Experimental Program with Beam in TESLA Test Facility

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Abstract

In order to establish a technical basis for a high energy e^+e^- collider using the superconducting RF technology, the test of a string of 32 cavities with beam at an accelerating gradient of 15 MV/m is planned in an installation at DESY [1]. Several experiments with beam in TTF will be performed, first with a low charge injector (40 pC, 216 MHz) then with a full charge one (8 nC, 1 MHz). The dissipated HOM power at helium temperature is a key issue for TESLA, its estimation requires careful calorimetric measurements and the full charge injector. Bunch wake potentials can be estimated with bunch charges of at least 1 to 2 nC. Multibunch measurements require a beam of a few hundreds of these bunches. The beam will be injected either on axis or off axis. RF steering due to couplers will be estimated by measuring the beam displacement for different RF phase settings. The expected resolution is well below the TESLA specification. The acceleration of dark currents will be observed for different settings of the focusing elements.

1. RF to beam power transfer

The beam energy stability will be carefully studied, along a beam pulse and from pulse to pulse. The bunch to bunch chromatic effects in the TESLA linac must be less important than the single-bunch ones. Lorentz forces detuning and microphonics [2] are the main sources of energy spread along the bunch train. An RF feedback system should guarantee a constant acceleration during the 800 µs beam pulse. The monitoring of energy and energy spread during the pulse, at time intervals of 1 µs, will be performed using a BPM and a profile monitor in the analyzing station. All these informations can be collected with the low charge injector.

2. Beam power deposition at 2 K

The loss factor due to the longitudinal higher modes has been evaluted to about 8.5 V/pC/cavity for a bunchlength of σ_z=1mm. For the TESLA bunch charge of 8 nC and the bunch rep rate of 8 kHz, the HOM power deposited by the beam is then 4.35 W per cavity. The low frequency part (up to 5 GHz) of this HOM power will be mainly extracted by the HOM couplers and has been estimated to about 30 %. In order to limit the cryogenic load, special HOM absorbers (at 70 K) are located at the end of each 8-cavity module. They are expected to dissipate 90% of the remaining power. The table 1 below gives the distribution of HOM power, together with the static and dynamic heat load at 2 K, for comparison.

A correct evaluation of the 2 K power deposition requires a high charge beam and a resolution of a few tenths of a watt in the cryogenic heat measurement.

HOM-couplers	10.4
70 K absorbers	22
HOM at 2 K	2.4
Static load at 2 K	2.8
RF load at 2 K	11.6

Table 1 : Heat loads (W) for one 8-cavity module

3. Cavity offset

The alignment tolerances on the quadrupoles (0.1 mm) and cavities (0.5 mm) in TESLA are not too tight in comparison with other room-temperature linear collider proposals. The final components displacements in the real cryostat environment will be carefully checked in the TTF linac. It is planned to monitor the motion of the inner components during cool-down, operation and warm-up by means of optical targets. In addition, the individual cavity offsets of one module can be measured by detecting with a spectrum analyser the dipole HOM power, excited by the beam assumed on-axis, coming from the HOM couplers. Due to the large bunch spacing, an harmonic of the beam spectrum is always close enough to a dipole mode frequency to give rise to resonant build-up of fields. Taking the TM_{110} mode (1875 MHz) of highest impedance and assuming the beam can be steered close enough to the centerline, cavity offset measurements with resolution better than 10 µm, would be possible. A beam of about one hundred full charge bunches is sufficient to make this measurement. The power induced on the longitudinal modes, including the fundamental, is harmless.

4. Bunch wake potentials

The knowledge of the short-range wakefields is of outstanding importance for the estimation of the emittance growth in the TESLA linac. These quantities are not easily computable for short bunches and will be carefully studied with the high charge injector. The beam will be observed either after the first module, with all 8 cavities non powered, or after the entire TTF linac operating at low gradient (about 5 MV/m). The former alternative assumes that the next modules have been removed to give way to beam monitors.

The longitudinal wake will be estimated by measuring the energy profiles for different bunch charges. Simulations show an energy spread of 0.5% for a charge of 1.6 nC after the first module and 0.7% for 8 nC after the entire linac. The plot 1 shows the correlated energy profile for 8 nC and acceleration through the linac at 5 MV/m.

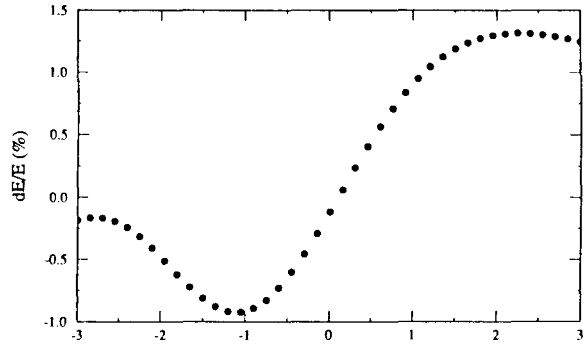

Figure 1 : Correlated energy profile at the exit of the linac ($N=5.10^{10}$)

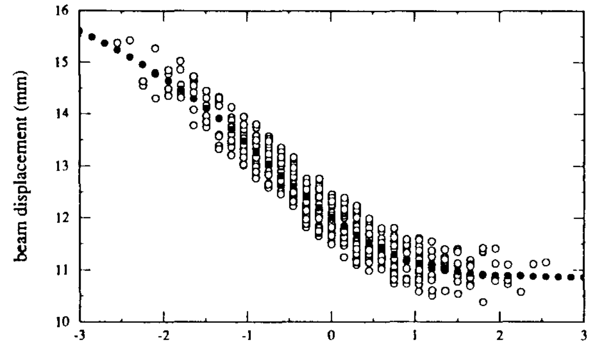

Figure 3 : Transverse profile with 10 mm offset at the exit of the TTF linac ($N=10^{10}$)

The dipole wakefield will be studied by injecting the beam 10 mm off-axis. When the beam is observed at the exit of the whole linac, the planned focusing scheme with quadrupole doublets providing a phase advance of 90° per module cancels out the wakefields effects. A weaker focusing with a phase advance of 30° per module is much more convenient in this case. Figure 2 shows the head (dotted line) and the tail (solid line) of a bunch injected 10 mm off-axis through the TTF linac with an accelerating gradient of 5 MV/m. The trajectory of the head is kept constant by means of steerers located at the quadrupoles. Owing to this weak focusing, both trajectories diverge clearly, almost 5 mm, at the exit of the linac. The focusing effect of the SW structures can be seen in the low energy part. The plot 3 shows the corresponding transverse profile of the bunch.

After the traversal of first idle module, a head-tail displacement of 5 mm is obtained with a bunch centroid displacement of 1.5 mm, which can be measured by means of the BPM located at the end of the module.

The energy profile and the transverse profile of the bunch will be best measured by means of a streak-camera associated with OTR located on the spectrometer and straight-ahead beam lines.

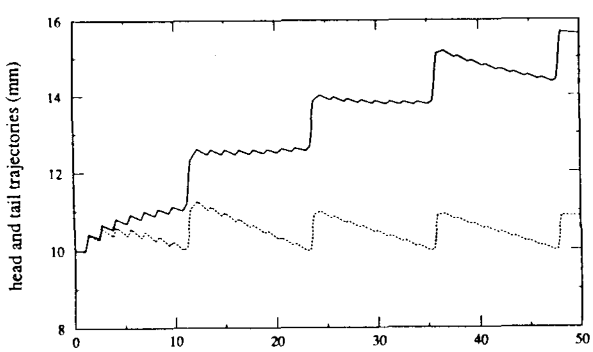

Figure 2 : Head and tail trajectories with 10 mm offset and weak focusing ($N=10^{10}$)

5. Multi-bunch Beam Breakup

The Beam Breakup phenomenon, caused by the long-range wakefields, is controlled in the TESLA linac through a mode damping combined with a large bunch spacing on the one hand and the natural cavity to cavity mode detuning on the other hand. The multi-bunch effects in the TTF linac will be however very weak, even with a beam travelling through all the cavities operating at low field level. The beam will be injected 10 mm off-axis into the first non-powered 8-cavity module and the position of the bunches will be observed at the BPM located at the end of the module. The bottom curve of the figure 4 shows a weak bunch displacement, once the steady-state is achieved. Ten dipole modes were used with an rms frequency spread of 1 MHz. A rms cavity offset of 0.5 mm was assumed. Each mode can be then studied individually by tuning the cavities to the resonant excitation $F_{res} = nF_b(1 \pm 1/2Q)$. The tuning system can be actuated because the cavities are not powered. The middle and the upper curves show the bunch displacements when two and four cavities, respectively, are tuned to the resonant condition for a TM_{110} mode, giving final relative displacements of 2.5 and 5 mm for the bunch population of 10^{10}. Due to the rapid build up of the steady-state, a beam of about two hundred bunches per pulse with a bunch charge of 1 to 2 nC is sufficient for this experiment.

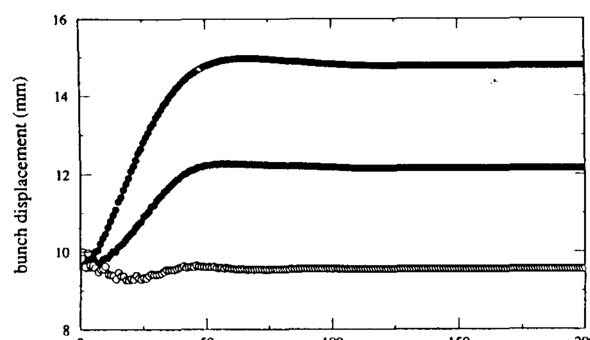

Figure 4 : Bunch displacement with 10 mm offset at the 8-cavity module exit ($N=10^{10}$)

6. RF steering

Radial asymmetries in the rf fields in the accelerating structures deflect the beam transversely. The static deflections of the beam centroid and the variations in the deflections due to field jitters from pulse to pulse can be compensated for by the dipole magnets and the fast kickers in the linac. Their contribution to emittance dilution through wakefield and chromatic effects will be small. Due to the finite bunch length, however, the rf kicks vary during the passage of a bunch, causing a tilt to the beam, driven by the out-of-phase rf component [3]. The main sources of rf deflections in TESLA are the input and HOM couplers. By varying the rf phase of one TTF module and monitoring the change in the beam position before the focusing magnets at the end of the module, the strength and the phase of the rf deflection can be inferred with a resolution below the TESLA tolerance (0.1 mrad). These experiments can be carried out with the low charge injector Figure 5 shows the expected BPM reading when the rf phase of the third module is varied, assuming a rf kick of 10 keV/c per cavity, without (solid circles) and with (empty circles) the effect of a random cavity tilt of 1 mrad.

The effect will be more sensitive at the low energy end of the TTF linac, but the rf focusing effects of the accelerating structures are stronger and must be taken into account.

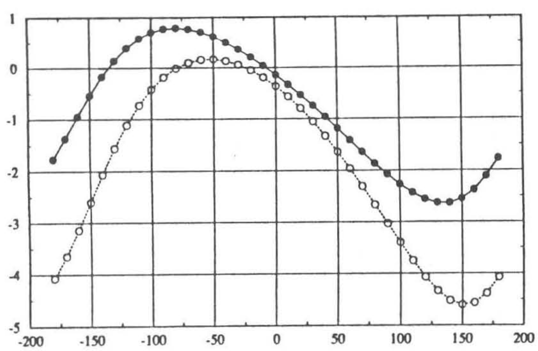

Figure 5 : Beam displacement (mm) for a rf phase variation (deg) of the 3rd module

7. Dark current

Field emission currents can be easily captured in the TESLA linac operating at 25 MV/m and 1.3 GHz. Instead of being accelerated over the full length of the linac, forming a halo to the beam and finally causing a significant backgroung problem to the interaction region, this dark current will be intercepted along the machine by the low energy acceptance of the focusing optics. Figure 6 plots the field emitted beam in transverse phase space after acceleration through a second cavity. The potential emitters were disclosed by a sweeping of the first cavity surface and of the rf phase.

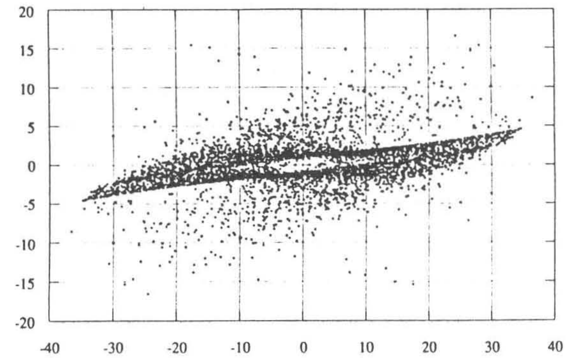

Figure 6: Field emission beam in transverse phase space (mm*mrad) after a 2nd cavity

This dark current has then be tracked through the TESLA linac,with usual components misalignments, the one-to-one correction, and induced wakes from the main bunches. The figure 7 shows the amount of particles lost along the machine, assuming that the current, formed by 10000 particles, was emitted from the first cavity of the linac after the DR (worst case). Most of the particles are lost in the first quadrupoles and the last particle after five FODO cells. In the TTF linac, 40% to 70% of the current emitted by the first cavity can be transmitted, depending on the quadrupole setting. These transmitted field emission currents will be measured at the end-station and scintillation counters will be placed at the critical points to measure the expelled current.

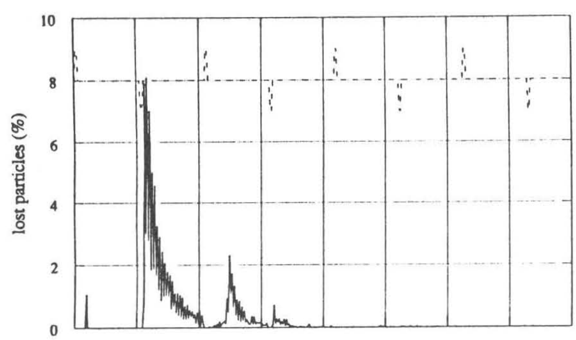

Figure 7 : Amount of particles in % lost along the TESLA linac

8. References

[1] H. Weise, for the TESLA collaboration, "The TESLA Test Facility (TTF)", *Proc. of 4th European Part. Accel. Conf., London, 1994.*

[2] A. Mosnier and J.-M. Tessier, "Field Stabilization in a Superconducting Cavity Powered in Pulsed Mode", *Proc. of 4th European Part. Accel. Conf., London, 1994.*

[3] J. T. Seeman, "Effects of RF deflections on Beam Dynamics in Linear Colliders", *Part. Accel., 1990, Vol. 30, pp. 73-78.*