TESLA

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Abstract

The layout of TESLA as described in the Technical Design Report (TDR) from March 2001 will be presented with the cost evaluation and the construction schedule. The present status of planning and further steps towards the realisation of the project will be described.

1 INTRODUCTION

There is a worldwide consensus that the next large project for high-energy physics must be a high luminosity e^+e^- linear collider of about 500 GeV CM energy upgradeable to higher energies of order 1 TeV. This consensus reflects itself in statements from ACFA [1] in 1997, ECFA [2] and the Snowmass physics groups [3] in July 2001. A timely realisation is recommended to obtain physics results from such a linear collider in overlap with the experiments at LHC.

Over the past decades, several groups worldwide have been pursuing different linear collider design concepts. Already in 1971 a group at the Institute of Nuclear Physics in Novosibirsk started detailed design work for a linear collider of several hundred GeV, addressing many of the relevant problems. Several years later, groups at CERN, at the Stanford Linear Accelerator Center (SLAC) in California, and the Japanese National Laboratory for High Energy Physics (KEK) in Tsukuba began work on linear collider designs. The feasibility of the concept has been demonstrated by the successful operation of the Stanford Linear Collider. All these concepts were based on normal conducting copper cavities.

A major challenge for all linear collider concepts is to obtain a large collision rate (luminosity) of electrons and positrons at the interaction point. This requires very small spot sizes of the beams at the collision point and high beam powers.

The TESLA approach differs from the other designs by the choice of superconducting accelerating structures as its basic technology. The TESLA linear collider based on superconducting accelerating structures is ideally suited to meet the requirements needed for a large collision rate, namely very small beam sizes and high beam power.

Superconducting technology provides important advantages for a linear collider. As the power dissipation in the cavity walls is extremely small, the power transfer efficiency from the RF source to the beam is very high, thus keeping the electrical power consumption within acceptable limits (~ 100 MW), even for a high average beam power. The high beam power is the first essential requirement to obtain a high rate of electron-positron collisions.

The second requirement is extremely small sizes of the electron and positron beam at the interaction point. The relatively low RF frequency of the TESLA linear accelerators is ideally suited for conserving the ultra-small size of the beams during acceleration. When a beam is accelerated in a linear accelerator, the charged particles induce electromagnetic fields (so-called wake fields), which act back on the beam itself and can spoil its quality by increasing the energy spread and the beam size. As these wake field effects decrease strongly with increasing distance between the beam and the surrounding cavity walls, wake fields are much weaker in the larger cavities of accelerators working at low RF frequencies than in smaller cavities operating at higher frequencies.

The advantage of superconducting technology has been acknowledged from the very beginning of the research and development on linear colliders, but the technology was considered to be considerably more expensive than conventional technologies.

By a focused development program, started in 1992, the international TESLA collaboration in co-operation with industry succeeded in developing superconducting cavities, which are capable of generating an accelerating gradient, five times larger than before 1990. In addition a reduction of the cost per meter of accelerator by a factor of four was achieved. Together, these achievements provide the basis for a realistic superconducting linear collider with all its advantages.

The Technical Design Report [4] for the TESLA linear collider was elaborated by the TESLA Collaboration and presented on March 23/24, 2001 at DESY in Hamburg, It was proposed to realise the linear collider with an integrated X-ray Free-Electron Laser Facility in the vicinity of DESY and to construct and operate the linear collider in an international collaboration of committed institutes - the Global Accelerator Network (GAN)[5].

2 THE BASE LINE DESIGN

The layout of the accelerators is based on the experience gained at the TESLA Test Facility (TTF). The

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technology for 9-cell cavities, constructed from niobium sheets by deep drawing and electron beam welding in industry, allowing for accelerating fields necessary for a 500 GeV linear collider in a reliable way (see Fig. 1) is by now well established, as has also been shown in many contributions to this workshop.

The test linac of TTF, set up as a complete system test comprising prototypes of all subsystems necessary for the TESLA linear accelerator, has been operated successfully for several years (see fig.2). Therefore the technical layout of the TESLA linear accelerators has a solid basis.

The cryogenic accelerator modules for TESLA will be about 17 m long, containing twelve 9-cell cavities instead of 8 for the 12 m long TTF modules. This way a cost reduction and a higher filling factor of the linear accelerator are achieved. For the same reason the length of the interconnection between adjacent cavities has been reduced (from 346 mm to 283 mm). For the fixed length of the linear collider of about 33 km a gradient of 23.4 MV/m is needed for 500 GeV operations. The total number of cavities for the main linacs is 21024 corresponding to 1752 modules and 584 RF-stations. These numbers contain an overhead of 2 % to cope with failing RF-stations.

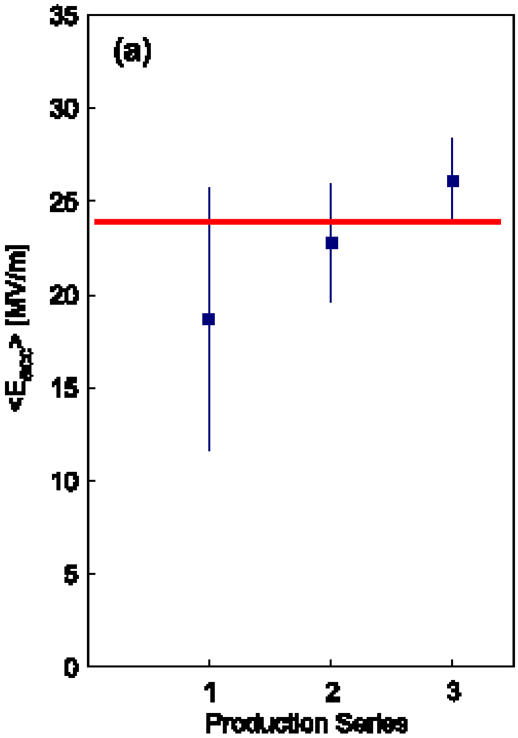

Figure 1: Average accelerating gradient at a quality factor $Q_0 \geq 10^{10}$ measured in the vertical test cryostat

3 THE COLLIDER FACILITY

The electron beam for the TESLA collider is generated in a laser-driven source. After a short section of conventional normal conducting linear accelerator, the beam is accelerated to 5 GeV in superconducting structures identical to the ones used for the main accelerator. The electrons are stored in a damping ring at 5 GeV to reduce the beam size to values adequate for high luminosity operation. As the train of 2820 bunches, accelerated within the RF pulse of about 1 msec, is 300 km long, a compression scheme is used to store the bunches in the damping ring. Reducing the distance between bunches by a realistic factor of 16 yields an 18 km circumference. Using the so-called “dog bone” design with two 8 km straight sections, most of the circumference can be placed inside the main accelerator tunnel (see fig.3). Only two 1 km loops are needed at either end. After damping, the bunch train is decompressed and injected into the main linear accelerator.

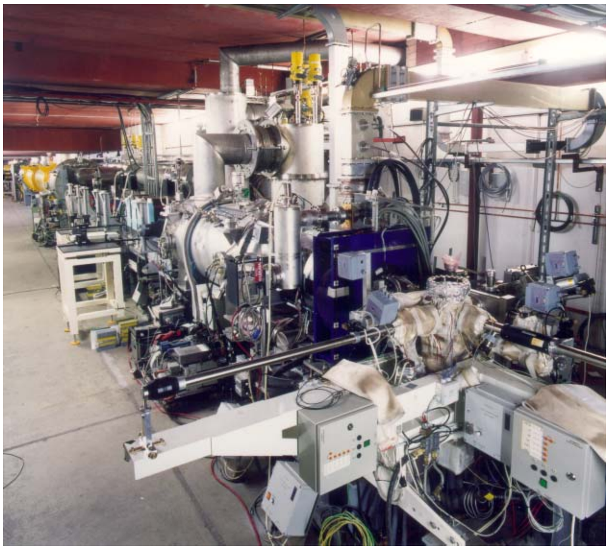

Figure 2: Test Linac of TTF

A conventional positron source cannot provide the total charge of about $5 \cdot 10^{13}$ positrons per beam pulse, needed for the high luminosity operation of the TESLA collider. Therefore an intense photon beam is generated by passing the high-energy electron beam through an undulator magnet placed after the main linear accelerator as proposed originally for VLEPP [6]. Positrons are produced by directing the photons onto a thin target in which they are converted into pairs of electrons and positrons. After acceleration to 250 MeV in a normal conducting linear accelerator the positron beam is transported to a 5 GeV superconducting accelerator, after which it is injected into the positron damping ring. This source can also generate a polarised positron beam.

The about 1.6 km long beam delivery systems between the linear accelerators and the collision point, where the experiment is located, consist of sections to remove the beam halo, beam diagnostics and correction magnets, and the final focus system, consisting of magnetic lenses which focus the beams at the collision point down to spot sizes of about 550 nm width and 5 nm height. The design of the final focus is essentially the same as the Final Focus Test Beam (FFTB) system successfully tested at the Stanford Linear Accelerator Center (SLAC) and the beam optics requirements of TESLA are comparable to those achieved at the FFTB. The beams can be kept in collision at the interaction point to a high precision by using a fast bunch-to-bunch feedback, which measures and corrects the beam-beam offset and crossing angle on a time scale comparable to the time between bunches. A prototype of the orbit feedback system has been installed and successfully tested at the TTF linear accelerator [7]. The beam delivery systems have been optimised for a single head-on interaction point. The magnet systems and the beam line layout are designed for beam energy of up to 400 GeV.

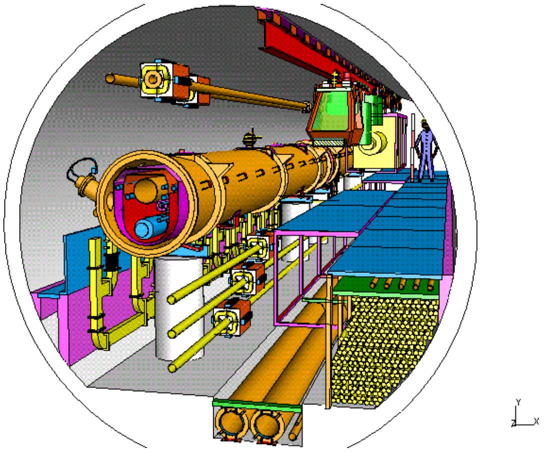

Figure 3: View into the TESLA Tunnel.

The cryogenic system for the TESLA accelerators is comparable in size and complexity to the one currently under construction for the Large Hadron Collider (LHC) at CERN. Seven cryogenic plants cool the linear accelerators to 2 K. The cooling capacity of the first section of the electron accelerator is higher than the rest to accommodate the additional load from the XFEL beam pulses.

The two linear accelerators as well as the beam delivery systems will be installed in an underground tunnel of 5.2 m diameter. One experimental hall is foreseen to house the big high energy physics detector set-up at the collision point; it can be extended for a second detector should a second interaction region be constructed. The seven surface halls for the cryogenic plants are connected to the underground tunnel by access shafts. The halls also contain the power sources (modulators), which generate the high voltage pulses for the klystrons located in the accelerator tunnel, thus allowing access to the modulators during machine operation. The exchange of klystrons, however, will require an interruption of the machine operation. Assuming an average klystron lifetime of 40,000 hours, a maintenance day every few weeks will be necessary.

To keep the future option of colliding electrons, accelerated in the TESLA linacs, with protons circulating in HERA the direction of the TESLA linac was chosen to be tangential to the West straight section of HERA. The countryside is flat at about 10 m above sea level. The tunnel axis is at 8 m below sea level, giving more than sufficient soil coverage for radiation protection. The soil, consisting mainly of sand, allows for easy tunnelling by the hydro shield method, which was also used at HERA. The tunnel follows the curvature of the earth over most of its length, except for a section of about 5 km to connect to the straight section of HERA.

A view into the tunnel is shown in fig. 3 at a section containing the straight sections of the “dog bone”-damping damping ring (upper left side) and several beam lines to the X-FEL facility (right below the cryomodule). At the top of the tunnel there is a monorail for the transportation of equipment and personnel.

4 ENERGY UPGRADE POTENTIAL

Higher beam energies than for the baseline design are possible within the site length since:

The physical limit for the gradient in niobium structures at 2 K is above 50 MV/m, and several 9-cell cavities have already reached gradients above 30 MV/m at TTF. Electro-polishing followed by low-temperature bake-out—a technology being developed by KEK [8]—has yielded systematically higher performance single-cell cavities, with gradients up to 42 MV/m.

The filling factor of the linear accelerators can be further increased by about 6% by a modified design of the cavity structure (superstructures)[9], and hence the maximum energy for a fixed accelerating gradient and site length.

A method has been developed and successfully demonstrated at TTF, which compensates the mechanical deformation of the cavities resulting from the strong electromagnetic fields. This active mechanical stabilization using fast piezo tuners [10] stabilizes the resonant frequency of the cavities and maintains an optimal power transfer from the RF generator.

Based on the ongoing progress in building high gradient cavities we assume that TESLA will be built from the very beginning with superstructures and mostly with cavities reaching gradients of on average 35 MV/m, thus allowing a total collision energy of 800 GeV without major changes to the accelerator modules. The beam delivery system and the magnets in the linear accelerators have been designed for a beam energy of up to 400 GeV.

Collision energies above 500 GeV can be reached in two steps:

A total energy of 650 GeV can already be obtained in the baseline design as the cooling plant capacity has a 50% overhead, thus allowing the gradient in the cavities to be increased by 20-30%.

In order to reach 800 GeV at maximum luminosity two upgrades are required: the cooling capacity of the cryogenic plant must be increased and the number of the RF stations must be doubled.

5 CAPITAL COST AND SCHEDULE

The investment costs given include all components necessary for the baseline design of TESLA. Not included are the costs for the High Energy Physics detector and the X-ray FEL experimental stations (undulators, photon beam lines, etc.). All numbers are quoted at year 2000 prices.

The manpower required for the different stages of the project--preparation, procurement, testing, assembly and commissioning—has been estimated on the basis of the experiences gained at TTF and in large projects like HERA. A total of 7000 person-years will be required. This manpower has to be supplied by the collaborating institutes. As the costing of manpower is depending on the institution and the country, it is quoted separately and is not included in the total capital cost, although part of this manpower may have to be hired.

To allow a comparison with other linear collider projects, the costs for the linear collider and X-FEL are given seperately:

The costs for the linear collider part of the TESLA project amount to 3136 million EURO.

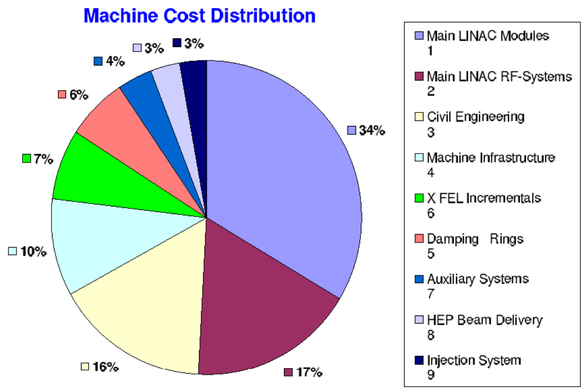

Figure 4: Contribution of accelerator sub-systems in percent of the total cost

The costs for the additional accelerator systems and civil engineering required for the X-FEL are 241 million EURO.

The total cost is divided up by the major sub-systems as shown in fig.4. The TESLA cryo-modules for the main linac with the superconducting cavities are the largest cost item with 1131 million EURO. The cost is dominated by the s.c. cavities, the cryostat and the assembly of the module. Niobium, cavity fabrication and treatment procedures each constitute a substantial part of the cavity costs.

It should be mentioned that the goal set to the TESLA collaboration in 1992 by Bjørn H. Wiik of 2000 US $/MV for the complete accelerating modules (including s.c. cavities, power couplers, cryostat, s.c. quadrupoles etc.) has been achieved within a few %.

Several collaborating institutes were responsible for evaluating parts of the cost. A planning group consisting of the persons responsible for each of the major subsystems, together with experienced senior scientists from the collaboration, has been continuously reviewing the technical layout of the system and the cost evaluations.

The cost estimates for all major components have been obtained from studies made by industry, and are based on a single manufacturer supplying the total number of a given component.

A production schedule of three years peak production plus one year for start-up for each component was specified. The four-year production cycles required for the various components are scheduled within the total construction time of 8 years. The schedule was considered feasible by the companies involved in the study. A core production period of three years plus one year for start-up corresponds to an average production rate of 32 m of accelerator per working day. The corresponding numbers for the proton storage ring of HERA were about 25 m/day; for the LHC about 40 m/day are planned.

In total, the costs for the operation of the accelerators have been estimated at 120 million EURO per year. The operating costs include the electrical power, the regular refurbishing of klystrons, water, and the helium losses. The numbers are determined assuming current prices and an annual operation time of 5000 hours. Costs for general maintenance and repair have been estimated assuming 2% per year of the original total investment costs, corresponding to the DESY experience. For critical components (such as accelerator modules) a number of spares will be produced; these costs have been included in the investment costs.

6 PREPARATION OF APPROVAL PROCEDURE

Following a conceptual design report in 1997 [11] a detailed plan for the TESLA site northwest of the DESY-Laboratory has been worked out and preparatory planning work has been pursued in close co-operation with authorities in the region. The tunnel of the linear accelerator starts at the DESY site in a direction tangential to the straight section West of HERA. The central research campus of the TESLA laboratory is situated about 16 km from the DESY site in a rural part of the North German State of Schleswig-Holstein, and accommodates both the collider detector hall for Particle Physics, and the FEL radiation user facility.

In March 1998 the State Governments of Hamburg and Schleswig-Holstein signed a treaty to jointly prepare all necessary planning steps and documents for the legal procedure (Planfeststellungsverfahren), which can start immediately after the project authorisation. In March 1999 the scope of the plan approval procedure has been fixed officially in an open hearing. The environmental aspects and the public participation are integral parts of this procedure. Environmental impact studies are being pursued and will be completed in the beginning of 2002.

The scientific council of DESY has evaluated the design report and has been supporting the proposal.

In preparation of the German position concerning the approval of the TESLA project the German Research

Ministry has asked the German Science Council (Wissenschaftsrat) to review TESLA together with other large-scale projects presently under consideration. The Science Council is an independent body set up to advise the federal and state governments of the Federal Republic of Germany on matters of higher education and research policy. A recommendation of the Science Council is expected by mid 2002.

On the initiative of ICFA an expert group has been asked to perform a technical comparison of the various proposed linear collider approaches. The report on the conclusion of this group is also expected by mid 2002.

A decision on the realisation of the project from the side of the German Government is expected in 2003.

7 REFERENCES

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