

# Beam Instrumentation for the Injector of the Tesla Test Facility Linac

R. Chehab and T. Garvey

LAL, Orsay

June 93

## Introduction

We discuss some options concerning possible beam instrumentation for the TTF linac. Beam-position monitors (BPM), intensity and transverse profile monitors, microbunch pulse duration measuring system and energy dispersion monitors are considered. Some ideas are also given for beam loss monitoring.

## I - RECALL OF TTF PARAMETERS

Some relevant beam parameters for experiments to be performed on the TTF linac and the required measurement resolutions for the parameters are listed below :

	nominal parameters	alternative parameters
Intensity	10 mA	50 - 200 $\mu$ A
Repetition Frequency	217 MHz	1 - 4 MHz

Precision on :

<ul style="list-style-type: none"> <li>● Intensity</li> <li>● Position</li> <li>● Profile</li> </ul>	5% 0.1 mm 0.1 mm	5% 0.1 mm 0.1 mm
--	------------------------	------------------------

## II - BEAM POSITION MONITORS

Near beam field detectors seem to be the most appropriate. Two sets of monitors can be considered : wide band monitors and resonators. BPM monitoring is required just before the analysing magnet, on either side of the superconducting capture cavity and prior to the first cryo-module.

### ● Wide-Band monitors

Buttons, loops, and striplines are all commonly used on linear and circular accelerators. Their sensitivity strongly depends on their geometry.

Appropriate BPM's for TTF might be electrostatic buttons. A typical system is a 10 mm diameter four button device presenting a capacitance of 3-5 pF for each button [1]. BPM electronics may include an RF multiplexer placed just after the electrodes, so as to avoid errors on position determination due to the shift in electronic treatment after the multiplexing point.

Obtainable accuracies are of the order of 100  $\mu$ m and agree with what is desired for TTF.

## ● Resonators

Due to the pulse structure of TTF beam we can use RF resonators whose filling time ( $\sim 1 \mu\text{s}$ ) is much smaller than the beam pulse duration.

Cylindrical  $\text{TM}_{110}$  and rectangular  $\text{TM}_{120}$  cavities can be used. As reported previously [2] the known sensitivity for a  $\text{TM}_{110}$  cavity under study is :  $3 \cdot 10^{-7} \text{ Watts}/\mu\text{m}^2$  for the TTF nominal current.

For a precision of  $100 \mu\text{m}$  this implies a minimum output power of 3 mW which is easily detectable with RF-matched solid state detectors. Many kinds of resonant cavities are under development for this purpose.

## III - INTENSITY MONITORS

Induction monitors are widely used. Very sensitives ones using ferromagnetic toroids (VACOPERM 100) can measure peak intensities as low as  $20 \mu\text{A}$ [3].

High sensitivity, high resolution beam current transformers have also been developed at CERN for LEP[4]. The resolution can reach 30 nA r.m.s. which is far better than required.

Wall current monitors (WCM), in use at LAL on the CLIO FEL, have sensitivities of 1 Volt/A. Such sensitivity would have to be increased for TTF applications but these monitors have the advantage that they provide position as well as intensity information.

Destructive intensity monitors, like Faraday cups, may also be used particularly for low power 'setting up' as used on the MACSE linac. Problems are related to acceptable beam power, secondary emission etc..

Non destructive intensity monitors must be located after the gun column before and after the capture section and at the end of the analysis line.

## IV - PROFILE MONITORS

Profile monitors are mainly used for emittance determination or energy dispersion. Beam profiles are obtained through thin wires in fixed position or scanning wires; considerable experience has been gathered on these kind of monitors. Optical beam images are also extensively used; they allow almost real time observation. The main features of these kinds of monitors are recalled below.

### IV-1 WIRES

Secondary electron emission on thin wires is used with multiwire secondary electron monitor (SEM) grids in fixed position w.r.t the beam and wire scanners for which the wire signal is sampled against the wire position.

### SEM-GRID

This monitor uses two grids of N wires, often from tungsten or beryllium, with diameters as low as tens of microns. The two grids may be equally separated from a positively biased collector made of a thin foil. With appropriate geometries ( $50 \mu\text{m}$  diameter wires equally spaced  $100 \mu\text{m}$  apart) resolution could be close to  $200 \mu\text{m}$ . Minimum sensitivities reported are of  $10^7 \text{ e}^-/\text{pulse}$ .

These SEM-grids are generally associated with integrating devices using low bias-current operational amplifiers<sup>[5]</sup>.

#### WIRE SCANNER <sup>[6,7]</sup>

This monitor is made of two wires (one for each of the horizontal and vertical profiles) moving rapidly through the beam, simultaneously or alternatively. Detection is ensured by scintillators associated with photomultipliers or by secondary emission current measurement. Wire characteristics are similar to those of the SEM-grid. Traversing speeds are of the order of 20 m/s. About 100 measurements per profile are currently used.

Problems encountered with these devices are linked to wire failures. Wire heating due to beam induced microwave fields and arcing between the wire and the support are the main causes of wire destruction. Reported destruction thresholds for wires concerns fluences of  $7 \times 10^{11}$  particles/pulse/mm<sup>2</sup>.

Comparison with SEM-grid shows that higher resolution could be reached with the wire scanner.

#### IV-2 OPTICAL BEAM IMAGING

Optical image of the beam, providing transverse profile determination, is obtained through different physical processes. Scintillation in screens, transition radiation in the optical frequency domain (OTR) or synchrotron radiation are already widely used. The devices concerning each of these methods are associated with optical detectors and data analysis <sup>[8]</sup>.

#### LUMINESCENT SCREENS

Different materials are used for this purpose. The main features attached to this kind of monitors are : the central wavelength for the light emitted, the photon production efficiency and the decay time.

One of the most interesting candidates seems to be the alumina screen activated with chromium. The central wavelength is close to the red and its sensitivity is quite high  $\sim 10^6$  particles/mm<sup>2</sup>. Reported damage thresholds are  $5.10^{14}$  e<sup>-</sup>/mm<sup>2</sup> <sup>[9]</sup>.

#### OTR <sup>[9]</sup>

The transition radiation produced at the interface of two media of different permittivity is increasingly used for beam observation. The thin screens used avoid serious heating problems encountered in thick targets. Moreover, the phenomenon being of subpicosecond time constant allows time structure measurements (see below).

Known sensitivities in the considered energy range for TTF are of some  $10^{-3}$  photon/electron. This overall sensitivity - integrated over the total solid angle increases logarithmically with beam energy.

Due to the peculiar distribution of the transition radiation, it is possible to observe not only the transverse beam distributions but also the angular distributions provided appropriate imaging optics are used. Such knowledge can lead to rapid determination of the beam emittance.

## SYNCHROTRON RADIATION

Radiation generated in bending magnets is widely used in storage rings. Observation of the light emitted in the first bending magnet after the capture section may bring information on the beam structure. This phenomenon is fast and could be also used for pulse duration determination

## OPTICAL DETECTORS

Provided, appropriate imaging optics are used to transport the beam image to the optical detector, high transmission efficiency could be reached.

The most popular detectors are TV tubes and CCD cameras. The former are used in high radiation regimes. CCD cameras associated with simple imaging optics are now increasingly used to observe the beam image. The main features of CCD cameras concern sensitivity, light integration time and radiation hardness. The latter is usually considered poor and it is essential to prevent this device from radiation damage.

Typical sensitivities reported are above  $10^4$  photons/s/pixel. Integration time is usually 20 ms. Sensitivity may be improved by the use of integrating devices with Peltier cooling elements to keep S/N ratio at acceptable level, or by adding an image intensifier like a Multi-channel Plate (MCP).

Video digitizers are necessary so as to allow data analysis.

## V - MICROBUNCH LENGTH MEASUREMENT

Bunch length measurements may be performed with various different devices.

- (i) Deflection cavity with the same frequency as the beam allowing transformation of the phase relationship between the particles in the bunch into transverse position relationship.
- (ii) Association of optical images of the beam brought by OTR, Cherenkov radiation or synchrotron radiation-with streak-cameras [10,11].

The first method presents very high resolution ( $\sim 1$  ps) provided the beam emittance is not too poor; the resolution is mainly determined by the beam dimensions in the deflecting cavity.

The second method needs a streak camera which is quite expensive. Present day sensitivities of the streak cameras are above some  $10^3$  photons.

This sensitivity associated with the beam intensity helps in choosing between the different physical processes which give different sensitivities i. e. number of photons/e<sup>-</sup>. The expected resolution is generally above 1 ps. As in the case of profile monitors, imaging optics need to be carefully studied.

## VI - ENERGY DISPERSION MONITORS

Energy dispersion may be measured at the focal plane of the bending magnet ; the transverse dimensions are proportional to energy dispersion. A profile monitor is then appropriate. SEM-grid or wire scanner may be used.

## VII - BEAM LOSS MONITORING

In order to avoid serious beam losses on cavity walls which would damage the superconducting accelerator it is important to detect the number of lost particles at given positions. A long coaxial ionization chamber filled with argon and carbon-dioxide should be appropriate for the purpose. Alternative systems consist of scintillators associated with photomultipliers. Although the rise time and dynamic range of these are very attractive such systems remain very sensitive to radiation damage. A less sophisticated system would use beam collimators with nearby x-ray diodes as employed on MACSE.

This list is far from exhaustive and other systems could be investigated.

## VIII - SUMMARY AND CONCLUSIONS

The beam parameters that require to be measured on the TTF linac are position, intensity, transverse emittance, bunch-length, energy spread and beam loss. We have presented a list of several diagnostics each having the possibility to measure one or more of the parameters to the required degree of precision. It is clear that the optimum choice of diagnostic for any given measurement may not be the most practical for reasons of cost, availability space requirements etc. We propose the following inventory of diagnostics and their positions on the injector which we believe covers all the beam measurement needs discussed at recent TTF workshops.

<b>DIAGNOSTIC</b>	<b>PARAMETER</b>	<b>NUMBER / LOCATION</b>
toroids	intensity	4 / exit of gun end of analysis line before and after capture cavity
viewscreens	profile	4 / see figure
Faraday cup	intensity	1 / after SHB (for commissioning)
wire scanner	profile / emittance	4 / see figure
SEM-grid	energy spread	1 / end of analysis line
WCM	intensity / position	2 / before and after capture cavity
Button monitor	position	2 / before dipole before cryo-module
OTR foil	profile / bunch-length	1 / before dipole
X-ray diodes	(for protection)	3 / see figure

As already stated the choice of each diagnostic represents a compromise between the optimum type and practical requirements. For example the intensity and position at the exit of the capture cavity might be better measured with a toroid and BPM respectively but the congested layout makes it preferable to combine these measurements with a single WCM. The measurement of the bunch-length with the OTR foil implies the availability, perhaps temporarily, of a streak camera and suitable data analysis software.

The resonators for position measurement might replace the button monitors if they are sufficiently developed when the time comes to commission the machine. The wire scanner may lead to emittance determination via the method of three-gradients (using the focusing coils for varying the beam profile)

Finally, it is expected that this list may 'evolve' as new restrictions or requirements come to light but it is proposed as a suitable starting point for discussions.

## References

1. Loyer-Scheidl, "Beam position monitors for the ESRF storage ring", European Beam Instrumentation Workshop, Montreux (Switzerland), May 3-5 1993.
2. R. Lorenz, "BPM for TTF", European Beam Instrumentation Workshop, Montreux (Switzerland), May 3-5 1993.
3. K. Derrikum, "High accuracy absolute charge measurements of a low intensity electron beam", European Beam Instrumentation Workshop, Montreux (Switzerland), May 3-5 1993.
4. K. Unser, "Recent advances in beam current transformer technology and avenues for further developments", European Beam Instrumentation Workshop, Montreux (Switzerland), May 3-5 1993.
5. R. Chehab et al., LAL-RT/85-05 and IEEE Trans. Nucl. Sci., NS-32 #5, Oct. 1985.
6. Ch. Steinbach and M. van Rooij, "A scanning wire beam profile monitor", CERN/PS 85-33, May 1985.
7. M. Ross et al., "Experience with wire scanners at SLAC", SLAC PUB 6014, Dec. 92.
8. R. Jung, "Image acquisition and processing for beam observation", European Beam Instrumentation Workshop, Montreux (Switzerland), May 3-5 1993.
9. R. Chehab et al., "Beam emittance determination using optical transition EPAC3, Berlin, March 1993.
10. M. Bergher, "Real time spectrum analyser" IEEE PAC-91, San Francisco, 1991.
11. E. Rossa et al., "Double sweep streak camera for LEP", CERN/SL 90-24.

# TESLA TEST FACILITY

## SCHEMATIC LAYOUT OF THE INJECTOR

