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Beam diagnostics for high intensity hadron accelerators

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Abstract

High intensity hadron beam accelerators have been recently proposed and developed either for the production of high intensity secondary beams for Nuclear and Particle Physics research (EURISOL, SPIRAL2, FAIR), or Applied Physics in the field of Accelerator Driven System and waste transmutation (EUROTRANS). For these applications, high power Linear Accelerator (LINAC) are planned to produce and accelerate hadron beams up to 1 GeV.

Both commissioning and operation of these accelerators require dedicated beam instrumentation able to monitor and characterize on line as completely as possible the produced beams having a power in the range of 1 MW. Beam current, transverse beam centroïd position and profiles and beam energy are the most important characteristics that have to be measured.

Due to the high average power of the beam, nondestructive or at least minimally intercepting beam sensors are required. Beam instrumentation for IPHI (CEA/DSM and CNRS/IN2P3 collaboration) which is a high intensity proton (3 MeV, 100 mA, CW operation) injector initially designed to be a possible front end for this kind of LINAC is under realization. Beam diagnostics already under operation, developments in progress will be described and will introduce a more general description of high power beam instrumentation.

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Keywords: Accelerators; Beams; Charged particle

1. Introduction

High intensity hadron beam accelerators have been recently proposed and developed either for the production of high intensity secondary beams for Nuclear and Particle Physics research (EURISOL, SPIRAL2, FAIR), or applied physics in the field of Accelerator Driven System and waste transmutation (EUROTRANS). For those applications, high power Linear Accelerator (LINAC) are planned to produce and accelerate hadron beams to an energy up to 1 GeV. Beam current may reach 100 mA.

Both commissioning and operation of these accelerators require dedicated beam instrumentation able to monitor and characterize on line as completely as possible the produced beams, the power of which lies in the range of 1 MW [1]. Beam parameters such as beam current, transverse beam centroid position and profiles and beam energy are the most basic measurements to be achieved.

Due to the high average power of the beam, nondestructive or at least minimally intercepting beam sensors are required. Beam instrumentation for IPHI (CEA/DSM and CNRS/IN2P3 CERN collaboration) which is a high intensity proton (3 MeV, 100 mA, CW operation) injector primary designed to be a possible front end for this kind of LINAC is under realization. Beam diagnostics already on operation, developments in progress will be described and will introduce a more general description of high power beam instrumentation.

2. Accelerator structure considerations

The recently proposed high intensity proton beam accelerators are attractive for hybrid reactor systems and generator of high luminosity secondary beams for nuclear and particle physics. For those particular applications,

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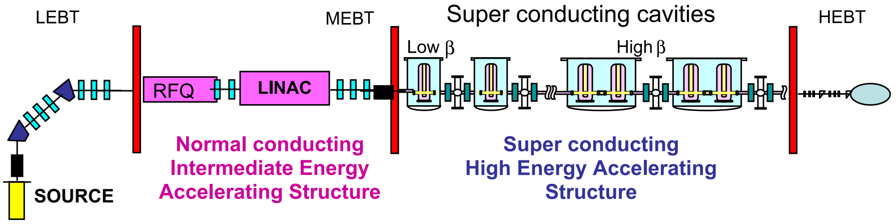

Fig. 1. General layout of a high intensity proton beam accelerator.

accelerators are of the LINAC type. They are planned to produce and accelerate mainly proton beams in the range of 1 GeV and a maximum intensity of about 100 mA.

The schematic representation in Fig. 1 shows the general layout of a high intensity proton beam accelerator. Four main sections may be distinguished:

- The source produces DC proton beam which energy remains below 100 keV. It may also operate under low duty factor pulsed mode. The proton beam is transported by the Low Energy Beam Transfer Line to the intermediate energy accelerating section.
- The proton beam is then bunched and accelerated by a Radio Frequency Quadrupole (RFQ) followed by a drifted tube LINAC or coupled cavity LINAC. The energy of the beam may reach few hundreds of MeV. The typical frequency of operation ranges from 100 MHz up to several tens of MHz. This room temperature section may include devices such as beam chopper or bunch suppressor.
- The superconducting accelerating structure follows the room temperature structure and accelerates the beam up the foreseen final energy.
- Then the High Energy Transport Line transports the beam to the target or the particle converter achieving the minimum beam losses along the path of the beam. If necessary, this high energy beam transport line includes a raster scanning system or an expansion system in order to paint uniformly the target.

The IPHI (High Intensity Proton Injector) project (CEA/CNRS/CERN collaboration), under realization at CEA Saclay, is based on an ECR proton source “SILHI” (95 keV, current ≈ 100 mA). After travelling along the Low Energy Beam Transport line (LEBT), a Radio Frequency Quadrupole (RFQ) will accelerate protons at 3 MeV. IPHI is able to work under pulsed mode operation for machine commissioning and experimental operation and under CW operation. The beam average power reaches 10 kW at the entrance of the RFQ and 300 kW at the exit.

3. Beam diagnostics requirements

A first type of measurement takes place during the initial start of the beam facility. At this stage, we want to diagnose as completely as possible the beam during normal or off normal beam operation. Beam diagnostics are then needed for:

- Machine commissioning.
- Beam dynamics calculation confirmation.
- Help in understanding the degradation of the beam quality.
- Beam loss control and minimization.

A second type of measurement concerns the full power beam current establishment and normal daily operation of the accelerator.

To carry these beam measurements, diagnostics must be designed to operate under various conditions: the CW 100 mA current beam will be obtained in a stepwise fashion. Various configurations are possible:

- low or high intensity CW current beam: 10^{-1} mA $< I_{\text{beam}} < 10^{-1}$ A;
- long pulsed beam operation: 10 ms < pulse width < 500 ms; 100 ms < repetition rate < 1 *s*;
- short pulsed beam operation: 100 μs < pulse width < 10 ms; 1 ms < repetition rate < 1 *s*.

Even if some intrusive sensors may be used for specific measurements, the large quantity of beam energy deposited in any material, especially in the low energy sections of the accelerator, forces us to use noninterceptive or at least minimally interceptive beam sensors. In addition to destroying the sensor, the interception of some fraction of the beam will lead to a high activation level in the structure of the accelerator and its surroundings.

Three main categories of diagnostic devices are needed to measure the following parameters:

- Beam intensity.
- Transverse measurements: position centroid of the beam, transverse profiles and emittance.
- Longitudinal measurements: phase, energy and energy spread.

4. Intensity measurement

4.1. CW and long pulsed mode operation

It is the most useful measurement to achieve. In the LEBT the maximum power lies in the range of several kW and allows the use of the well-known water cooled Faraday cup. The Faraday cup is a beam destructive monitor which