THE TESLA ACCELERATOR MODULE TEST FACILITY

B.Petersen,W.D.Moeller, B.Sparr, S.Wolff,
DESY, Notkestrasse 85, D-22607 Hamburg, Germany

Abstract

The superconducting TESLA linear accelerator will consist of about 1800 cryomodules. Before their installation in the TESLA tunnel, the accelerator cryomodules have to be qualified after the assembly in random tests. The qualification includes the check of the general mechanical dimensions and the measurement of the cryogenic performance of all systems, in particular,the performance of the cavities.

In addition, all about 21000 single cavities have to be tested before the assembly in the cryomodules at a rate of about 24 per day. The paper presents the layout of the test facility.

1 INTRODUCTION

The Tera-eV Energy Superconducting Linear Accelerator (TESLA) will consist of about 21000 superconducting RF 9-cell cavities of pure niobium, cooled in a 2.0 K helium bath. The cavities will be assembled in groups of 12 in about 16-17 m long cryostats (cryomodules). Among other things, the cryomodules will be equipped with thermal shields at 40-80 K and 5-8 K temperature levels respectively.

Before their installation in the TESLA tunnel, the about 1800 accelerator cryomodules have to be qualified. The qualification includes the check of the general mechanical dimensions and the measurement of the cryogenic performance of all systems, in particular, the performance of the cavities. At the start of the cryomodule series production the tests will cover 100 % of the cryomodules, in order to check and adjust the fabrication. As soon as the non-acceptance rate will decrease below a value in the order of 1 %, only about 25 % of the cryomodules will be tested.

These random tests can be applied with low risk for the commissioning of the accelerator, because all main single components, like cavities and magnet packages, will be tested to an extent of 100 % before the assembly of the cryomodules. In addition and in contrast to the operation of superconducting high energy physics storage rings like HERA and LHC, the low performance of single cryomodules can be tolerated for the operation of the linac to some extent.

For the time being, the performance of single superconducting RF-cavities can only be monitored by cryogenic tests. Industrial studies [1] have shown that the effort, needed for the cryogenic tests of single cavities pays, as soon as the failure rate of the single cavities exceeds 1.2 %. Also the overall accelerating gradient of the linear accelerator can be improved in the range of more than 10% by sorting of the RF-cavities according to their performance. For the fabrication of the TESLA cryomodules more than 21 000 single cavities have to be tested at a rate of about 24 cavities per day.

In addition, about 800 packages of superconducting magnets (quadrupoles and steering dipoles) have to be tested in vertical dewars at an average rate of one package per day.

In general, with the exception of the tests of prototypes, the tests will aim only at quality insurance. For the cavities as well as for the cryomodules the test results from the test facility will be used as a fast feedback into the series production in order to avoid failures and to increase the performance.

2 DEFINITION OF THE TEST PROGRAMMES

2.1 Test Programme for the Vertical Tests of Single Cavities and Magnet Packages

The maximum accelerating field and the corresponding unloaded quality factor Q_o of each single cavity will be measured at a temperature of 2 K in a bath cryostat. To increase the throughput of the vertical tests stands, eight cavities are assembled in one cryostat insert. According to estimates of the test schedule [2], about 20 hours are needed for one complete test run for eight cavities, including the assembly and disassembly of the insert to the cryostat and the cool-down and warm-up procedures.

The inserts will be assembled at the cavity preparation site and delivered to the test facility. Cavities, which will have passed the tests successfully, will be sent to the cryomodule manufacturer. Cavities with low performance will be fed back into the preparation procedures.

The superconducting performance of the magnet packages will also be tested in the bath cryostats. In particular the current performance will be monitored. Two magnet packages will be tested at a time in one cryostat.

2.2 Test Programme for the Accelerator Module Test Benches

The cryogenic performance tests include the integral leak check of all vacuum systems and cryogenic process tubes, the test of the instrumentation, measurements of the static heat loads and of the maximum accelerating field of the cavities. The corresponding unloaded quality factor Q_o will be monitored by cryogenic heat loss measurements. During the performance tests of the cavities, also the x-ray radiation and the related dark currents will be measured by means of two ionisation chambers at each test bench and by dark current monitors at both ends of the beam tube of the cryomodules, respectively.

The pre-conditioned RF-couplers will be further conditioned. The RF-phase will be adjusted in the order of +/- 20 degrees. There will be the possibility to treat the cavities by means of high peak power processing [3].

The instrumentation of superconducting magnet packages will also be tested.

About 170 cryomodules will be equipped with cryogenic valves, temperature sensors, flow sensors and liquid level indicators (string interconnection equipment). Also this instrumentation will be tested on the test benches.

According to estimates of the test schedule [2], about eight to nine days are needed for the complete test of one accelerator cryomodule, including the mechanical assembly and disassembly on the test bench.

3 LAYOUT OF THE ACCELERATOR MODULE TEST FACILITY

3.1 General Layout

From the given test rates and the estimates of the test schedules [2], it follows that 6 test benches for cryomodules and at least 3 vertical dewars have to be installed in the module test facility.

The number of test benches includes an overcapacity of about 20 % for the test of 25 % of the modules. In order to increase the efficiency of the vertical tests, 6 vertical dewars are foreseen(see Fig.1).

Each individual module test bench has to be surrounded by a concrete shielding of 0.8 m thickness in order to establish radiation safety in all parts of the test hall. A roof shielding of 0.8 m thickness will cover the test benches. Lead plates will be installed at both ends of the test benches in addition. There will be an inner space of 23 m x 4.4 m x 2.5 m for one test bench. Three test benches will be grouped together as a block.

The vertical dewars will be inserted into ground pits and covered by movable concrete shielding blocks of 1.2 m thickness. The cryostat inserts will be transported from the storage area into the cryostats by use of the hall crane.

3.2 Cryogenic Supply

For the continuous operation of the test hall, cooling capacities of about 10 KW at 40-80 K, 1.0 KW at 4.5 K and 0.6 KW at 2.0 K are needed. In order to reduce the effort of the helium distribution system, only the 40-80 K and 4.5 K circuits will be branched to the test benches and the test dewars. At the cryomodule test benches as well at the vertical cryostats the 2 K liquid helium will be supplied by the isenthalpic expansion of the 4.5 K helium, which will be sub cooled to 2.2 K before the expansion by means of counter flow heat exchangers. Distributed warm compressor systems will be used to lower the vapour pressure of the helium baths to 31 mbar [4]. As a result, a helium liquefaction rate of about 50 g/s has to be supplied on average from the helium plant. Peak liquefaction rates will be buffered by means of two 10 m^3 liquid helium storage reservoirs.

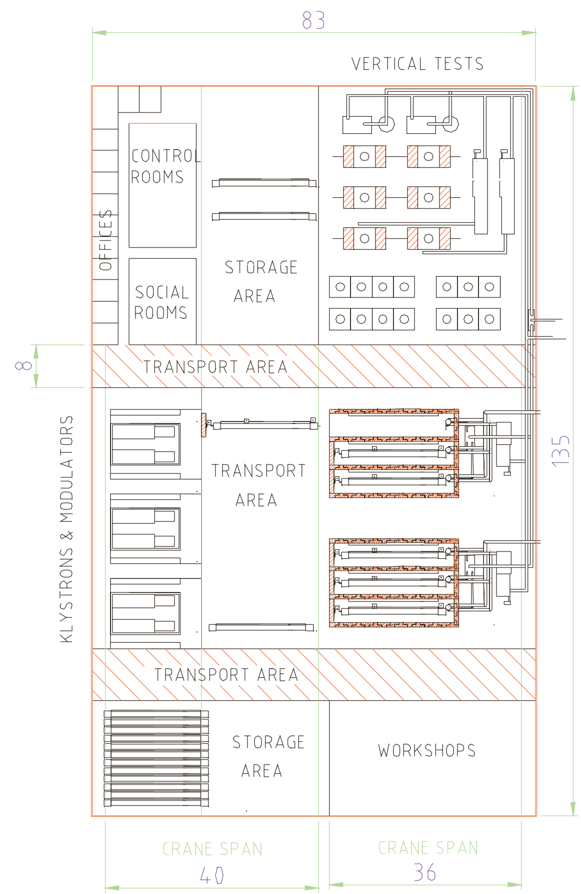

Figure 1: Ground Plan of the Accelerator Module Test Facility

The test facility can by connected to any helium refrigerator plant, which can supply the capacities mentioned, in particular to the HERA refrigerator or TESLA refrigerator on the DESY site.

3.3 Cryomodule Test Benches

The cryogenic supply of the test benches is divided into two 'layers', in order to operate the test benches independently from each other, to avoid air condensation on cryogenic valves during the exchange and installation of modules, and to reduce the consequences of leaky valves. One layer are the feed-boxes of each module test bench, the other layer are the sub-cooler & valves-boxes, to which a group of three module test benches will be connected (see Fig.2). In order to supply the cryogenic 40-80 K and 4.5 K shield circuits as well as the 2 K circuits of the cryomodules, each cryomodule test bench has to be equipped with a feed-box, a feed-cap and an end-cap. The feed-box will be fixed on the ground inside the shielding of the test bench and will contain cryogenic valves for each supply and return tube, a small 4.5 K sub-cooler and an 2 K counter flow heat-exchanger. The 4.5 K sub-cooler of the feed-box is used to stabilize the supply temperatures of the 4.5 K and 2 K circuits. All safety vent lines and relief valves are connected to the feed-box. The feed-cap, which is attached to the feed-box will contain all connection flanges to the cryomodule. The end cap will be fixed to the module support structure and will contain only the short circuits of all cryogenic tubes

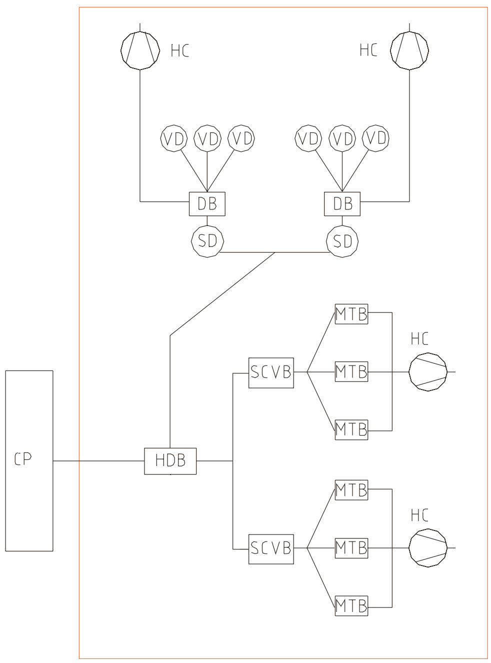

Figure 2.: Block Diagram of the Cryogenic System
CP= cryogenic plant (HERA or TESLA), HDB= hall distribution box, SCVB= sub-cooler & valves box, MTB= module test bench (consisting of a feed-box, a feed-cap and an end-cap), HC= helium compressor, SD= storage dewar, DB=distribution box, VD= vertical dewar

and a 2 K liquid reservoir. The position of each end-cap can be adjusted easily to the different lengths of cryomodules.
Each cryogenic supply tube in the feed-box is equipped with a Venturi flow meter. In the feed-cap as well as in the end cap all supply and return tubes are equipped with redundant thermometers. Redundant liquid level indicators and pressure sensors are installed in the 2 K reservoir of the end cap. The pressures of all cryogenic circuits will be monitored.
Each group of three feed-boxes will be supplied via transfer lines from one sub-cooler & valves-box. The connecting transfer lines consist of 4.5 K supply, 4.5 K return, 40K supply and 80 K return tubes. The sub-cooler & valves-box contains one 4.5 K sub-cooler and cryogenic valves for all process tubes of the different transfer line branches, and all corresponding warm-up and cool-down tubes and valves connected to the transfer lines. The sub-cooler has to compensate the heat losses of the transfer lines from the refrigerator to the test benches. As a result of the combination of feed-boxes and sub-cooler & valves-boxes all cryogenic supply and return tubes are separated from the test bench by two cryogenic valves in series. The sub-cooler & valves-boxes will be supplied from the test hall distribution-box (see Fig.2).
The 2 K vapour return tubes of three-test bench feed-boxes are connected to one 300K-helium compressor unit respectively. In the exhausts of the compressor units the pumped mass flows can be measured by warm gas flow meters. At a constant liquid helium level in the 2 K liquid reservoirs of the end caps, the heat load of the 2 K circuit can be monitored with a resolution in the order of +/- 0.1 W by means of these flow meters.

3.3 Vertical Test Cryostats

Also for the supply of the vertical dewars two 'layers' of valves in the dewars and in distribution-boxes will be installed (see Fig.2). The design of the vertical dewars can be scaled from the vertical test dewars of the TESLA test facility [4]. The vertical dewars will contain a 2.2 m^3 liquid helium volume, cryogenic valves and a 2 K counter flow heat-exchanger, installed in the vacuum jacket. Three dewars will be connected to one distribution-box respectively. The distribution-boxes will contain all warm-up and cool-down connections and valves. One 10 m^3 liquid storage dewar will be connected to each distribution box respectively, in order to buffer the loads for the refrigerator. The storage dewars will be supplied from the test hall distribution-box and will also be used as sub-coolers.

3.4 RF Systems

In order to avoid time consuming installations of the RF equipment between the module tests benches, one 10 MW klystron and modulator set will be installed at each accelerator module test bench, including a permanent RF distribution system.
The vertical tests will be supplied by additional RF systems, which will operate in cw-mode.

4 REFERENCES

[1] ACCEL industrial study
[2] W.D.Moeller, B.Petersen, B.Sparr: A Proposal for a TESLA Accelerator Module Test Facility TESLA Report No. 2001-08
[3] J. Graber, PhD thesis, Cornell University, 1993
[4] G.Grygiel, U.Knopf, R.Lange, B.Petersen, T.Peterson, D.Sellmann, and J.Weisend II, Status of the TTF Cryogenic System, Adv. in Cryogenic Engineering, Plenum Press, Vol. 41 a, pp. 847-854, N.Y. (1996)