THE RADIOFREQUENCY PULSING SYSTEM AT INFN-LNS

L. Calabretta, A. Caruso, A. Spartà, E. Zappalà, INFN-LNS, Catania, Italy
Xu Zhe, Jianmin Zhao, IMP, Lanzhou, PR China

Abstract

From January 2000 the beam delivered from a superconducting ECR source[1] has been injected through the axial beam line in the K-800 superconducting cyclotron[2]. Along the axial hole the beam is bunched by the Axial Buncher, placed at ½ metre from the median accelerator plane of the cyclotron. In addition, along the injection line, to vary the duty cycle of the injected beam, a Low Energy Chopper is positioned. In the near future LNS has to deliver beam bunches as short as 500 ps FWHM with a separation time of 100÷200 ns. This will be accomplished by a new beam chopping system, the Chopper 500. It will be installed along the cyclotron extraction beam line instead of the H.E. Chopper[3] and, together with the buncher should ensure these performances. A description and status report of the axial buncher, chopper 500 and low energy chopper is presented.

1 AXIAL BUNCHER

1.1 Description

The Axial Buncher consists of a drift tube, placed in the axial hole of the cyclotron yoke, at 0.5 metre before the inflector. The electrode is driven by an RF signal, in the range of 15÷50 MHz. The length of the buncher electrode is 41mm equal to 210° when it works at the same frequency as the RF cyclotron or 105° when ½ subharmonic is used. This means, in the case of 210° a factor gain of 1.95 times the modulation voltage and in the case of 105° a factor gain of 1.55. The position relatively near the median plane allows us to reduce the bunch length at the time focus but increase the modulation voltage. This buncher is similar to the AGOR one and this solution was selected to achieve the shortest beam bunch length possible when used to deliver a beam to the experimental users. Although this kind of buncher has lower efficiency than a buncher driven by two frequencies, this should not be a limiting factor on the final beam current delivered from the cyclotron. The lower efficiency of the buncher is counter-balanced by the higher beam current delivered by SERSE, the superconducting ECR source. On the other hand there are some advantages: the absence of grids on the beam line; both the length of the drift tube and the gap are not critical; a relatively easy tuning operation. A buncher efficiency between 3.5 and 4.5 has been measured on the extracted beam with a beam bunch shorter than 1ns FWHM. The buncher is already installed in the cyclotron.

1.2 Main components and function

In figure 1 the layout of the axial buncher system is shown. The reference signal, coming from the RF cyclotron, is directly connected to the input of the system. This signal, delivered by an RF power amplifier, a 200 Watt broad band solid state, class A amplifier, is applied to the matching box. This is a tuning-box that normalises the impedance between the power amplifier and the drift tube at 50 Ohms, allowing perfect coupling. At the same time it ensures the higher voltage antinode on the electrode with the minimum RF power in the range of 15÷50 MHz. The matching box is a pi-filter with a fixed inductance L, of 0.2 μH, two variable high voltage vacuum capacitors, C_2 and C_3 both covering a capacitance from 2 to 500 pF and a third variable capacitor C_1, from 3 to 30 pF in series with the input to ensure the coupling to 50 Ω. The coaxial line T_1 connects the matching box to the electrode. Inside the cyclotron, under 10^{-8} mbar of vacuum level for about 1 metre, we use a water cooled ½ inch air dielectric coaxial line. Outside the cyclotron, a vacuum feedtrough matches another 2.5 metres of 1"5/8 rigid coaxial line. A ceramic feedthrough and a special T-junction permit the connection between the transmission lines and the water-cooled circuit. The termination of the coaxial line is the drift tube, from the electrical point of view an equivalent capacitance of about 20 pF.

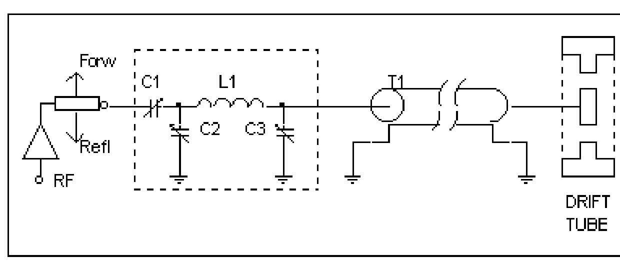

Fig.1: Layout of axial buncher system

Not shown in the layout but already present is the control system. It contains the turn on/off device, the protection circuits, the swr alarm, the electronic motor system to position the capacitance value and the automatic tuning system. The system have two types of operation: manual and the automatic. The first is usually used for the tuning at low power, the second, with protections and correction loops inserted, at high power. We do not really use the auto-tuning loop often because the self stability of

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the buncher system, with forced air and cooled water, respectively in the matching box and in that part of the coaxial line under vacuum, is enough to ensure a very low mismatching. The drift tube with the coaxial line could be considered as a fixed frequency resonator. A resonance of 76 MHz was found with a Q-factor of about 600. With the help of the matching box, we are able to reduce the resonant frequency down to our range, 15÷50 MHz. At the same time the 50 Ohms matching for the output stage of the RF amplifier is achieved. Therefore, the combination of the matching box, the coaxial line and the drift tube is a sort of variable resonator with the voltage antinode localised on the electrode. In the last period of cyclotron maintenance programme we installed the new design water-cooled circuit of the electrode, because last year a leakage in the old circuit compromised the normal operation of the axial buncher.

2 CHOPPER 500

The goal of the chopper 500 is to reduce down to 500ps the length of beam bunches, 1.5÷2ns, delivered by the cyclotron. It consists of two deflecting plates in the beam line followed by a pair of selection slits. We estimate a voltage lower than 200 kV on the electrodes to deflect the high energetic beam from the cyclotron. In order to reduce the voltage, a long drift space of about 3.5 metres separates the chopper electrodes from the slits. To obtain a short beam bunch down to 0.7ns FWHM from the cyclotron requires a lot of work. This result is achieved by the fine tuning of the phase slits, the adjustment of the axial buncher, the position of electrostatic deflectors and phases among the RF cavities. The setting of these parameters is not simple and a lot of beam current is lost, typically more than factor 10. The next generation of experiments at LNS demand beam bunches of 0.5ns FWHM and a “clean interval” between the pulses. Using this chopper, we expect to avoid or limit this complex procedure in the suppression of eventual spurious tails around the selected time interval. The chopper consists of a couple of electrodes which are driven by a sinusoidal voltage, $V(t)=V_0 \sin(\omega t+\Phi)$. With $\omega=2\Pi f$ and f is a harmonic frequency of RF cyclotron. A beam particle which crosses the chopper will be deflected in vertically as happens in the present H.E. Chopper[3]. To design the chopper it was necessary to match the short bunch of time with the high speed of the beam particle. To select a beam bunch of 0.5ns a high frequency voltage is applied to induce a fast variation of the electric field at a time interval of ±0.25ns during the passage of the particles. But the high frequency means short $\beta\lambda$ and then an upper limit on the usable electrode length. So the harmonic frequency chosen is a balance between the requirement to have an electrode length $Ld=\beta\lambda/2$ as long as possible, a frequency as high as possible to minimise the peak voltage and a long distance to the slits. Where L is the length of the electrodes, d is the distance between the electrodes, $\beta\lambda$ is the known wave length of the ion. Table 1 summarise this compromise, also taking into account a reasonable frequency bandwidth for the cavity and the RF amplifier. Assuming a typical phase acceptance of 40° RF for our cyclotron, means that a chopper performance in relation to this time interval is capable of sweeping the beam particles onto the collimator slits. In this table we assume an electrode long 400mm and a peak voltage of 200kV able to sweep the unselected beam on the slits placed at 3.5metres from the end of the electrodes.

Table 1

Ion q/A	E/a MeV/amu	Fcyc [MHz]	Hchop	Fchop [MHz]
0.16	20	22.8	4	91.2
0.5	35	29.8	3	89.4
0.5	100	48	2	96
0.25	50	35.2	3	105.6
0.16	20	22.8	3	68.4
36/238	10	16.25	4	65
8/40	10	16.25	5	81.25

Another target of the Chopper is the separation time between two consecutive bunches. With the axial injection the superconducting cyclotron operates in harmonic 2, this means one beam bunch every RF period. The radiofrequency range of the cyclotron gives a separation time between 20 and 66 ns but if we want a separation time of 100-200 ns among the bunches, a suppression of some bunches is necessary. In Table 1, harmonic 3,4, and 5 are used for different ions, so we are using an integer harmonic number. If the integer harmonic number ensures the short beam bunch of 500ps, it is not useful to suppress the bunches in order to reach the desired separation time. The solution is to choose a harmonic not integer multiple of the fundamental RF cyclotron. In fig 2, a graphical example is given. The dotted blue sinusoidal signal is the RF of the cyclotron, the red sinusoid is the chopper harmonic. The red one is 3.125 times higher than the blue one. This means that in every four periods of RF cyclotron the two waves meet at 0, Π or 2Π. In the other three cases the sinusoids will be in a phase relation capable of suppressing the remaining bunches. In order to reach the right separation time we can decide this multiplication factor in the frequency operative range of the chopper.

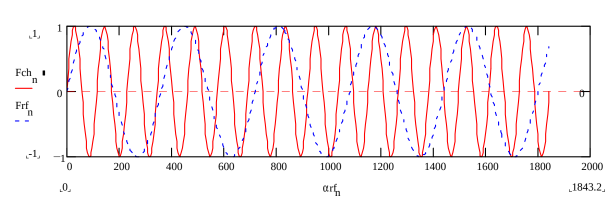

Figure 2: RF signals of cyclotron and chopper in relation.

In brief the technical characteristics of the chopper are:

- λ/4 coaxial resonator
- inner coaxial 180 mm, outer coaxial 500 mm
- Z_0 56.3Ω
- Electrode length, width, gap (400, 70, 30 mm)
- Coaxial length 1035 mm
- Maximum voltage 200 kV
- Frequency range 60-110 MHz
- RF power 50 kW

All the main components of the chopper 500 are on site but only the power amplifier, the driver and its control system have been installed and tested successfully on the dummy load. The other components, RF cavity, coupling system, 3”1/8 rigid line, reflectometer and power RF switch are ready to be installed. Due to the final location of the chopper 500 along the extraction beam line of the cyclotron, we cannot install all the remaining components until the next scheduled accelerator maintenance programme.

3 LOW ENERGY CHOPPER

The low energy chopper is used as a variable attenuator of the injected beam. A section of the beam line hosts a pair of deflecting electrodes as shown in the figure 3.

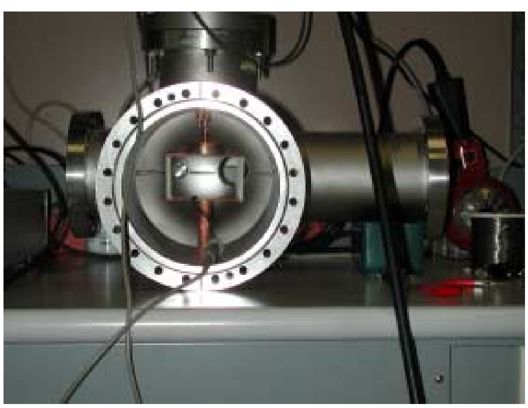

Fig.3: the deflecting plates inside the beam line

In the mechanical mounting of the deflecting electrodes a special T-line has been used. The distance between the plates is 50mm, the length is 100 mm and the width is 70 mm, the total capacitance is about 43pF. With this simple apparatus we are able to modify the duty cycle of the continuos beam from the ECR sources. The layout of the system is shown in the figure 4. The core is a compact pulse generator module producing fast, high voltage wave forms to 1500V, the switch in the layout. It is driven by a remote controlled TTL frequency generator. Through this generator it is easy to change the frequency and the duty cycle. We can also change the amplitude of the pulse voltage applied to the deflecting plates. We test the system on different continuous particle beams. The duty cycle setting of the pulse generator was followed with the same rate of attenuation by the accelerated beam current. Repetitive tests have been carried out from 1 to 90% of attenuation. This device is very useful in setting the cyclotron parameters with high peak current to investigate for space charge effects, but with a low duty cycle in order to avoid activation inside the accelerator chamber or on the wall of the electrostatic deflector. The performances of the chopper are linked to the main parameters of the pulse generator. The maximum voltage delivered is ±1500V, the rise/fall time is 25ns (10% to 90%), the pulse recurrence frequency is 75 kHz single shot. These specifications are valid if a 50pF load connected with 2 feet of RG-62 cable are used. In our case we test the system at 850V, measuring the same or better performances with a pulse recurrence frequency in the range of 1-10 kHz. Before the final destination along the cyclotron injection line some other tests have been done with this chopper. We drive the plates with a sinusoidal and a saw-tooth signal up to the maximum frequency of 6.9 MHz. Through a 50W broad band RF power amplifier, terminated at 50Ω, the signals have been applied to the chopper’s plates. The results were very interesting because the system was very linear in both cases of driving input signals. A peak to peak voltage of about 150V has been measured for the sinusoidal and saw-tooth waves. A rate of about 1/1000 was measured between the voltage on the electrodes and the coaxial pick-up. We retain the results to be very interesting which point in the direction of improving the present pulsing system in the injection line of the cyclotron.

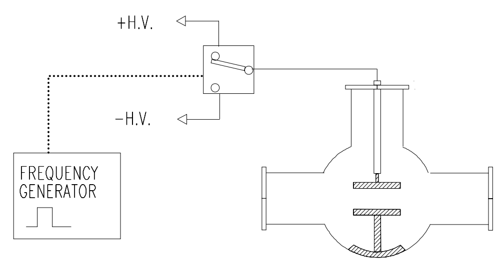

Figure 4: the layout of the low energy chopper

To have a maximum grade of freedom in the choice of the right frequency, of the low energy chopper and also for the chopper 500, we are testing new frequency sources based on the direct digital synthesizer technology. It is a commercial device able to generate, when referenced to an accurate clock source, a highly stable, in frequency and amplitude, sine wave output. A first prototype has been made along with successful preliminary tests.

REFERENCES

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