RESULTS OF THE IPHI DRIFT TUBE LINAC'S HOT MODEL CW TESTS

P.-E. Bernaudin[*], G. Congretel, DSM/DAPNIA/SACM, CEA Saclay, France
A. Fontenille, E. Froidefond, M. Fruneau, D. Marchand, M. Planet, J.-C. Ravel, IN2P3/LPSC,
CNRS, Grenoble, France
P. Balleyguier, DIF/DPTA, CEA DIF, France

Abstract

In the course of the IPHI project (high intensity, cw proton injector), a Drift Tube Linac hot model has been built and tested. The main difficulty associated with these machines is the high RF thermal losses inducing significant heating and deformations if not kept under strict control. Therefore the hot model has been tested under nominal RF conditions (40 kW cw for an accelerating field of 1.75 MV/m) to verify the suitability of the technical choices made: materials, mechanical designs, construction techniques, vacuum... This prototype includes four accelerating cells, three full drift tubes, two of which enclose a quadrupole electromagnet. Results show that a stainless steel envelope can be used even at these high power densities, provided that it is copper plated both inside and outside to enhance its thermal conductivity and lower the temperature gradients. This solution leads to a cheap and reliable machine. The new kind of drift tube / magnet assembly tested in this DTL model ("flooded drift tube"), where the whole drift tube is filled with water cooling simultaneously the magnet leads and the drift tube walls, is also a suitable solution, cheap and more efficient than the usual ones. With the successful tests of this hot model, one more step has been made towards a cw Drift Tube Linac for high intensity light ions accelerators.

INTRODUCTION

The IPHI project [1] included in its original version, after the RFQ accelerating section, a 1 MW DTL (Drift Tube Linac) intended to accelerate the 100 mA protons beam from 5 to about 11 MeV. To pave the way for this machine, a 4 cells full scale model has been designed, built and tested under full RF power conditions (but without beam).

DESIGN OF THE DTL HOT MODEL [2]

The DTL hot model is made of four symmetrical and identical cells, similar to the full DTL's first one. It therefore includes three full drift tubes plus two half ones fitted on the end caps of the model. Two of the drift tubes enclose an electromagnet designed to provide the maximum strength required by the DTL (4.70 T). The accelerating field is 1.75 MV/m, corresponding to 40 kW of RF power.

Drift tubes and magnets' design

Two different drift tube / quadrupole assemblies have

_____
[*]pebernaudin@cea.fr

been designed and built.

The first, most conservative one was designed by AES. It includes a standard, hollow conductor, iron-cobalt electromagnet. Cooling of the drift tube is on the outer radius of the drift tube only. The major weakness of this design is the complexity of its structure, including a difficult transparent welding, which makes it costly. On the other hand, it is a well established design.

The second, more innovative drift tube / magnet design is called "flooded" because the whole drift tube is filled with the cooling water [3]. The magnet's leads are cooled externally by this flow. Its iron pole and yokes are protected from corrosion by electrolytic copper plating. The main advantage of this design is that it is more efficient (cooling is better and the better optimisation of the drift tube's internal space allow to use a bigger magnet) and far more simple to manufacture (and therefore cheaper). On the other hand, corrosion should be considered carefully for long lifetime accelerators.

Figure 1: The hot model's girder with all three drift tubes fitted.

Tank's design [4]

The tank is made of a stainless steel envelope, copper plated both inside and outside. The inner plating is obviously for RF conductivity purposes whereas the outer plating allows decreasing significantly thermal gradients and stresses by artificially enhancing the stainless steel conductivity. Nevertheless, all massive, non welded parts like the girder and the end caps are made of copper.

All drift tubes are fitted on a single girder (figure 1) on which they can be aligned outside of the tank. Each drift tube is fitted with a mechanical tuning device allowing precise positioning of the drift tube at any moment. Copper bellows are used as a flexible link between the drift tubes' stems and the girder. Combined RF and

thermal simulations have been made to ensure that the troubles encountered with such a project in the past were not to happen again [5].
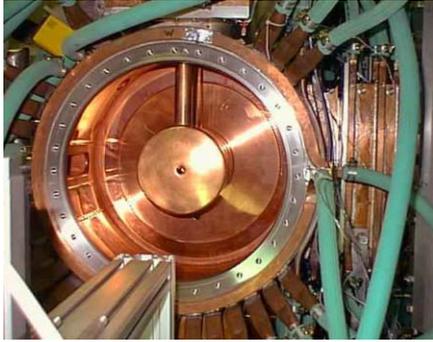

Figure 2: Inside view of the hot model tank with drift tubes fitted.

The full tank was thermally baked during manufacturing process to outgas the hydrogen. Pumping block includes a turbo molecular, titanium sublimation and ionic pumps. Helicoflex seals are used for mechanical reference faces; otherwise standard conflat copper seals are used.

RF power is coupled through an iris whose length is optimised. Two small shutters allow tuning of the coupling factor.

RF seals (silver plated copper-beryllium springs) are used on the end caps and on the girder flanges. RF computations indicated that these are not necessary for the stem-girder link.
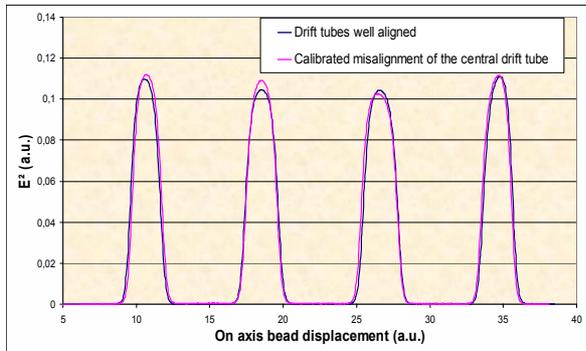

Figure 3: Low power measurement of the accelerating field using the bead perturbation technique. Blue curve: all drift tubes well aligned. Rose curve: central drift tube displaced.

HOT MODEL TESTS

RF measurements

Low power measurements performed indicated that the Q factor was only 2/3 of the *SUPERFISH* value. It was even lower without using the RF seals, which is a strong indication of their efficiency. The relatively low Q value can be explained by the very strong end effects (the model is very short) and by the size of the various ports (vacuum, RF coupling) with respect to the model size.

The absence of RF seals around the stems is certainly another factor of explanation, as underlined by the bellows heating phenomenon (see below).

Accelerating field aspect has been checked using the bead perturbation technique. The influence of a drift tube misalignment has been verified (figure 3).

At high power, the accelerating field has been measured using the bremsstrahlung spectra of the electrons in the cavity (figure 4). By measuring the maximum energy (100-150 keV) of the spectrum one can get the accelerating field value. Results show that the accelerating field is lower than expected, with a very good agreement with the Q factor measurements (better than 3%).
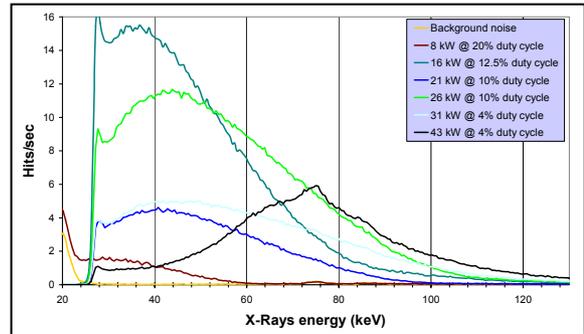

Figure 4: Measurement of the accelerating field using X-ray spectrometry method for different power levels.
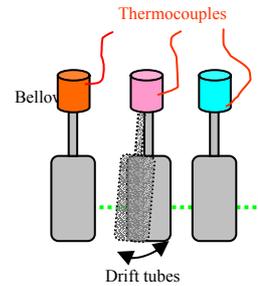

Figure 5: Measurement of the drift tube's misalignment influence on the bellows heating. Top: principle of the test; the central drift tube is shifted left or right and the temperature is measured on all three bellows (at different altitudes). Bottom: heating on all three bellows. The central bellow (rose curve) is the hotter, and the influence on adjacent bellow is sensible but smaller. Tests are performed at 25% of the nominal power.
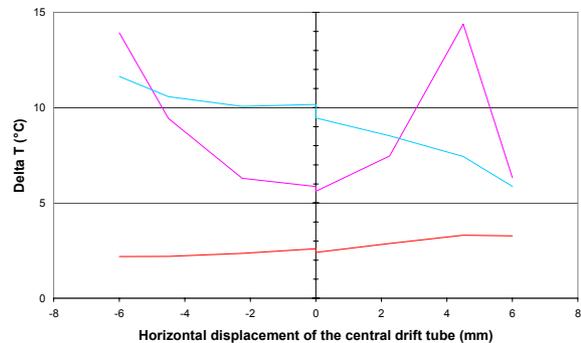
Thermo mechanical aspects

Several thermocouples have been placed in points where heating should have been the strongest according to computations, and in several other representative or sensible points (by example inside the empty drift tube). The temperature on the stem has also been checked using a pyrometer.

All heating are adequate with expectations but for two points: RF coupling iris and the copper bellows linking the stem to the girder.

The heating of the RF coupling slot is caused by the fact that the iris is not copper plated outside.

The heating of the copper bellows is ten times higher than expected (some 30 to 50°C to be compared with 4 or 5°C). The lower part of the bellow is the hotter one, indicating than the power deposit is strongly non linear along its length. It has been verified that a dissymmetry of the cells have a strong influence on the temperature of the bellows, as shown by the *MAFIA* computations (figure 5). Nevertheless, even in this case power deposits remain strongly higher than expected for still unknown reasons. Anyway, the copper bellows system is adequate. This phenomenon plays undoubtedly a significant part in the Q factor decrease. The use of RF seals to shelter the bellows would probably help to raise somewhat the Q factor and to decrease heating as well.

The displacement of the drift tube's axis has been measured. A thin slot has been placed in the drift tube aperture and a laser has been diffracted by this slot. The light intensity of the diffraction figure's central fringe varies linearly with the displacement of the slot. The precision of this measurement is around 5 microns. The measured values are of some 180 microns, which is in good agreement with computations. The major contribution (around 150 microns) of this displacement is caused by the tank's dilatation and can be compensated by supporting the tank at the girder's level.

A mechanical problem related with the flooded drift tube has been discovered. If the water pressure is too high, the drift tube's thin wall is deformed and leads to a frequency shift of several dozens kilohertz (depending on the pressure). If the water pressure is unstable (which happened during the first part of the tests) the RF system becomes unstable (as the resonance frequency itself changes with pressure). This problem can easily be solved by strengthening the drift tube's structure; several solutions are considered.

Other tests

Several other tests have been performed on this prototype. Before the high power tests, the efficiency of the flooded drift tube's cooling system has been verified. The magnets gradient has also been measured. In both cases results were as good as expected.

Vacuum was constantly checked during operations. Conditioning proved fast, indicating that surfaces were reasonably clean: very few sparks were observed. Multipactoring happened only at very low power (below 2 kW). Outgasing proved higher than expected at first, but decreased quickly. Nevertheless, baking of the cavity after the copper plating process would certainly be useful. The replacement of all Helicoflex seals by Viton ones led to an increase of the pressure by a factor of 2.
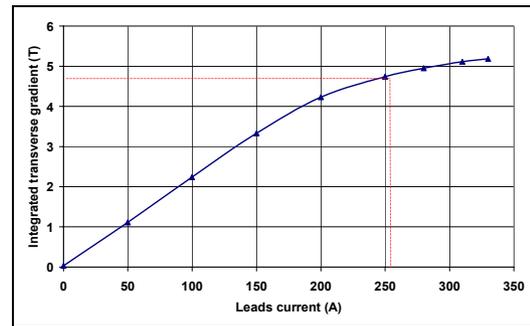

Figure 6: Integrated gradient measurement of the flooded quadrupole magnet for various currents. Effect of saturation is clearly shown.

CONCLUSION

The feasibility of a cw, 352 MHz DTL is well established, using reliable and relatively cheap technologies. Several design improvements have been identified: the mechanical structure of the flooded drift tube should be strengthened, the tank should be supported at the girder level, but these remain minor changes. The next step should take into account all problems related with a long structure, like the number of girders to be used or the length of the tank sections.

ACKNOLEDGMENTS

REFERENCES

[1] P.-Y. Beauvais, "Status report on the construction of the French high intensity proton injector (IPHI)", EPAC 2002.

[2] P.-E. Bernaudin, "Etude et optimisation d'un linac à tubes de glissement pour accélération de forts courants de protons en continu" (2002), CEA thesis ref. DAPNIA-02-05-T.

[3] P.-E. Bernaudin & al., "Technical innovations for a High-Gradient Quadrupole Electromagnet Intended for High Power Proton Drift Tube Linacs", IEEE Trans. App. Sup., Vol.12, No.1, March 2002.

[4] M. Painchault & P.-E. Bernaudin, "Conception thermo-mécanique d'un tank de DTL", CEA report DAPNIA/SEA/01-33.

[5] B.G. Chidley, "Conditioning experiments on the 100% duty factor 3 MeV Alvarez linac", Linac 1979.