The IPHI Project

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Abstract : High Power Proton Accelerators (HPPAs) are studied for several projects based on high-flux neutron sources driven by proton or deuteron beams. Since the front end is considered as the most critical part of such accelerators, the two French national research agencies CEA and CNRS decided to collaborate in 1997 to study and build a High-Intensity Proton Injector (IPHI). The main objective of this project is to master the complex technologies used and the concepts of manufacturing and controlling the HPPAs. Recently, a collaboration agreement was signed with CERN and led to some evolutions in the design and in the schedule. The IPHI design current was maintained at 100 mA in Continuous Wave mode. This choice should allow to produce a high reliability beam at reduced intensity (typically 30 mA) tending to fulfill the Accelerator Driven System requirements. The output energy of the Radio Frequency Quadrupole (RFQ), was reduced from 5 to 3 MeV, allowing then the adjunction and the test, in pulsed operation of a chopper line developed by CERN for the Superconducting Proton Linac (SPL). In a final step, the IPHI RFQ and the chopper line should become parts of the SPL injector. In this paper, the IPHI project and the recent evolutions are reported together with the construction and operation schedule.

Keywords: Accelerator, RFQ.

INTRODUCTION

Over the last 15 years, in-depth studies have been carried out on the feasibility of high-power proton accelerators capable of producing beams of several tens of MW. With heavy targets, such beams can produce extremely intense spallation neutron flux. Several applications could benefit from the performance of this new generation of high power proton accelerators [1]:

- spallation neutron sources for condensed matter studies,
- hybrid reactors for nuclear waste transmutation,
- neutrino and muon factories,
- technological irradiation tool,
- production of radioactive ion beams,
- production of radioisotopes, etc…

In 1997, the two French national research agencies CEA and CNRS decided a strategy covering this topic. They restricted the R&D to a limited number of subjects with a maximum overlap on different projects: The activities covered the construction and test of low beta superconducting cavities, improvement of codes for accurate beam dynamics calculations and IPHI.

IPHI ("Injector of Protons for High-Intensity beams") is a low energy demonstrator project which could be used as front end for these high-power proton accelerators [2]. The main IPHI objectives were:

- Master the complex technologies used
- Develop in Europe the concepts of manufacturing
- Develop the concepts of controlling
- And benchmarking

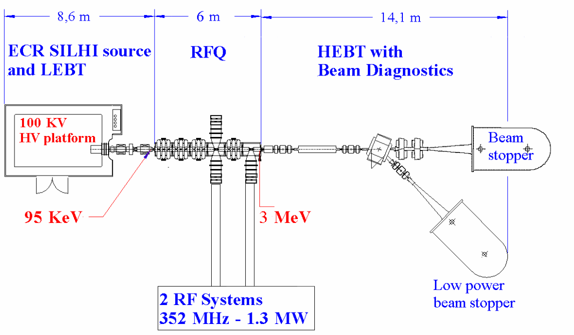


FIGURE 1. IPHI layout

The funding difficulties encountered in 2002 and 2003 led us to redefine the characteristics and the performances of the accelerator. We also sought to develop this important R&D effort by a possible later use of this machine as injector of a high energy Linac. CERN developing such a linac (Linac 4 and SPL projects), we decided to reduce the final energy of the RFQ cavity to fit the one of the CERN projects. This paper describes the present project and performances.

CONSTRUCTION STATUS

The fundamental objectives of the IPHI project as defined from 1997 [1,3] have been maintained, especially those of a feasibility demonstrator of the HPPAs and those linked to the Accelerator Driven Systems (ADS) problematics. The beam characterization in pulsed mode as well as in CW mode still keeps the main place. A long duration run with a reduced intensity beam (typically two or three months uninterrupted and around 30mA) will end the test period at Saclay. The installation of the main parts of IPHI at CERN in 2007 is a new challenging objective which demands to start the RF conditioning at the latest during the first semester of 2006.

The main change concerns the output energy of the RFQ cavity which decreases from 5 MeV to 3 MeV. The nominal intensity is maintained at 100 mA in CW mode. The construction of a second accelerating stage – a drift tube linac - which had been chosen in the first IPHI design to increase the energy from 5 to 11 MeV is abandoned. Nevertheless, a short hot model was developed, built and successfully tested at nominal electric field to validate the technological choices [4].

The SILHI Source

The proton source SILHI and its LEBT developed at Saclay produces now routinely a high intensity beam (100 mA @ 95 keV) fulfilling the IPHI requirements. Several long duration tests at different beam currents showed good performances in terms of reliability and availability [5]. SILHI is presently used to optimize diagnostics for the high energy line.

RFQ

The initial design of the RFQ comprised 8 sections of 1 meter long each assembled in 4 segments separated by coupling plates [6]. As the energy at the exit of the third segment was calculated to be 3 MeV (table 1), the energy modification has consisted mainly in suppressing the last segment. Obviously, to provide a good matching with the diagnostics line, the end of the sixth section was modified to integrate a fringe field and a Crandall cell.

TABLE 1: IPHI RFQ parameters

Structure	4 vanes
Frequency	352.2 MHz
Total length	6 m
Resonant coupling plate	2 (3 segments of 2-m)
Vane voltage	87 to 123 kV (Kp = 1.7)
Output energy	3 MeV
Theoretical transmission	>99.3 %(accelerated)
Beam power	300 kW
Max total power	1200 kW (two 1.3 MW klystrons)

The design is based on a 4-vane brazed RFQ, allowing at this frequency to master the RF power deposition in the cavity. It is made of segments separated by coupling plates. This segmentation, as developed by the LEDA project in Los Alamos [7], allows to damp the longitudinal distortions. At the location of the coupling plates, “fingers” can be inserted to allow dipole modes separation. [8].

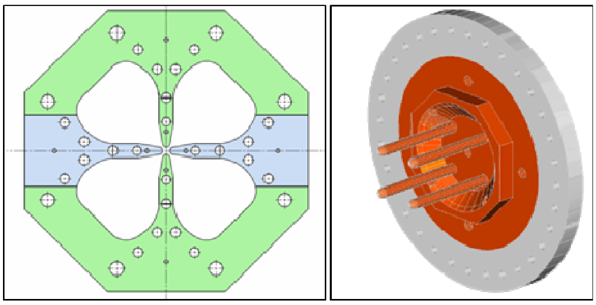


FIGURE 2. The four brazing parts and a coupling plate with the dipole fingers.

The assembly of 2-m long segments, its non homogeneity and the severe electromagnetic tolerances have required the development of a comprehensive tuning formalism. This formalism interprets field measured in real RFQ in terms of ends detuning and slug tuners commands. The tuning formalism has been experimentally validated for:

- Non - constant & constant mean aperture R_0
- Modulated & non-modulated vanes
- Homogenous & non-homogenous (i.e. non-constant transverse resonance frequency) RFQ
- Segmented or continuous electrodes
- Constant & variable voltage profile
- Any resonance frequency
- Different RFQ lengths

The formalism is not empirical but uses a mathematical formalism [8-10]. We achieve relative voltage error of the order of 10^{-2} within 3 steps of slug tuners displacements. We are also able to see fabrication errors with a comparative measurement allowing detecting 20 µm vane displacements [10].

The first section has been already machined and brazed (figure 3). It is a great success in terms of achieving the mechanical tolerances. However, a problem encountered during the brazing process required to carry out 4 brazing repairs, the last one in May 2004. Precise vacuum tests have been made to validate this section. The tests showed some very small leakage, but at an acceptable level (~10^{-9} mBar.l/s). RF tests will be performed to definitely validate this section as the first section. The order for the last sections was done in May 2004. The sections are presently under construction by the MécaChrome groupe company [11].

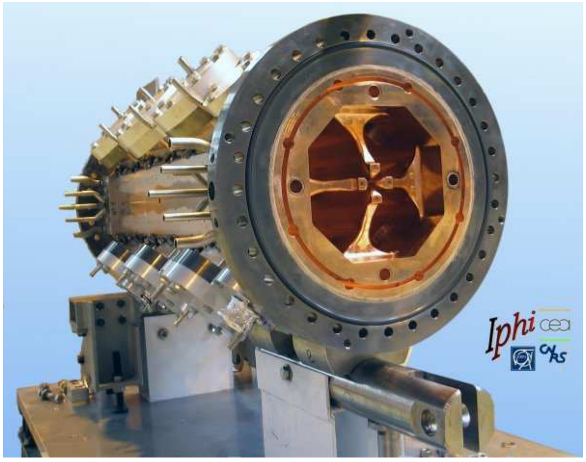


FIGURE 3. the first RFQ section viewed from the beam entrance side.

RF ports

In the original configuration, the RF power provided by the 2 klystrons was injected in the cavity by 4 RF ports disposed on 2 different sections. For the new design (figure 4), we chose to keep a maximum power level per port almost identical to the original one (400 kW). So, the number of ports was reduced from 4 to 3, all arranged on the fourth section.

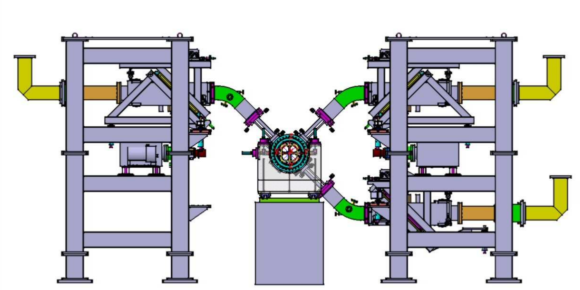


FIGURE 4. Arrangement of the three RF ports on the fourth section

The original design of the RF ports comprised a ridged taper (LEDA). The experimentations carried out on the 6-m long RFQ cold model (figure 5) showed that this configuration does not allow a good matching. It is planned to replace the taper by a quarter wave length transformer. The first measurements achieved seem to confirm the validity of this choice, decoupling the tuning between the transition and the iris. Thermal calculation confirmed that the iris needed to be in Glidcop.

FIGURE 5. View of the 6-m long RFQ cold model

RF systems

The power RF system uses two 1.3 MW/352 MHz Thales™ klystrons coming from the CERN LEP. The installation of this system is achieved (figure 6) and first tests using a salt water 1.4 MW load are planned late 2004.

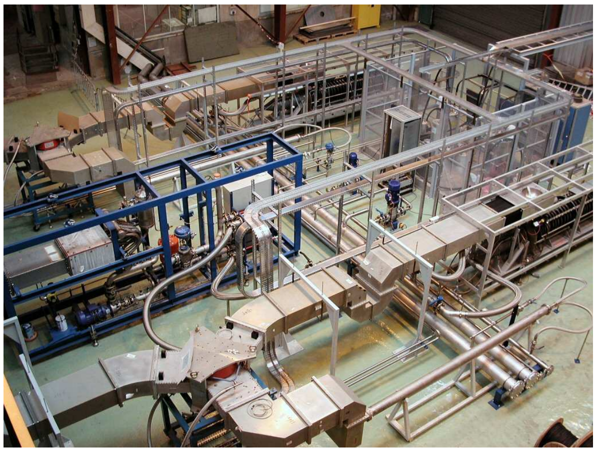


FIGURE 6. View of the RF power system assembly

Water cooling system

The cooling system is a good example of the complexity of such CW RFQ. The six 1-m long sections will “see” different power deposition ranging from 107 kW (T2) to 180 kW (T6). The associated deformations were calculated and led to different vane tips displacement along the RFQ and 2D cavity enlargement. The deformations are minimized with 6 cooling passages per quadrant with different water temperature. The close loop water temperature is adjustable for each 2-m coupled segment and will maintain the RFQ frequency during operation. On top of this, the water temperature elevation in the cooling passage leads to frequency shift along the sections of about 40 kHz. It is already enough to induce a vane voltage law error above the ±1% tolerance. So the low level tuning should take into account this high power deformation.

Diagnostics line

A major simplification of the beam diagnostics line was decided to gain in compactness and cost. The high power beam dump is now located in straight line about six meters downstream of the RFQ. New beam dynamics calculations allowed then to use a set of existing compact magnets (figure 7). The diagnostics covered a wide range of measurements [12,13]: The energy is measured with time of flight technique (resolution 10-3), the energy spread with the dipole (10 to 20 keV resolution). Beam current measurement is provided with an ACCT (10 µA rms on test bench) a Bergoz DCCT, electrical and power deposition measurement on the beam stop. The profile and position are analyzed with a wire scanner, back scattered proton (profile independent of low energy particles), 6 BPMs (for position, dynamic 45dB) and optical measurement with intensified CCD camera. Transverse emittance will be available with the wire scanner.

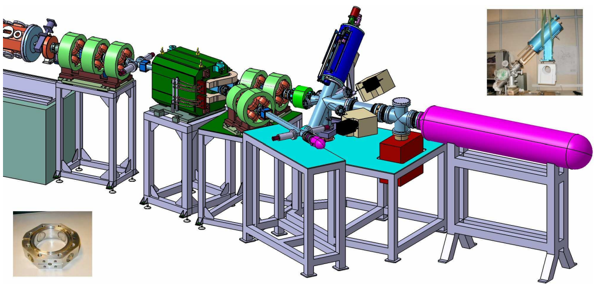


FIGURE 7. 3D representation of the new diagnostics line

The energy spread measurement using the deviated line was planned initially at full CW beam. It will now be performed only at low duty cycle (10^{-3}). The system chosen is a classical spectrometer and comprises a 28.5° dipole, two slits and a Faraday cup. By choosing properly the couple of slits, the resolution should be better than 10^{-3}.

The mechanical drawings of the main parts of the diagnostics line are completed. All magnets are available and power supplies will be ordered this year. The fabrication of most of the beam diagnostics units is in progress. Some of them such as the wire scanner or Beam Position Monitors have already been delivered and are under test.

Beam Dump

Due to the reduction of the beam energy, the beam dump has now to withstand a maximum beam power of 300 kW plus some safety margin. Beam dynamics calculations show that a conical shape is acceptable and allows limiting the power density to 120W/cm^2. Thus, a monophasic cooling system combined with a static pressure of about 5 bars (higher boiling temperature) can be used instead of a biphasic one as envisaged previously.

The beam dump is presently in a development process. Beam dynamics and thermo mechanical calculations have been performed which validate the design (figure 8). The technical specifications should be completed at the end of 2004.

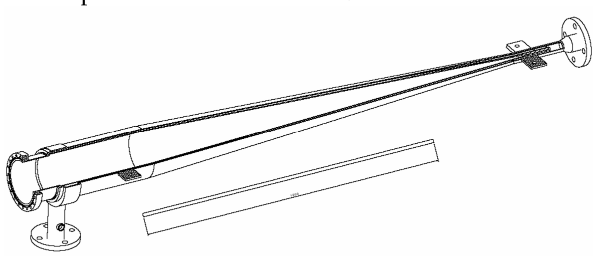


FIGURE 8. 3D view of the conical beam dump showing the water inlet and outlet.

The material intended as active part of the beam dump was part of an experiment on the Van de Graff tandem accelerator of IN2P3-Orsay. Nickel seems to be a good candidate as inner tube. It can be massive nickel or nickel plated copper, the choice being linked to activation and vacuum points of view. The experiment tested pure nickel, plated nickel and pure copper at 3 and 5 MeV. Short and Long period were measured, as well as the yields. The contribution of impurities was evaluated. As preliminary results (see table 2), one can indicate that (p,n) reactions dominates with no significant (p,α). The copper activity is important even at 3 MeV. The Nickel plating samples showed different results depending of the impurities, and it is necessary to qualify the metal before machining. The massive nickel is chosen for these reasons.

TABLE 2. Bq extrapolation based on measurements

	6 months @ 100mA p 3 MeV	1 day after	1 week after
Ni	1.7E+10	1.9E+09	1.80E+06
Cu	1.2E+11	1.20E+11	1.17E+11

Building and utilities

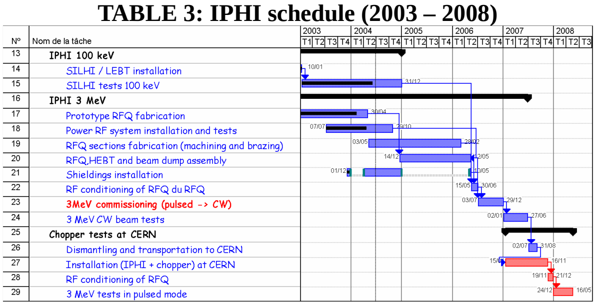
The IPHI building is now available. The construction of the radiation shielding will be spread over the next twelve months. The general cooling system will be operational from October 2004 to allow the klystron power tests to be undertaken.

CONSTRUCTION SCHEDULE

The second RFQ section delivery is expected at the end of 2004, ready for brazing at CERN in February 2005. The last section is expected at the end of 2005.

The IPHI construction schedule such as presented (table 3) is fairly tight. First beam is expected by June 2006. The fabrication of the RFQ sections is clearly on the critical path. From the delivery completion up to beam operation, four months at least are necessary to assemble, to tune and to condition the RFQ cavity. Moreover, the CERN team is strongly interested to have a test stand operational before the end of 2007.

TABLE 3: IPHI schedule (2003 – 2008)



IPHI AT CERN

In 2007, IPHI will be delivered to CERN, first as a part of a chopper line test. It will work in pulse mode (~10% df), accelerating about 30 mA of H^- particles. The goal is to test the chopper line and chopper equipment, and again to measure realistic beam parameters. It will then be used as the 3 MeV RFQ preinjector of the SPL/Linac 4 project [14]. The beam current may then increase to 50 to 60mA, at 10% df, the parameters being not yet finalized.

CONCLUSION

Since 1997, the IPHI reference design and the performances have changed many times. 2003 was an important year for the project. The decision to insure a future to IPHI after the tests completion at Saclay - by using the main components as part of a high energy linac - created a new dynamic. It also permits to obtain additional financing. In exchange, the schedule - and especially the period allocated to the commissioning and to the beam characterization in CW mode as well as in pulsed mode - is limited to one year at best. The section 2 is expected before the end of 2004.

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