THE RF-SYSTEM OF THE FLATTOP-ACCELERATION STRUCTURE IN THE SIN 590-MeV-RING-CYCLOTRON

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Abstract

Ring cyclotron tests with flattop acceleration will be started next year. These tests will be performed with a third harmonic RF-signal, added to the fundamental to flattop the wave form of the accelerating voltage. This reduces the energy spread of the beam and the usable phase spread is increased. The phase error between the fundamental and the third harmonic must not exceed .05° (with respect to 50 MHz) and an amplitude stability $\Delta U/U$ of 10^{-3} is sufficient. The arrangement which produces the third harmonic consists of: one cavity resonator, 60 kW transmitter, preamplifier, phase- and amplitude-regulation loops.
A temporary setup of the whole system has been put into operation and tested. It will be installed in the ring cyclotron at the end of 1978.

Introduction

The general theory and the application of the flattop acceleration at the SIN 590 MeV ring cyclotron was studied in[1,2].
The newly designed injector for the SIN ring cyclotron is expected to produce a maximum proton current of 1 mA with a pulse width of about 15° RF.[3] This relatively large phase width eases the problems of longitudinal space charge forces and ion source output parameters. In order to keep beam losses in the 590-MeV-ring-cyclotron as small as possible, a very good beam quality is required. In addition the extraction efficiency has to be much better than 99%. This means that clearly separated turns at extraction are necessary. This requires the accelerating voltage to be flat over a wide phase range. With a third harmonic (150 MHz) superimposed to the fundamental (50 MHz) the accelerating voltage can be made sufficiently flat. (Principle of flattop acceleration) (Fig. 1)

To get perfectly separated turns at extraction, the energy spread in the beam has to be substantially smaller than the energy gain per turn. This leads to a tolerable energy spread of $\Delta E/E < 0.1\%$ and a usable phase spread of 30° RF. (At present, the ring cyclotron operates with a pulse width of only 5° RF in order to yield separated turns at extraction.)[4,5]
This requirement can be satisfied by adding a third harmonic. The voltage of the third harmonic has to be about 12% of the fundamental amplitude. This condition has not to be fullfilled locally, but rather averaged over all revolutions. Therefore, the radial extension of the 150 MHz cavity was designed such that the decelerating voltage of the third harmonic

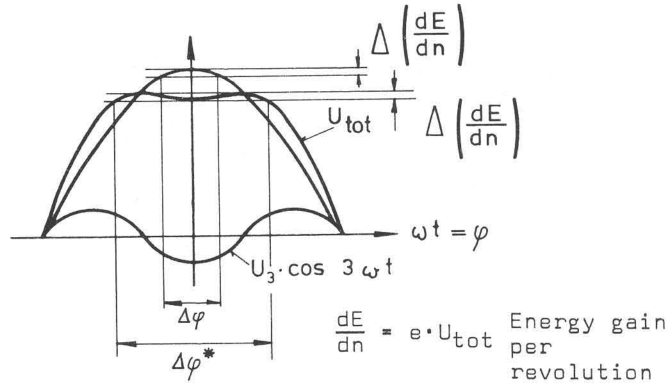

Fig. 1 Principle of flattop-acceleration
$\Delta\phi$ usable phase width without flattop
$\Delta\varphi^*$ usable phase width with flattop

at injection and extraction is smaller than the average value. RF power requirements for a third harmonic cavity are considerably less than for a second harmonic cavity. Furthermore, a third harmonic cavity (150 MHz) can be shaped to fit the existing cyclotron structure rather well.

Alternatively, using the fourth or higher harmonics, the usable phase width would decrease to unacceptably small values, the phase stability requirements between the fundamental and higher harmonics become harder and harder to satisfy, and the construction of such a cavity will present great difficulties.
The above mentioned investigations[1,2] call for the following tolerances for the flattop cavity:
Amplitude stability: 10^{-3}
Phase stability between the third harmonic and the fundamental: $\Delta\phi < 0.05°$ (with respect to 50 MHz).

One additional cavity, resonating at 150 MHz is sufficient to generate the flattop accelerating voltage[6]. Furthermore, there would be no room for a second cavity in the present accelerator arrangement. The induced asymmetry in the orbits is tolerable due to relatively large injection energy of 72 MeV.

Fig. 2 shows a block diagram of the 50 MHz and 150 MHz RF-systems and associated amplitude and phase feedback-systems.

The entire RF-system is driven by one master-oscillator (50 MHz). The third harmonic is generated by a frequency multiplier. The reference signal for the phase and amplitude of the flattop RF voltage is the summed voltage of the four 50-MHz-cavities. The summation circuit consists of a four-way 100 W power multicoupler.

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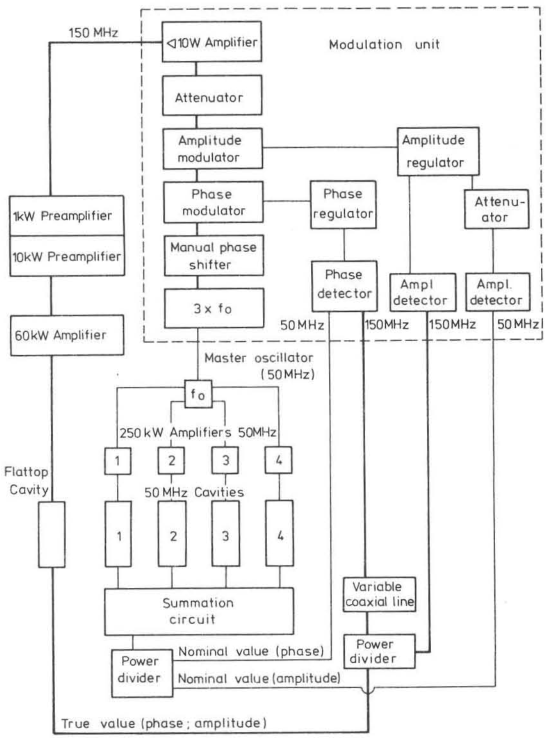

Fig. 2 Block diagram of the flattop system. (150 MHz RF path: thick lines)

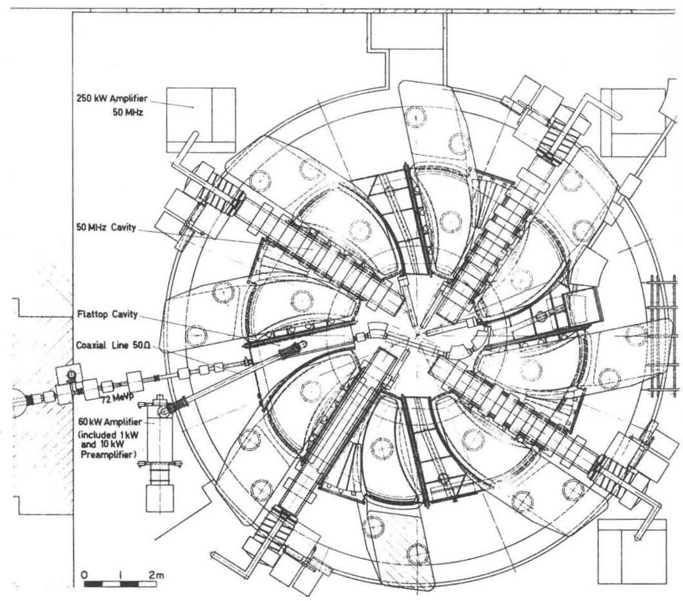

Fig. 3 Outline of the SIN 590-MeV-ring cyclotron. Position of the flattop cavity and power amplifier

Cavity and transmitter

Assuming the peak voltage in one 50 MHz cavity is 600 kV, (i.e. 2400 kV in total) the peak voltage of the flattop cavity has to be 370 kV. A rectangular water-cooled cavity (dimensions: .96 m, 2.7 m, .4 m) made of aluminum was built. Omitting gap electrodes, the resonance frequency is 167 MHz, adding electrodes lowers the resonance frequency to 150 MHz, with a Q-value of 28200.
Therefore, 35 kW RF power is required to generate 370 kV peak cavity voltage. The location of this cavity and associated amplifier chain in the ring cyclotron are shown in Fig. 3. The coupling loop is situated in a ceramic cup, which reaches into the cavity and acts as a separating medium between air and vacuum. (Fig. 4) The coupling loop is designed to match 50 Ω. A hydraulic system mechanically squeezing the cavity, similar to the one used in the 50 MHz cavity, is used for automatic frequency tuning. Instead of a motor driven oil pump, it consists of a servo valve-driving piston arrangement. Compared to the 50 MHz tuning system this arrangement has a higher response speed.

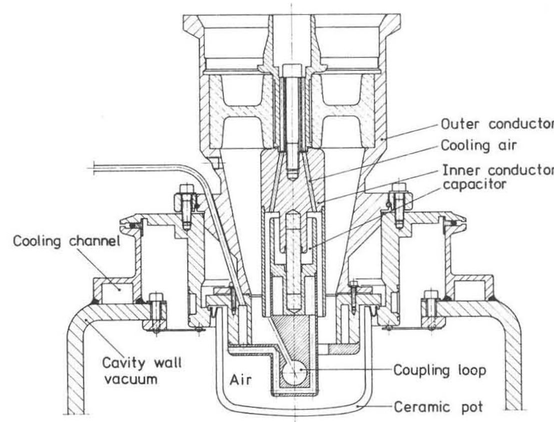

Fig. 4 Coupling system of the flattop cavity

Transmitter

For reliable operation of the flattop-cavity, an RF power level of 60 kW must be provided. A power amplifier in grounded screen configuration has been constructed, using a Siemens power tetrode type RS 2004 J[7]. This amplifier has a gain of 11 dB, an anode efficiency of 55%, and a bandwidth of 1 MHz.

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Coaxial structures are used for anode, screen grid and input circuits. Special coaxial coupling capacitors made of a teflon cylinder copper-plated by electroforming are used in anode- and input circuits (C_1, C_2) Fig. 5. A Siemens TV-transmitter, 10 kW output power, serves as a pre-amplifier stage. It has been modified to allow operation at 150 MHz.

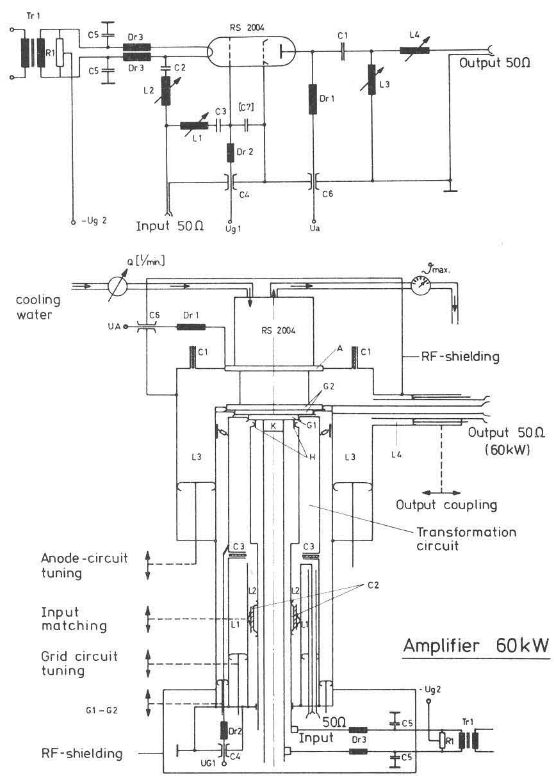

Fig. 5 Schematic diagram and layout of the 150 MHz 60kW amplifier

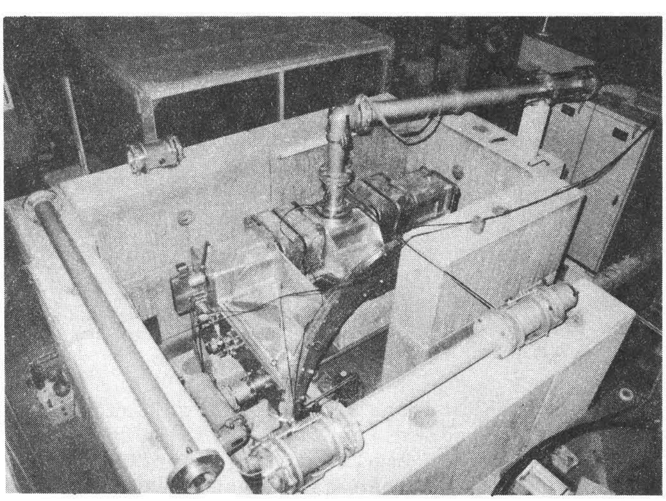

Fig. 6 Flattop cavity and coaxial 50 Ω line. (Preliminary setup)

Regulation and stability

In an analogous way to the control principle in the 50 MHz system, the method of direct modulation of the RF-signal is used to stabilize phase and amplitude to the required values. The constraints on the phase regulation loop are very strong and therefore a special effort was made to develop a sensitive phase detector and in selecting cables of a high phase stability. The phase detector is designed to detect the phase shift between the two different frequencies. An odd harmonic signal may be detected as the difference between the peak value of sum and difference voltages of signal and reference 50 MHz[8]. In addition very high sensitivity is required which can be reached by using a high input level (5 V_{rms}). The sensitivity then is 20 mV/.1° (50 MHz) (Fig. 7).

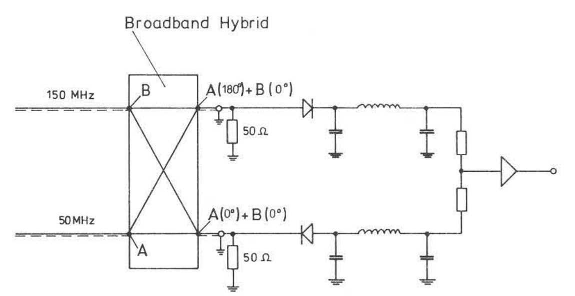

Fig. 7 Schematic diagram of the phase detector

Prodelin Type Spir-o-line 64-500 1/2" cables were chosen for reference and nominal value. This type of cable shows a maximum phase shift of $\Delta\phi$ = 0.045°/100 m °C. Previous measurements and calculations have shown[9], that the length of the RF-path (i.e. the length of the RF cables) should be as short as possible, preferably < 20 m. Thus dead time becomes negligible and this has a very favourable effect upon the transient behaviour on the regulation loop (Fig. 8, 9).

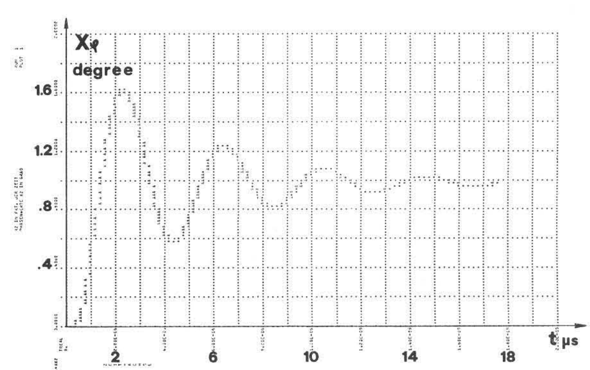

Fig. 8 Calculated step response of the flattop phase regulation loop with an RF-path length of 100 m. Step amplitude 1°.

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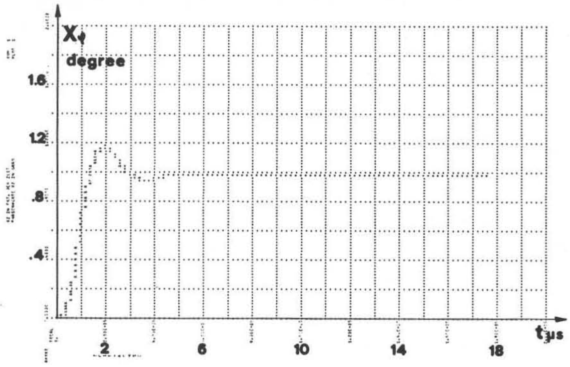

Fig. 9 Calculated step response of the flat-top phase regulation loop with an RF-path length of 5 m. Step amplitude 1°

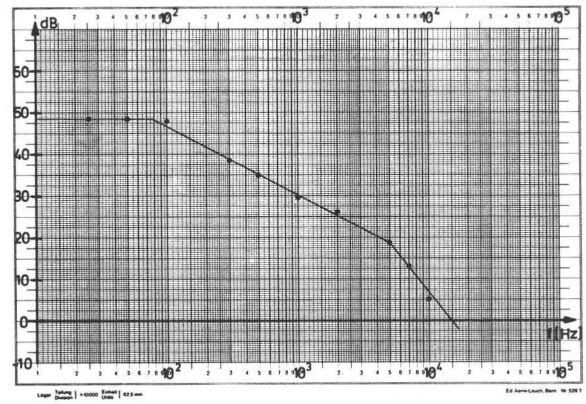

Fig. 11 Open loop gain of the amplitude regulation loop

A commercial broad band ring modulator is used as an amplitude modulator. The phase modulator consists of a hybrid, where two ports are terminated with tunable reactances. They shift the RF phase between the two other ports of the hybrid as a function of the applied error signal.
The spectrum of phase variations on the RF signal shows that frequencies between 50 Hz and 3 kHz are dominant. Therefore, a sufficiently large open loop gain is desired in this region. The same is true for the amplitude regulation loop.
Operation in conjunction with the cyclotron will show whether any changes in the feedback loops (e.g. compensation networks) will be necessary.

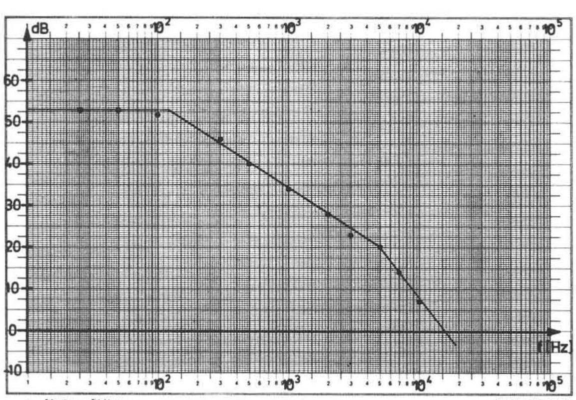

Fig. 10 Open loop gain of the phase regulation loop

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