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Upgrade Scenarios for the TBTS

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Abstract

We present several possible scenarios for upgrade of the Two-beam Test Stand (TBTS). In particular we look at instrumentation for RF breakdown studies in the presence of beam, test of CLIC modules and an increased repetition rate.

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1 Introduction

The Two-beam Test Stand (TBTS) has been constructed for the development of PETS and accelerating structures towards CLIC as well as research of physics phenomenons related to the operation of these structures. The commissioning of the first PETS has recently started and the first accelerating structure is foreseen to be installed soon. Preliminary results of the PETS commissioning are promising. To improve the RF breakdown and beam dynamics studies an upgrade of the instrumentation is required as discussed in section 2.

After successful completion of PETS and accelerating structure tests, in a few years time, a first CLIC prototype module is to be tested in the TBTS. Installation of multiple modules will enhance the test capabilities for alignment and stabilization. The installation of a CLIC module will require some minor modifications to the TBTS as the test areas of drive and probe beam are slightly shifted (555 mm). In section 3 it will be discussed how to modify the TBTS to accommodate the installation of one or several CLIC modules.

To increase the testing efficiency, a high effective beam time has to be reached. Besides an optimal availability of the TBTS and the beams it requires also a relevant beam pulse repetition rate, the so called ramp rate. Section 4 presents some options on how to optimize the usage of the TBTS.

2 Upgrade of Instrumentation

The TBTS will be used in the coming years to investigate the power production and accelerating structures as well as related beam dynamics and RF breakdown effects. To improve these studies, instrumentation must be added to measure the RF dark and breakdown current intensity and energy distribution in the presence of the drive and probe beam. For the beam dynamics studies, a time resolved spectroscopy of the beam energy is needed to understand the shape of RF power pulses and beam loss measurements.

2.1 Study of RF Breakdown Currents

Instrumentation is being prepared for investigation of RF breakdown currents and to be installed as a so called flashbox into the beam line vacuum. A first version of the flashbox is being prepared for installation upstream of the probe beam test area. A second and improved flashbox should be prepared for the downstream side. The two flashboxes can then correlate breakdown effects between the upstream and downstream side of the structures and will give a time resolved energy spectrometry of the breakdown currents.

The first flashbox will contain

- a solenoid to measure the beam and breakdown pulse intensities and timing
- an electron and ion spectrometer, consisting of two plates with eight electrodes in the horizontal plane around the beam line. The small chicane formed by the orbit corrector magnets before and after the flashbox, provides the magnetic field required for this spectrometer.
- two plates with one electrode in the vertical plane around the beam line. Can be used as a stripline BPM for beam and breakdown pulse intensity and timing.

A flashbox design for the drive beam might be more complicated due to the high beam current and therefore the need to adapt the impedance of the flashbox so as not to disturb the drive beam before entering the PETS.

2.2 Time Resolved Spectroscopy

The beam energy measurements at the end of the drive and probe beam are presently done with a beam position monitor (BPM) and a video display monitor (MTV). The MTV image is an integration of the beam position (energy) over the whole pulse, while the BPM signals indicate the average beam position over the pulse length. A time resolved measurement of the beam position and spread will give a time resolved measurement of the beam energy and energy spread which can be done by

- sending the MTV signal through an optical beam splitter towards a multi-anode photomultiplier [1].
- a segmented beam dump

The option with the multi-anode photomultiplier may be limited by background due to beam loss radiation for which the photomultiplier is highly sensitive.

NOTE: we need also a time resolved measurement of the beam energy upstream of the test area for comparison in order to calculate the beam loss accurately. At present the BPMs in the TL2' line can be used to measure the average beam energy along a pulse.

2.3 Light Spectrometry

In the 30 GHz test stand light spectrometry measurements have been performed to study the plasma created during RF breakdown. It is not yet understood how this will influence or is influenced by the beam. A light spectrometry set-up is prepared for the TBTS probe beam, but is based on a Faraday cup with front mirror plane that can not be used in the presence of the beam.

Options

- move the light spectrometry to an optical window downstream of the spectrometer dipole CA.BHB 0800.
- an optical window downstream of the spectrometer dipole CM.BHB 0600
- as proposed by NorduCLIC for the 12 GHz test stand, polarized laser spectrometry of the breakdown plasma [2].

  In the drive beam this is possible by using optical windows downstream of the spectrometer dipole CM.BHB 0600 and upstream of dipole CM.BHL 0200. This will give a clear line of sight through the PETS and can be used to observe the effect of the breakdown discharge on the transmitted light of e.g. an external laser. Using a crossed polarizer configuration, none of the laser light will, under normal circumstances, reach the end of the optical line. A breakdown discharge plasma will likely affect the polarization of the laser light and a fraction of the laser pulse will then pass the analyzing polarizer, giving a time resolved signal of the discharge process.

The major difficulty here might be the relatively long distance from the optical windows to the structure in the test area.

2.4 Beam Position and Current Monitoring

The present 10 BPMs installed are inductive pick-ups also used for beam current monitoring, all similar to the CTF3 drive beam linac BPMs [3, 4]. The beam current monitoring (BPM sum signal) is used to compare to and predict the RF power output from the PETS [5, 6]. From the analysis it turns out that there is a slight mismatch between the predicted and measured RF power which may be due to bandwidth limitations in the BPM sum signal. The bandwidth of the BPM is around 250 to 300 MHz while the bandwidth of its electronics is limited to 200 MHz with an ADC sampling rate of about 500 MHz[7]. On the other hand, the RF power is measured over a diode with a 1 GHz bandwidth on a 250 MHz bandwidth Acqiris DC270 ADC. A 1 GHz bandwidth Acqiris ADC is available for short term loan. Therefore it is of interest to replace the BPM CM.BPM 0370 downstream of the PETS with a higher bandwidth device.

2.5 Video Display Monitors (MTV)

At present two video display monitors are installed, one each in the spectrometer lines of both drive and probe beam. These so called MTVs are of a similar design but using an OTR screan in the high intensity drive beam and a ceramic luminisent screen in the probe beam. The screen is monitored by a CCD camera mounted in a lead shielding under the beam line. The camera read-out is software triggered and the present electronics limits the read-out to about 1 Hz with only one camera in CLEX in operation. Two upgrades should be considered:

- hardware triggering. A hardware triggered camera should provide a reliable correlation between the picture sampling and beam pulses, especially when running at higher beam repetition rates.

- read-out frequency. For operation of and measurements at the TBTS in two-beam acceleration mode it will be necessary to read-out both MTVs in drive and probe beam simultaneously at the same repetition rate as the beam pulses.

The first upgrade requires a replacement of the existing camera, the second upgrade is either in the read-out electronics hardware or software.

2.6 Other Beam Line Instrumentation

There is an interest for emmittance and bunch length measurement in order to study energy loss and gain. It is not yet clear how this can be done best.

2.7 Summary Instrumentation

There is a need for more instrumentation in the TBTS. The segmented beam dump and flash-box are obvious candidates. The possibilities for light spectrometry should be investigated. Upgrades of some of the BPMs and MTV electronics should be considered.

3 Installation of CLIC Modules

After tests of accelerating structures and PETS in the coming years will converge towards a CLIC prototypes, it will be essential to install and test a complete CLIC prototype module to investigate its design and integration issues. Installation of multiple modules will enhance the test capabilities for alignment and stabilization. Both of a module itself and in between modules which requires at least two but preferably three modules in series.

The scenarios below are based on the TBTS and CLEX layout according to the model drawings [8, 9, 10].

3.1 Present Situation and Boundary Conditions

The actual installation space for the test areas, as limited by two vacuum sector valves, and the length of a CLIC module are

- drive beam test area: 2000 mm [8]
- probe beam test area: 2200 mm [9]
- CLIC test module: 2100 mm [11]

The girders up and downstream of the test area contain a vacuum sector valve, orbit corrector magnets, BPM's and a vacuum pumping pot.

Boundary conditions are given as

- The drive beam test area starts 555 mm upstream compared to the probe beam test area. To align the downstream ends of the two test areas, the drive beam test area must be extended by 755 mm.
- The corridor in between the beam dumps at the end of the TBTS and the wall of the CLEX building towards CTF2 should be respected if possible. This corridor is important for installation and maintenance work.

3.2 General Modifications for CLIC Module Installation

Installation of a CLIC module requires a free floor space. This might require modifications of the present installation:

- cable trays: The cable trays are installed along the girder feet.
- cooling water: The cooling water lines run in between the drive and probe beam girders.

It has to be investigated if it would be possible to keep the cable trays and cooling water lines in place by lifting the modules over them. Otherwise a possible solution is to either put the cabling and cooling water along the ceiling or to make a channel in the floor. The last option might be the most practical.

3.3 A Single CLIC Module

Installation of a CLIC module requires a free space of 2100 mm in parallel areas of the drive and probe beam. The drive beam test area is only 2000 mm long and starting 555 mm before the probe beam test area. Thus an additional space of 555 mm has to be created upstream of the probe beam test area plus 100 mm around the drive beam test area, or 755 mm downstream of the drive beam test area:

1. (easiest) shorten the girder after the drive beam test area. This 2200 mm long girder contains the vacuum sector valve, a BPM, two orbit correctors and a vacuum pumping pot with ion pump. Enough space will remain on the girder for all beam line elements after shortening. Probably a single orbit corrector magnet might be sufficient. Minor recabling might be required as well as a realignment of the BPM. In case beam kick measurements are no longer foreseen in this configuration, the BPM in question is no longer necessary.

2. move the two girders after the drive beam test area further downstream. This will require intensive recabling and realignment of all beam line elements.

3. (complicated) if the flashbox is no longer required, the upstream girder from the probe beam test area can be shortened. One of the orbit correctors would be removed, the other relocated between pumping pot and BPM. This would give 622 mm. In the drive beam line, the vacuum sector valve and BPM plus orbit corrector magnet immediately downstream of the test area should have to be moved by 100 mm and the girder shortened with the same amount.

Note: it has to be investigated how to install the CLIC module while leaving the existing cable trays intact. If this is not possible, extensive recabling is required for all downstream elements (in the probe beam).

3.4 Two CLIC Modules

Two CLIC modules will require an installation space of 4200 mm.

In the case of two or more CLIC modules installed, beam kick measurement results might be difficult to interpret. Assuming that these measurements have no longer a priority the BPMs necessary for these measurements can be discarded. This will increase the available installation space:

- drive beam test area. An installation space of 1900 mm is available. An extra 755 mm is required downstream to align it with the probe beam test area.

  The girder immediately downstream of the test area can be removed except for the vacuum sector valve and one of the orbit correctors. These can be installed on a shortened girder with one single support pillar: $\sim$1500 mm space. The second girder can be moved downstream towards the spectrometer dipole. At present there is a drift space covered by a 1955 mm long beam tube.

  This creates a total space of 5355 mm, or 4600 mm aligned with the probe beam test area.

- probe beam test area. An installation space of 2200 mm is available.

  The girder immediately downstream of the test area can be removed except for the vacuum sector valve. This girder releases 2129 mm of space but the valve requires 150 mm. The second girder downstream has an orbit corrector as first element. This corrector can be moved easily by 100 mm downstream creating 130 mm of support space on the girder for the vacuum sector valve. The support of the valve can be adapted to fit into this envelop.

  This creates a total space of 4329 mm.

To summarize, the major work will be to move the second girder downstream from the drive beam test area. It should also be studied how to install the CLIC module keeping the present cable trays along the probe beam line.

3.5 Four CLIC Modules

The installation of up to four CLIC modules requires 8400 mm and is of interest for alignment studies. Studies of the structures and beam behaviour will be difficult due to the low available drive beam power which will inhibit powering of all accelerating structures. The space allocated for kick and breakdown instrumentation can be used for the module installation. If some of the modules are of a type with build-in quadrupoles, the downstream girders with quadrupoles can be removed.

If, for the alignment studies, beam energy measurements are not of interest, the spectrometer lines can also be removed. The measurement of energy loss or gain in the accelerating structures will be difficult to interpret there not all structures will be powered: the none powered structures will decelerate the beam.

- drive beam test area. An installation space of 1900 mm is available while an extra 755 mm is required downstream to align it to the probe beam test area.

  Removing the two downstream girders and the drift space to the spectrometer dipole, including the vacuum sector valve, gives 2×2200 mm + 1955 mm = 6355 mm. Removing the spectrometer dipole will give 774 mm while up to almost 1500 mm can be gained between dipole and dump. The total available installation space is then over 9 m (excluding the 755 mm required to align to the probe beam test area).

- probe beam test area. An installation space of 2200 mm is available.

  Removing the two downstream girders liberates 4329 mm. Removing the spectrometer dipole adds 774 mm. The beam dump (from the spectrometer line) can be moved next to the drive beam dump (replacing the drive beam spectrometer beam line dump). This adds approximately 2500 mm to a total available installation space of over 9.5 m.

- In addition the downstream girder of both probe and drive beam test area can be removed except for the vacuum sector valve. For the drive beam girder, enough space would remain to keep one of the two BPM's and orbit corrector magnets. This would add $\sim$1500 mm extra space.

To summarize, by removing the two girders downstream of the test areas as well as the spectrometer lines there is enough space to install up to four CLIC modules in the TBTS. The downstream cable trays can be removed to ease installation of the modules as they are no longer necessary after removal of all downstream beam line elements.

3.6 Summary CLIC Module Installation

From the scenarios describes above it is clear that up to four CLIC modules can be installed in the TBTS without major difficulties. The location of the beam dumps does not have to be modified, thus leaving intact the corridor between the dumps and the wall towards the CTF2 building. An issue is however the rerouting of cable trays and cooling water lines.

4 Increased Repetition Rate

Efficient testing and conditioning of structures requires a high effective beam time. This can be achieved either by high repetition rates of the beam pulses or by long periods of beam time. The TBTS will share the drive beam time with the TBL. This implies that for a high effective beam time in both lines the problem is enhanced.

Pulse switching operation between TBTS and TBL for the drive beam might be possible, but requires to replace the present dipole bending magnet CM.BHL 0100 with a fast switching (kicker) magnet. On the other hand, the present hardware is foreseen to handle just one type of beam, and might thus not be compatible with pulse switching that requires different beam types for each pulse. Therefore pulse switching does not seem attractive as it would require the same beam type in both TBTS and TBL. It would be more convenient to run on a (bi-)weekly basis for each line.

The enhanced beam time availability implies long periods of beam time which require a large pool of available manpower and will not be discussed here. Thus, the only reasonable solution to enhance the testing efficiency is to increase the beam pulse repetition rate.

4.1 Enhanced Drive Beam Repetition Rate

The present repetition rate of CTF3 (drive) beam is 0.8 Hz: synchronized with the 1.2 s PS cycle. Enlarging the repetition rate of the CTF3 drive beam can be done in several steps that require different measures to be taken. Up to 10 Hz should be possible without large investments as it is compatible with the available hardware and at present limited by the radiation levels outside the accelerator hall:

- 5 Hz repetition rate:
  - extra shielding around the access doors (chicanes) has been installed,
  - extra beam development time to limit beam losses,
  - verify the radiation levels in the extension of the klystron gallery, and if required close it during operation,
  - use the RAMSES radiation monitoring system as a beam loss interlock.
- 10 Hz repetition rate:
  - establish the beam at 5 Hz operation, decrease the beam losses and only then go to 10 Hz operation
- 25 Hz repetition rate:

  - requires upgrade of two linac modulators charging power supplies (i.e. klystron high voltage transformers, cost ∼100 kCHF)
  - study of radiation levels required:
    * if 10 Hz possible with recombination, 25 Hz might be possible when bypassing the delay loop and combiner ring
    * or, bypass the delay loop with 2× recombination in the combiner ring
    * or, with lower power and PETS recirculation

4.2 Enhanced Probe Beam Repetition Rate

The present repetition rate of CALIFES (probe) beams is 0.8 Hz: synchronized with the 1.2 s PS cycle. Higher repetition rates requires:

- 5 Hz repetition rate:
  - according design
- 10 Hz repetition rate:
  - upgrade of the laser
  - upgrade of the klystron modulator power supply
  - study of the beam dump radiation level
- 25 Hz repetition rate:
  - as for 10 Hz

4.3 Summary Optimized Usage

It should be possible to increase the drive beam repetition rate from the present 0.8 Hz to 10 Hz and the probe beam repetition rate to 5 Hz without major investments.

5 Conclusions

Several options have been presented for future upgrade of the TBTS in order to enhance the possible research capabilities. An instrumentation upgrade is required for improved RF breakdown studies and beam energy measurements. An enhanced beam pulse repetition frequency will greatly decrease the required structure conditioning time and the measurement time required for the RF breakdown and related studies. Furthermore possibilities exist to install several CLIC prototype modules in the TBTS without having to extend the overall length of the facility. This will greatly enhance the test possibilities for alignment and stabilization.

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