BEAM PHASE MONITOR SYSTEM DESIGN FOR 100MEV CYCLOTRON

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Abstract

The beam phase monitor was designed to address phase slide issue, which can lead to significant beam loss inside 100MeV cyclotron. The measured phase information can be used to direct cyclotron magnetic field fine tuning. The system describes in this paper consists of the following part: 10 sets of beam phase pickup, a phase detector, a set of RF multiplexer and a phase shifter to compensate different phase offset generated by cables, connectors etc. The last one is a computer interface consisting of two 16 bits AD converters, one ARM 7 processor was included in this module to support RS232 connection and perform necessary signal process. All parts except the probe were located in one 3U VME standard crate, 8 slots were occupied and one user defined backplane was developed to carry necessary power supply lines and inter-connections. A preliminary test for the electronic system has been performed, and a good result was obtained in the procedure. Yet the leakage from RF cavity in the 100MeV cyclotron is still an undermined limitation for this application.

INTRODUCTION

In the BRIF project, a 100MeV H- cyclotron is selected as the driving accelerator [1]. The CYCIAE-100 is a fixed field, four sectors AVF cyclotron. With two cavities installed in the valleys [2], beam will be accelerated 4 times per turn. One of the other valleys will be selected to install 10 sets of phase probes, beneath the trim coils, as close as possible with respect to mid-plane to get maximum signal to noise ratio. The test stand for phase probe system in CRM cyclotron is shown in Fig. 1.

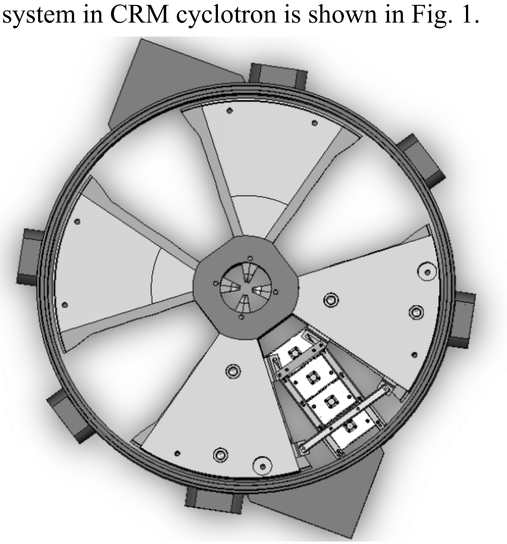

Figure 1: Test stand for phase probe (in CRM cyclotron).

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The signal to noise ratio is a critical issue for phase probe, however it's related to the asymmetries of RF system. The most significant noises come from the accelerating structure located in the neighbouring valley. The RF field leakage can cause a noise orders higher than the signal itself. Typically, there are two ways to suppress this kind of noise.

One is taking advantage of the coupled signal form RF structure is 180 degree out of phase for the upper and lower pickup, in the mean time, the signal generated by beam are in phase for the two pickup. Therefore summing can increase the SNR significantly, if the pickup electrode, signal path before combiner and the combiner amplitude/phased balance are well matched for upper and lower pickups [3].

The other way is to use low frequency chopper to modulate the beam, in this case the chopped beam will create sidebands (with frequency shift equal to chopping frequency) on the pickup, where the accelerating structure has no noise contribution. A high Q band pass filter is necessary for this scheme to filter out cyclotron RF system components. Down to tens of nanoampere beam phase measurement are feasible by employ this method and network analyzer [4].

The project adopts the first method, as whether the chopper system is available or not remains unknown for the moment. Therefore, this design follows the strategy to suppress fundamental and taking 2nd harmonics for phase measurement.

MEASURING SYSTEM

System Layout

Inside the cyclotron, when the charged beam enters/leaves the slit from by the pickup electrode and shielding ground, the mirror charge of the beam will excite a pulse signal [3,5,6]. Such a signal in frequency domain contains fundamental, second, and other high harmonics of cyclotron RF. The signal from upper and lower pickup electrode will be sum up in a zero degree power combiner to eliminate fundamental and enhance 2nd harmonic. An attenuation of about 20 dB on the fundamental RF frequency is expected to be obtained in this way [4].

The output goes through a bunch of high isolation RF switches, and then treated by phase detector, compared with cyclotron 2nd harmonics reference signal, yields in phase and quadrant phase DC components. These two signals are sampled by AD converter, converted to phase by ARM-7 processor and send to PC via RS-232 communication protocol. The ARM processor will response for: Select different pairs of probe for measurements; Set different phase offset for DDS to compensate cable miss-alignment; Beam on/off line phase correction; Data processing, communications etc. The reference RF signal is taken from RF system Master oscillator carried by low phase noise cables. Analogue phase lock loop was selected to bring 10MHz signal to 400MHz one for driving the DDS. The DDS is controlled by the ARM-7 processor, generating 2nd harmonics of RF with different phase offset corresponding to the probe selected for measurement.

All the electronics located in one 3U VME standard crate, 8 slots was occupied for different modules and one user defined backplane was developed to give necessary power supply support and inter connections. The system layout was shown in Fig. 2 below.

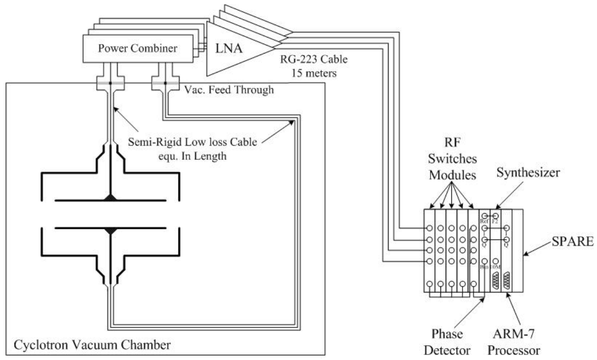

Figure 2: System layout.

The Phase Probe

In the CYCIAE-100 cyclotron an array of 15 non-destructive beam phase pick-ups will be installed. Each probe consists of two electrodes placed symmetrically with respect to the median plane.

To prevent signal reflected back and forth, 50ohm characteristic impedance is necessary for pike up strip lines [7].

$$d = \frac{W}{\frac{2}{\pi}\left\{B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right]\right\}} \quad (1)$$

$$,where\ B=\frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

Where W is the Inner conductor width, in our case is 50.7mm. ε_r is 1.0 for vacuum and target impedance is 50 ohms. These parameters yield a height of 10.33 mm to obtain the required impedance.

To give initial design parameters for electronic design, the structure together with 1uA Gaussian distributed beam were simulated using 3D FITD codes, yields an output power spectrum on 50ohm load. The velocity of the beam is obtain by

$$\beta = \sqrt{\frac{2\mathrm{w}}{m_0}} \quad (2)$$

Where w is the energy in eV. $m_0 = 938.26\times10^6\ eV$. The length for Gaussian distributed bunch is assumed to be 10mm. The charge is set to 1.42E-14 Colombo (per bunch) corresponding to beam current 1uA. The phase probe modelling structure and simulation results is shown in Fig. 3 and Fig. 4.

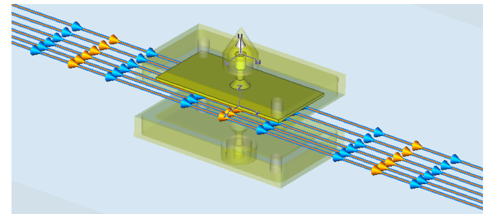

Figure 3: Phase probe 3D model.

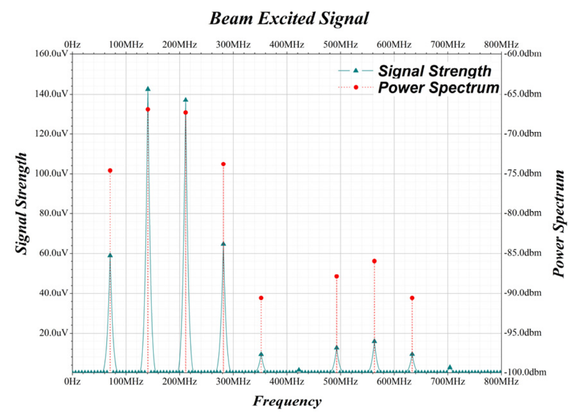

Figure 4: Power spectrum (6 beam bunches).

Reference Clock and Phase Compensation

Considering, in the project only a 10MHz oscillator (from RF, phase relevant to the accelerating cavity) is available for beam diagnostics, there is not too much choice but to implement a synthesizer to obtain reference clock. On the other hand, the Direct Digital Synthesizer is a nice technology for its high precision phase shift ability. Taking these two points, a DDS were selected to generate required frequency, in the mean time also response for compensating different RF transmission path generated phase offset.

Although DDS has a phase noise reduction of $20\log(f_{out}/f_{in})$, the PLL act in an exactly versus way. In our case, when using PLL to obtain 400MHz from 10MHz, a phase noise degradation of 32dB is generated, then the noise will suppressed about 15dB by DDS, therefore in total 17dB degradation of phase noise is expected. Specially, in this application, the cut-off frequency of PLL loop filter is set higher than the phase detector IF filter, to reduce the “peaking” phase noise phenomena.

Phase Detector

For phase detection, double balance mixer is selected for its low price, high phase detection sensitivity. A six stage logarithmic amplifier was included to increase system dynamic range. Also the +7dbm phase detection mixer were driven in saturation mode to avoid

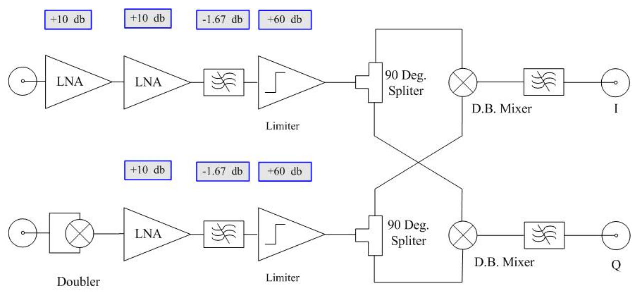

Figure 5: IQ detectors block diagram.

amplitude/phase cross talks while performing detection. The block diagram for phase detection is shown below.

Thermal Noise

Although thermal noise is not the key issue in noise contribution in such an application, the design still takes a strategy to minimizing the SNR degradation along the signal transmission path. The way is to add a preamplifier as near as possible, in the mean time one might prefer to make the system easy for maintenance. Considering this two conflict goal, it's decided to add the preamplifier outside of the vacuum chamber, right after the power combiner.

Software Correction

Software correction algorithm takes care of the system residual error, which is related with RF leakage. It assumes that the 2nd harmonic RF generated by final stage amplifier is time stable. By comparing system output phase without and with beam, it will generate a compensated vector, which is only related with beam itself [3].

IMPLEMENTATION & TESTING

The preliminary measurement test with beam will be carried on the Central Region Model (CRM). The RF fundamental frequency is $70.487 MHz$.

The Phase detector, RF switches and ARM 7 processor board is now finished soldering. All the modules have been integrated in the VME crate as shown in Fig. 6. Functional tests is then been performed on each board, the results are described below.

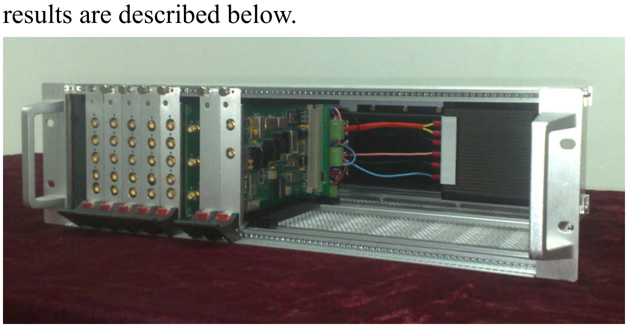

Figure 6: The phase monitor system for CRM cyclotron.

For power modules, in order to have a lower EMI environment, linear regulated power supply module is selected for the system with stability better than 1.5×10^{-5} .

Also, sensitivity test for phase detector has been performed, using a phase shifter to simulate the signal from pickups. In the experiments, under $104MHz$, the maximum phase shift can get in is about 18 degrees (measured by network analyzer). When the phase shifter is at one end, the in phase output is $I_{out} = -322mV$, while the quadrant output is $Q_{out} = -677mV$; when phase shifter is at the other end, the output is $I_{out} = -514mV$ and $Q_{out} = -544mV$. Therefore, the corresponding phase measurement result is coherent with the one get by network analyzer.

For the RF switch modules, using signal generator and spectrometer, the channel to channel isolation about $-40db$ is confirmed. The off isolation for each channel is also tested to be around $-55db$.

ARM 7 processor board has been tested, parts of software has been finished, including the data acquisition and part of the data processing etc. The communications between microprocessor and computer can be completed.

SUMMARY

The design for beam phase measurement system has been finished with positive bench tests results for individual modules. For the moment, except the DDS board, all the other electronics are ready for testing in CRM cyclotron. The mechanical part e.g. the cables and the probes are waiting to be scheduled for installation. Cable calibration and probe alignment will be done afterwards.

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