Linear Collider Studies at DESY

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ABSTRACT

This paper summarizes the present status of the studies for a superconducting Linear Collider (TESLA) and for the approach using conventional S-band technology (SBLC).

I. INTRODUCTION

During the past years, several High Energy Physics Laboratories are performing design studies and technical developments towards a next generation TeV-scale electron-positron linear collider. An overview of the different approaches for a machine with an initial center-of-mass energy of 500 GeV and a luminosity of about $5 \times 10^{33} cm^{-2} s^{-1}$ is given in ref. [1]. In the following, we discuss the linar collider design studies which are coordinated at DESY, namely the TESLA and the SBLC approaches. These studies are done in the framework of an international collaboration, with many institutes from 8 different countries (China, Finnland, France, Germany, Italy, Poland, Russia, USA) participating in both the development of the accelerator technology and the overall design of the collider.

A. Basic Concepts and Machine Parameters

The fundamental difference of the TESLA approach compared to other designs is the choice of superconducting accelerating structures. The challenge of pushing the superconducting linac technology to a high accelerating gradient and at the same time reducing the cost per unit length, both necessary in order to be competitive with conventional approaches, is considerable, but the advantages connected with this technology are significant. TESLA uses 9-cell Niobium cavities cooled by superfluid Helium to T=2K and operating at L-band frequency (1.3 GHz). At this low frequency, wakefield effects in the accelerating structures become very small which makes the TESLA linac ideal for transporting a high quality, low emittance beam, as required for obtaining optimum performance of the linear collider. The design gradient for a 500 GeV collider is g=25 MV/m with an unloaded quality factor of $Q_0 = 5 \cdot 10^9$. The power dissipation in the cavity walls is extremely small which allows to produce the accelerating field with long, low peak power rf-pulses and yields a high transfer efficiency of rf-power to the beam (the overall AC-to-beam efficiency for TESLA is close to 20%). With a high average beam power, the required luminosity can be achieved with a spot size at the interaction point (IP for short) only moderately (about a factor of 3.5) smaller than what has been achieved at the Final Focus Test Beam experiment performed at the SLAC linac [2]. At the same time the AC power consumption remains within acceptable limits (below 100 MW). The long rf-pulse allows for a large bunch spacing (see table I), making it easy for the experiment to resolve single bunch crossings. In addition, a fast bunch-to-bunch feedback can be used to stabilise the orbit within one beam pulse, which makes TESLA practically immune to mechanical vibrations which could otherwise lead to serious luminosity reduction via dilution of the spot size and separation of the beams at the IP. Further benefits of the long pulse are the possibility to use a head-on collision scheme with large-aperture superconducting quadrupoles in the interaction region and to employ a safety system which can "turn off" the beam within one pulse in case an emergency is indicated by enhanced loss rates. The long pulse and high beam intensity need special designs for the damping ring and the positron source, as discussed below.

The SBLC approach uses conventional linac technology at a frequency of 3 GHz. A wealth of experience exists for this technology, including the one obtained at the only existing linear collider, the SLC, from which the SBLC design can most directly profit. Another advantage of this choice of frequency, to a less extent than for TESLA but still significant when compared with the higher frequency designs, is the relatively low level of wakefield effects. The accelerating gradient at E_{cm}=500 GeV is 17 MV/m. The pulsed rf-power is generated in some 2,500 klystrons of 150 MW peak power each. The design gradient is achievable without the need for rf-pulse compression, which yields a relatively high overall efficiency with a 2μs long beam pulse. In order to obtain the same luminosity as for TESLA, the required spot size at the IP is somewhat smaller and the AC-power about 45% higher. A comparison of the main parameters for TESLA and SBLC at E_{cm}=500 GeV is given in table I.

B. Energy Upgrade

The center-of-mass energy reach of TESLA is clearly limited by the maximum gradient achievable with the superconducting cavities and can not, unlike designs using conventional accelerating structures, be increased by upgrading the rf-pulse power. In order to go to energies beyond $E_{cm} \approx$1 TeV, the length of the machine would therefore have to be increased significantly. We do believe, though, that a significant energy upgrade of TESLA will be possible within the site length for the 500 GeV design by operating the cavities at a gradient above 25 MV/m. The main reasons which justify this optimism are:

- The fundamental limit for the gradient in a Nb-structure at 2K is above 50 MV/m.
- Cavity tests at the TTF (see below) have shown that field emission can be very effectively suppressed and a quality factor far in excess of the design value ($Q_0 = 5 \cdot 10^9$) at 25 MV/m is feasible.
- Accelerating gradients around 40 MV/m have recently been achieved with single-cell L-band cavities at CEBAF

	TESLA	SBLC
energy E_{cm}/GeV	500	500
gradient $g/[MV/m]$	25	17
frequency f_{rf}/GHz	1.3	3.0
site length L_{tot}/km	32	34
# of klystrons	616	2512
klystron power $/MW$	8	150
rep. rate f_{rep}/Hz	5	50
pulse length $T_P/\mu s$	800	2
# of bunchesn_b	1130	333
bunch spacing $\Delta t_b/ns$	708	6
bunch charge $N_e/10^{10}$	3.63	1.1
emittance $\gamma\epsilon_{x,y}/10^{-6}m$	14, 0.25	5, 0.25
beta at IP $\beta^*_{x,y}/mm$	25, 0.7	11, 0.45
beam size at IP $\sigma^*_{x,y}/nm$	845, 19	335, 15
bunch length at IP σ_z/mm	0.7	0.3
beamstrahlung $\delta_E/\%$	2.9	3.0
luminosity $L/10^{33}cm^{-2}s^{-1}$	6	5
beam power P_b/MW	16.3	14.5
AC power P_{AC}/MW	95	140
AC-to-beam efficiency /%	17.2	10.4

Table I: TESLA and SBLC parameters for $E_{cm} = 500GeV$.

	TESLA	SBLC
energy E_{cm}/GeV	800	725
gradient $g/[MV/m]$	40	24.7
frequency f_{rf}/GHz	1.3	3.0
site length L_{tot}/km	32	34
# of klystrons	1232	2512
klystron power $/MW$	8	150
rep. rate f_{rep}/Hz	3	50
pulse length $T_P/\mu s$	640	0.5
# of bunches p. pulse n_b	2260	125
bunch spacing $\Delta t_b/ns$	283	4
bunch charge$N_e/10^{10}$	1.82	1.2
emittance $\gamma\epsilon_{x,y}/10^{-6}m$	12, 0.025	5, 0.10
beta at IP $\beta^*_{x,y}/mm$	25, 0.5	13, 0.3
beam size at IP $\sigma^*_{x,y}/nm$	618, 4.0	303, 6.5
bunch length at IP σ_z/mm	0.5	0.3
beamstrahlung $\delta_E/\%$	2.3	5.3
luminosity $L/10^{33}cm^{-2}s^{-1}$	10	5.1
beam power P_b/MW	15.6	8.6
AC power P_{AC}/MW	110	140
AC-to-beam efficiency /%	14.2	6.1

Table II: TESLA parameters for an upgrade to 800 GeV and SBLC parameters at 725 GeV.

[3] and at KEK [4].

With further R&D it seems conceivable that a maximum gradient of about 40 MV/m at $Q_0 = 5 \cdot 10^9$ can be reached with the 9-cell TESLA cavities. The average gradient for the entire linac is likely to be lower initially, so that a possible scenario for an energy upgrade in steps could be to exchange groups of modules containing the "weakest" (i.e. lowest g) cavities with new, high-performance modules. This upgrade path leads to a maximum energy of E_{cm}=800 GeV. The subsystems for TESLA (in particular the beam delivery system) are designed such that the energy upgrade can be accomodated without further hardware modifications. In order to obtain optimum luminosity at higher energy, an upgrade of the rf-system is also necessary, though. At higher gradient, either the rf-pulse power or pulse length must be increased to maintain a reasonable ratio of beam-on time to rf-on time. We follow the first approach, which has the advantage that the modulators providing the pulse power for the klystrons do not have to be modified. The 800 GeV version of TESLA would then have twice as many klystrons and modulators as the initial stage at 500 GeV. The pulse repetition rate is reduced so that the dynamic load for the cryogenic system remains almost constant and the AC-power consumption is only slightly increased.

The potential of TESLA to maintain an extremely small emittance in the accelerator becomes particularly important at higher energies. This can be seen from the following aproximate luminosity scaling law, which holds for all linear collider designs independent of the choice of technology:

$$L \approx 5.82 \cdot 10^{20} \times \frac{P_b}{E_{cm}} \times \left(\frac{\delta_E}{\epsilon_{y,N}}\right)^{1/2} \times H_D \qquad (1)$$

Here, P_b denotes the average beam power (limited by AC-power and the overall power transfer efficiency), δ_E the fractional beam energy loss due to beamstrahlung and $\epsilon_{y,n}$ the normalized vertical emittance. The factor H_D accounts for the pinch effect, typically $H_D \approx$1.5. Since emittance growth in the TESLA linac can be kept very small, a further reduction of $\epsilon_{y,N}$ by an order of magnitude seems conceivable and allows to keep beamstrahlung at a low level at higher energy *and* higher luminosity. A parameter set for E_{cm}=800 GeV which takes this option into account is given in table II. A further upgrade to Energies beyond 1 TeV will require to increase the machine length. Parameter studies for this case show that a low level of beamstrahlung ($\delta_E \approx$5%) can be maintained up to E_{cm}=1.5...2 TeV with a luminosity of about $2 \times 10^{34} cm^{-2}s^{-1}$.

With the SBLC concept, a low-cost energy upgrade by about a factor of 1.5 is possible by adding SLED pulse compression systems. It is conceivable that by the time the upgrade program starts, experience has been gained to reduce emittance dilution so that a somewhat smaller emittance than for the first stage of operation can be assumed. A consistent parameter set for this upgrade of SBLC to E_{cm}=725 GeV is shown in table II. A further adiabatic increase of energy is feasible by adding klystrons, eventually reaching 1 TeV with roughly twice the number of klystrons as for the 500 GeV version. Going beyond 1 TeV will, as for TESLA, require to increase the machine length.

II. BEAM DYNAMICS

The choice of a low frequency results in small transverse and longitudinal wakefields in the accelerating structures. This leads to relaxed alignment tolerances for the linac components re-

quired for the transportation of a low emittance beam. It is instructive here to compare the different linear collider design concepts on a basis of simple scaling arguments [5]. One of the most essential contributions to emittance dilution results from short-range transverse wakefields due to random offsets of the accelerating structures w.r.t. the beam orbit. The emittance dilution from this effect can be written as

$$\frac{\Delta\epsilon}{\epsilon} \propto F \cdot \bar{\beta} \cdot \delta y_c^2 \qquad (2)$$

where $\bar{\beta}$ denotes the average β-function in the linac (the stronger the focussing, the smaller $\bar{\beta}$), δy_c the rms-offset of the structures and F the dilution factor which depends on the beam parameters and very strongly on the linac frequency. The considerable variation of F for different linear collider designs is shown in fig. 1. It becomes clear that TESLA can afford very much relaxed requirements for the alignment tolerances and for the beam optics. For SBLC, the emittance dilution factor is comparable to the one calculated for SLC parameters.

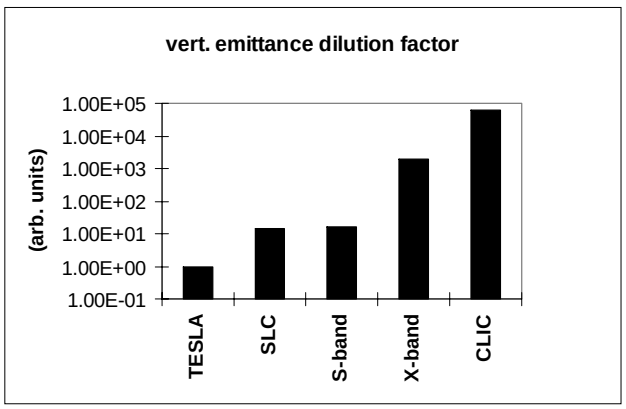

Figure 1: Wakefield emittance dilution factor for different 500 GeV linear collider designs. The SLC is included for comparison.

Another important effect leading to emittance growth is due to the bunch energy spread in connection with spurious dispersion generated by random orbit kicks which result from quadrupole and BPM misalignments. In contrast to the dilution from wakefields, this effect grows with stronger focussing. Therefore the beam optics in the linac have to be chosen such as to find a compromise between dilution from wakefields and from chromatic effects. Because of the much smaller wakefields, the optimum focussing in TESLA is weaker than in SBLC. This, together with a small energy spread of 0.06% (compared to 0.35% in SBLC), leads to a tolerance of 0.1 mm (rms) of the BPM and quadrupole alignment for about 10% emittance growth, which is close to what is achievable with state-of-the-art methods at installation time. With additional beams-based methods [7] the alignment tolerance could be relaxed to 0.5 mm or, since we expect the installation accuracy to be better than that, the emittance dilution could be further reduced, thus allowing for a beam emittance much below the design value quoted in table I. The random misalignment of the superconducting cavities with a tolerance as large as 0.5 mm contributes another 10% of emittance dilution. This effect can also be further reduced by intentionally introducing orbit deviations (non-dispersive bumps).

For SBLC the corresponding alignment tolerances for a relative emittance dilution similar as in TESLA are 50 μm for the accelerating structures and of the order of 10μm for the quadrupoles and BPM's. This will be achieved by applying the above mentioned beam-based methods and by adjusting the structures w.r.t. the beam by measuring the induced higher order modes (HOM) and minimizing them using remote controlled movers. The effect of long-range HOM can also lead to emittance dilution from the so-called multi-bunch beam break-up (BBU) effect. The effect is kept within tolerable limits by damping the HOM with a layer of poorly conducting material on the irises of the structures. The damped modes have quality factors of about 3,000, sufficiently small to reduce the additional emittance dilution from BBU to a few percent. In TESLA, thanks to the large bunch spacing, HOM damping requirements are less serious and the BBU effect is practically negligible.

An important issue concerns the short and long-term stability of the alignment of the linac components. Seismic ground motion, cultural noise, long-term diffusive and linear ground motion as well as temperature variations and noise from ventilation, watercooling, etc. are of concern. We take here a conservative approach in estimating the effects in the linear collider from the observed orbit motion in the HERA storage ring [8, 9]. In a somewhat crude approximation, the results of this analysis can be summarized as follows.

At frequencies above 3 Hz, i.e. in a range where a slow orbit feedback in SBLC is not efficient any more (the bandwidth is limited to about 1/20...1/10 of the repetition frequency), an rms-amplitude of uncorrelated quadrupole motion of about 100 nm must be expected. This leads to orbit jitter at the interaction point which would reduce the SBLC luminosity by roughly 10%. Two methods are foreseen to decrease this effect. The quadrupole supports can be actively stabilized, reducing the vibration amplitude to about 20 nm [10]. Furthermore, a fast feedback stabilizing the beam orbits at the IP w.r.t. each other seems feasible [11]. We thus conclude that pulse-to-pulse orbit jitter will be handable in SBLC. In TESLA a fast orbit correction within the bunch train can be applied (thanks to the large bunch spacing), so that orbit jitter is not an issue.

The slow orbit motion observed in HERA (on a time scale from 1 h to several weeks) is consistent with the so called ATL-rule of diffusive ground motion [12], where $A \approx 10^{-5}\mu m^2/m/s$. One effect of ATL-like motion is that the orbit will drift while performing the beam-beased alignment procedure. This has been investigated for SBLC and it is found that the time passed between taking difference orbit measurements (after changing quadrupole strengths) must not exceed about 2 min. in order not to cause a further emittance dilution, see fig. 2. In addition, the orbit must be steered back to the optimum one found by beam-based methods about every 20 min. and the beam-based alignment procedure be repeated once per

week. With a properly designed machine control system, this does not seem to be a problem.

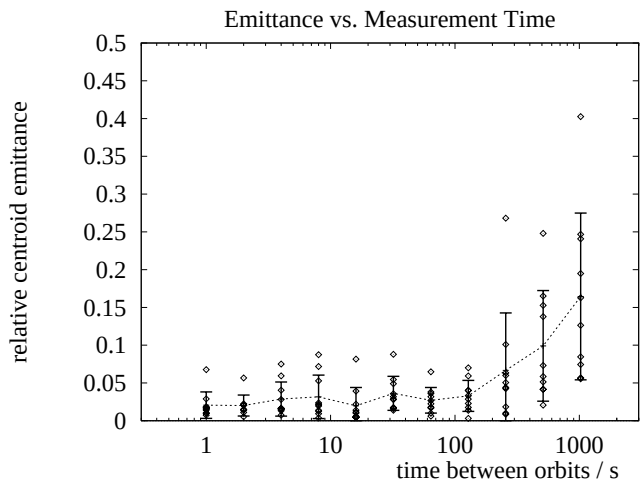

Figure 2: Emittance dilution in SBLC from orbit drift during the beam-based alignment process. An ATL-like diffusive ground motion with $A = 10^{-5} \mu m^2/s/m$ is assumed.

In the case of TESLA, diffusive ground motion has a much smaller effect. Orbit steering must be applied about once per hour and beam-based alignment becomes necessary only after operating the machine for more than a year.

A special problem occurring in TESLA is related to mechanical deformations of the cavities during the beam pulse (Lorentz-force and microphonics). The phase shift resulting from the detuning of the resonance frequency is corrected by a feedback loop and the bunch-to-bunch energy spread can be kept below 2×10^{-4}.

III. INJECTION SYSTEM

The preparation of electron and positron beams which match the requirements concerning the intensity and the transverse and longitudinal dimensions demands specially designed subsystems within the linear collider complex. In the following, some important aspects of these subsystems are discussed.

A. Positron Source

As mentioned above, a special design is foreseen to produce the high positron intensity required for both TESLA and SBLC. The method [13, 14] uses the spent high energy electron beam after the interaction which is transported through an undulator to yield a high intensity photon beam. The photons are converted to electron-positron pairs in a thin target, after which the positrons are captured and pre-accelerated before injection into the damping ring. The main advantages of this method are a strongly reduced heat load in the conversion target compared to conventional sources and the possibility to produce polarized positrons by using a helical undulator.

Since the beam energy spread and the emittance are considerably increased during the collision, capturing the spent beam is not an easy task. Beam optical systems with large momentum bandwidth have been designed and investigated by computer simulations. It is found that a suffiently high positron yield can safely be obtained for the less ambititious layout with a planar undulator for unpolarized positrons. The production of polarized positrons seems also feasible, but the safety factor is smaller and the helical undulator technically more difficult.

B. Damping Rings

The required small beam emittances make it necessary to store the positron beams in damping rings during the time between pulses. The same is true for the electron beams, unless flat-beam low-emittance rf-laser guns become available. The SBLC damping ring has a length of about 650 m to accomodate the 2μs long beam pulse. In a first attempt to optimize the lattice layout a solution for a ring operating at 3.15 GeV was found which matches the requirements for the damping time, equilibrium emittance and dynamic aperture. The alignment tolerances are of the order of 0.1...0.2 mm, likely achievable with existing technology. No detailed investigation of collective effects has been done yet, but it should be noted that the stored current of 300 mA is not far from what has been achieved in existing storage rings with comparable size and energy and much below the goals for the B-factories presently under construction at KEK and SLAC. Presently, further studies of the damping ring beam optics are under way with the goal to determine the lattice type most suitable for optimum performance.

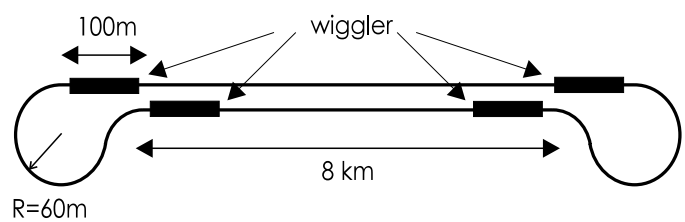

Figure 3: General layout of the “dogbone”-shaped damping ring

In TESLA we have a special situation due to the 800 μs long bunchtrain. Obviously, the bunchtrain must be stored in the damping ring in a compressed mode with reduced bunch spacing. We have chosen a ring layout with a length of 17 km, yielding a bunch spacing of 50 ns. In order to avoid having to build a ring tunnel of that size, the ring is shaped like a “dogbone” with two long straight sections entirely placed inside the linac tunnel and only the roughly 400 m long loops at the ends in additional tunnels (see fig. 3). Sufficient radiation damping is provided by four wiggler sections of about 100 m length each. The operation energy of the ring is 3.2 GeV. Detailed studies of the beam optics have been performed and it was shown that with alignment tolerances of 0.1...0.2 mm both a sufficiently large dynamic aperture and the required small beam emittance can be obtained. By applying beam-based alignment and correction techniques similar to the one successfully tested at HERA [15], even much smaller emittances are achievable. With a stored current of 100 mA a feedback system to suppress multi-bunch

instabilities must be foreseen. The required system is similar to the one routinely in operation in the HERA electron ring, the main difference being a factor of two larger bandwidth. A prototype kicker for the injection/extraction system is presently under construction, which is expected to yield a pulse width of about 20 ns, well below the maximum allowed width of 50 ns.

IV. BEAM DELIVERY SYSTEM

The beam delivery system, placed between the end of the linac and the IP, consists of three parts: (1) the collimation section, which protects the interaction region from background-generating large amplitude halo particles, (2) the tuning and diagnostic section, where beam optics and emittance distortions are analysed and corrected and (3) the final focus system which provides demagnification of the beam size by two orders of magnitude. The total system is layed out for a maximum beam energy of 400 GeV and comprises about 1.2 km of magnet lattice for TESLA and 1.4 km for SBLC (see fig. 4). The geometry of the system is such that it fits into a straight tunnel. This will leave maximum flexibility for later modifications and upgrades. A second interaction point, possibly for $\gamma - \gamma$ collisions, can be arranged by adding a second beamline and an IP switch. Work on a detailed layout for such an option is in progress.

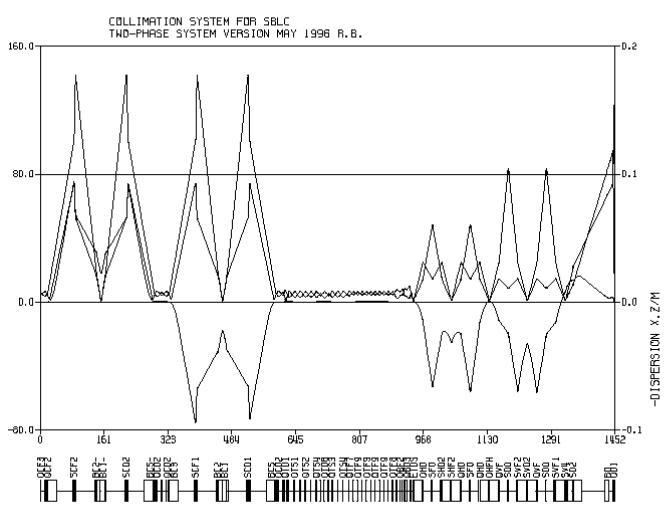

Figure 4: Beam optical system between the end of the linac and the IP for SBLC.

The requirements for the collimation section are determined from the aperture available in the final quadrupoles just before the IP. The particle trajectory amplitudes are restricted such that synchrotron radiation generated in the quadrupoles upstream from the IP passes freely through the doublet downstream. In TESLA superconducting final quadrupoles with large aperture (24 mm radius) and a head-on collision scheme are used. This is possible, because the first parasitic interaction of the incoming and outgoing beam would occur more than 100 m away from the IP, which leaves enough space to install an electrostatic separator outside of the interaction region (see fig. 5). With this scheme the acceptance for synchrotron light is large and the maximum allowed trajectory amplitudes are 15 horizontal by 48 vertical standard deviations.

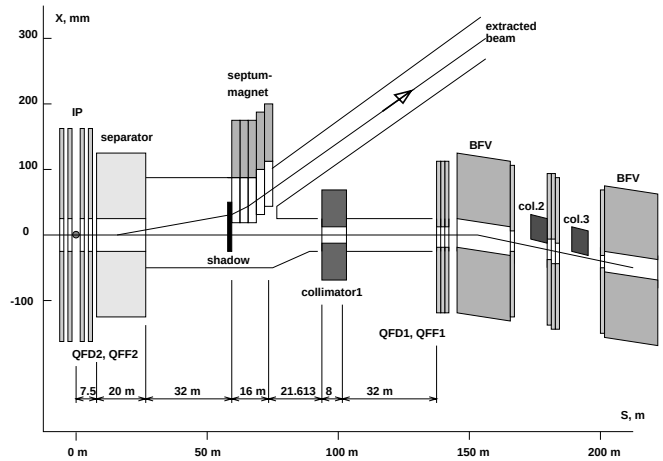

Figure 5: Separation of the outgoing from the incoming beam in the TESLA final focus section.

In SBLC, with a bunch separation of only 6 ns, a 6 mrad crossing angle geometry is necessary to avoid parasitic interactions. In that case, a conventional final quadrupole design is chosen, which provides an aperture of 10 mm for the outgoing synchrotron light. Consequently, the collimation requirements for SBLC are somewhat tighter than for TESLA ($10\sigma_x \times 25\sigma_y$).

The concept of collimation is the same for TESLA and SBLC and based on the idea of mechanical collimation outlined in ref. [16]. Particles with large betatron amplitudes (or momentum deviation) pass through thin (2 R. L.) spoilers after which they are stopped in absorber blocks. A critical issue concerns protection of the spoilers from intolerable heat load which can result if an entire bunchtrain passes through the spoiler by accident. In case of TESLA the bunchtrain can be “switched off” by firing a dump kicker in the gap between two bunches in case the loss rate at the spoiler exceeds a tolerable value. For SBLC this is not possible and the beam optics in the collimation section must be layed out such that the spoilers can stand a full train of 333 bunches. This seems only possible by using graphite spoilers, whereas Titanium can be used for the TESLA system. The graphite has to be coated with a material of high conductivity in order to reduce the resistive wall wakefield effect.

The design of the tuning and diagnostic section follows the concept used in the NLC [17]. Several spot size monitors are required to analyse the phase space distribution of the beam. Possible candidates for these monitors are either carbon wires (only possible with reduced beam intensity), laser wires [18] or synchrotron radiation from quadrupole wigglers [19]. From the spot size measurements the required strengths of correction quadrupoles and skew-quadrupoles are derived to tune the beam optical functions towards their design values.

The design of the final focus system uses essentially the same concept as the successfully tested FFTB experiment [2]. The

large chromaticity of the final doublet is corrected by two pairs of sextupoles arranged in a non-interleaved scheme. The SBLC system employs several additional sextupoles in order to optimize the momentum bandwidth of the system (this is not required for TESLA where the beam energy spread is only about 0.1%). The remaining chromatic and geometric aberrations are small and cause a spot size dilution of only a few percent.

Stabilisation of the luminosity is one of the most critical issues for the beam delivery system. Orbit jitter can cause beam separation at the IP and longer term drifts of magnet positions lead to an increase of the spot size. In TESLA the orbits of the colliding beams w.r.t. each other can be very efficiently stablized by a fast feedback within the bunchtrain. The signal for driving a fast steering device is derived from the kick which the bunches experience during interaction in case of a non-vanishing transverse offset. The response time of the feedback is of the order of the bunch spacing, so that only the luminosity of the first (or first few) bunch collisions will be affected by orbit jitter. A similar system, although not quite as efficient because of the much shorter beam pulse, is foreseen for SBLC [11].

Long term spot size stability is investigated on the basis of the ATL-model as described above. It is found that orbit correction in the TESLA beam delivery system is required about every two minutes to avoid significant spot size dilution. Mainly because of the larger energy spread, the SBLC spot size is roughly an order of magnitude more sensitive to magnet motion. A full simulation of luminosity stabilisation for both designs is presently in preparation.

V. DEVELOPMENT OF LINAC TECHNOLOGY

To demonstrate the availability of the technical components required for the main linac of a linear collider is of utmost importance for every linear collider approach presently under investigation. The goal is to build and operate test accelerators with components reaching the full performance of the ones required to build the collider. Test facilities for both TESLA and SBLC are presently under construction at DESY.

A. TESLA Test Facility

In order to demonstrate the feasibility of the TESLA technology, an R&D program in the framework of the TESLA Test Facility (TTF) was launched several years ago [20]. The TTF [21] includes the infrastructure for applying different processing techniques to the Niobium cavities obtained from industrial series production. Of particular importance is the preparation of ultra-clean surfaces with chemical treatment and high-pressure rinsing methods. About 10 cavities have been processed and tested at the TTF so far. Several of the cavities have reached or even surpassed the TESLA goal (see fig. 6). Thus the possibility of producing high-performance cavities which are essentially free from field-emission limitations has in principle been proven. Nevertheless, these excellent results are not yet sufficiently reproducible (other cavities show limitations at lower gradients) and the R&D program to investigate and eliminate these limitations is still in progress.

As one contribution to reducing the cost of the superconducting linac, a modular concept with groups of 8 cavities contained in a common cryostat is used. The completion of the first module is scheduled for February 1997. A first stage injector has already been successfully commissioned [22] and acceleration of a beam with the first module will take place in spring 1997. The test linac will later be extended with up to 4 modules (32 cavities) in order to demonstrate acceleration of a beam up to 800 MeV. Operation with an rf- and beam-pulse structure as in the linear collider design is foreseen, so that a full integrated system test relevant for the TESLA linear collider is possible.

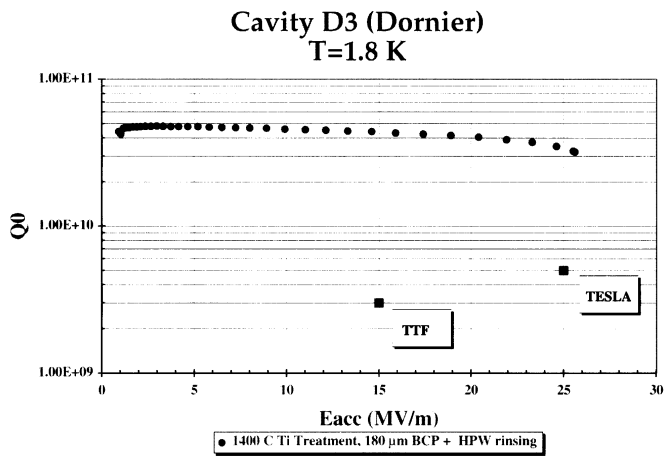

Figure 6: Quality factor vs. accelerating gradient for one of the 9-cell TESLA cavities tested with CW-rf in a vertical cryostat. The initial goal for the TTF and the design goal for TESLA are indicated.

While demonstration of a successfully working superconducting linac system is the primary goal at the TTF, its construction will also provide a sound basis for a cost analysis. Studies of cost effective component design are under way and the preparation of a detailed cost model for all major components and sub-systems of TESLA will be the next step of our design work.

B. S-Band Test Facility

The S-Band test linac consists of 4 6 m long accelerating structures which are powered by two klystrons to yield a loaded accelerating gradient of 17 MV/m. The klystrons, built at SLAC in collaboration with DESY and TH-Darmstadt, have both reached their design goal of 150 MW peak power with a pulse length of 3 μs. The fabrication and alignment accuracy of the accelerating structures is an important issue for beam stability in SBLC, as explained above. So far, a straightness accuracy of 0.14 mm (rms) over the full length has been achieved, about a factor of two above the design goal. High power tests have been performed with short sections containing the layer of lossy material on the irises for HOM damping [23]. The injector

for the test linac has been commissioned successfully [24]. The modulator-klystron system is being tested [25] and first beam tests of the linac will begin in autumn 1996. Among the foreseen tests are the measurement of HOM excitation and the remotely controlled precision alignment of the structures using the HOM signal.

VI. ADDITIONAL OPTIONS

The main task of a future linear collider is clearly to provide a facility for experimental Particle Physics research at the energy frontier. There are, however, also fascinating additional applications for such a machine which can be integrated in the design and provide research opportunities in a broader field of science.

The capability of delivering an excellent beam quality makes a linear collider an ideal driver for a Free Electron Laser in the Angstroem wavelength regime. Such an option could be realised with an S-Band linac [26], but especially the TESLA linac with its extremely small wakefields is perfectly suited for this purpose. The layout of an X-ray FEL user facility as an integral part of a linear collider is presently under study [27] and tests of an FEL using the TTF linac [28] are planned for 1998.

In case the linear collider is constructed at the DESY site, another option could be integrated at relatively low additional cost. By using additional beam pulses in the lower energy part, the TESLA linac can be used as an injector for the HERA electron ring, the latter operating as a stretcher ring to provide a high duty cycle beam for Nuclear Physics experiments. A feasibility study of this option has recently been completed and it is found that beam properties similar to the original ELFE proposal can be achieved [29].

VII. CONCLUSIONS

The linear collider studies coordinated at DESY are making good progress and the conceptual design for both the TESLA and the SBLC approach is essentially completed. Further results from the test facilities and, last but not least, cost estimates are needed before a decision can be taken, which of the two concepts is to be pursued further in the future at DESY.

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