First Thoughts on Commissioning of the TESLA Collider*

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Abstract

The TESLA collider[1] is a large scale project with a large amount of complex and partially innovative systems. In a project of such characteristics, the stage of test of its various parts and the commissioning of the whole facility requires a considerable amount of effort, expertise and time. Moreover, a prompt delivery of luminosity to the experiments depends strongly on a successful commissioning. Therefore, preparation of a detailed commissioning plan and schedule together with some account of the personnel resources needed is mandatory. This study should be included in the plans of the construction and installation work of the TESLA collider. A working group of the TESLA collaboration meeting held in Saclay in April 2002 started to address these problems. Neither time, personpower nor cost have been considered in detail. In principle, the commissioning of completed parts of the collider has to be adapted to the installation schedule. Nevertheless, we suggest to consider the possibility to partially change the installation schedule in order to commission some sections earlier. Moreover, some additional infrastructure is necessary to close and shield parts of the tunnel, and to dump low energy beams. The commissioning of the XFEL part has not yet been considered at this stage of the study.

1 Motivation

The luminosity commissioning of the TESLA collider can take place only when all its parts have been installed and commissioned. Although all subsystems for TESLA are designed to be compatible for operation in the TESLA tunnel in terms of reliability, operability and maintainance, some minor imponderabilities are expected to occur. In order to detect and resolve these in an early stage, commissioning of parts of the accelerator must start as soon as possible. Furthermore, the operation experience gained in this stage will subsequently improve the performance of the TESLA linear collider when the operation begins.

In order to reduce the time between the end of the construction and the luminosity delivery to the experiments, the commissioning of the injectors, damping rings and linacs

*from the minutes of the working group on Commissioning of the TESLA Linac held in Saclay on 4th April 2002.

have to start as early as possible, i.e. as early as the construction of these parts is finished. Therefore, commissioning of the equipment in the TESLA tunnel has to be scheduled while the installation in other sections is still in progress. Most important, beam commissioning of several parts are considered as essential milestones in such large projects.

Most of the large scale colliders around the world have been built in the presence of an already existing chain of injectors and pre-accelerator systems. At the end of the construction time of the new collider, the commissioning profits from a operational and reliable injection system, which delivers beam to the new collider. At that time, the pre-accelerators have accumulated many thousand hours of operation and have been commissioned for the delivery of beams that meet the goals for the injection into the new collider. The luminosity commissioning is, then, greatly facilitated and the required time reduced to a minimum.

There is a general consensus on the need to test and commission sections of the accelerator and its subsystems as early as possible, as well as to establish full beam performance of these parts. The test and commissioning of the first completed systems (for example, injectors) will be beneficial for the whole project. Firstly, early tests of accelerator components in place provide a very important validity check of all its subsystems in their final working environment. These tests can eventually bring up some problems or failures which are not evidenced during the phases of design and lab tests of individual components. At the moment of the first installations, the production and installation of the subsequent sections can be still influenced and the problem can be fixed before the final installation of all sections. In that sense, the test of a complete 2.5 km cryogenic unit in the tunnel with all its subsystems (cryogenics, RF, power and water supplies, etc.) reaching its performance (23.4 MV/m, etc.) is a relevant step in the project. Secondly, an early commissioning of complicated systems involving complex procedures is desirable in order to gain experience, to establish procedures, to train personnel and to speed up the process of testing and commissioning of large parts of the accelerator. Especially relevant is the commissioning of the damping ring which has to deliver flat beams with small vertical emittance to the main linac. Finally, electronics and front-end software for the diverse subsystems, remote software for failure diagnostics and for accelerator control can start their testing/debugging phase on short parts of the accelerator, mainly on the injectors and pre-linacs. These systems contain basically all the subsystems of the main linac (except for the final focus system and the damping ring). Reliable and fairly well debugged software (in all its levels: servers, communications, applications, etc) for injectors, pre-linacs and RF systems is of fundamental importance for their stability and reliability in delivering beam, which is of fundamental importance in a smooth luminosity commissioning.

2 What can we learn from TTF linac commissioning?

One of the main goals of the TESLA Test Facility (TTF) is to prove the capabilities and potentials of superconducting technology to accelerate electron beams at gradients and currents comparable to the TESLA parameters. Another main goal is the proof of principle of SASE FEL at wavelengths smaller than ever achieved. Additionally, TTF is the test bench of TESLA RF systems, photo-cathode guns, beam instrumentation techniques, bunch compressors, kickers, etc. However, we can not expect that all the key issues of the commissioning of the collider can be tested at the TTF linac. It has been proposed to organize a working group in order to study in detail the contributions from the TTF experience on the various subsystems (vacuum, cryogenics, RF, controls, interlocks, diagnostics, etc). This working group should report on the differences between TTF and TESLA commissioning.

3 Commissioning chain

The luminosity commissioning can be done as early as both electron and positron linac are commissioned with beam. A schematic view of the commissioning dependency chain is shown in fig. 1. The main positron linac receives the beam from the 5 GeV positron linac through the positron damping ring. Therefore, the positron injector, 5 GeV linac and damping ring have to be commissioned before injecting into the positron main linac. The positron beam is obtained by colliding photons onto a target. These photons are created by the electron beam from the main electron linac in its passage through an undulator. The whole positron accelerator chain depends, therefore, on the successfull commissioning of the electron injectors and main linac. Alternatively, an auxiliary 500 MeV electron injector will be installed upstream the photon target. This electron injector serves for beam commissioning of the positron injector by delivering electrons to the target to produce a low intensity positron beam. Additionally, the electron beam (bypassing the target) is used for beam commissioning of the 5 GeV positron linac and of the positron damping ring. In the electron linac the damping ring can be bypassed in order to inject the 5 GeV electron beam into the main linac for commissioning purposes.

4 Commissioning phases

It is obvious that the luminosity commissioning is possible only when the installation of all collider parts are completed. However, several parts of the TESLA collider can be installed and commissioned during the construction and installation of the rest of the facility. The early commissioning of the 5 GeV injector linac, of the electron damping ring and of the main electron linac are of great importance. The commissioning of these parts can be taken in a series of four well defined phases:

Phase 1 Commissioning of the 500 MeV electron injector.

Phase 2 Commissioning of the 5 GeV electron linac, the 500 MeV auxiliary electron linac and the positron injector.

Phase 3 Commissioning of the electron damping ring (with beam) and a 2.5 km cyrogenic unit (without beam).

Phase 4 Commissioning of the electron main linac.

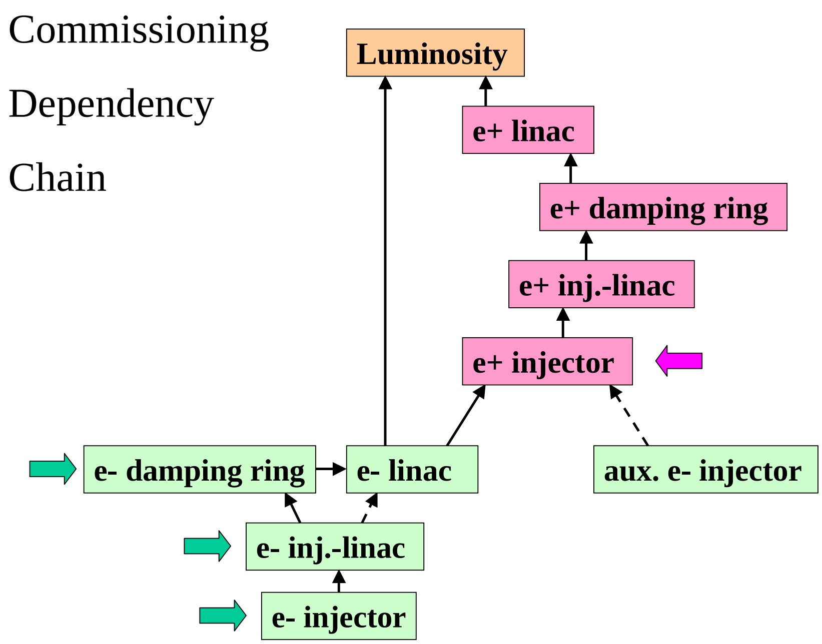

Figure 1: Schematic dependency chain of the commissioning with beam of the relevant sections of the TESLA collider. The beam commissioning of the electron damping ring, injector linac and injector (indicated with horizontal green thick arrows) and of the positron injector (indicated with purple arrow) are important milestones in this chain. Possible alternative injection schemes that allow an earlier commissioning are indicated with thin dashed black arrows.

A schematic view of the areas to be commissioned during the construction of TESLA is shown in fig. 2.

Commissioning of cryogenic and RF systems can be done as the installation work is completed along the tunnel. The RF commissioning of each main linac can be subdivided in six units (see section 8). The installation of the first cryo-modules differs from the scheduled presented in the TDR for reasons explained in section 9.

In the following sections the commissioning of the various parts of the TESLA collider is decribed in more detail.

5 Commissioning of electron injectors

In the TESLA collider, the electron injector(s) with an energy up to 500 MeV can be built and commissioned before or in parallel to the tunnel construction. They need a relatively small space (about 100 m) and a minimum of infrastructure. The beam commissioning of the electron injectors to their full performance should be carried out in a very early stage of the project construction. The injectors need to be fully commissioned and ready to allow an early commissioning with beam of the 5 GeV linac. On the other hand, the reliability of the injector systems is of vital importance for achieving high integrated luminosity. Failures at the injector can decrease drastically the performance of the whole collider, whereas same failures in the linac (like klystron failures, quadrupoles, etc.) have

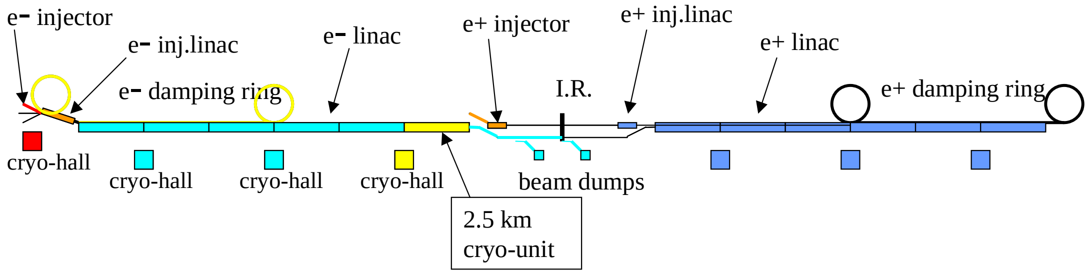

Figure 2: Schematic view of the commissioning phases of the TESLA collider. Commissioning phase 1 in red color, phase 2 in orange, phase 3 in yellow, phase 4 in magenta. (I.R.: interaction point)

a lower impact on the performance, since the energy gain or focusing can be compensated using neighboring components. A goal in the commissioning of the collider is, therefore, to demonstrate a reliable run of the injectors over a long period. Using the experience in the maintenance, in the technical and in the operational aspects accumulated over several years, injectors can be considered as almost 'turn-key' systems and most of the effort can be concentrated on the new parts of the collider to be commissioned.

In order to commission the electron injectors as early as possible, the civil construction and installation schedule must be optimized to satisfy the requirement for early commissioning. TESLA collider injectors include an unpolarised e^- source and a polarised e^- source. The commissioning of the unpolarised e^- source has priority over the polarised e^- source. A beam dump system accepting 500 MeV long bunch trains and the appropriate shielding have to be in place. The operation of these injectors has to be independent of the construction of the rest of the collider. Therefore, the necessary personnel safety measures should be fulfilled to allow the installation of the pre-linac section in parallel to the commissioning with beam of the injectors.

The polarised e^- source needs a considerable amount of test and beam commissioning time. There must exist the possibility to carry out tests on the polarised e^- source while delivering beam to the linac with the unpolarised e^- source. Vice versa, the unpolarised e^- source is the backup of the polarised e^- source when the latter in not available. The stand-by status of the unpolarised e^- source is the continuous delivery of full beam train to the 500 MeV dump (perhaps at a lower repetition rate). [1]

6 Commissioning of positron injector

The source of positrons is located just downstream of the main electron linac. The high-energy electron beam is used to generate high-energy photons in an undulator section. The photons are used to produce electron-positron pairs in a thin conversion target. Since the positrons have a broad distribution of transverse and longitudinal momenta, they must first be accelerated in RF cavities embedded in a solenoid field. The positron beam is captured and pre-accelerated to about 250 MeV in the normal conducting positron pre-accelerator (PPA). The beam is then transported through a transfer line under the

[1] For luminosity delivery runs a second polarised e^- source is forseen as backup.

detector hall, to the superconducting positron injector linac, where it is accelerated to 5 GeV.

For the commissioning of the various positron accelerator systems (see section 12), a similar 500 MeV electron injector as used for the electron linac can be used to produce a few per cent of the design positron current at the same positron target. An array of diagnostics is located at the exit of the PPA. This includes a spectrometer dipole deflecting the positron beam to a dump. Capture efficiency, collimation and acceleration can thus be optimized before the electron main linac delivers beam to the undulator. The commissioning of the positron source consists of:

- RF conditioning of normal conducting cavities.
- Commissioning of target system.
- Commissioning of instrumentation and collimation.
- Achieving nominal capture efficiency.
- Reliable and stable run with full beam loading.

The installation of the second electron source for the commissioning of the PPA can start as early as the tunnel construction is finished. Radiation safety issues and further installation of the final beam focus system have to be planned accordingly. A special requirement is the installation of the part of the beam delivery line which is around the positron area before the commissioning of the positron injector starts.

7 Electron pre-linac commissioning

The acceleration from 500 MeV up to the damping ring energy of 5 GeV is done at the so-called pre-linac or injector linac. This section is about 300 m long and is a short version of a TESLA main linac. The 5 GeV electron pre-linac has the same components and systems as the main linac. It is made of a series of TESLA accelerating modules cooled by one single cryogenic unit. The installation of the e-pre-linac is scheduled to start in the 4th year presumably using pre-series modules from industrial production. For the test and commissioning of the e-pre-linac, it is necessary that the installation of the cryogenics, RF and other systems is completed and that all these systems are ready and operational.

In the TDR it is mentioned a 5 GeV dump, however, for the beam coming out from the damping ring only. This dump serves for commissioning and tune up of the damping ring. Additionally, the dump can be used as an emergency dump. In case of a technical failure in the main linac while accelerating long bunch trains, the bunches stored in the damping ring can be dumped instead of injecting them in the main linac. This dump should serve as well for beam commissioning of the e-pre-linac. Therefore, the beam line needs to be modified to allow the transfer of the beam from the e-pre-linac to the dump directly.

An early commissioning with beam of the e-pre-linac is to be one of the most relevant milestones in the construction of the TESLA collider. First beam tests have been conducted at the early construction of other colliders in the past (also in the case of collider rings). For example, HERA and RHIC first beam tests were performed as soon as one section of the ring magnets has been installed. The reach of this kind of tests in accelerator rings, however, is limited. Complex beam operations as accumulation, energy ramping, and high current can only be tested in a fully completed machine. In a linear accelerator one can, however, demonstrate maximal acceleration of full beam even on short sections.

The commissioning with beam of a 5 GeV linac which includes all basic systems of the main linacs has a large number of benefits. Most important of all, a reliable delivery of beam to the damping ring and to the linac is assured for their commissioning. Moreover, a long pre-running of the 5 GeV linac brings up:

- Test of all subsystem interphases.
- Experience on operation of RF, cryogenics, etc. at the integrated systems in their final installation in the tunnel.
- First experience on handling with failures in the integrated systems.
- A first record of reliability of main linac components installed in the tunnel.
- Operational experience for establishing beam from the injectors to the damping ring.
- Well-established procedures for the operation.
- A well-developed high-level software for assistance of the operation team.
- Experience on global accelerator network issues as well as training of operators from different laboratories.

A few questions still remain open for discussion:

- About diagnostics: which type of diagnostics are needed at 5 GeV? Can we use the diagnostics of the beam transfer from the damping ring to the main linac?
- What is needed for machine protection?
- Do we need a direct transfer to the main linac bypassing the damping ring for commissioning purposes?
- Location and layout of the beam dump.
- Radiation safety in other tunnel sections.

8 Main linac commissioning

From the point of view of cryogenics, power lines and cooling lines, each of the main linacs is subdivided in six cryo-units. Each cryo-unit is a continuous string of modules of about 2.5 km length which is connected to one cryogenic supply box at the beginning and to one end box.

The proposed commissioning schedule for both main linacs tries to combine the test and commissioning of already completed cryo-units with the installation of the next cryo-units. The benefits are

- Conditioning of couplers and klystrons.
- Early cool-down and early leak checks can be performed.
- Test of all subsystems in the tunnel.
- Final test of cavities at nominal gradient and beyond.
- Cavities and couplers are not over long period without RF (only during the time between tests and final installation).
- The commissioning time of the entire main linac overlaps with its installation time. Therefore, the commissioning with beam can start soon after the installation is completed.
- The personpower required for this commissioning is reduced to a minimum which handles a small linac section at a time.
- A certain learning process in the commissioning takes place during the commissioning of the first cryo-units. During this time people are trained and procedures are developed. The commissioning is expected to speed up after a given learning period.
- In the case some difficulties are encountered, there is enough time to handle/repair the problem(s) without delaying the schedule for luminosity commissioning.

The commissioning of the parts of the main linac with beam requires, however, a dump for beam energies of 40 GeV and beyond. The construction of such dumps would require substantial extra cost in construction. Moreover, the tunnel would need to be shielded if installation work is done in parallel. On the other hand, the benefits from beam commissioning of parts of the main linac are very limited. Therefore, the commissioning with beam is done after the entire main linac and the beam line to the dump is finished (see section 10).

As the module installation in the tunnel progresses at 30 m per day, a 2.5 km cryo-unit is completed approximately every three-four months. Once the installation of one cryo-unit is completed, some shielding has to be put in place to separate this cryo-unit (to be tested with RF) to the next one being installed. By then, the installation of klystrons, waveguide distribution, power cables, and other infrastructure needed for this 2.5 km cryo-unit has to be finished as well.

With the tunnel still opened for person access, klystrons can be tested and conditioned. The klystrons themselves are shielded so that they can be tested by experts in situ. Warm coupler conditioning with cavities off resonance can take place right after the commissioning of the klystrons.

Leak checks and cool-down can be done as soon as the cryogenic plant is ready and the 2.5 km section is shielded for dark current from superconducting RF cavities. After the cavities are tuned, cavities can be operated at the nominal gradient.

The same commissioning strategy (without beam) applies to the main positron linac.

9 Commissioning of the electron damping ring

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The damping rings have a length of 17 km and are installed over a length of about 7.5 km inside the linac tunnel. The two straight sections of the electron damping ring are placed between the injectors and the cryogenic hall at 7.5 km from the electron injector. The commissioning of the electron damping ring can take place after the construction and infrastructure work in the tunnel are finished. The installation of the beam lines required for the damping ring should not require more than a few months, whereas the installation of modules over 7.5 km can take longer than one year. Therefore, it has been proposed to start the installation of modules at the second half of the main linac. The commissioning with beam requires:

- Beam from the e-pre-linac (5 GeV).
- Tunnel shielding from eventual beam losses to allow installation work of the cryo-units in the second half of the electron main linac.

After all equipment checks, the commissioning starts with single bunch operation:

1. Injection to the damping ring.
2. Establish first turn, multi-turn, then closed orbit (RF capture)
3. Ejection/extraction from the damping ring to the 5 GeV dump (through the spin rotator and bunch compressor).
4. Operation at nominal bunch charge.

For these operations, some basic diagnostics (screens, beam position monitors, bunch charge monitors) are needed.

Once the beam reaches the diagnostic section downstream the bunch compressor, the commissioning of the wire scanners for emittance measurements can start. After establishing first closed orbit in the damping ring, beam diagnostics are commissioned. As the measurement of the closed orbit gets reliable and precise, improvements in closed orbit of the damping ring can be made in parallel. Orbit correction is achieved through beam-based alignment and dispersion correction algorithms. These are procedures which have to be tested and debugged. Their impact on beam emittances can be checked with emittance measurements. Some expected performance of the damping ring can be demonstrated with a single bunch:

- Horizontal and vertical extracted emittance after 1 or n turns.
- Damping time measurements.
- Detailed checks of linear beam optics.
- Best working point of horizontal and vertical tunes. Optimization of local coupling to reduce vertical space charge tune shift.
- Chromaticity, momentum compaction measurements.
- Impedance measurements.
- Measurements of the transverse and momentum acceptances.
- Transverse stability of injection/extraction kickers.
- Commissioning of bunch compressor.

This list includes just some basic measurements of beam dynamics parameters in a storage ring and it is therefore not exhaustive. Special machine studies need to be dedicated to the optimization of the vertical emittance through orbit correction and orbit stability issues (including fast and slow orbit feedback). The commissioning of the extraction, coupling correction and bunch compressor can be done in parallel to the above program.

The commissioning of the damping ring with long bunch trains is expected to happen once the damping ring deliver bunches to the dump reliably and the losses are minimized. Short bunch trains are necessary to check the timing of kickers during injection and extraction. Effects on current limitations need to be investigated. By increasing the length of the bunch train, one can study the various effects of multibunch instabilities.

The benefits of commissioning of the damping ring before the completion of the main linac are:

- The demonstration of small vertical emittances as a milestone to high luminosity
- The establishment of operation procedures to achieve injection/extraction, timing with short and long bunch trains, orbit correction and optimization, feedbacks, etc.
- In the case that any physics issue or any hardware problem is encountered, one can take some time to investigate the problem and its consequences to the final performance, in the form of extensive machine studies or via detailed simulations, and to try solutions and/or repairs or, eventually, to upgrade the systems to overcome that problems.
- After the commissioning of the main linac is done, the damping ring is ready to deliver small emittance, short beams for the commissioning of the beam delivery line.

Last but not least, the experience gained in the electron damping ring is applied in the commissioning of the positron damping ring. By then, many beam physics aspects of damping rings with such layout are understood. Moreover, the hardware of both damping rings are of the same type and the software and the operational procedures can be easily copied and adapted to the positron damping ring. Like this, its commissioning time is very much reduced.

10 Main electron linac commissioning with short pulses

Once all six cryo-units are commissioned with RF (see section 8), the main electron linac is ready for commissioning with beam provided that:

- The electron injector and the 5 GeV linac are commissioned with beam.
- The beam line from the main electron linac to the Fast Emergency Extraction Line (FEXL) is finished.
- The FEXL, which serves as by-pass system to the Final Focus System (FFS), is completed.
- The installation of the positron dump is completed (which also serves as a electron dump for the beam in the FEXL).
- Appropriate shielding for beam commissioning until positron dump.

Additionally, for a smooth main linac commissioning, it is required to have the correct polarity and excitation current of all cold quadrupoles and the measurement of the position and charge of the first bunch with self-triggered BPMs.

Tracking simulations of the first pulse through the uncommissioned linac have been done by N. Walker. Random errors on quadrupole misalignment, cavity gradients and phases have been included in a Monte Carlo simulation. Assuming an incoming 5 GeV beam on-axis, the probability to lose the beam as a function of the distance has been plotted under various scenarios of quadrupole and gradient settings. The procedure proposed consists of having all cavities at zero gradient (although tuned) and selecting quadrupole settings for a 5 GeV beam. Assuming bunches of 3 nC and 1 mm length the beam energy loss in the cavities is about 0.5 GeV. In this case, about one third of the tracks gets through the 14.4 km linac before any orbit correction is applied. The remaining two-thirds are being lost on the wall. Using the position and charge measurements delivered by self-triggered BPMs, first order orbit corrections can be applied to bring the beam through the entire linac and dump it at the positron dump. In order to avoid any risk of cavity damage due the loss of a small beam into the wall, the incoming beam should have poor emittances in both x and y planes. In the present design, the beam has to be injected into the damping ring in order to be sent to the main linac. For establishing beam through the main linac, the beam is extracted from the damping ring after one turn (or very few turns). Additionally, even larger emittance beams can be generated by inserting a graphite foil at the 500 MeV section. In that case, the large size beam has to be transported from the 5 GeV linac to the damping ring and extracted to the main linac using DC-field kickers to allow for a larger aperture. Otherwise, the graphite foil can be located at the transfer line to the main linac.

The first beam transported through the linac to the dump is therefore obtained after measuring and correcting the beam trajectory (if needed, in several iterations). Then, a first measurement of the cavity phases[2] at zero gradients is possible using the beam transients signals of a total bunch train charge about 10 nC, i.e. with 3 or 4 bunches. These first phase measurements yield a phase calibration error of ±5 degrees. Next step is to switch on RF gradually (maybe in two or three steps) to nominal gradient, set new quadrupole currents for the corresponding beam energy and correct orbit. At each step, the RF gradient of each cavity is measured using the beam transients signals and beam energy is measured at the end of the linac.

Once the acceleration of short pulses (3-4 bunches) to 250 GeV has been established, the commissioning of beam diagnostics for a precise measurement of beam energy and trajectory starts. With commissioned diagnostics, the steering along the linac is optimized and beam-based alignment techniques can be tested. The pulse-to-pulse stability of beam energy and trajectory can be studied.

11 Main electron linac commissioning with long pulses

The commissioning of long pulses starts with the test of the machine protection system, which includes the test of fast kickers, beam loss monitors and fast interlock systems. The commissioning of the machine protection system can be done using long pulses at 100 kHz bunch repetition frequency. Thus, the bunch spacing is increased by a factor 30 (as well as the beam loading is decreased by a factor 30) which allows the normal RF regulation to cope with beam loading without an extra feedforward compensation.

Once the machine protection system is commissioned, the average beam current can be increased for commissioning the RF feedforward compensation of the beam loading in the cavities. In order to apply the extra RF feedforward power for exactly compensating the beam loading, a precise measurement of the bunch charge is needed before the bunch is injected into the linac. Not only that, the charge information has to reach to the RF regulation within a few microseconds before the bunch enters the cavity. The only possibility to deliver this information early enough is to measure the bunch charge in the damping ring. In one turn around the damping ring, the bunch is 'delayed' by about 57 μs which is sufficient time to 'prepare' the RF regulation (provided that the bunch charge measurements are done bunch to bunch). During the commissioning of long pulses, the loss of small emittance beams should be avoided. Therefore, the bunches has to be extracted after the first turn in the damping ring (or the equilibrium emittance in the ring artificially increased) and injected into the linac. The long pulse operation can be established increasing gradually the length of the bunch train. At each step, the bunch energy along the train is measured and the RF feedforward regulation adjusted.

[2] Optionally, a phase pre-adjustment can be applied before injecting any beam into the main linac.

12 Commissioning of the positron linac

The commissioning of the positron linac benefits from the experience gained in the commissioning of the electron linac as most of the systems are similar. There are, however, a few differences:

- The positron target, capture and pre-accelerator, which can be tested using an auxiliary electron injector.
- The 5 GeV linac, which consists of special superconducting modules containing a higher number of quadrupole doublets. This linac allows for higher beam acceptance in order to transport beams with larger emittances.
- The current limitation in the positron damping ring is driven by other physics processes than in the electron rings.

The positron injector can be commissioned in an early stage of the collider contruction (see section 6). The positron damping ring and the main linac can, however, be commissioned with beam after the complete installation work is finished. For beam commissioning purposes, the auxiliary electron injector (located near the positron target area) will be used. The commissioning will be thus facilitated since the emittances of the electron beam delivered by this source are smaller than the emittances of the positron beam created in the target. Moreover, the commissioning is decoupled from the operation of the electron linac (which could be commissioned in parallel). Once the commissioning with electron beams of the positron linac is finished, the commissioning with positron beams starts.

13 Luminosity commissioning

At this stage of the TESLA collider commissioning study, the research on the commissioning of the final focus beam linac and of the luminosity is still not finished. Nevertheless, some main ideas that were discussed in the TESLA Collaboration meeting held in Saclay in April 2002 are described in the following.

13.1 Commissioning of the electron final focus beam line

The commissioning of the final focus beam line is an essential step in the preparation of the commissioning of the high luminosity. The most important aspects are:

1. Energy collimation and magnetic energy spoiler.
2. The spoiler protection system, which deflects the beam to the fast emergency extraction line if beam energy or position are wrong.
3. Betratron collimation and associated diagnostics (transverse profile monitors).
4. The laser interferometer for single beam profile measurements in the Interaction Point (IP).

5. Beam-based alignment and orthogonal IP tuning procedures.

6. Fast kickers for the position feedback.

7. Use of emittance bumps in the linac.

The requirements for beam commissioning of the final focus beam line are:

- The installation of the electron dump (located 240 m downstream of the IP) is finished.

- Appropriate shielding of the experimental hall and of the positron tunnel is in place.

- The damping ring delivers beam with nominal emittances.

Most of (if not all) these subjects need further study.

13.2 Luminosity commissioning

First luminosity can be obtained by colliding large emittance beams with high-β at the IP (interaction point). This would avoid the fine tuning in the linac and in the beam delivery system needed for colliding two tiny beams. With collisions at larger beam size, the luminosity is much less sensitive to wakefields, misalignments, etc. In this regime, we can test, for example, the timing (using stripline BPMs with a resolution of 1 ps) and the fast feedback. Moreover, the first (stable) collisions may serve for commissioning of the HEP detector.

The focusing at the IP can be gradually turned to a low-β regime and the emittance can be decreased, in order to investigate the effect of fine tuning tools (already commissioned, see section 13.1) on luminosity. A detailed scenario for the commissioning of the luminosity is being pursued. Many issues are still opened to discussion, for example, the beam energy for the first collisions, the commissioning of the extraction of disrupted beams after the IP, etc.

14 Conclusions

The overlap of test and commissioning of parts of the TESLA collider during its construction and installation period is a must for a prompt luminosity commissioning and delivery to the HEP experiment. A careful planning of the installation and commissioning is therefore needed. The combination of installation and test presents multiple benefits for the reliability of the whole facility. Additionally, it gives to the controls and operation crew (technicians, engineers and physicists) the possibility of getting involved at very early phases of the completion of the project.

The commissioning of the TESLA collider follows a series of milestones:

- e^- injector, 500 MeV: 1st beam/full beam loading

- e^- pre-linac, 5 GeV: 1st beam/full beam loading

- Auxilliary e^- injector: 1st positron beam captured and accelerated
- e^+ injector, 250 MeV: nominal efficiency
- e^- damping ring: closed orbit/low emittance
- One cryo-unit: cooldown/nominal gradient and long RF pulse
- e^- main linac, 250 GeV: 1st beam/positron production/full beam loading/low emittance/final focus
- e^+ pre-linac, 5 GeV: 1st beam
- e^+ damping ring: closed orbit/low emittance
- e^+ main linac, 250 GeV: 1st beam
- first e^+e^- collisions, (maybe at 500 GeV c.m.)/observation of first Higgs
- gradually improve luminosity

An early commissioning of subsystems and sections has also certain drawbacks that should be considered in further detail. For example, it imposes an early choice on the technology for the control system, and forces the acquisition of computer hardware which performance increases substantially every year in the market. Another issue not considered in detail in this paper is the AC power consumption (and cost) needed for the commissioning phase and for keeping the commissioned part running (cryogenics, RF, etc) until the luminosity commissioning.

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