Beam performances of MACSE, the Saclay superconducting test accelerator

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Abstract

MACSE is a short superconducting electron linac operated at Saclay[1], to study the problems of acceleration with S.C. cavities. Main beam characteristics like transverse and longitudinal emittances have been measured after the injection line, after the capture cavity and after the main cryomodule. Results are given, discussed and compared to predicted values. Measurement apparatus and methods are described.

1. INTRODUCTION

Over the past 3 years, most of MACSE operationnal time has been devoted to RF experiments with the S.C. cavities, that constituted the main part of its goal. Producing and measuring an electron beam was also, of course, an aspect of the projected experimental program. Beam specifications had been oriented to study the problems of a future machine for nuclear physics : Main nominal parameters are 100 µA and 100% duty cycle. The program of the beam experiments therefore consisted, first to demonstrate the capability of delivering such a beam, in reproducible and stable conditions, then to measure its main characteristics.

2. BEAM MONITORING OVERVIEW

From the beam monitoring point of view, MACSE presents 3 regions : the 100 keV injection beam forming line that precedes the capture cavity; the 2 MeV transfer and analyzing beamline between the capture cavity and the main cryomodule; the high energy (capable of 20 MeV) transport and analyzing beamline. The latter is a long line (~20m), comprising 4 triplets, which transports the beam in a separate room (to avoid radioactivity near the accelerator) where the dipole and the beam dump are located.

These energy variations do not justify different design of the monitoring devices.

For setting up the beam, a pulsed regime has been defined : The pulse length (3 µs) is much shorter than the cavities filling time, so that low level RF loops do not see it, and the repetition rate (25 Hz) is low enough so that the beam can hit any place, as long as necessary, without damage. 25 Hz being half the network frequency, it permits to measure beam parameters free of residual ripple. A synchronous but non 50 Hz submultiple frequency (24.39 Hz) is also available to allow observation of residual ripple at low beam power.

The beam intensity monitoring is performed by toroids transformers. In D.C. beam regime, they still can be used thanks to 3 µs, 3000 Hz "notches" that are made in the beam intensity control signal of the electron gun. These toroids also are in charge of the beam loss monitoring by mean of differential measurement between the begining and the end of the operated beam line.

Beam centering is performed in using viewing screens (made of Cr doped Al_2O3). In the injector beamline, isolated collimators also give a convenient information. At the entrance and the exit of the cryomodules we have installed non isolated collimators that can produce a centering signal thanks to X-ray sensitive photodiodes [2] placed outside the beam tube. This device permitted an ultimate centering of the beam when D.C tests were carried out.

Beam profiles are made with wire scanners that translate an L shaped, 30 µm carbon wire across the beam. They are driven by a stepping motor, at low speed if the pulsed regime is used and at higher speed (40 mm/s) in D.C regime. The control is made through a dedicated VME crate and the signals can be displayed and interpreted on the screen of the control room work station (Fig 1).

These monitors are installed both on straight beam lines for emittance measurements and on deviated ones for energy spread measurement.

3. D.C BEAM TESTS

We have obtained hours of stable run at 100 µA after careful centering of the beam and also careful setting of the beam loss monitoring and interlocking. One injector collimator had to be redesigned to improve its cooling : We had observed a slow evolution of the intercepted current that was attributed to a local dilatation under the beam impact.

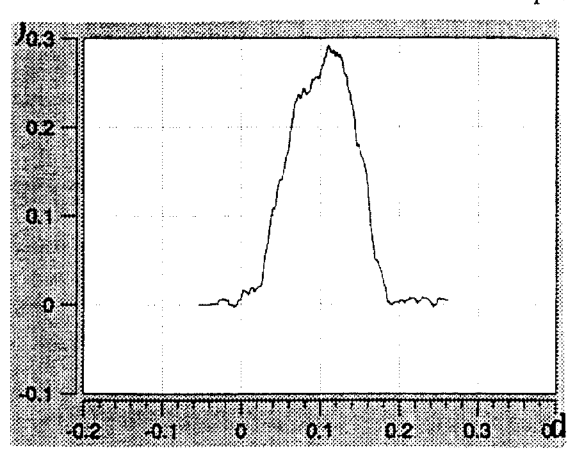

Figure 1 Beam energy spectrum at 12.2 MeV, (σE=7 keV) obtained from a wire scanner (horizontal scale in %)

4. EMITTANCE MEASUREMENTS

In all emittance measurements we have used a multigradient method, i.e. a lens or a triplet force was varied and the beam size measured some distance away in correlation. The calculation then is made in using the method described in [3] when a solenoidal was used (fig. 2). As a D.C. beam could easily burn a hole, only a 40 μA peak, pulsed current has been measured.

Following results give the quantity $4\beta\gamma\varepsilon_{rms}$.

100 keV station : The measurement has been made on the chopped beam. We have found 1.1 π.mm.mrad. The maximum emittance is defined upstream by 2 collimators at 1.3. We can therefore say that the cancellation of transverse deflections by the 2 cavities of the chopping system, following the scheme developped for the NIST micrtron [4] worked quite well.

2 MeV station : We have found an emittance of 2.4 π.mm.mrad, i.e roughly twice the input emittance This is a disappointing result with respect to the 20% maximum increase predicted by Parmela simulations [5]. New and careful measurements should permit to understand this difference that we can for now share between beam misalignment and measurement errors.

High energy station: Measurements have been made with a beam energy of 12.2 MeV. We have found 4.7 π.mm.mrad, i.e., again, a doubling between the input and the output of the 4 cavity cryomodule,.that may have the same causes.

5.ENERGY SPREAD

After the capture cavity, the energy is about 2 MeV. Energy spread (Fig. 2) is optimized by RF phases and amplitudes of the prebunching and capture cavities. Typical measured σE is 7 keV i.e. twice the predicted value.

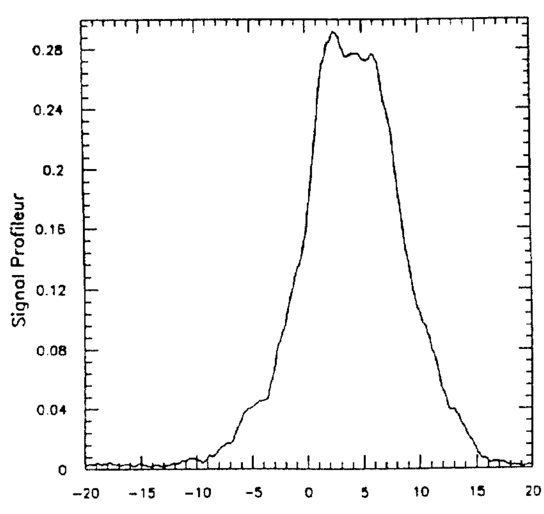

Figure 2 Energy spectrum after the capture cavity. Beam energy is 1.94 MeV. σE=7 keV.

At the high energy station, measurements at 12 MeV, in pulsed regime, for a 40 mA peak current, gave also σE= 7 keV. Increase of energy dispersion due to a finite bunch length is in fact negligible.

6. BUNCH LENGTH

We have not installed any direct bunch length monitor. Instead we have used the very classical "backphasing" method [6]. For the experiment, the 3 first cavities of the main cryomodule (out of 4) were used. The capture cavity and the 2 first cavities accelerated the beam to 8.31 MeV. The 3rd cavity was attenuated to contribute by only 0.46 Mev when phased. Its phase was then shifted by +90° and -90°. Both corresponding energy profiles were recorded. The bunch angular length can then be calculated by :

$$\Theta_{bunch} = \left| \frac{\Delta E_{+90} - \Delta E_{-90}}{2 E_{cav3}} \right|$$

where $\Delta E_{+/-90}$ are the total energy spreads, E_{cav3} is the energy contribution of cavity 3.

We have measured ΔE_{+90}=30.1keV and ΔE_{-90}=10.9keV, hence Θ = 1.2° which is close enough to the expected 1°. The measurement was made very unpractical because of the necessary retuning of the long transport line to the analyzing magnet whenever phases were shifted by a large amount.

7. OTR BEAM PROFILE

Using optical transition radiation for analyzing electron beams profile is a very promissive technique. We have demonstrated its suitability for our low energy, low intensity beam : The radiator was made of a polished stainless steel plate. The pulsed beam frequency was pushed up to 250 Hz. In using a 10^{-4} lux S.I.T. camera, built by Sofretec (France) we have obtained quite satisfactory images. Beam profiles were very conveniently extracted in using the image processing software Laserlab, on a P.C.(fig. 3)

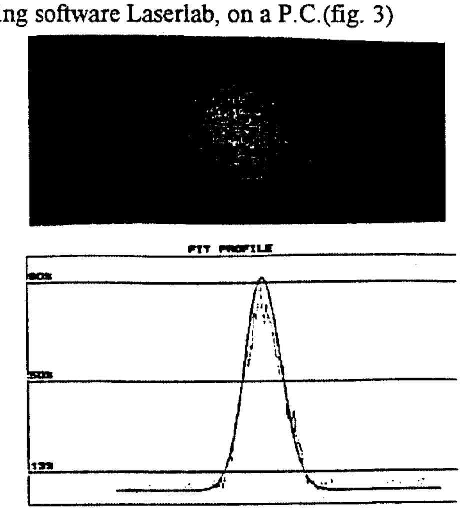

Figure 3 Beam image from optical transition radiation. Below, gaussian fit of the tranverse horizontal profile.

8. NEXT PROGRAM

Our group is now involved in the TESLA collaboration and participates in the construction of TTF (Tesla Test Facility) at DESY. MACSE has permitted to test schemes of pulsed feeding of the cavities under Lorentz forces detuning [7] : A 8 MV/m gradient in a MACSE cavity causes the same relative detuning (with respect to its bandwidth) as will be experienced by the 9-cell TTF cavities at 15 MV/m.

To complete this work, experiments with beam will be soon undertaken : In removing the emittance limiting collimators of the 100 keV line, beam intensity can be raised to 2 mA. 1 ms pulses will be generated. The goal is to reach 100% beam loading, as in TTF design, and to test it.

9. CONCLUSION

Though too few operationnal sessions have been available for these experiments, we conclude that MACSE beam specifications have been achieved. Beam monitors and the computer control system have proven quite a good efficiency. If energy spread and bunch length measurements have been found in sufficient agreement with computer predictions, too a big emittance growth has been observed. MACSE has also proven to be a useful tool for various experiments that were not in its initial program.

8. REFERENCES

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