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THE TESLA CRYOGENIC DISTRIBUTION SYSTEM

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Abstract

The construction of the 33 km long 500 GeV centre-of-mass energy (upgradeable to 800 GeV) superconducting linear collider TESLA at DESY with an integrated X-ray FEL facility of 0.1 nm wavelength has been proposed by an international collaboration. The collider will consist of more than 21000 superconducting 9-cell 1.3 GHz RF cavities assembled in about 1800 cryomodules containing also a superconducting magnet package with a quadrupole and dipole steering coils.

The paper describes the cryogenic distribution system necessary for cooling to 2 K, mainly consisting of twelve 2.5 km long cooling chains (cryogenic units) of cryomodules, and gives information on the heat load budget, on operating modes as well as on the energy upgrade philosophy.

1 INTRODUCTION

The 33 km long 500 GeV centre-of mass energy e^+e^- linear collider TESLA (Tera-eV Energy Superconducting Linear Accelerator), proposed by an international collaboration [1] consists of two 15 km long linear accelerators of 250 GeV each. The linacs pointing to each other and operated at 5 Hz beam pulse repetition rate are placed in a 5.2 m diameter underground tunnel starting from the DESY site in north-northwest direction. A high energy experimental area is placed in the centre of the linacs. The first 3 km of the electron linac are also used for accelerating electrons for an X-ray Free Electron Laser (FEL) with wave lengths down to 0.1 nm.

The accelerating structures consist of 1.3 GHz superconducting 9-cell cavities of pure niobium. There are more than 21000 cavities to be cooled to 2 K. The required accelerating gradient for 500 GeV centre-of-mass energy is 23.4 MV/m at a quality factor $Q_0 = 10^{10}$. The cavities are assembled in about 1800 cryostats (cryomodules) [2] forming a 15 km long cryogenic chain in each linac. In addition to the main linacs there are 3 e^- injectors of 500 MeV (one for standard high energy beam, one for polarised electrons, one for the FEL beam) and 5 GeV pre-accelerators for $e^-$and e^+.

2 CRYOGENIC DISTRIBUTION

The cooling of the collider is performed from 7 refrigerators [3] in above-ground service halls placed along the linacs at distances of about 5 km in each linac. Generally each refrigerator supplies two 2.5 km long cryogenic units consisting mainly of cryomodules housing the cavities and magnet packages. The symmetry is broken only at the first 5 km of the electron linac where the 2 first refrigerators (one on the DESY site, the other 4.7 km away) serve only one unit, each. The reason is a very crowded urban area near DESY with difficulties to find a proper space for a refrigeration hall and the fact that higher heat loads occurs here from the additional 5 Hz for the FEL operation. Unit 1 and partly unit 2 are declined by -8 mrad until the tunnel follows a line levelled with respect to gravity.

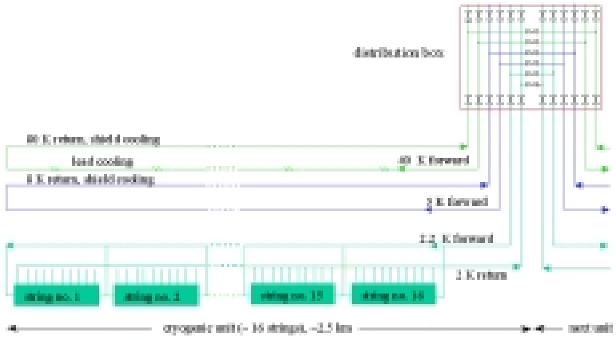

Fig. 1: Cryogenic unit (one out of 12)

A cryogenic unit (Fig. 1) consists of about 150 cryomodules, one feed-box, one end-box and vacuum barriers at distances of 500 m for limiting the pressure increase in the cryogenic pipes in case of an accidental insulation-vacuum break [4] and for better leak checking. In order to limit the flow of liquid in the 2-phase helium filling tube the 2.5 km cryomodule section is separated into up to 16 cryogenic strings of about 170 m length.

The cryomodules house all helium tubing necessary for the cryogenic process [2]. Each standard 16 m long cryomodule contains 12 cavities, housed in titanium helium vessels, connected with the 2-phase helium filling tube and supported at the 2 K gas return pipe (GRP) which also acts as a girder. This cold mass surrounded by insulation vacuum with thermal shields at 5-8 K and 40-80 K is supported at the vacuum vessel by three glass-fibre support posts. The cavities are equipped with HOM couplers, RF antennas, mechanical motor- and piezo-electric-driven tuners [5] as well as main RF input couplers connecting the cavity end with the outer vacuum vessel wall. More than 1/3 of the cryomodules also contain a superconducting magnet package with quadrupole magnets for beam focussing and one or two dipole magnets for beam steering. A beam position monitor (BPM) is attached to each magnet helium vessel. These cryomodules are 17 m long.

For assembly purpose the beam tube at both ends of the cryomodule is closed by hand valves. A higher order mode (HOM) absorber is placed at the beam tube interconnection of the modules.

Some special cryomodules with 8 cavities and one magnet package, respectively 4 cavities and 4 magnet packages are necessary in the e^-/FEL injectors and in the positron pre-accelerator. A list of main cryogenic components is shown in Table 1.

A cryogenic string (Fig. 2) generally consists of 10 cryomodules, the last of which contains 3 control valves (two for cool-down and warm-up, one Joule-Thomson (JT)-valve for steady state operation), 3 flow sensors, a liquid helium separator and a small helium reservoir (both with level sensors, the reservoir with a heater). In addition to the above mentioned 2 K helium 2-phase tube there is a manifold for feeding cool-down or warm-up helium to the bottom of the cavity and magnet helium vessels.

A 200 mm diameter warm gas tube connects the refrigerators of each linac in order to allow helium gas exchange in case of a complete refrigerator break-down.

Table1: Main cryogenic components

type	number
modules (12 cavities, mo magnet package)	1004
modules (12 cavities, 1 magnet package)	742
modules (8 cavities, 1 magnet package)	8
modules (4 cavities, 4 magnet packages)	27
vacuum barriers	48
feed-boxes	19
end-boxes	19
injector feed-boxes	3
standard distribution boxes	6
single distribution box	1
injector distribution box	1
transfer lines (m)	824

3 INSTRUMENTATION

For proper control of cooling, RF and beam operation a lot of instrumentation is necessary. Because of the large numbers of cavities and cryomodules involved the instrumentation has to be kept to the necessary minimum. In the string interconnection cryomodules (the one with the valves) and in the feed- and end-boxes platinum sensors as well as low temperature sensors (carbon-glass, CERNOX or TVO) will be installed in the cool-down/warm-up lines, in the 2 K supply line, at the entrance of the 2 K 2-phase helium tube and at the 2 K gas return pipe for cooling purposes. The cool-down/warm-up lines as well as the 2 K helium entrance to the string will be equipped with cold flow meters. Liquid level sensors will be installed in the liquid separator and in the small helium reservoir, heaters in the reservoir only. In addition each cryomodule will be equipped with platinum sensors at each RF main coupler (each cavity) and at the 50 K intercept of the HTS current leads for the magnet packages. All temperature sensors are installed redundant. For protection of the current leads voltage taps are necessary. RF antennas are installed at each cavity and at the beam position monitor. The mechanical tuner at each cavity is controlled with a stepping motor and a piezo-electric quartz.

Table 2: Total numbers of instrumentation

type	number
platinum sensors (Pt)	45574
low temperature sensors (Lt)	1322
superconducting level sensors (L)	748
carbon resistor chains	374
cold flow meters (F)	580
electrical heaters (H)	374
HOM antennas	42400
pick-up antennas	21200
e^- sensors	21200
BPM antennas	3108
voltage taps	8010
motor steering	21200
piezo-electric quartz steering	21200

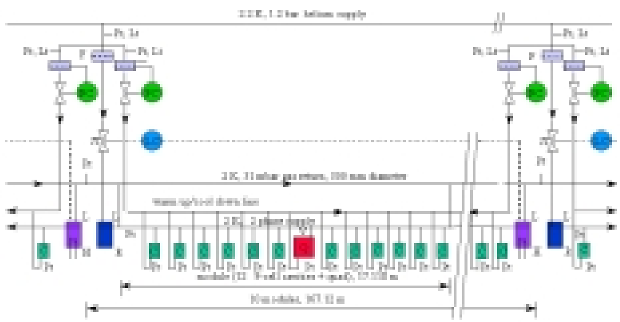

Fig. 2: Cryogenic string (C: cavity, Q: quadrupole, Pt: platinum sensor, Lt: low temperature sensor, F: flow meter, JT: Joule-Thomson valve, FC: flow control, LC: level control, L: level sensor, H: heater, R: reservoir)

4 OPERATING MODES

During steady state operation, helium of 2.2 K and 1.2 bar is flowing from the distribution box of the refrigerator via the feed-box through all cryomodules of one unit. At each string interconnection cryomodule (and at the end-box) a fraction of the helium is diverted and expanded to 31 mbar over the JT valve into a liquid helium separator. From here it flows through the 76 mm diameter 2 K 2-phase tube connecting all cavities. This tube is generally filled to the half with liquid (except for the declined section in units 1 and 2) thus keeping the helium vessels of cavities and magnets filled. At the end of the string the helium is filling a small reservoir equipped with a level sensor and heater, both used for control of the helium flow through this branch. At each cryomodule interconnection the 2-phase line is connected to the GRP through which the evaporated helium returns to the refrigerator. The mass flow for nominal operation is 68 g/s (for 1.411 kW load) resulting in a pressure drop of 0.33 mbar in the GRP over the unit.

Detailed investigations of the 2-phase Helium II flow have been made showing temperature, pressure and liquid level distributions and thus the validity of the concept [6].

During cool-down helium gas of varying temperature is fed from the distribution box of the refrigerator over the feed-box through the cryomodules in the line mentioned above (in the tube later used for one-phase 2 K helium). At each cryogenic string interconnection the helium is then conducted via flow meters and control valves into the manifolds on both sides of this module from which it flows in narrow tubes to the bottom of the cavity and magnet helium vessel, cooling the cavities and magnets and returning through the GRP to the refrigerator. The time needed to cool-down the about 700 tons (2 units) to 2 K is about 10 days. In addition 2 ½ days are needed to fill the helium vessels with liquid. Similar times are needed for warm-up where the helium flows in the same way.

5 HEAT LOAD BUDGET

Heat loads have been calculated for all individual cryogenic components in the cryogenic units starting with the cryomodules and including vacuum barriers, feed- and end-boxes and transferlines. Assumed is an acceleration gradient of 23.4 MV/m at $Q_0=1*10^{10}$. Some of the units contain additional equipment for the injectors and pre-accelerators (units 1 and 7), for the superconducting RF used in the damping rings (units 1 and 10) and for 5 cryomodules used in each bunch compressor (units 1 and 12). In units 1 and 2 (partly) the operation of the X-ray FEL leads to additional heat loads (acceleration gradient 21.1 MV/m at $Q_0=1*10^{10}$) . A factor of 1.5 has been applied to the calculated heat loads for establishing the design refrigeration power of the cryogenic plants which generally serve 2 units except hall 1 (only unit 1) and hall 2 (only unit 2) (Table 3).

Table 3: Design heat loads [kW] at refrigeration halls

T	hall1	hall2	hall3	hall4	hall5	hall6	hall7
2 K	3.70	3.07	4.23	4.21	3.87	5.13	4.22
5 K	4.73	4.60	7.42	7.39	6.88	8.25	7.36
40 K	44.6	53.5	80.7	79.6	74.4	78.6	80.5

6 ENERGY UPGRADE PHILOSOPHY

The centre of mass energy of the proposed TESLA is 500 GeV. Seeing the progress achieved in the cavity development, gradients of above 35 MV/m may be reached with slightly reduced Q_0 ($5*10^9$) [7]. This would allow to operate TESLA at energies up to 800 GeV, especially if the newly proposed 2-nine-cell superstructure version [8] for the cryomodules is used. As the dynamic heat load in the cavities scales with the square of the gradient, the refrigeration capacity must be increased considerably. The proposed solution is to double the refrigeration capacity in the cryogenic halls [3]. An operation at 4 Hz beam pulse repetition rate should be possible.

7 SUMMARY AND OUTLOOK

A cryogenic distribution system has been proposed for TESLA consisting of 12 cryogenic units of 2.5 km length, each, with up to 16 about 170 m long cryogenic strings as the smallest cooling loops. Steady state and transient operation modes have been investigated. The calculated heat loads have been used to define design refrigeration capacities for the refrigeration halls. The proposed scheme allows an energy upgrade to 800 GeV if the refrigeration capacity is doubled.

8 REFERENCES

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