RF SYSTEMS DEVELOPED FOR CYCLONE 3D AND CYCLONE 10/5.

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Abstract

The design of the rf systems developed for CYCLONE 3D (3MeV deuteron cyclotron) and CYCLONE 10/5 (10 MeV protons, 5 MeV deuteron cyclotron) is reviewed.here The necessity for reliability and simplicity determined our choice of auto-oscillators powered by low mu industrial triodes. Mechanical and thermal stability of the accelerating electrodes and other parts of the resonant structures allows the use of a free running oscillator. Neither the frequency nor the dee voltage are regulated for CYCLONE 3D,whilst a P.L.L. stabilises the frequency for CYCLONE 10/5. Careful design of triode biasing circuits allows the use of an unregulated anode power supply. Full scale models of the rf cavities were manufactured in order to assess the validity of the inner helical resonator design.

CYCLONE 3D RF system

Introduction

CYCLONE 3D (2) is a classical cyclotron working in the first harmonic mode. It produces 3.5 MeV deuterons at an extraction radius of 210 mm.
The dees are located in the constant magnetic gap (50 mm) and have an average angle of 90°. There are excited in opposite phase with rf peak voltage of 30kV.
The basic principle of CYCLONE 3D rf system is shown in the fig. 1

RF cavities

The dees are held in the magnetic gap by four supports in ultra pure alumina (99.98%). Their very low dielectric loss (tgδ =1.10^{-4}) allows a compact construction even with very high electric field constraints (fig 2).
CYCLONE 3D has a single resonator connected to the dees. It is located directly above the machine in the oscillator cabinet. The resonator has the shape of a big helix with an acceptable "Q" value.
The poles are copper plated and they drive rf current via the vacuum chamber up to the oscillator.
The power required to produce the accelerating voltage is about 8 kW.

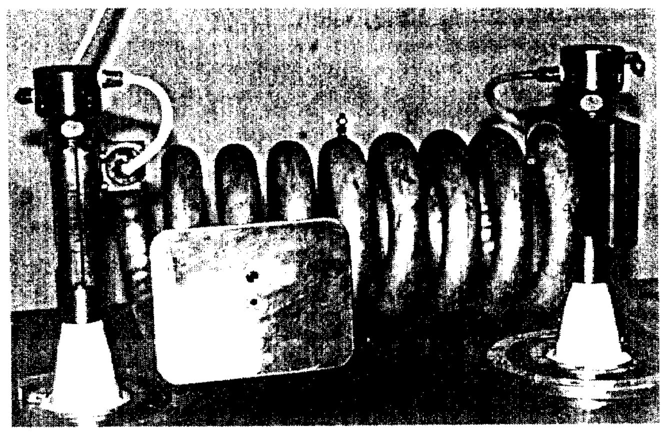

Fig 2: Resonator connected to the dees via support in Alumina.

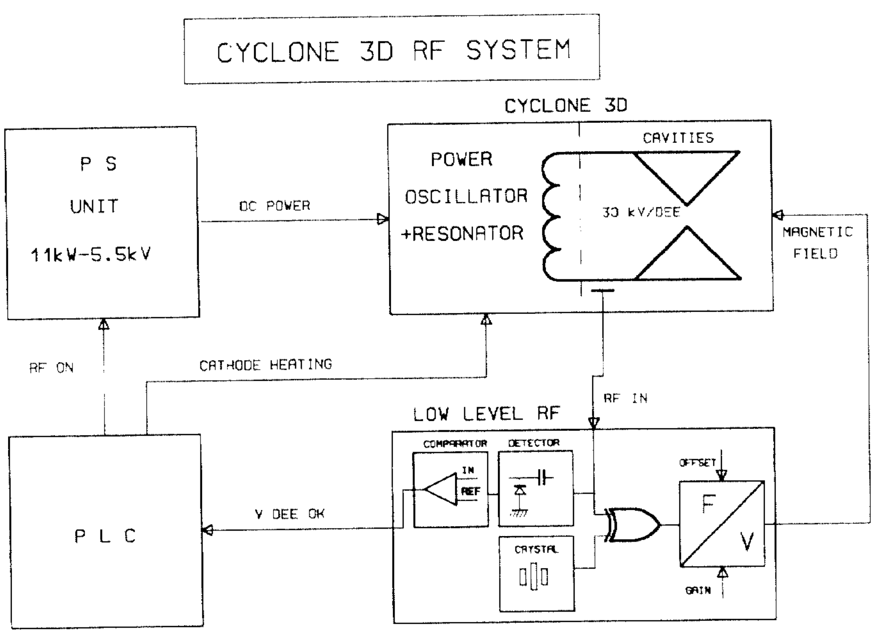

Figure 1

Oscillator

This is produced by a low μ power triode providing high reliability at low price (400$).
The rf tube chosen for the application is a ITK5-1 from ABB (Asea Brown Boveri) having the capacity to deliver 10 kW (4). This tube is specially designed for rf oscillator with inevitable load variation. Due to the possibility of the maximum permissible grid dissipation being exceeded, the most unfavorable conditions always arise when the load is suddenly remove which may cause the AC anode voltage and the grid current to rise considerably. Spurious oscillations may produce this load variation. The grid bias limits automatically the power during this event. Moreover, the tube plate circuit is designed to avoid parasitic resonances because its own resonance is far enough from the cavity resonance. The open loop gain is greater at the cavity frequency than at the anode frequency.
The oscillator configuration (TPTG) chosen reduces the grid feed back of 12 dB/oct. and automatically decreases quickly the open loop gain for lower frequencies.
The oscillator works in class C with a $\eta \sim 75\%$.
The power coupling to the cavities is entirely capacitive allowing a very quick dismantling (fig. 3)

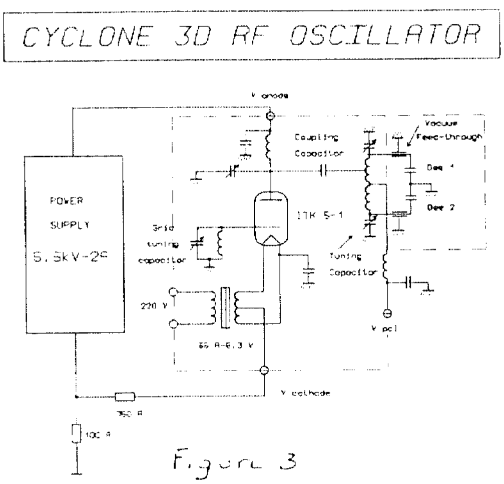

Figure 3

The triode bias is fully automatic and is obtained by two big resistors placed in the power supply cabinet. A careful mixing of cathode bias and grid bias procures a quick rise-up of dee voltage and a good anode voltage regulation. This feature prevents multi-pactoring effects and reduces power supply filtering dimensions. Therefore, no pulsing system has been required.
Up to now, our prototype rf system has started without any difficulty even with a relatively poor cyclotron vacuum (2.10^{-4} mbar).

Auxillary equipement:

The isochronism is maintained by an open loop action on the magnetic field. The oscillator frequency is compared to the frequency of a quartz; the frequency difference is converted in a DC signal acting proportionnally on the magnetic field. This way to maintain the isochronism avoids the delicate regulation of the oscillation frequency. The frequency shift is no more than 0.1%.

CYCLONE 10/5 rf system

Introduction

Cyclone 10/5 accelerates protons up to 10 MeV in the second harmonic and deuterons up to 5 MeV in the fourth harmonic (1).
Like Cyclone 3D, the rf power is produced by a self-oscillator (fig 4).
A 1/1 scale model was made to confirm the helical lines theory. Those helical lines with coaxial cooling have been carefully designed. The following tables summarise the characteristics of the model.

Caracteristics :

Turns of coil	: 5 turns
Conductor diameter	: 20 mm
Middle coil diameter	: 100 mm
Copper plated cavity	: 50 μm

measurements :

Frequency resonance	: 39.41 MHz
Frequency band	: B = 22 KHz
Quality rate	: Q = 1900
Line lenght	: L = 1.502 m
Dee capacity	: C = 18.6 pF
Main coil diameter	: D = 96 cm
Line impedance	: Zo = 150 Ω

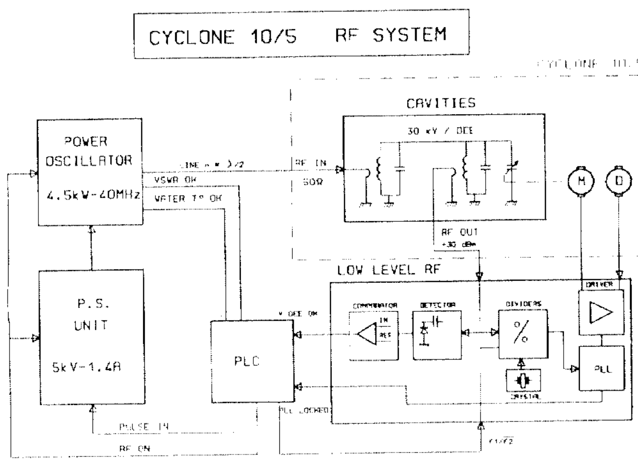

Figure 4

Cavities

The cavities are entirely located in the valleys and the dee angle is 30°. This concept allows a very low dee capacity and then a moderate power to produce 30 KV dee voltage. The rf frequency is variable between 40 MHz and 41 MHz for respectively proton and deuteron acceleration. Four helical lines compensate the reactive power of dee capacitance with a high "Q" value. The input coupling is inductive and easily variable to match the input impedance of the cavity.
The measured input impedence of the cavity is shown on figure 5.

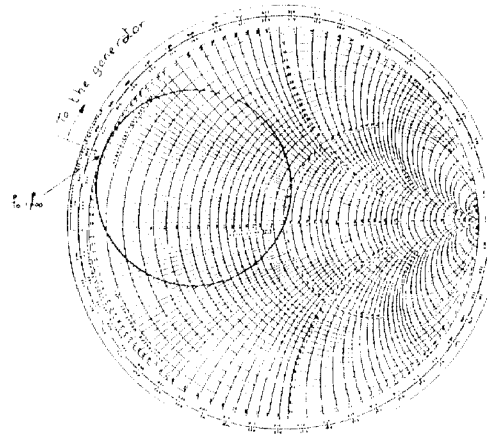

figure 5 : Smith chart showing the input impedence of the cavity for a f_0= 39.433 MHz and a $Z_0 = 50\ \Omega$

Frequency tuning system

The cavity tuning is realised by two variable capacitors (one per cavity). They are driven by an external hydraulic system. The movement is made in two steps, first by a on/off movement giving the frequency adapted to the proton or deuteron acceleration. The fine tuning is afterwards ensured by a servomotor. This servomotor is driven by a PLL circuit with two programmable frequency dividers which can be easily set . Two rf pick-ups enable to measure the rf voltage on the dees.

Pulsing system

A fast switching of rf voltage avoid the multi-pactoring on the cavities. This switching is realised in the grid bias circuit. The switching sequence is programmed in the PLC.(3).

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