Proposal for the
Cryogenic Supply of a
Single TTF / FEL - Cryomodule Test Bench

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Abstract
A test bench for the test of single TTF/FEL-cryomodules is proposed. The general equipment and the layout of the cryogenic supply are described.

1. Introduction

For the time being, TTF- cryomodules can only be cold tested after their installation into the TTF / FEL – linear accelerator. Special tests and procedures, which are planned in view of the TESLA accelerator, can be conducted only in the TTF/FEL-linac. Sometimes such kinds of tests are shifted in order not to jeopardize the operation of the linac.

The design of TESLA cryomodules will differ significantly from the present modules in some details – in particular the cryostat design and the length will change. The quadrupoles will be cooled in the 2.0 K liquid bath instead by the 4.5K cooling circuit. The influence of the design changes on the performance of the modules as well as the performance of the module components have to be tested before the installation into the linac.

In addition, design studies for new cavity and module concepts –like superstructures- for the TESLA500 linear accelerator will be conducted independently from the operation of the TTF / FEL – linac .

Also, after a repair, TTF/FEL-cryomodules should be tested before the installation into the linac.

The results of numerical studies /1/ underline the necessity of experimental investigations of fault conditions for TESLA cryogenic components in line with experiments for similar helium systems / 2 // 3 /. At least on the scale of one TESLA cryomodule the effect of the breakdown of the insulation vacuum and the beam vacuum has to be studied in a real experiment.

Also the extensive thermal cycling of prototype cryomodules will be an important topic for a module test bench.

Though this proposal is restricted to the cryogenic layout of the test stand, some overall review of the test program and the general equipment of the test stand is collected as a basis for the design of the cryogenic system

In view of the TESLA 500 project the test program and the equipment of a single module test stand can be taken as a model for the concept of a cryomodule test facility.

2. Test program

2.1. Mechanical check of the components

Before the installation of the cryomodules on the test stand the alignment of all components, which have to be connected to the test stand – beam tube, cryogenic tubes, coupler flanges, vacuum flanges, feedthroughs etc. have to be checked.

2.2. Leak tests of the vacuum systems

Beam vacuum, coupler vacuum and isolation vacuum have to be checked for leaks. The cryogenic helium process tubes have to be set to their test pressures and leak checked in addition. All leak tests have to be conducted under warm conditions and after the cool down of all helium circuits to the operating conditions.

2.3. Conditioning of the main RF-couplers (cavities off resonance)

The main RF-couplers have to be conditioned. The procedure could be similar to the usual conditioning at the horizontal test of single equipped cavities (CHECHIA-test) and at the TTF-linac / 4/: the conditioning can start before the cool down of the module and can be continued during the cool down.

2.4. Conditioning with resonant cavities (check of tuning systems)

The cavities have to be tuned to their resonant frequencies by means of the cold tuning systems – this will include a system test of the cold tuning systems. The conditioning of the couplers has to be continued with the cavities on resonance.

2.5. Measurement of the dynamic cryogenic loads of the cavities (Q versus E_{acc} characteristics of the cavities)

The dynamic heat loads of the individual cavities in the modules have to be measured to get the Q versus E_{acc} characteristics of the cavities and their maximum acceleration fields at the TTF / FEL – linac operating conditions. These tests may be repeated after different steps of HPP-treatment of the cavities (2.6.).
During these tests, the gamma radiation around the cryomodule has to be monitored, to get some indication for field emission events in the cavities.

2.6. HPP-treatment of the cavities

Depending on the performance of the cavities in the module in comparison to the original tests results during the vertical tests of the individual cavities and depending on the onset of field emission, the cavities will be treated by HPP procedures.

2.7. Test of the superconducting quadrupole

The superconducting quadrupole will be powered to the quench limit. The current leads will be checked during this test. There will be no magnetic field measurements.
According to the present TESLA cryomodule design, the quadrupoles will be operated in the 2K liquid helium bath. The use of HTSC-current leads and the corresponding 2K heat loads will be studied. Also the consequences of quenches in the 2K circuit will be monitored by means of additional quench heaters.

2.8. Measurement of the static cryogenic heat loads

The static cryogenic heat loads on the different temperature levels in the module cryostat will be measured (40 / 80 K , 4.5 K, 2.0 K temperature levels).

2.9. Measurement of the alignment of the cavities during cool down and warm up

At least some of the modules of the new cryostat design will be equipped with a streched wire measurement system to monitor the effects of cool down and warm up on the alignment of the cavities.

2.10. Monitoring of dark currents

At both ends of the beam tube of the cryomodules, monitors for the measurement of dark currents will be installed.

2.11. Fault conditions and thermal cycling

For the time being, the design of the pressure release installations of the TTF and TESLA cryogenic systems is based on numerical simulations only / 1/. Beside the investigation of technical details the concepts of the safety systems for TESLA have to be demonstrated to the official authorities and safety review committees.
As a consequence, at least on the scale of one cryomodule, the simulations have to be validated by experimental data.
The test program will include the sudden venting of the insulation vacuum and the beam vacuum with air and helium
In addition, prototype cryostats and the related systems should be extensively thermally cycled, to investigate the influence on the performance of the cryomodules.

3. Equipment of the module test bench

3.1 Hall Layout

The module test bench will be installed in the FEL-cyrogenic building close to hall III on the DESY side. With reference to former technical concepts the area, which was foreseen for the module test bench, could take one 12.2 m cryomodule of the TTF-design (see fig. 1a). In view of the latest module design for the TESLA accelerator, the test bench layout has to be changed, so that also modules of up to 17m lengths can be tested.
The cryomodules will be installed on a support structure, which has also to take the vacuum forces of the cryostat (similar to the support structures of the TTF/FEL-linac).
Due to the limited area inside the hall, the test bench will be extended to the outside of the hall (see fig.1b) for 17m modules..
For the installation of 12.2 m modules the crane in the FEL cryogenic building will be used. (For the installation of a cryomodule the roof plates of the concrete shielding have to be removed).
In case of 17m cryomodules a door will be installed in front of the concrete shielding in the extension of the building.
The front door together with the module support structure can be moved horizontally on railways into the free area in front of the FEL cryogenic building. For the installation of a cryomodule on the test bench, the cryomodule will be moved by a mobile crane from the storage area to the test bench and will be installed on the support structure. After installation, the support structure will be moved back into the shielding of the test bench. During the installations inside the shielding, the front door can be shifted relatively to the support and will stay open.

3.2. Cryogenic Equipment

The cryogenic equipment of the test bench will consist of a test bench feed box, a feed cap and an end cap. The feed box will be connected to the TTF/FEL cryogenic system by a transfer line to the FEL-sub cooler box / 5 /.
A 300K/1.05 bar gas tube will connect the feed box to the 1.05/18 bar screw compressors of the helium plant. The first set of helium compressors will be used to lower the vapour pressure of the helium of the 2K volume of the test bench feed box via a pump tube.
In addition, all safety tubes and safety valves, which are needed to vent the 40/80K, 4K-8K and 2K volumes of the test bench in case of an accident, will be connected to the feed box (see fig. 2a,b and section 4).

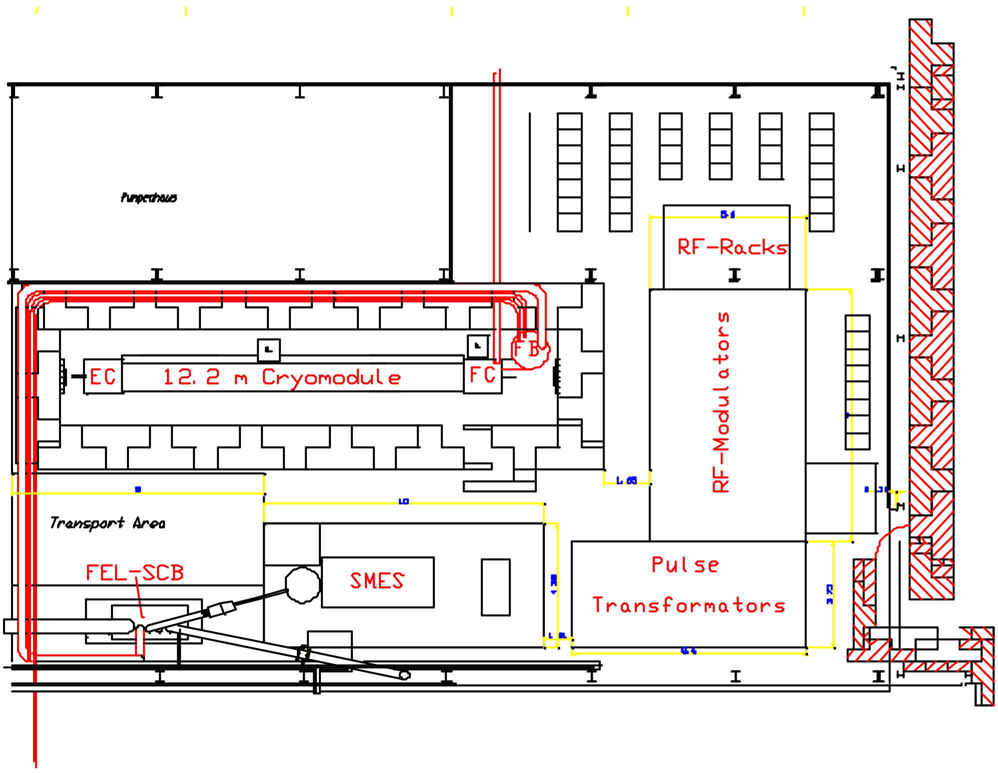

Figure 1a : Layout of the FEL-Cryo-Building including the Module Test Bench
FB = Test bench Feed Box, FC= Module Feed Can, EC= Module End Cap,
FEL-SCB= FEL Sub Cooler Box, SMES= Superconducting Magnetic Energy Storage

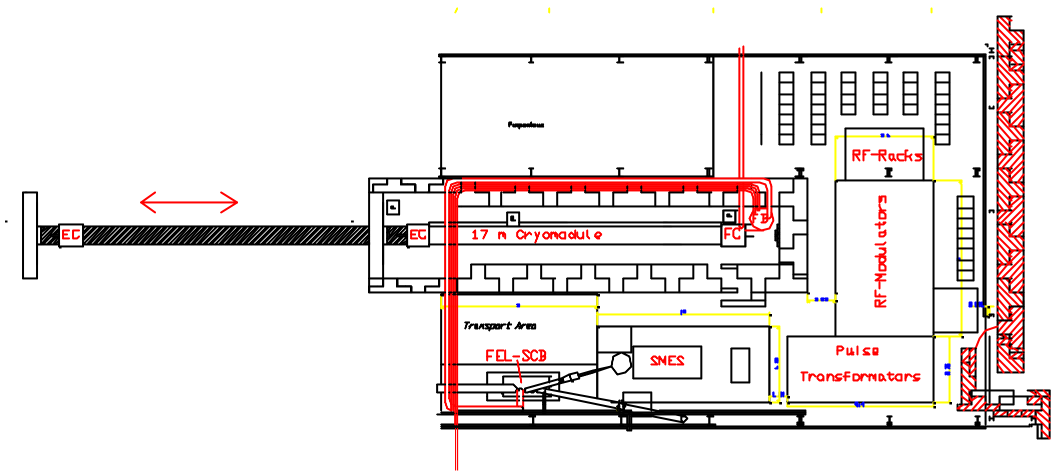

Figure 1b: Module Test Bench for 17 m Cryomodules

3.3. Vacuum Equipment

Suitable vacuum equipment to pump and control the beam vacuum, the coupler vacuum and the insulation vacuum is needed.

Insulation Vacuum

For the insulation vacuum of the cryogenic systems standard turbo molecular pump units are foreseen. The cryomodule test bench will get its individual turbo molecular pump unit. The other cryogenic equipment will be connected to the net of pump stands of the TESLA test facility, which will also include the insulation vacuum of the test bench helium transfer line

Main Coupler Vacuum

The main RF couplers of the cryomodule will be equipped with one pumping tube connected to the pumps without individual valves. There will be only one manual valve at the pumping tube. The set of pumps and pumping tube will stay at each individual cryomodule from the assembly, during the tests until the installation in the TTF/FEL-tunnel.

Cavity Vacuum

During the tests on the module test bench, one turbo pump unit will be connected to the cavity vacuum.

3.4. RF Equipment

For the RF-performance tests of the cryomodule cavities one klystron and one modulator have to be available during the tests including all electronics for RF controls. A wave-guide distribution system has to be connected to the module. The HPP treatment will need a power of 1 MW per main coupler and cavity to get acceleration fields in excess of 25 MV/m. If a 10 MW klystron will be available for the tests, the power can be distributed evenly to all couplers of the module in parallel; if only a smaller klystron will be in operation the wave guide plumbing has to be changed for the treatment of each individual cavity.

3.5 Mechanical Equipment

The cryogenic supply and end caps have to be prepared with flanges for the stretched wire measurement system.

3.6 Radiation shielding

The vicinity of the test stand has to be shielded against the gamma rays, which can be emitted, by the cavities. For the time being, the walls of the shielding will be made of ore loaded concrete blocks of 1.6 m thickness (fig. 1). (For radiation safety, a wall thickness of 0.8 m will be sufficient, it is planned to use already existing 1.6 m blocks.) Concrete blocks of 0.8 m thickness will cover the roof. At both ends additional lead plates of 0.15 m thickness will cover the inner sides of the concrete shielding

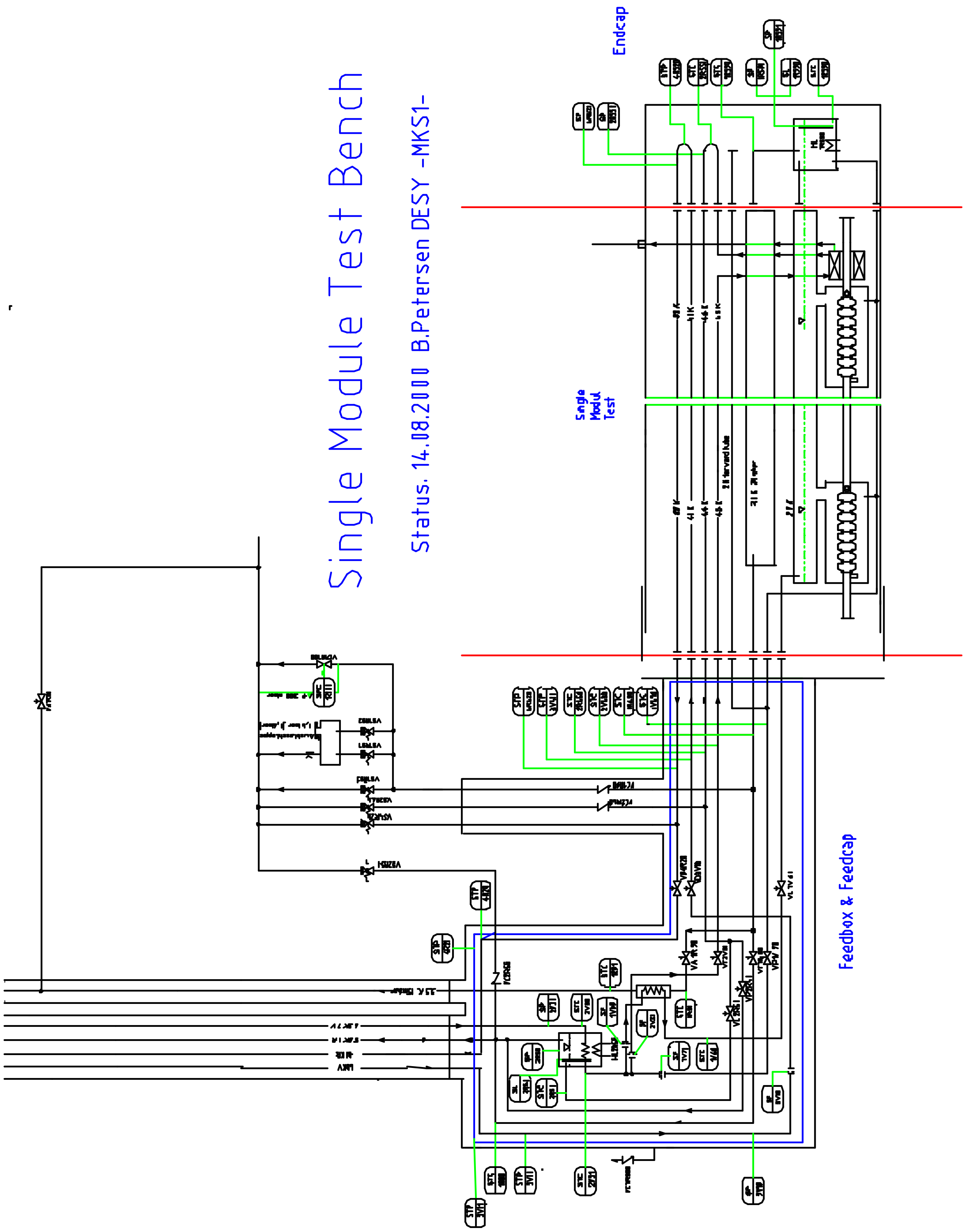

Figure 2 : Cryogenic Flow Scheme of the Module Test Bench

4. Cryogenic Layout

4.1. Cryogenic process

The TESLA cryomodules on the test bench, each containing superconducting 1.3 GHz niobium cavities cooled in a 2 K helium bath, a superconducting quadrupole package at 4.5 K – or according to the present TESLA design at 2K - and thermal shields at 4.5 K-8.5K and 40/80 K temperature levels, have to be supplied with cooling capacities at the corresponding temperature levels.
The cryogenic supply of the module test bench will be incorporated in the extended cryogenic supply of the TTF / FEL-linac / 5 /. The 40/80 K shield and 4.5 K helium circuits are supplied from the HERA-refrigerators and are branched to the different users by means of the FEL-sub cooler and distribution box in the FEL-cryogenic-building. The cryogenic system of the module test bench itself consist of a sub cooler box, a feed cap and an end cap (see fig 2). The module sub cooler box is connected to the FEL-sub cooler box by a 4-fold 30 m long transfer line (SMTB-transfer line).
The feed cap and the end cap of the module test stand are almost identical to the corresponding parts of the TTF / FEL –linac. The end cap will contain short connections of the 40/80K, 4.5K and 2.0K circuits, a small reservoir for 2.0K helium liquid and 4.5K and 40/80K thermals shields.
The module test sub cooler box is equipped quite similar to the CHECHIA test cryostat / 6 /, to achieve stable supply conditions for sensitive measurements of the 2.0 K heat losses in the module with a resolution of better than +/- 0.2 W.
In the module-test-sub cooler-box the 4.5 K supply mass flow is directed through a heat exchanger in a liquid helium bath and sub cooled to the temperature of the bath (4.41 K). The 4.5 K heat load of the module test transfer line is transferred into heat of vaporisation of the liquid this way, resulting in a stable temperature as well for the 4.5 K shield supply as for the supply of the 2.0 K volume in the module. The liquid in the sub cooler vessel is supplied by the isenthalpic expansion of the 4.5 K return flow from the module (via the Joule-Thomson valve VL2R50).
The 2.0 K helium mass flow is branched from the 4.5K supply and sub cooled from 4.41 K to about 2.2 K in a counter flow heat exchanger by the pumped vapour of the 2.0 K bath in the module. The isenthalpic expansion from about 2.5 bar to the vapour pressure of the 2.0 K bath via a Joule-Thomson valve (VL1V60) gives about 87 % helium II liquid. The pumped vapour leaves the counter flow heat exchanger at a temperature of about 3.5 K and is returned directly to the warm helium compressors through a pipe. The pumped gas will be warmed up by the heat transfer to the surrounding air and by additional electrical heaters wrapped around the pipe.
Two sets of warm helium compressors are part of the extended cryogenic supply of the TTF / FEL-linac / 5/. One set will be exclusively used for the linac the other set is connected to the test cryostats of the TTF laboratory and to the module test bench. The sensitive heat load measurements on the 2.0 K bath of the module under test, which need warm mass flow sensors in the discharge of the helium compressors, can be conducted completely independently from the operation of the TTF / FEL –linac.

In general, the layout includes some ‘over-designs’, which may not be deduced strictly from the presently known data and which may also appear as inconsistent in some details.

For a single test bench the design has not to be optimised to minimum efforts but has to cover uncertainties of future developments and shall also allow driving the systems under test to their limits.

For the time being the layout of the test bench has to deal with original TTF-cryomodules (8 x 9-cell cavities, 4.5 K quadrupole), TESLA superstructure cryomodules (4 x 4 x 7-cell cavities, 2K quadrupoles), TESLA compressed cryomodules (12 x 9-cell cavities, 2K quadrupole) and TESLA mini-superstructure cryomodules (6 x 2 x 9-cell cavities, 2K quadrupoles).

Table 1: The heat load budget of the module test bench

	40/80 K shield / W	4.5 K shield / W	2.0 K circuit / W
Cryo module static	95.3	13.6	1.36
Cryo module dynamic	64.6	6.0	31
Transfer line (30m + 2 Vacuum Barriers)	100	10	
Feed-Box Feed-Cap	140	13	11
End cap	20	2	2
Current leads		1.8	
Sum of calculated Loads	440	46.4	45.4
Design load	**660**	**70**	**100**

4.1.1 Heat load budget

The cryogenic loads of the test bench are estimated from the heat load budget of a compressed TESLA cryomodule . The values for the dynamic loads are extrapolated to 5 Hz pulse repetition rate and to an acceleration field of 40 MV /m (see table 1).

4.1.2 Process mass flows

For the 40/80 K shield helium circuit an inlet temperature of 40 K is assumed. With the given heat load of table 1, a shield gas flow of 5 g/s results in a return temperature of about 60 K.

Table 2: the 4.5 K helium mass flows at the different temperature levels resulting from the heat load budget in table 1 and some boundary conditions discussed in section 4.3.

	4.5 K supply From FEL-sub cooler-Box g/s	4.5 K supply of Cryomodule Shield & quadrupole g/s	4.5 K Current leads g/s	2.0 K supply of Cryomodule g/s	4.5 K Return Flow excess liquid g/s	4.5 K Return Flow gas & liquid g/s
Quadrupole outlet temperature < 4.6 K	12.73	10.5	0.2	2.23	7.6	10.3
Quadrupole outlet temperature < 4.8 K	6.97	4.72	0.2	2.23	2.28	4.72
minimum excess liquid T Quad = 4.91 K	5.73	3.5	0.2	2.23	1.07	3.3
8K return Quadrupole at 2K	3.47	1.13		2.34		1.13
Design	**21**	**16**	**0.2**	**5.0**	**11.5**	**15.8**

The 4.5 K helium circuit is supplied from the FEL-sub cooler box . A design heat load of about 15 W in the supply of the module test transfer line has to be transferred into the

liquid bath of the module test sub cooler. Also the 4.5K massflow will be sub cooled to about 4.41 K, corresponding to a helium vapour pressure of 1.2 bar of the bath (see table 3). The sub cooler vessel is supplied with liquid from the Joule-Thomson valve VL2R50 in the 4.5K return flow from the cryomodule.

The minimum 4.5 K helium mass flow in the module 4.5 K supercritical shield loop is defined by the maximum allowed temperature of the superconducting quadrupole in the cryomodule of the TTF-design (see table 2). If the nominal design temperature of 4.6 K of the quadrupole has to be guaranteed, the 4.5K mass flow must not be lower than 10.5 g/s. If a temperature of 4.8 K is allowed for the quadrupole, the mass flow can be lowered to 4.72 g/s. The excess of liquid in the sub cooler vessel depends on the 4.5K mass flow, as shown in table 2.

If the excess of liquid is optimised for stable temperature conditions only, the temperature of the quadrupole will increase to about 4.91K.

The enthalpy of the excess liquid in the return flow to the FEL-sub cooler box is lost for the use in the module test bench. But the liquid will be separated from the return gas in the FEL- sub cooler box and will contribute to the supply of the overall cryogenic plant.

In the latest design of the TESLA cryomodules, the quadrupole is cooled by the 2.0K liquid bath. Therefore, the temperature of the '4.5K-shield' can float up to about 8K

If a return temperature of 8K will be adjusted for the 4.5K shield loop for special tests, the sub cooler of the feed box will run dry. Without sub cooling, the 2.0K supply will enter the low temperature heat exchanger at a temperature of about 4.89K and will only be cooled to about 2.7K before the 2K Joule-Thomson valve VL1V60. The efficiency of liquefaction will drop from about 88% to 82%. (In any case, the cryomodules of the latest TESLA design can be operated like the TTF-cryomodules if the 4.5K mass flow is increased until the feed box sub cooler is filled with liquid.)

The design mass flows are shown in table 2. The layout will allow for the variety of operating conditions discussed in section 4.1.2.

4.1.3 Specification of the heat exchangers

Table 3: Specification of the module test sub cooler liquid bath heat exchanger

	4.5 K supply from module transfer	4.5 K supply module shield	4.5 K liquid helium bath
Temperature / K	4.611	4.410	4.407
Pressure / bar	2.500	2.490	1.200
Δ (dQ/dt) /W	-21		+21
Mass flow design / g/s	21	21	1
D (dQ/dt) design /W	**- 40**		**+ 40**

The heat exchanger surfaces will be designed for a heat transfer of 40 W. The liquid volume of the sub cooler is estimated to about 40 liter. The sub cooler vessel will be equipped with two redundant heaters of 40W each.

Table 4: Specification of the low pressure counter flow heat exchanger

	2.5 bar supply inlet	2.5 bar supply outlet	31 mbar return inlet	31 mbar return outlet
Temperature / K	4.41	2.2	2.0	>3.18
Pressure / bar	2.490	2.480	0.031	0.030
Δ (dQ/dt) /W design	-33		+33	
Mass flow design / g/s	5		5	

Heat exchangers of similar specifications are already in use in the TTF vertical cryostats and in the horizontal cryostat CHECHIA /6/.

4.2 Cool down and warm up

Warm gas for the warm up of the different cryogenic volumes of the test bench is supplied from the FEL-sub cooler box via the 40K and 4.5K supply tubes of the SMTB-transfer line at a maximum inlet pressure of 18 bar. The FEL-sub cooler box is also equipped with warm up/cool down valves for the return gas of the 40/80K and 4.5K circuits. By means of these valves the module test bench as well as the SMTB transfer line can be warmed up/ cooled down.
The tube dimensions of the transfer line result from the flow conditions at a temperature of 300 K for the warm up of the test bench: all tubes will have a size corresponding to DN 25.
In the FEL-sub cooler box warm and cold gas can be mixed to match the supply temperatures in order not to exceed given limits of the thermal gradients in the cryomodule during warm up and cool down.
For the supply of the 2.0K volume of the crryomodule, the Joule-Thomson valve VL1V60 and the low temperature heat exchanger will be bypassed by the valve VP1V70.
Depending on the temperatures, the return gas from the 4.5K circuit and 2.0K volume of the cryomodule is either directed via the cooldown/warm up valves VT2R40, VT1V70 and the SMTB transfer line to the FEL-sub cooler box or send via the process valve VA1R90, the 31 mbar return tube and the warm up valve VA1R110 directly to the 1.05 bar warm gas tube (see fig. 2). (Due to the sensibility of the niobium cavities the 2.0 K the maximum allowed pressure of the 2.0K volumes is 2 bar. As a consequence, there is only a Δp=0.7 bar to drive the warm gas return flow. It is therefore favourable to use the large DN150 31 mbar return tube for the warm up/ cool down return gas).

The return gas of the 40/80K circuit is directed via the process valve VD4R20 to the FEL-sub cooler box.
At 300 K there will be a mass flow of 30 g/s in the 40/80K circuit and 4.5K and 2.0K circuits respectively.

4.3 Pressure release system (see fig. 2 and table A.2)

The 40/80K, 4.5K and 2.0K return tubes in the feed cap are connected to safety release valves, the exhaust gas is vented into the 1.05 bar warm gas tube. In addition, the exhaust of two parallel large safety valves for the 2.0K volume vent into a vessel, which is purged with helium gas. This vessel opens to atmosphere via a weight loaded flap (a similar system is already in use for the TTF/FEL-linac). By means of these installations the risk of air contamination into the subatmosperic helium volume is minimised.
The vent tubes of the 4.5K and 2.0K circuits are equipped with check valves, in order to avoid thermo acoustic oscillations.

4.4 Process valves (see fig.2 and table A.1)

All cryogenic circuits of the test bench are separated from the other parts of the TTF/FEL cryogenic system by two 'layers' of valves. One 'layer' is in the test bench feed box, the other is in the FEL sub cooler box, in order to avoid air condensation onto cold valves. Also the consequences of leaky valves are reduced. The module test bench and the other parts of the TTF/FEL cryogenic system can be operated without mutual disturbances.
In general, cryogenic valves of 600 mm length are used. All components of the valves, including the electronics of the actuators, have to tolerate a gamma ray radiation equivalent to a dose of 5×10^6 Gry (HERA valves specification).

4.5 Cryogenic Instrumentation (see fig. 2 and table A.3)

In general all connections of cryogenic process tubes in the feed cap and in the end cap are equipped with low temperature thermometers. At operation temperatures below 40K CERNOX sensors are used, above 40K the temperatures will be monitored by platinum sensors. Also the absolute pressures of all cryogenic circuits will be measured by warm pressure gauges, which are connected to the process tubes by capillaries.
There will be mass flow sensors (orifices or venturi flow meters) in the supply tubes of all cryogenic circuits.
Heaters will be installed in the sub cooler vessels of the feed box and of the end cap. Super conducting level sensors will monitor the liquid levels. There will be redundant thermometers, heaters and level sensors.

5. Control System

For the time being, there will be a mixture of several control systems for the RF, vacuum und cryogenic systems, mainly EPICS and DOOCS.

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Appendix

Table A.1 Cryogenic Process Valves

SMTB Status:02.01.2001

Specification of cold process valves

Valve Name	Remark	Position	DN Valve	Di Tube [mm]	KVS-Value	T in [K]	Mfl [kg/s]	P in[bar]	DP [bar]
SMTBVD3V10	warm (*)	40 K supply	15	15	4.73	300	0.03	11.5	0.5
SMTBVD3V10		40 K supply	15	15	4.73	40	0.005	12	0.002
SMTBVD4R20	warm (*)	80 K return	15	15	4.84	300	0.03	11	0.5
SMTBVD4R20		80 K return	15	15	4.84	80	0.005	12	0.003
SMTBVT2V30	warm (*)	4.4 K supply	15	15	3.87	300	0.03	5	2
SMTBVT2V30		4.4 K supply	15	15	3.87	4.4	0.016	2.5	0.003
SMTBVD2R40	warm (*)	4.4 K warm up	32	32	20	300	0.03	1.7	0.2
SMTBVL2R50		4.4 K JT	6	10	0.23	5.3	0.016	2.5	1.3
SMTBVL1V60		2.0 K JT	4	10	0.07	2.2	0.005	1.05	1.019
SMTBVP1V70	warm (*)	2.0 K supply	15	15	3.87	300	0.03	5	2
SMTBVT1R80	warm (*)	2.0 K warm up	32	32	20	300	0.03	1.7	0.2
SMTBVA1R90		2.0 K return	50	50	38.71	4	0.005	0.031	0.001

warm(*) : warm condition defines valves size

Specification of warm process valves

Valve Name	Remark	Position	DN Valve	Di Tube [mm]	KVS-Value	T in [K]	Mfl [kg/s]	P in[bar]	DP [bar]
SMTBVD1R100		2.0 K overflow	40	40	30	300	0.06	1.7	0.4
SMTBVA1R110		2.0 K warm up	40	40	30	300	0.06	1.7	0.4

Table A.2 Check- and Safety Valves

Check Valves	Remark	DN Valve	KV-Value	Position	T/K	m /kg/s	P in /bar	dP /mbar	
SMTBVC2R50		DN 25	25	4 K return sub cooler	5	0.265	2	30	
SMTBVC2R40		DN 32	31	4 K return cryomodul	5	1	5	120	
SMTBVC1R90		DN 150	1000	2 K return cryomodul	6	11	2	30	
Safety Valves	**smallest diameter**	**valve size**	**outflow coefficient**	**Position**	**T release / K**	**m / kg/s**	**P release / bar abs**		**Size**
SMTBVS2R50	17 mm	DN 25/50	0.6	4 K return sub cooler	5	0.265	2		DN 25/50
SMTBVS4R20	3.4 mm	3/4" x 1"	0.6	80 K return cryomodul	67	0.021	20		3/4" x 1"
SMTBVS2R40	20 mm	DN 25/50	0.6	4 K return cryomodul	5	1	5		DN 25/50
SMTBVS1R92	85 mm	DN 100/150	0.6	2 K return cryomodul	6	5	2		DN 100/150
SMTBVS1R91	85 mm	DN 100/150	0.6	2 K return cryomodul	6	5	2		DN 100/150
SMTBVS1R90	38 mm	DN 50/80	0.6	2 K return cryomodul	6	1	1.7		DN 50/80

A. Table A.3 Cryogenic Instrumentation

Type	Number	Range[K]	Power[W]
Platinum thermometers			
SMTBSTP3V10	2	30-300	
SMTBSTP3V11	2	30-300	
SMTBSTP4R20	2	30-300	
SMTBSTP4R21	2	30-300	
SMTBSTP4R420	2	30-300	
SMTBSTP3V410	2	30-300	
SMTBSTP4R520	2	30-300	
Cernox thermometers			
SMTBSTC2V30	2	4-300	
SMTBSTC2V31	2	4-300	
SMTBSTC2R50	2	4-300	
SMTBSTC1V60	2	1.8-300	
SMTBSTC1R80	2	4-300	
SMTBSTC1R90	2	1.8-300	
SMTBSTC1R91	2	1.8-300	
SMTBSTC2R450	2	4-300	
SMTBSTC2V430	2	4-300	
SMTBSTC1R490	2	1.8-300	
SMTBSTC1V470	2	1.8-300	
SMTBSTC2R550	2	4-300	
SMTBSTC1R590	2	1.8-300	
SMTBSTC1R591	2	1.8-300	
Pressure Indicators		**[bar]**	
SMTBSP3V10	1	0-20	
SMTBSP2V30	1	0-20	
SMTBSP2R50	1	0-2	
SMTBSP4R520	1	0-20	
SMTBSP2R550	1	0-20	
SMTBSP1R590	1	0-2	
SMTBSP1R591	1	0 - 0.1	
Flowsensors		**[g/s]**	
SMTBSF3V10	1	1.0 - 30.0	
SMTBSF2V30	1	1.0 - 50.0	
SMTBSF1V60	1	0.5 - 10.0	
SMTBSF1V70	1	1.0 - 50.0	
Levelindicators		**[%]**	
SMTBSL2R50	2	0 - 100	
SMTBSL1R590	2	0 - 100	
Heaters			
SMTBHL2R50	2		100
SMTBHL1R590	2		100