A Drift Tube Accelerating Structure for CRYRING

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A conceptual design has been developed for a driven (non-resonant) drift-tube (DD-T) accelerating structure for CRYRING. Because the ring is small and accelerating voltage requirements not too large, it is possible to use a DD-T to cover the broad frequency range required at modest cost. The DD-T control requires only a frequency signal from a beam position pick up and a voltage level signal. The DD-T makes possible none-sinusoidal wave forms for bunch shaping to improve the space charge limit. A full scale low power model was used to verify the essential features of the design.

1. Introduction

CRYRING is a planned heavy ion synchrotron-storage ring for research with internal and extracted beams [1]. Highly charged ions $0.25 \leq q/M \leq 0.5$ from an electron beam ion source, CRYSIS , will be accelerated by a RFQ accelerator to 300 keV/u before injection into the ring. The ions are then accelerated to the desired energy, limited to a maximum rigidity of 1.44 T-m. In storage mode the desired energy may be below the injection energy requiring deceleration by the RF structure.

For CRYRING, which is relatively small in circumference and requires only modest voltages, the driven drift-tube (DD-T) described in [5] and with some improvements shortly here, meets the basic requirements at significantly low cost. As CRYRING is small in circumference, the DD-T length can be a significant fraction of it. Also the injected beam energy spread, the magnet ramp rates and orbit frequency range are such that the DD-T can be driven with a reasonable broad band class A amplifier. In addition DD-T provides a flexibility of operation not possible with a resonant cavity i.e. the use of non-sinusoidal wave forms, fast pulse-to-pulse voltage changes and damping by high frequency phase feedback.

2. General Parameters of the Accelerating Structure

2.1. Frequency

In the accelerating ring the frequency of the RF system depends on the ion velocity and the circumference of the ring, i.e.,

$$f = \frac{h\beta c}{2\pi R}, \tag{1}$$

where h is the number of rf cycles per orbit period of the ions, βc is the ion velocity and $2\pi R = 51.63$ m is the ring circumference.

2.2. Voltage

The accelerating voltage required depends on the ion charge to mass ratio, q/M, the velocity spread in the injected beam, $\Delta\beta_0$, the magnetic field ramp rate, $\dot{B}$, and the harmonic number, h. The peak of a sinusoidal voltage on an accelerating gap, $\hat{V}$, for a "full bucket" may be expressed as [3]

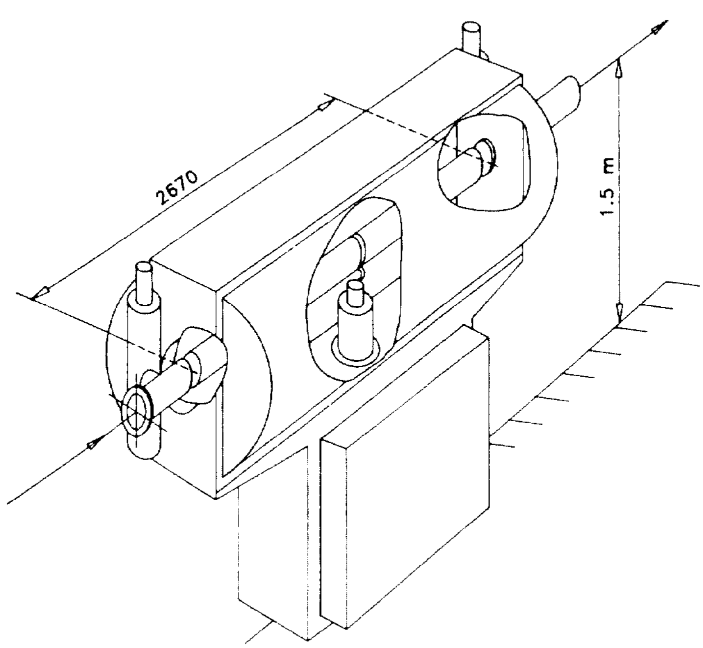

Fig. 1. Assembly of 2.67 m DD-T.

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$$\hat{V} = 2.91 \times 10^9 \left(\frac{h}{q/M}\right)\left(\frac{\Delta\beta_0}{\alpha(\Gamma)}\right)^2, \tag{2}$$

where $\alpha(\Gamma)$ is the ratio of accelerated to stationary bucket area for acceleration at a stable phase ϕ_s and $\Gamma = sin\phi_s$. Considering the CRYRING reference values [1]:

$q/M = 0.25$ and 0.5
$h = 1$
$E/u = 300$ keV/u $\quad \frac{\Delta\beta_0}{\beta_0} = 0.005$
$\rho_0 = 1.2$ m
$2\pi R = 51.63$ m
$\dot{B} = 8$ T/s max. (7 T/s average).

we have that the maximum $\hat{V}$ required is about 1200 V at 8 T/s [5]. To provide this accelerating voltage with a drift tube requires a voltage $\hat{V}_D$ on the drift tube [4] of

$$\hat{V}_{acc} = 2 \cdot \hat{V}_D sin(h\theta/2) cos\phi_s, \tag{3}$$

where $\theta = 2\pi\ell/(2\pi R)$ and ℓ = the length of the drift tube. The parameters of the DD-T for CRYRING are summarzed in table 1.

Table 1

Driven Drift-Tube Parameters

Frequency range	f_0	10 kHz to 1.5 MHz
Length	ℓ	2.67 m
Accelerating Voltage	$V_{acc.}$	0 to 1200 V
Drift-tube Voltage	$\hat{V}_D$	0 to 3700 V
Power	P_{rf}	$\sim$ 10 kW

3. Technical Design of the CRYRING DD-T

3.1. Structure

The mechanical design of the drift tube is determined primarily by vacuum system requirements and is limited in length by space between the dipoles (fig. 1). The insulators at each end of the tube form also the vacuum boundary. In the centre section only the beam tube is under vacuum, the external components are in air. An outer housing or shield contains the power amplifier tube mounted at the bottom and the water cooled plate resistor. The outer housing is made large to reduce the drift tube capacitance and hence the loading on the amplifier.

All the vacuum components are fitted with a bakeout heater and insulation for baking to 300 °C. This is covered by a water cooled copper jacket to provide good conductivity for the rf currents along the drift tube. The outer housing is aluminium which is also a good conductor for rf and requires only a little air cooling.

A full scale model was set up to explore the essential features of the structure. It was driven by a small tetrode set up with power supplies that were available. This allowed operation up to 600 V peak on the tube. Characteristics were tested over the full frequency range.

3.2. DD-T Amplifier

A broad band class A amplifier is used to drive the drift tube. The load for the power stage is the capacitance to ground of the drift tube assembly which is estimated to be 150 pF. The resistance and inductance in the plate circuit of the power stage are made variable so that gain vs frequency may be optimized for the particular maximum frequency required so as to minimize the power required. A 10 kV plate voltage shown would be suitable for $\hat{V}_D$ = 3.7 kV.

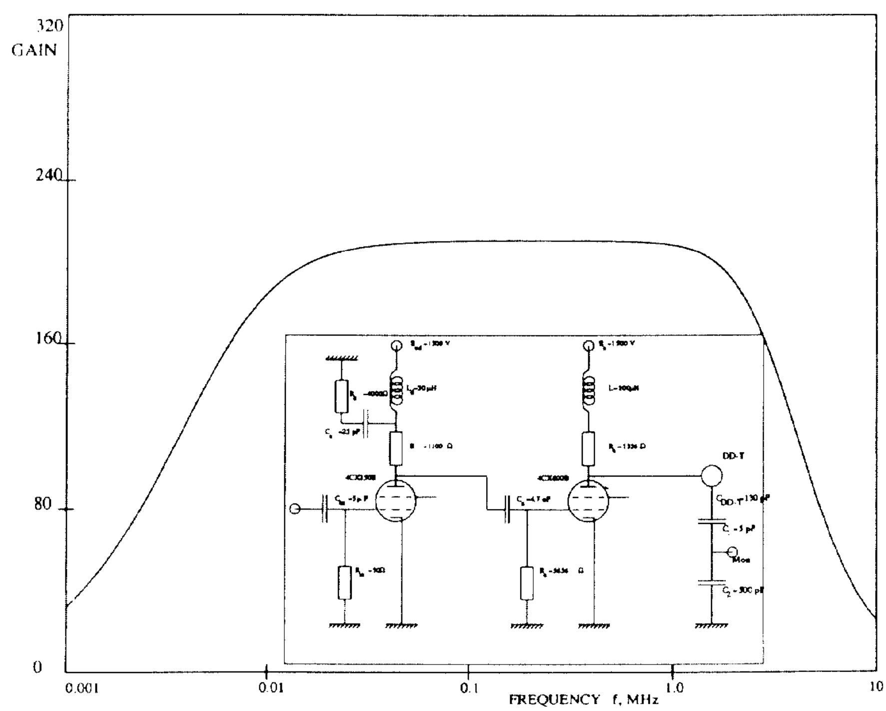

Fig. 2. Computed Frequency Response of the DD-T Model-Amplifier.

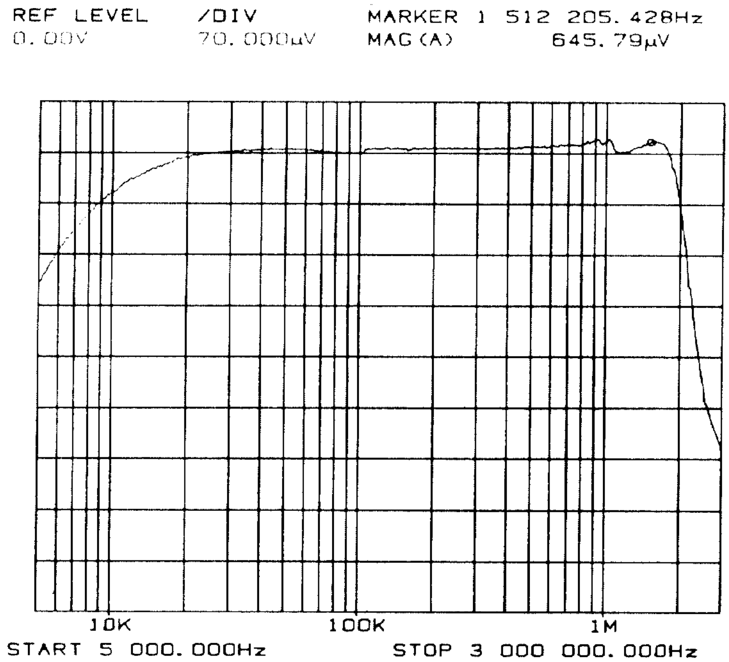

Fig. 3. $\hat{V}_D$ versus frequency for the 2 m DD-T model showing a gain variation less than 6% between 10 kHz and 1.5 MHz.

The most satisfactory variant of computed power amplifier (fig.2) has been tested. The model was driven by a network analizer sweep generator for swept measurements. The voltage in the drift tube was monitored via either a capacitive divider or a resistor divider. The frequency range that we can easily reach is quite enough for the work of the DD-T in CRYRING.

From power considerations we get: we need a tube in the power stage of about 20 kW, the plate resistor has to dissipate about 26 kW and the plate power supply has to provide about 40 kW. These estimations have been done for a duty factor of 100 %. Taking in consideration the working cycle of CRYRING we can reduce the duty factor to about 50 %.

3.3. Control of the DD-T

In the control circuit of the DD-T the drive frequency is generated by a voltage controlled oscillator (VCO), which drives the drift tube through an amplitude modulator and power amplifier. The frequency also follows the control voltage signal $V_s \propto f_o(t)$ provided by the computer but modified by an error signal from a beam radial position pick up. This centres the beam in the beam tube by adjusting the VCO frequency (or phase) and hence energy gain.

4. Results and Conclusions

As shown in fig. 3, the gain variation can be kept within 6% between 10 kHz and 1.5 MHz and easily within the control range of a voltage leveling circuit. This flat gain characteristic was obtained by adjusting the inductance and capacitance in the plate circuit of both stages of the amplifier.

The maximum $\hat{V}_D$ was about 600 V, limited by the plate supply voltage of 1500 V and the power in the plate load resistor.

Control of the system is relatively easy, it requires only two feedback loops - a leveling circuit for the voltage and a beam position pick-up signal to keep the frequency (or phase) such that the beam is centred radially.

The DD-T would allow beam bunch manipulations , it means: in the synchrotron operation, non-sinusoidal wave forms could be used to "flatten" the bunch and improve the space charge limit, or shorten the bunch for fast extraction. In higher mode operation, sub-harmonic modulation could be used to preferentially accelerate one bunch for extraction.

The frequency range is wide enough to cover both synchrotron and low energy storage modes which requires deceleration to low energies without mode changes.

References

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