ALTERNATIVE CAVITY TUNING CONTROL FOR CRM CYCLOTRON

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Abstract

In the commissioning phase of CRM cyclotron, the RF cavity resonance frequency changes rapidly due to cavity thermal instability and electronics interference inside tuning loop. To solve the later issue, a set of cavity tuning control electronics has been re-designed, fabricated and tested in 2008. The new tuning control electronics and related experimental results will be described in this paper. A wide dynamic range phase detector with double balanced mixer was selected to detect the cavity detuning angle by comparing the phase difference between the cavity pickup signal and cavity driven signal. One analogue P. I. controller was utilized for loop regulation, taking advantage of shorter developing time. A current amplifier is also included to magnify the driven ability of the P. I. regulator for cavity fine tuning motors. A careful layout has been performed to avoid interference between RF part, DC small signal part and the current amplifier part. The desk experiment yields good phase detection sensitivity and acceptable stability after the mixer reaches natural thermal balance.

INTRODUCTION

The CRM cyclotron [1, 2] is a four sectors AVF cyclotron with two accelerates cavities installed in the valleys of magnet. The hot-arms for the cavities are interconnected beneath central region, therefore the cavities share one set of power coupling and tuning. For simplicity, the tuning system utilizes one cavity inductive pickup (Pickup-C) instead of using vector sum, for phase detection. The other pickup is located on the transmission line (Pickup-T1), near the capacitive coupling window, as shown in Fig.1.

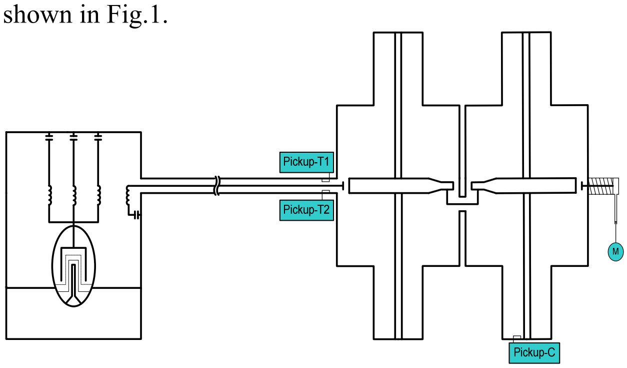

Figure 1: Illustration for CRM RF system.

Initial commissioning for the tuning loop was unsuccessful due to electronic-magnet interference, parasitic resonance introduced by transmission line and amplitude-phase cross talks on the PC Board of tuning loop. After the reason was clarified and understood, the transmission line length was adjusted to avoid parasitic resonance. In the mean time, a new version of tuning electronics was carried out to solve the interference issue, which is described in this paper.

TUNING SYSTEM

System Layout

The tuning capacitor is fixed by a spring to the vacuum chamber to counter-act the atmosphere pressure. The balance can be brought to another position (which means another cavity self resonance frequency) with a hydraulic device, driven by a DC motor. A tuning range of 0.08 MHz and monotonicity have been confirmed by offline measurement with network analyzer. The tuning mechanics is driven by low level circuits with a complementary current amplifier as the final stage.

The close loop regulation part for tuning circuits includes a phase detector, a proportional controller and a current amplifier. For phase detection module, the two signals are taken from the cavity and the directional coupler on transmission line respectively. The phase different between the two signals is set to 90 degree, by a phase shifter serial placed in the path, thus maximum phase sensitivity was achieved. The proportional controller and the integral nature of the DC motor form a P.I. controller for loop regulation. The loop gain can be changed by means of changing error signal gain with a variable gain amplifier before the controller. The current amplifier was included for load driven abilities.

As the cavity thermal deformation [3] can bring the self resonance frequency quiet a bit, a resonance searching circuits has been added to open loop part of the system.

The system diagram is shown in Fig.2.

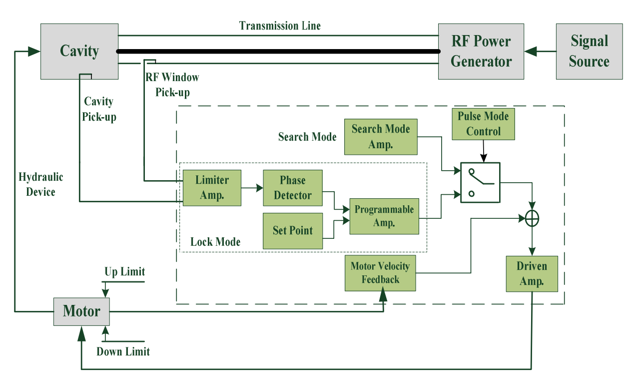

Figure 2: System layout.

The system can change state from open loop to close loop or from close loop to open loop automatically. This is achieved by means of envelop detection circuits, with the aid of amplitude loop. When the amplitude loop in CRM cyclotron LLRF system senses that the Dee voltage is lower than a threshold, it brings the RF into pulse mode.

When there's a chance to increase Dee voltage, the amplitude loop will take advantage of a positive feedback to change pulse duty circle, therefore bring the system towards continuous wave. The tuning circuits utilize a comparator to check the envelop output from the limiting amplifier at input stage of the phase detector. Then the signal is compared with a 90% duty circle average threshold, to change system between open loop and close loop automatically.

The Phase Detector

Two kinds of phase detector have been designed and tested respectively in the commissioning, which are Double Balanced Mixer (DBM) and Edge Trigger Phase/Frequency Detector (ETPD). As passive mixer, DBM takes advantage of excellent port isolation in broad band and large linear range due to the differential input which makes the differential current added with phase reversely. When DBM is used as phase detector, it provides higher phase detection efficiency and yields a higher sensitivity. ETPD compares signal in time domain, changing its states according to input signal edge. The output is averaged and amplified by differential amplifier to get a potential proportional to input phase difference.

Table 1:Parameter comparison of DBM and ETPD.

Parameter	DBM	ETPD
Phase Detection Range	$\pm\pi/2$	$\pm 2\pi$
Linearity	nonlinear	linear
Main Noise Source	Temp. drift	signal jitter
Sensibility	higher	lower

Usually, analogue phase detector has higher sensibility while the digital one has better linearity and large phase detection range [4]. The drawback of DBM based phase detector comparing to ETPD type one is that the monotonicity is not guaranteed, e.g. there's two zero crossing point, one is for 90 degree and another is 270 degree, with different signs of slop respectively.

Controller and Gain Issue

The controller for tuning loop includes a proportional controller, a DC motor and an assistant loop, as shown in Fig.3.

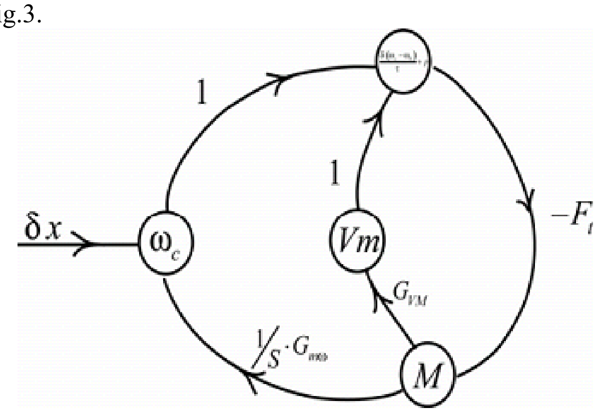

Figure 3: Signal flow chart.

The controller [5] provides a proportional negative feedback gain $-F_t$. As VGA was included, the gain can be adjustable. An assistant loop, consisting of a velometer and a voltage limiter, was added to dump the loop itself. Although the transfer function $G_{m\omega}$ from motor to resonance frequency is a quasi linear one, test shows that it's good enough for the loop.

Resonance Searching

The two modes, Search Mode and Lock Mode, change automatically by the control of a voltage comparator to check whether the system works in continuous wave. If the system is not working in CW, tuning loop will stay in Search Mode, thus the motor will move back and forth within up and down limit to search possible resonance frequency. Otherwise, tuning loop stays in Lock Mode. The motor moves according to phase difference of the two pick-ups, the bigger the faster, the smaller the slower. If phase differential equals the set point, the motor will stop to keep the resonance.

Setting Working Point

For a fixed frequency, transmission line with variable length will get different phase difference between input and output. To keep 90 degree phase difference between two pick-ups, length of transmission line has to be adjusted. The cavity resonance frequency varies due to thermal deformation caused by RF power feed into cavity. Therefore, for a variable frequency, transmission with fixed length gets the same phase shift. Working point circuit has been designed to save from the trouble of changing transmission line every time. Tuning error signal is yielded by differential amplification of phase detector and set point.

Signal Isolation and Routing

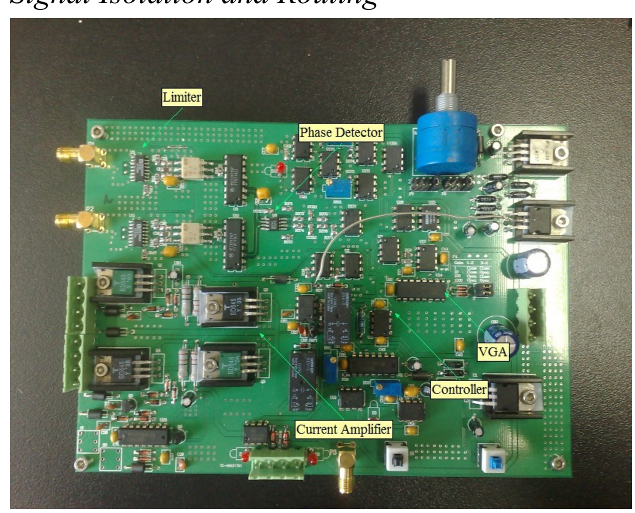

Figure 4: The tuning circuits.

Care had been taken to design the RF signal routing, e.g. parts between limiter and phase detector in Fig.4. The two RF signals routing before the mixer should be as symmetrical as possible and the length of routing equal to avoid phase difference in transmission. In the mean time, widen the distance between RF pin and ground and place the RF circuit closely, relatively concentrated and far from the other parts, to eliminate RF interference [6]. Iron cores for digital ground filtering were added before the connection with analogy ground.

COMMISSIONING

In offline test, two sinusoid waves (70.5MHz) with 90 degree phase differential serve as cavity pick-up and RF window pick-up. The test yields phase sensitivity of 12mV/deg while maintaining good phase stability of 0.017mV/20 min, after the mixer reaches natural thermal balance. For the digital phase detector a sensitivity of 6mV/deg is achieved.

The commissioning of the tuning loop begins with low loop gain in a relative low RF power case. The cavity is manually brought target frequency in hot condition before closing the loop. This step is necessary because the tuning range is limited comparing with frequency thermal drifting. Also, before closing the loop, cables for two pickups were calibrated, to get a 90 degree phase input for double balanced mixer phase detector. The set point for loop regulation was obtained with offline method, by temporally disconnecting the output to motor while changing phase shifter after the directional coupler. After getting a near zero error signal, the output was connected back to motor, which brings the system online. The loop gain is adjusted afterward, which yields a better tracing ability for tuning capacitor. Under the circumstance that less than 5kW power delivered from the F.P.A. to the cavity, the loop can stable the resonance frequency quiet well, while maintaining the residual detuning angle less than five degrees for all time.

However, it was found that, in the commissioning the loop is unable to stabilize the system any longer than one minute, for there’s too much sparking and a strange phase shift in the system. By diagnostics with spectrum meter, it was found that there was a strong side resonance near the fundamental frequency. The solution is to adjust the transmission line length to half lambda. By cold measurement using network analyzer, the two impedance side peaks was successfully shifted to upper and lower 2.3MHz [7]. Also the double balance mixer phase detector was changed to a type II digital one to guarantee the polarity of the feedback. After these modifications, the loop can work for longer time, but sometimes, it still can detune the cavity into a non-optimal condition, which needs more power than necessary to establish the required accelerating voltage. Investigation is undergoing to check the anode circuit of the final stage power amplifier for there’s a parasitic resonance sitting just 0.5MHz lower than the working frequency. In the mean time, modifications for the cavity to increase shunt impedance and investigations for sparking are taken into agenda.

SUMMARY

The new tuning circuits have been successfully tested at half power condition, yet the high power test shows that there’s still some problem. The reason for it is believed to be related with parasitic resonance in F.P.A. anode circuits, which will induce extra phase shift when output power exceeds a certain amount. However, as the circuits itself, the result can be considered as acceptable, for the reason that there isn’t evidence of interference and amplitude-phase cross talks any more. The next steps for CRM cyclotron RF system is to hunt down the parasitic and better the shunt impedance of the cavity.

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