STATUS REPORT ON THE KARLSRUHE SUPERCONDUCTING PROTON ACCELERATOR

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ABSTRACT

A 60 MeV superconducting proton accelerator is constructed at Karlsruhe as a pilot project for a larger proton accelerator. Parameters for the first part of the pilot accelerator are given and motivated.

Introduction

There exist plans in Germany to build a π meson factory, i.e. a high current (1 mA) proton accelerator in the energy range of about 0.5 to 1 GeV with a duty cycle of 1.

In order to put this project on a sound basis it has been decided first to build a pilot accelerator. This should give the opportunity to solve all the technical problems, demonstrate the feasibility and make a reliable cost estimate possible. The final energy of this pilot accelerator should be about 60 MeV. It is built as a collaborative effort of a group at Karlsruhe and a group at Frankfort.

The meson factory will have to consist of two types of structure. For high energies, cavities not unlike those used in electron accelerators can be employed. For the low energy part different structures are adequate. In order to simulate this situation it was decided to make the pilot accelerator also out of two sections with the two types of structures as similar as possible to those of the final accelerator.

At the moment all our efforts are concentrated on the low energy part, so I will restrict myself to the description of this section.

I propose to go briefly over the various parts of the projected accelerator. In each case I shall give the main parameters and the arguments behind them. I shall also mention the status reached.

A. Injector

Table I gives the main parameters. It is a well tested inexpensive source of high current. So it is the obvious choice provided a structure can be found that can take over protons at this low energy. The injector is ordered and will be installed at the end of this year.

Table I

Injection System

Type	Cockcroft-Walton
Energy	800 keV
Current	3 mA
Emittance (normalized)	0.1 πcm rad for 80 % of the beam
Ion source	Duoplasmatron

B. Chopper buncher system

Such a system is required for two reasons

1. One cannot rely on a superconducting accelerator to do its own bunching, because the rejected particles would dissipate too much heat at liquid helium temperature (e.g. 40 W for 50 μA loss at 800 keV).
2. The second part of the accelerator will be operated at a frequency about 8 times higher than that at the first section. A frequency jump without loss of beam at about 15 MeV is possible only if the longitudinal phase space at injection is only filled in its central part.

A bunching to better than $\pm$ 15° and a very low number of particles between bunches is aimed at. The system selected is shown in figure 1.

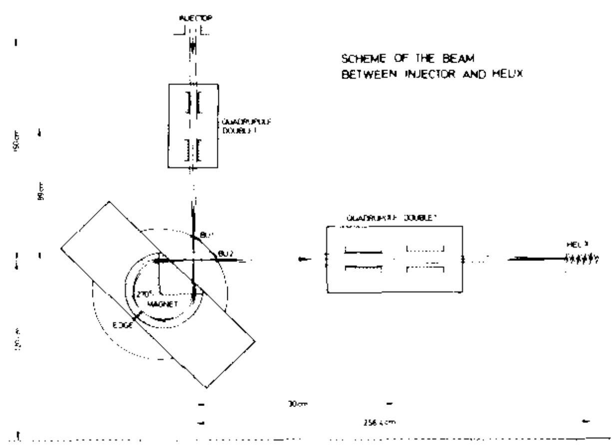

Fig. 1: Chopper Buncher-System

Two bunchers are separated by 270° degree deflecting magnet. The beam waist is located after half the deflection; here about 50 % of the beam is intercepted by an edge. Fig. 2 explains the action of the system.

Table II gives the parameters of the system; the choice of frequency will be discussed below. Fig. 3 shows the design of the buncher: the heavily loaded structure is quite small. In the particular version shown the two bunchers are combined into one structure which the beam passes twice. Fig. 4 shows a photograph of the buncher.

Table II

Chopper Buncher-System

Frequency	90 MHz
First buncher	
modulation amplitude	± 3.4 %
drift space (effective)	0.4 m
Deflector	
Field	0.654 T
radius of curvature	0.2 m
Second buncher	
modulation amplitude	± 4.4 %
drift space	2.3 m
phase difference between bunchers	0.772 π
bunch length at end of system	± 11°
Normalized beam emittance	0.2 π cm rad
RF power consumption	2kW

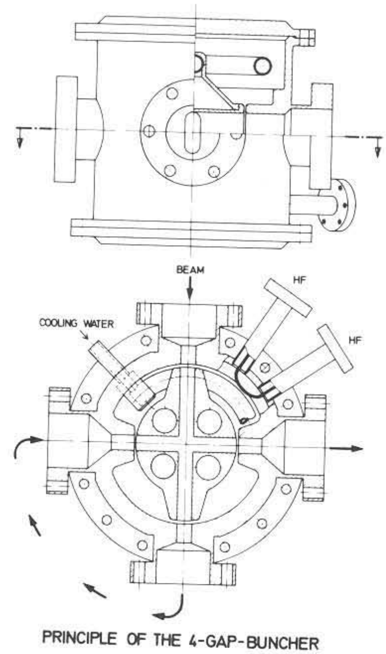

Fig. 3: A double buncher (diameter of structure 18,5 cm)

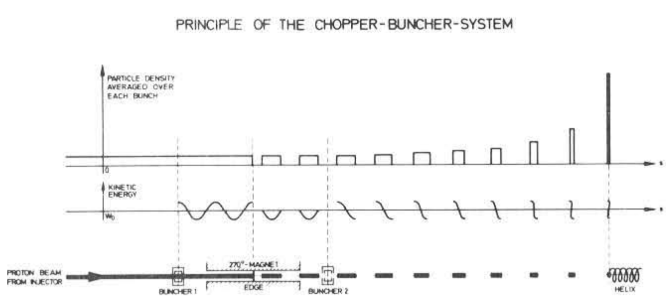

Fig. 2: Principle of the Chopper-Buncher-System

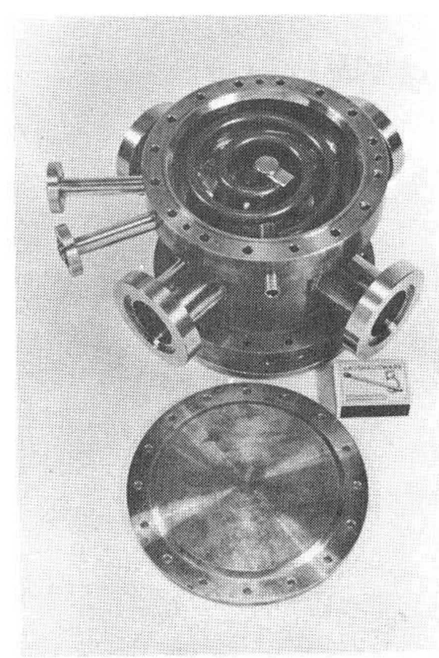

Fig. 4: Buncher

C. Accelerating Structure

We have decided to give the helix structure a try. The reasons are the following:

From the point of view of beam dynamics low frequencies are favoured, in particular if a low injection energy is aimed at. The focussing, the radial dependence of the energy gain and the resistance against beam break up all become better at low frequencies. For normal conducting accelerators considerations of power consumption go in the opposite direction, since shunt impedance is proportional to $\omega^{1/2}$ in this case. But for a superconducting accelerator the shunt impedance goes as $\omega^{-0.7}$, so low frequencies are favoured again.

But most structures operating at low frequencies are large, so it would be difficult and costly to make them out of superconducting material. An exception is the helix structure. Due to the heavy loading, it has small dimensions even at low frequencies.

Table III gives the main parameters of the first section of the helix accelerator, up to 4 MeV.

Table III: Accelerating structure

First section:	
Operating frequency	90 MHz
Input energy	0.8 MeV (β=0.04)
Output energy	3.9 MeV (β=0.09)
Stable phase	-30^o off crest
Energy gain	2 MeV/m
Peak electric field	28 MV/m
Peak magnetic field	0.07 T
Helix radius	3 - 4 cm
Number of tanks	3
Number of coupled helices/tank	3 - 5
Length of individual helix	$\beta\lambda/2$ = 7 - 15 cm
Pitch	1.0-1.7 cm
Helix tube	0.6 - 1.0 cm o.d.
Tank radius	20 cm
Length electric	155 cm
Length technical	274 cm

The frequency is a compromise between the desire to use a low frequency and the need to reduce the frequency jump between the two parts of the accelerator.

The dimensions of the helix are chosen in such a way as to keep the fields at the helix below certain limits and to minimize power dissipation. The helix structure is built up out of short niobium helices with a length $\beta\lambda/2$. In this way the maximum possible number of mechanical supports is provided: at the same time the length of tube from which heat must be removed to the storage pipes is minimized. I shall come back to the point of cooling below. The individual helices are electrically coupled very strongly, so that they can be considered as one longer helix electrically.

The energy gradient has been chosen tentatively. It gives rise to the maximum electric and magnetic fields listed in the table. Higher fields have been achieved for niobium in laboratory experiments at Stanford. Experiments will have to show, which fields can be reached at our frequency in a routine manner. Parameters will have to be revised accordingly. These experiments will start as soon as our UHV furnaces will be installed for outgassing the niobium.

The tank radius is chosen in such a way as to make the fields at the tank surface very small. In this case, lead plated copper can be used for the outer tank, since the properties of lead at low fields are quite adequate.

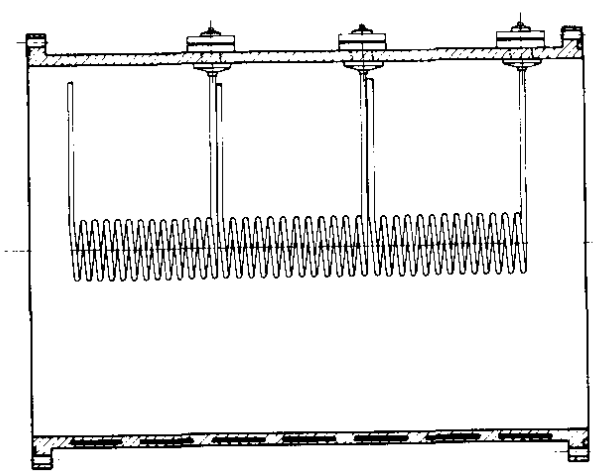

Fig. 5 shows a drawing of the helices in the first tank.

I shall not describe the experimental work on helices and on niobium surfaces here, since they will be the subject of a separate paper.

Figure 5: Arrangement of helices in accelerating tank

D. Focussing System

Quadrupole focussing with small superconducting lenses is used. The lenses are superconducting in order to reduce heat dissipation near the accelerating tanks. Magnetic fields are shielded from the cavities by superconducting niobium sheets. Moreover the quadrupoles will be energized only after the tanks have become superconducting. Table IV gives the parameters of the focussing system.

Table IV

Focussing System

Lattice	TFDTFDTOFD
T	accelerating tank
O	straight section for pumps
Quadrupole length	10 cm
Half aperture	3 cm
Max. gradient	20 T/m
Admittance based on a 2 cm halfaperture	0.8 π cm mrad

E. Cooling system

The helices are cooled internally by means of superfluid helium at 1.8K. The outer tank is cooled in the same way through cooling channels. The design of a cryostat is shown in fig. 6. The helices and channels are connected to a pair of He storage pipes within the cryostat. The heat is removed by superfluid heat conduction. This is possible provided the heat flow does not exceed certain limits. It has been checked experimentally that for the surface resistance expected this limits is not exceeded. Table V gives the parameters of the cooling system. The cryostat is

Table V

Cooling parameters

First section (4 MeV)	
Shunt impedance (warm)	7,5 ÷ 27 MΩ/m
Expected improvement factor	10^6
Power dissipation	3 W
Power per $\lambda/4$	0.1 W
Power that can be removed by superfluid conducting per $\lambda/4$	0.5 W
Heat leaks	3 W

designed as a double vacuum system, avoiding leaks between the ultra high vacuum in the accelerating system and atmospheric pressure. It is under construction now. The sputter ion pumps are operated at liquid nitrogen temperature. The helium is fed into the storage pipes from a helium refrigerator, which can remove 300 W at 1.8 K. Fig. 7 shows a partial view of the helium plant, which is operating now.

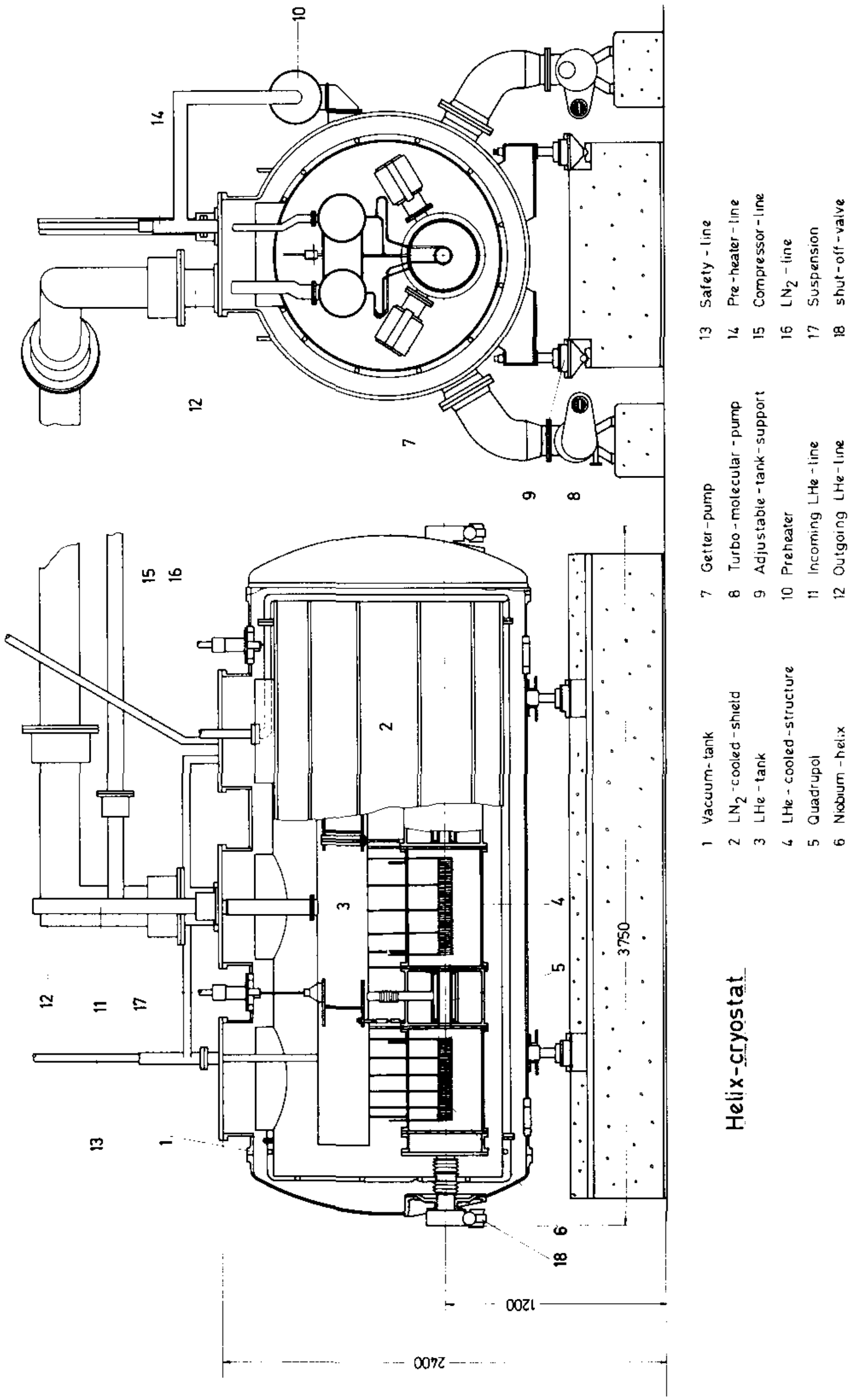

Fig. 7: Helix cryostat

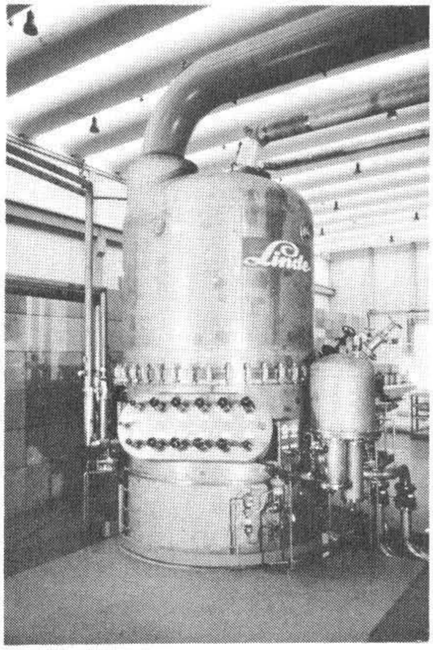

Fig. 7: Helium Refrigerator

F. RF and stabilizing system

A 15 kW transmitter has to feed the chopper buncher system as well as the different accelerating tanks. Since the band width of the resonators, loaded by the coupling system, is only about 30 Hz, it will be a difficult task to tune all the cavities to this frequency with the required accuracy and to stabilize them at this frequency. The tuning can be done by a deformation of the wall. Another possibility is to pass a direct current through the helix: the forces acting between windings are sufficient to provide a tuning mechanism. Variations of 1 A at a current of 50 A produce a detuning by about 50 Hz.

The stabilisation is more problematic. Due to the low stiffness and high mechanical Q of the helix it tends to pick up mechanical oscillations from the environment, which modulate its electrical resonant frequency. Frequency shifts of 100 Hz, with a modulation frequency up to 100 Hz were observed under typical working conditions. They may be reduced by mechanical insulation of the whole cryostat. But also the RF fields can, under certain circumstances, induce oscillations, due to coupling between the mechanical and the electrical system. More details are given in a separate paper of this conference. A fast stabilisation system has to be provided to counteract these oscillations. We are considering at the moment a system using ferrites. These have to be located in a cavity at room or liquid nitrogen temperature. A fraction of the stored energy corresponding to the relative amplitude of the frequency modulations to be suppressed has to be coupled into these cavities. Experiments on this system are in progress.

Summary

The main outstanding problems are the production of niobium helices with satisfactory superconducting surface resistance at high fields and the fast servo tuning system for stabilizing the cavities. We shall concentrate our efforts in the coming year on these two problems.

Finally I would like to list the names of the collaborators. The Karlsruhe group is listed completely. I have added the names of those members of the Frankfort team who have made major contributions to the superconducting helix project.

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DISCUSSION

(The discussion of this paper follows LCO-017, "Measurements of Loss Tangent of Dielectric Materials at Low Temperatures" by K. Mittag, R. Hietschold, J. Vetter, and B. Piosczyk.)