V15 - II_Ts10[C] -2.8	V27 - I_Ts8[C] -5.31
	V16 - II_Ts11[C] -6.5	V28 - I_Tx9[C] -6.45
	V17 - II_Ts12[C] 1.568	V29 - I_Ts11[C] -5.7
	V18 - II_Ts13[C] 1.486	V30 - I_Ts13[C] -4.78
	V19 - II_TOM3[C] -20.8	V31 - I_TOM3[C] -17.4



Monophase test performed with Genova Stave Prototypes - Fluid C_6F_{14}

Summary for the Monophase Tests:

- **Specs for the pixel stave were not met; It seems to be very problematic to cool down the pixel barrel structures [possibly also discs]**

- **We were close to the specs only at nominal power, nevertheless pressure drop were high and we could not lower with the inlet temperature due to the insulation problems**

- **For maximal projected power we were far away from specs, pressure drop went up to 3 bar and liquid pressure at the inlet of the stave exceeded 4.3 bar_a and we were over the cooling power of the unit and also over the range installed flow meter.**

- **Measured values of pressure drops agreed with theoretical predictions for mono phase presented in June 99 [by Vic] within ± 10 %**

Real Scale Circuits and Coming Tests and Measurements

- **Two systems were built for future tests in 2000:**

- **Small circuit** – described in details in December [see the database].
  - The cooling circuit is designed to proceed with test up to the cooling power 300 W @ - 20°C [depending on evaporative temperature] and is also suited for possible modifications to test HEX, control system features, etc.

- **Large circuit** – equipped with Scroll compressor
  - The circuit is designed for higher cooling powers – up to 3 kW. Test of the cooling capacity are going on – to be finished by next week
  - The larger prototype objects will be tested there, manifolding, heat exchanger and pipe routines problems [designed as close as possible to the real equipment] will be studied with this system, new LMB DAQ system will be used during the measurements [Already used for SCT barrel stave tests]

-

Large Cooling Circuit - Test:

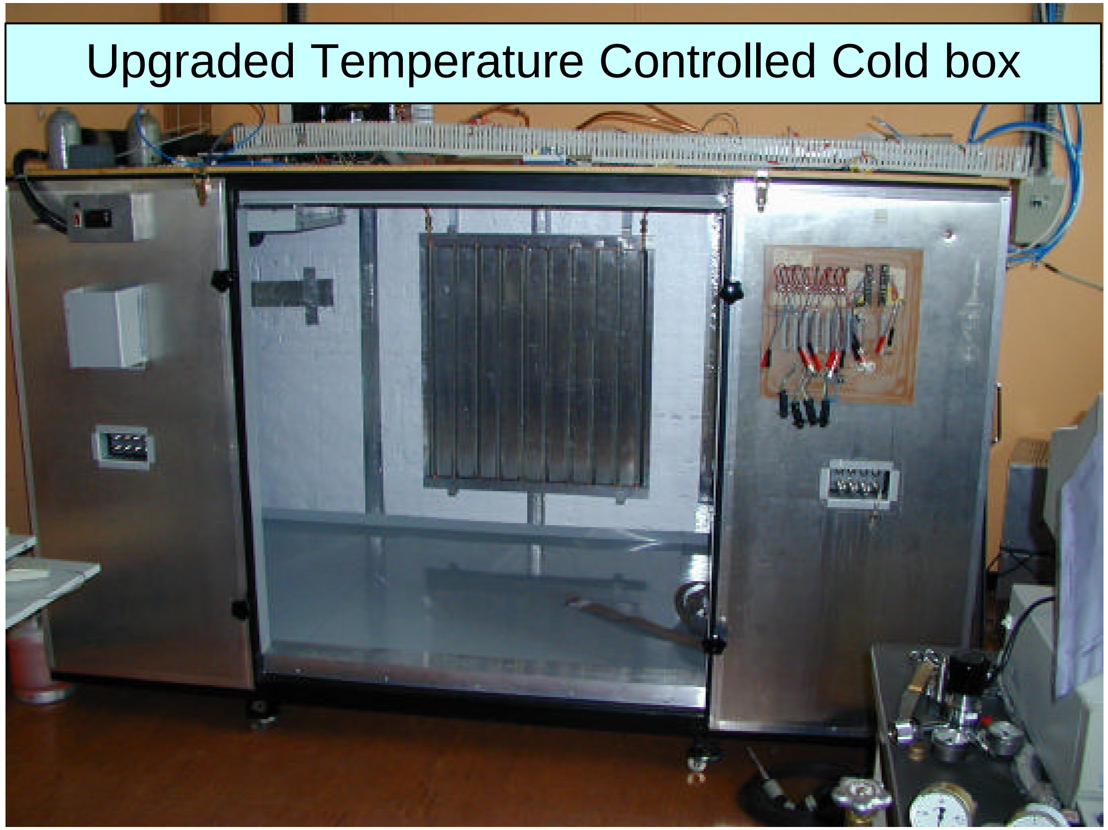
Completed Scroll condenser unit attached to the power meter (Boiler – evaporator)

New shaft seal system have been designed and introduced during the first week of January 2000

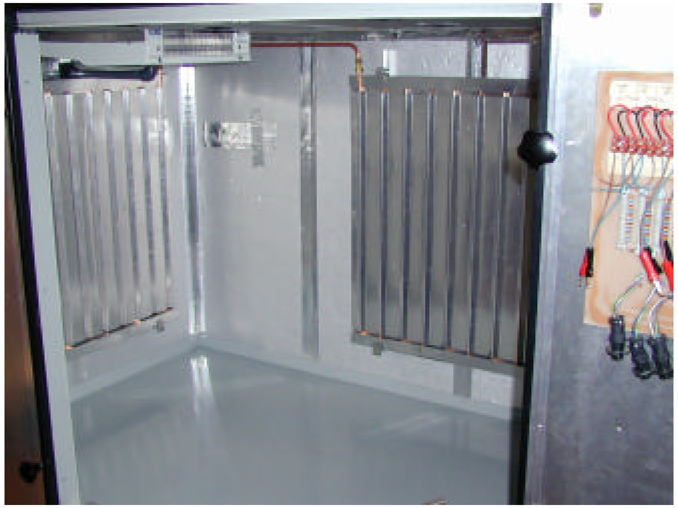
Leak tightness tests were satisfactory; so cooling power tests started immediately

Cold Box Preparation

Upgraded Temperature Controlled Cold box



New Flat Panel Heat Exchangers installed in the cold box



Large cooling system is ready for a final assembly!