DESIGN AND EXPERIMENT OF A FREQUENCY REGULATION SYSTEM OF A HEAVY-ION CYCLOTRON D-BOX

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Abstract: A frequency regulation system of D-Box which is designed for a new Heavy-Ion Cyclotron is presented. The construction, stability and accuracy of the system are discussed. Experiment of the system has been done on a probative D-Box under the condition considered, and the results show that the performance of the system is satisfactory.

Introduction

In order to abtain beem current with high quality, the D-Box cavity of the cyclotron must be tuned to work at the same frequency as the driving signal which is used to form the accelerating electric field. Since the D-Box is very huge in structure and works within a wide frequency band, the whole frequency regulation system of D-Box is designed to be consisted of two sub-systems, the coarse tuning system and the fine tuning system, to meet the requirenment of high accuracy. The coarse system is a pre-tuning unit, by which the frequency band is selected and the relative frequency deviation $\Delta f/f$ is maintained to be less than 10^{-4} through regulating the position of a capacitance plate. Based on the pre-tuning result, the fine system is used to maintain the $\Delta f/f$ to be approximately 10^{-6} by regulating the angular position of a inductance ring within the whole working frequency band (6.5 MHZ to 14 MHZ).

Construction of the Fine Tuning System

The block diagram of the fine tuning system is shown in fig.1, and its mathematics model in fig.2.

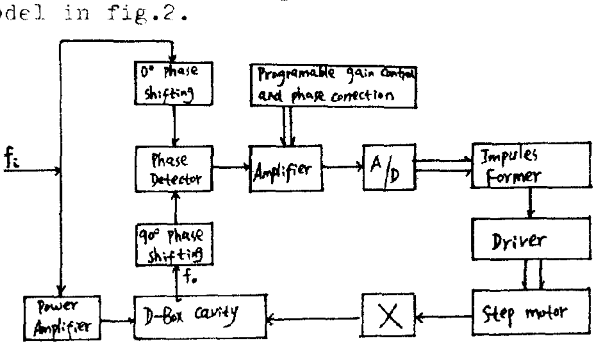

Fig.1 Block diagram of the fine system

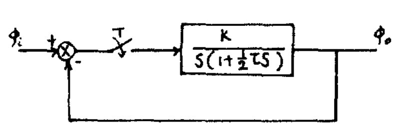

Fig.2 Mathematics model of the fine system

Practically we have k=1, τ=10 ms, T=500 ms and analysis shows that the system is stable. Since the transfer function of the inductance ring varies with frequency, a programable automatic gain control and phase correction circuit is connected with the main loop to asure the system to work stably and accurately within the whole working frequency band.

Experiment

Experiment of the system is done on a probative D-Box:

Experiment Condition

1) The Q value of the cavity is rather lower.

when f=6.5 MHZ, Q=800
f=10.0 MHZ, Q=3800
f=14.0 MHZ, Q=5000

2) Under normal atmospheric pressure, no cooling water.

3) Low power driving.

Experiment Contents

1) The deviation of the electric phase ϕ_e per step (0.2° mechanical angle) of the inductance ring, which determines the resolution and the tuning accuracy of the system.

2) The maximum deviation of ϕ_e when the ring is in the maximum angular position (±32.5°), which determines the maximum regulation range of the system and the exchanging sensitivity between the coarse system and the fine system.

3) The relationship between ϕ_e and the position of the capacitance plate; the minimum effective accuracy of the plate which should be less than half of the maximum tuning range of the inductance ring in terms of ϕ_e .

Experiment Results

1) The $\phi_e \sim \theta$ relationships are given in fig.3, 4 and 5, where

ϕ_e: electric phase angle
θ: mechanical angle of the inductance ring

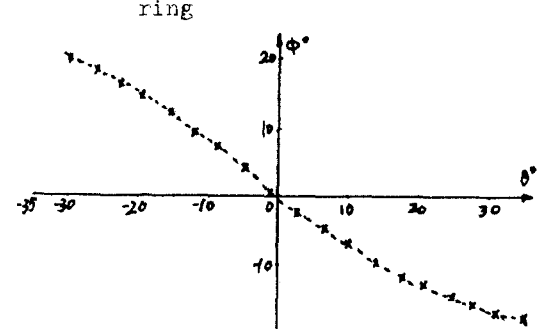

Fig.3 f=6.5 MHZ, Q=800

From the curves shown , we can get the approximate values of the deviation of ϕ_e per step (0.2°) of the inductance ring and the maximum ϕ_e when the ring is at its maximum angular position (±32.5°) as shown in table 1.

2) The relationships between ϕ_e and the position of the capacitance plate at diff-

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ferent frequencies are shown in fig.6, 7 and

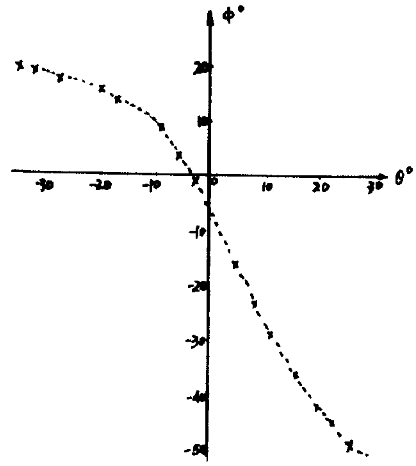

Fig.4 f=10 MHZ , Q=3800

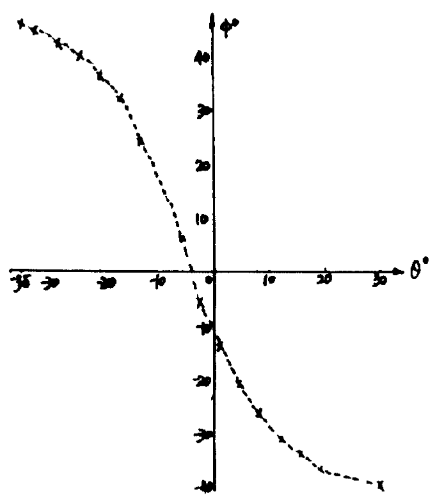

Fig.5 f=14 MHZ, Q=5000

Table 1

f(MHZ)	Q	$\phi_e\,(\theta=0.2°)$	$\phi_{e\,max}$
6.5	800	0.15°	±20°
10	3800	0.45°	±50°
14	5000	0.52°	±45°

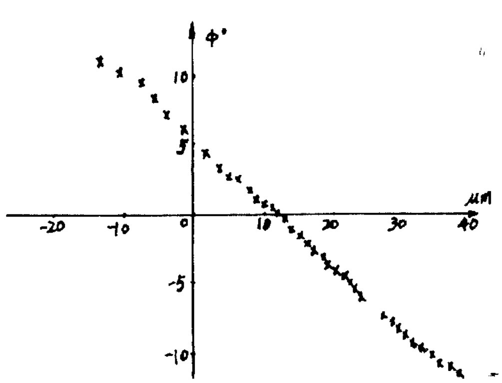

Fig.6 f=6.5 MHz, Q=800

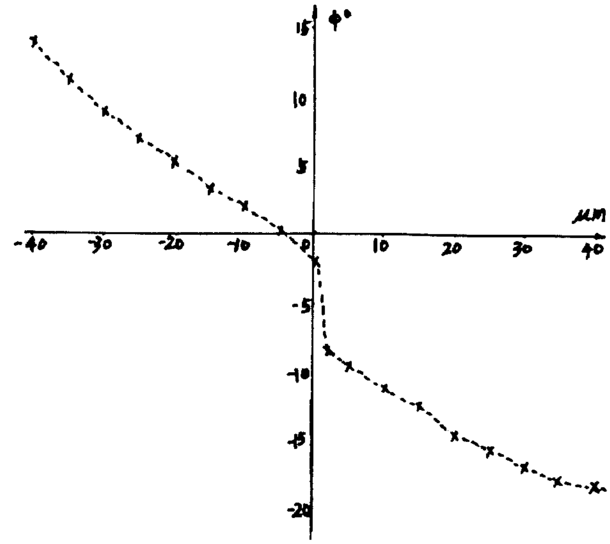

Fig.7 f=10 MHZ, Q=3000

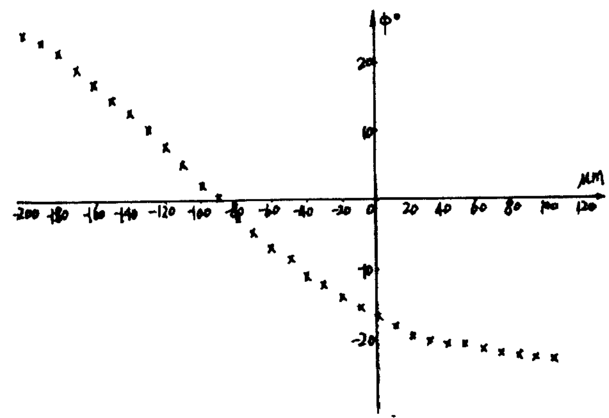

Fig.8 f=14 MHZ, Q=5000

8, from which we also get approximately

f(MHZ)	shifting of the plate(μm)	ϕ_e
6.5	10 μm	10°
10	10 μm	6°
14	10 μm	5°

The coarse system has a mechanical error about ±4μm statiatically.

Analysis of Experiment Results and Conclusion

The relationship between ϕ_e and the mechanical angular position of the inductance ring can be calculated as follows. According to the size and position of the ring, when $\theta=0.2°$

$$\phi_e(\text{theoratical value})=tg^{-1}(2Q\Delta f/f)=0.22°$$

where f=6.5 MHZ, Q=800 under working condition.

$$\phi_e(\text{experimental value})=0.17°$$

So, the relative error

$$\Delta\phi_e\%=20\%$$

when the ring is set at ±32.5°, the maximum deviation of ϕ_e is

$$\phi_{e\,max}(\text{theoratically})=\pm 27°$$

$$\phi_{e\,max}(\text{experimentally})=\pm 19°$$

So, the relative error

$$\Delta\phi_e\%=28\%$$

Based on above relative errors, when Q=7000, $\theta=0.2°$, we have

Φ_e (theoraticaaly)=1.9°

Φ_e (experimentally)=1.5°

and when θ =±32.5°

$\Phi_e$max(theoratically)=±77°

$\Phi_e$max(experimentally)=±71°

Φ_e changes 0.47°(experimental value) per 1μm of the capacitance plate displacement when Q=800 and 4.1° when Q=7000. Since the accuracy of the capacitance plate is ±4μm, the accuracy of Φ_e then is 4.1°× 8=33° accordingly. Because Φ_e max=71° when the inductance ring angular position is 32.5°, the minimum effective accuracy of the capacitance plate is half of the maximum tuning range of the inductance ring in terms of Φ_e, which meets the design requirenment.

Analysis and experiment results show that the performance of the system is satisfactary.