TTF2 BEAM MONITORS FOR BEAM POSITION, BUNCH CHARGE AND PHASE MEASUREMENTS

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Abstract

An overview of the basic beam instrumentation with regard to electromagnetic beam monitors for the TESLA Test Facility phase 2 (TTF2) is given. Emphasis is put on beam position monitor (BPM) and toriod transformer systems for beam orbit and bunch charge observations. Furthermore broadband monitors, i.e. wall current and bunch phase monitors, are briefly presented.

INTRODUCTION

During the past 10 years, the TESLA Collaboration has established the TESLA Test Facility (TTF) on the DESY site in order to develop the technology for a superconducting linear electron-positron collider and a X-ray free electron laser facility. The first phase of this project, TTF1, was successfully completed in 2002 with an extended operation period for first scientific applications of the saturated FEL beam below 100 nm wavelength [1].

Convinced of the unique possibilities provided by this new kind of radiation source, DESY is now upgrading the TTF accelerator and implementing the VUV-FEL user facility [2]. As in case of TTF1 the task in operating TTF2 will be twofold:

- Test accelerator for further development of superconducting L-Band (1.3 GHz) acceleration structures in the frame of a HEP linear collider, as well as for DESY's upcoming XFEL project.
- Drive linac for the 4th generation synchrotron radiation user facility based on a SASE FEL-undulator with a wavelength regime down to 6 nm.

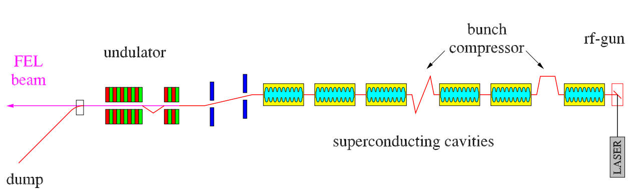

Figure 1: Schematic overview of TTF2.

Fig. 1 sketches the major components of TTF2, a new photoinjector (already tested with beam), five superconducting accelerator modules (a sixth module, for a 1 GeV upgrade, is under construction) of the TESLA type each containing eight L-band 9-cell cavities, two bunch-compressors, a collimation section and finally a 30 m long SASE FEL-undulator (divided in six 5 m long sections).

Based on the experience with TTF1 and other accelerators on the DESY side, a set of monitors for the basic beam instrumentation have been developed for TTF2. Emphasis was put on homogenous systems with high reliability, good maintenance and operational properties, rather than on "high-end instrumentation".

Table 1: Parameters of the TTF2 electron beam

max. beam energy	=	800 MeV (1 GeV)
max. rep. rate f_{rep}	=	10 Hz
macro pulse length t_{pulse}	=	800 μs
bunch spacing $\Delta\, t_b$	=	*110 ns or 1* μ*s*
N_e *per bunch*	=	*0.1...4 nC*
bunch length σ_z	$<$	50 μm
norm. emmittance ϵ_{norm}	=	2 mm mrad

Table 1 presents the beam parameters of TTF2, relevant for beam instrumentation. All monitors have to resolve single bunch information, thus the measurement (integration) time has to be $<$ 110 ns. Due to the use of high gradient superconducting cavities, special care has to be taken to avoid dust or other particles in the vacuum system, even though most of the diagnostics is installed outside of the cryostats.

BEAM POSITION MONITORS

About 60 *beam position monitors* (BPM) are installed in the warm sections of TTF2, half of them are stripline and half of them button BPMs, mainly installed in sections with limited space, e.g. in the undulator. Resonant cavity and re-entrant cavity type BPM's, with special read-out electronics, as they are used in the cold accelerating modules are not covered here.

Stripline BPM's

Based on a design for the S-Band LC test facility, the TTF2 *stripline-BPM's* are manufactured in two slightly different versions for the two standard vacuum chambers diameters of of 34 mm resp. 44 mm diameter. Since the outer shape of the BPMs maps to the contour of the poles inside the quadrupoles, it was possible to install the BPMs *inside* the quads, i.e. where the optical axis of the machine is defined. A stretched-wire calibration procedure was applied to these BPM-quadrupole units to measure the difference between electrical axis of the monitor and magnetic axis of the quad.

Fig. 2 shows the orthogonal arrangement of the four 20 cm long, longitudinal slotted coaxial electrodes, fixed with ceramic spacers, in the BPM body.

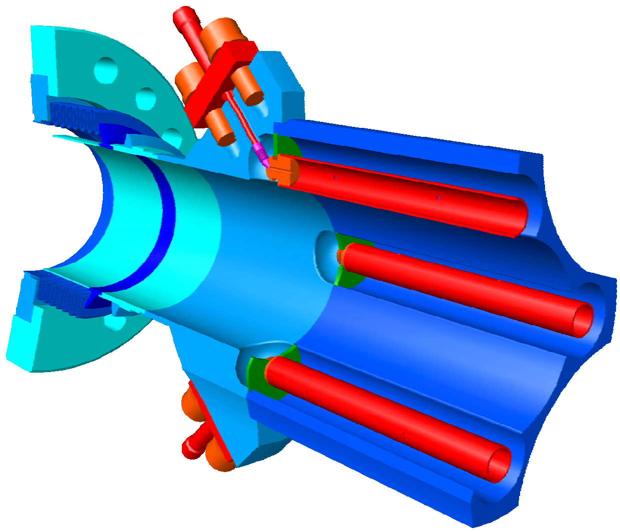

Figure 2: Sectional view of a TTF2 stripline-BPM.

Key characteristics of the TTF2 stripline BPM's are:

- Installation inside and collinear to the quadrupole axis. Calibration of BPM and quad axis with respect to each other with a resolution of 10...20 μm, using a stretched-wire technique [3].
- Strong signal levels, already at these moderate frequencies, allows a sufficient long integration period in the read-out electronics and results in a high S/N-ratio, even at bunch spacings of 110 ns.
- The resistive 50 Ω source impedance minimizes reflection effects between BPM pickup and read-out electronics, and therefore improves the single bunch measurement capability.
- The normalized position sensitivity (signal ratio) close to the center is $\approx$ 2 dB/mm.
- The coupling coefficient for a centered beam is $k \approx$ 6.5 %.
- Two BPM versions for 34 (resp. 44) mm diameter aperture with 6 (8) mm diameter "semi"-coaxial stainless steel tube electrodes ($Z_0 = 50\,\Omega$) of 20 cm length ($f_{\text{center}} = 375$ MHz).
- Cleanroom class 100 approved construction, copper-plated stainless steel monitor body with brazed end-pieces.

Electrostatic "Button" BPM's

In regions of limited space, i.e. the injector, the bunch-compressors and of course in the undulator section *electrostatic "button"-type BPM's* are installed. Depending on the space requirements and beam pipe diameter two types of flange mounted pickup electrodes are used:

"Trumped" styled button (custom made by *Metaceram*) of 8 mm diameter, are flange-mounted in an 90^0 orthogonal arrangement in the 34 mm vacuum chamber of the injector. They are also used in an "array"-like arrangement in the flat, rectangular vacuum chamber of the bunch-compressors.

Tiny, pin-style electrostatic BPM electrodes are used in the 10 mm diameter vacuum chamber of the FEL undulator [4]. The space limitations inside the FEL undulator dictates a non-orthogonal arrangement of these flange mount, commercial feedthrough electrodes (custom made by *Meggitt, ex. Kaman*). With the change of the beam optics in TTF2 the need of BPM's *inside* the FEL undulator sections is relaxed. Two BPM pairs installed inside, plus one BPM between undulator sections allows a beam orbit monitoring every 30^0 phase advance.

Read-out Electronics

The *read-out electronics* has to interface the electrode signals of BPM pickup's to the analogue input of the existing VME-based data acquisition system. Therefore the successful operated undulator BPM read-out electronics of TTF1 [5] was re-designed, upgraded and modified to accomplish all the TTF2 needs:

- Monopulse and ringing band-pass versions of the *AM/PM normalization* based electronics to read-out both, button-, as well as stripline-BPM's.
- Remote controlled settings for offsets, timing, etc. to allow in tunnel operation.

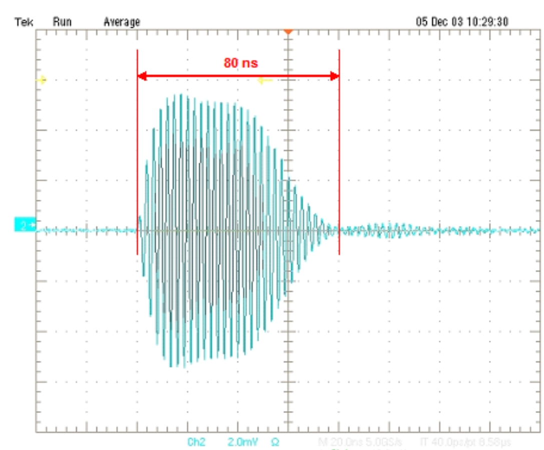

Figure 3: Measured TD impulse response of the band-pass input filter – stripline version of the read-out electronics.

For the stripline version of the read-out electronics, a new ringing band-pass input filter was developed. It is based on a rectangular impulse response low-pass prototype. Fig. 3 shows it's time domain response, which gives $\approx$ 20 oscillations of 375 MHz, well damped within 110 ns to insure the single bunch detection capability.

The electronics hardware is realized as VXI C-size mainboard, holding 9 rf submodules which keep the critical analogue functions. This rf building block concept simplifies future changes, features easy adaption to new monitors and supports maintenance and improvement aspects.

BUNCH CHARGE MONITORS

The bunch charge (beam intensity) measurements in TTF2 are based on *inductive, broadband toroidal transformers* (toroids). Fig. 4 sketches the tunnel-installed hardware, consisting out of the actual toroid, a set of signal combiners (only one shown), a low-pass pulse-forming network and broadband amplifiers. For compatibility and maintenance reasons the in-house developed toroid was preferred to a commercial version, since it is cut in two half rings. Therefore it can be (dis)mounted without breaking the vacuum. Due to the unavoidable air-gaps the lower cut-off frequency is limited, the usable bandwidth ranges $\approx$ 10 kHz...$>$ 100 MHz.

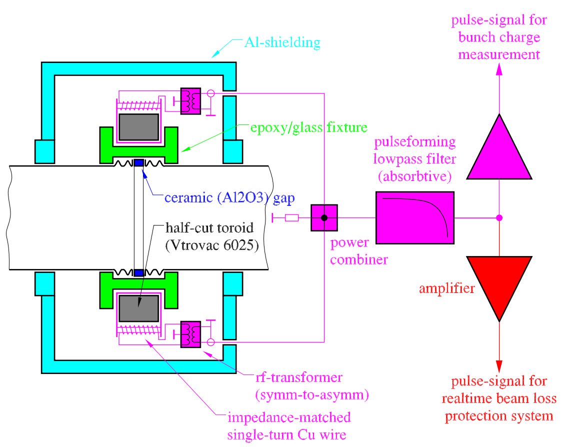

Figure 4: Toroidal transformer with front-end electronics for beam intensity measurements.

11 toroid units matched to the 3 different vacuum pipe diameters are installed along the TTF2 linac to keep track of the accelerated charge and therefore the transmission through the accelerator. Selected pairs of toroids are also used for beam loss monitoring; as source for the fast protection system [6]. In order to provide a sufficient beam loss resolution we have to matched the transfer responses of these toroid couples to $< 10^{-3}$.

OTHER BROADBAND MONITORS

Bunch Phase Monitors

The operation of a SASE FEL, like TTF2, is very sensitive to the compression of the beam in order to reach the required high peak currents. This process depends critically on the phase of the rf-voltages, used to produce the energy chirp within the bunch. Therefore, the a precise tuning of the rf-phase with respect to the beam to the 0.1^{0} level or even better is essential. Furthermore, beam related trigger signals, to determine arrival time or to evaluate jitter properties on the some 100 fs level are required. Therefore a *bunch phase monitor* is used to pickup a beam position independent, broadband bunch signal. It consists out of a simple *ring electrode* of 100 Ω characteristic impedance, fixed by two adjacent 50 Ω rf-feedthroughs. This arrangement was simply integrated into a thick flange.

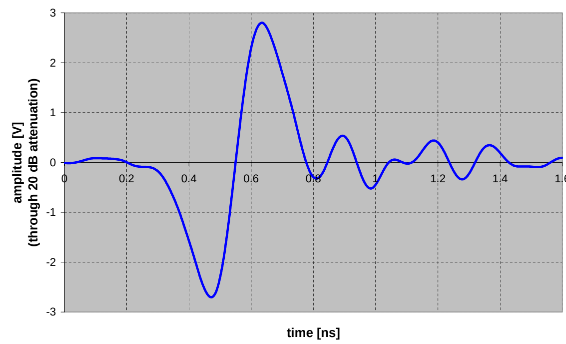

Figure 5: Time domain signal from a bunch phase monitor.

The monitor delivers a well differentiated output signal, as first preliminary measurements indicates (here limited by the 4 GHz bandwidth of the observation instrument, Fig. 5). The theoretical band-limitation is expected in the 8...10 GHz region, due to the ring diameter and reflection effects at the feedthroughs. In TTF2 phase monitors are installed after each section including dipole magnets plus one injector before the compression stages. Thus it is possible to locate phase jumps, introduced by rf-systems, through a time-of-fight measurement. Further monitors are installed to extract timing signals.

Wall Current Monitors

A set of very simple *wall current monitors*, based on the ceramic gap of the toroids, is installed in TTF2. The time-constant is build from the gap capacitance of $C_{\text{gap}} \approx 55$ pF and eight gap resistors $R_{\text{gap}} = 25/8\,\Omega$ in parallel with eight passive summed load-lines $R_{\text{load}} = 50/8\,\Omega$, and leads to an upper frequency limit of $f \approx$ 1.4 GHz.

This broadband bunch current monitor is only required for unusual operating modes, i.e. a bunch spacing $\ll$ 110 ns, as used during the TTF1 HOM measurement experiments, etc.

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