COMMISSIONING & OPTIMIZATION OF INDUS-2 RF SYSTEM FOR 2 GEV/100MA

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Abstract

Indus-2 is a synchrotron light source designed for 2.5 GeV / 300mA. Four RF cavities each excited by individual RF station has been used for beam acceleration from 550Mev to 2.5Gev and synchrotron radiation loss compensation. Each station of Indus- 2 RF system consists of Klystron amplifier, solid state driver amplifier & Low Level RF (LLRF) to maintain the field inside the RF cavity stable. Commissioning of Indus-2 RF system at 2 GeV/ 100mA requires proper optimization of RF parameters.RF phase optimization for maximum injection current and for higher beam energy was done. This insures the equal RF power distribution amongst all operating RF stations at higher energy with good injection rate in the beginning. Coupling coefficient (β) of all cavities was adjusted to 2.8 to have proper operation at higher energy & higher beam current. For stability of the beam RF cavities resonance frequency was kept 1.5 kHz lower than the excitation generator frequency. RF Cavities which are not in operation are detuned by 200 kHz to have less effect of beam loading. For smooth ramping of beam from 550 MeV to 2GeV auto ramping profile implementation was done. Amplitude control Loop (ACL) and Phase control Loop (PCL) were also optimized. After this optimization 175 mA beam current at injection and 129 mA at 2 GeV has been successfully achieved.

COUPLING COEFFICIENT

In all four cavities, Inductive Loop couplers are used for RF power coupling. Input Impedance at the input port of RF cavity changes with the change in beam loading condition, perfect match is obtained at the specified beam power and hence specific current at any energy. The input mismatch results the poor RF efficiency and over heating of the ceramic window. Therefore proper coupling coefficient adjustment of each RF cavity is needed for maximum power operating efficiency and coupler reliability. The coupling coefficient (β) of the coupler can be changed by changing the magnetic flux linkage through the loop area. The optimum-coupling coefficient for an RF cavity under beam loading is given by

$$\beta = 1 + \frac{P_b}{P_c}$$

Where P_c, and P_b are the RF power losses in the cavity wall & RF power for the beam loading respectively. β of each cavity was adjusted to 2.8, this will provide 250 mA beam current operation at 2 GeV (P_b = 38.8 kW) with 375 kV gap voltage in each cavity (P_c = 21.3 kW). Two graph of loaded quality factor and input VSWR during β measurement of Indus-2 RF cavity are shown in fig.1 below.

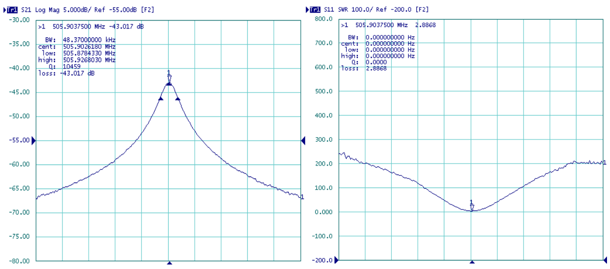

Figure1: β measurement of Indus-2 RF cavity.

PHASE OPTIMIZATION

Particle should reach the RF cavity at the proper phase for proper acceleration & hence acceptance in the ring. At injection if the phase is not proper the acceptance efficiency reduces and the maximum stored current in the ring also gets limited. Equal contribution from four cavities at higher energy level is very important, improper phase will cause the imbalance of the power among different station hence will limit maximum stored current and reduce life time of the stored beam. Phase optimization was done in two-step, first at injection with sufficient RF signal for control loops to operate. Second at 2GeV energy to make sure all station contribute equal power to the beam. Synchronization of operating RF stations with respect to Booster Synchrotron RF and between the stations is done so that the proper injection rate as well as equal power distribution among stations is achieved. Phase synchronization of all four cavities from injection to 2GeV was done for 100mA operation.

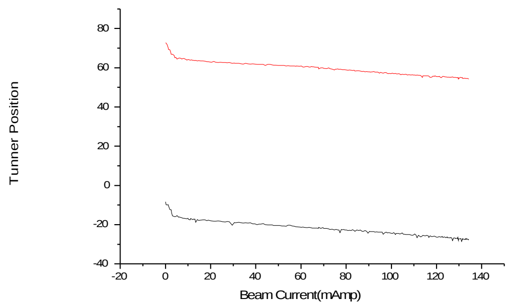

Figure 2: Tuner Movement showing the same beam loading in both RF stations.

DETUNING

INDUS-2 RF cavities are set to operate at 50°C cooling water temperature .Independent LCW chiller units are provided for each RF cavity to operate at any temp.from 35°C to 85 °C with the accuracy of ±0.1 °C of the cavity reference temperature.Change in resonance frequency of RF cavity occurs because of thermal & beam loading. Frequency sensitivity with temperature is around 8.5 kHz/°C for ELETTRA make bell shaped RF cavities. Due to beam loading effect the resonance frequency of the RF cavity changes with the stored beam current. To compensate this beam loading the cavity gets detuned which is kept on tune at the desired frequency by frequency tuner loop. The amount of detuning depends on the amount of beam power from the station which can be calculated as follows.

$$\frac{\nabla f}{f} = -\frac{P_b}{2Q_0 P_c}\tan(\phi_s)$$

f and Q_0 are resonant frequency and the unloaded quality factor of the cavity. ϕ_s is the synchronous phase.

To take care of Robinson instabilities RF cavities in operation are kept detuned below resonance by 1.5 KHz. With this detuning the reflected power increases. A plot of reflected power with detuning is shown in the fig 3 below. To avoid the beam loading due to beam induced voltage in the cavities which are not in operation they are kept 200 kHz detuned.

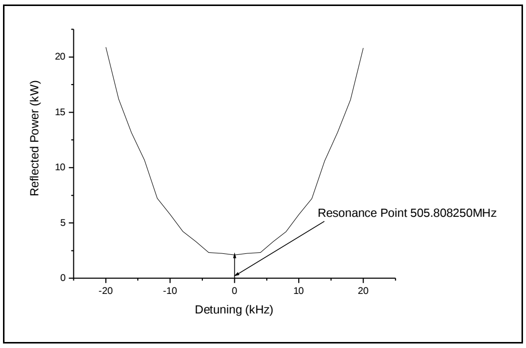

Figure 3: Reflected power with detuning

ACL AND PCL OPTIMIZATION

Amplitude and phase control loops (ACL & PCL) are used to keep the electromagnetic field inside the RF cavity stable within the specified limits. Amplitude loops are designed with amplitude stability ±1% and phase stability of ±1 deg. Results of amplitude and phase stability with the beam current at 2GeV of one day operation is shown in fig.4 , showing amplitude stability of +/- 0.7% & phase stability of +/- 0.3 deg.

AUTO RAMPING

In Indus-2 ring energy of the beam is ramped from 550Mev to 2 GeV, cavity gap voltage requirement at injection energy is very low of the order of 2kV where as the gap voltage requirement at 2 GeV is much higher of the order of 700 kV . Initially cavity gap voltage ramping was done manually during regular shift duty operation. An auto ramp profile as shown in Fig. 5 below was generated and implemented for smooth ramping of beam energy avoiding chance of beam kill due to manual error.

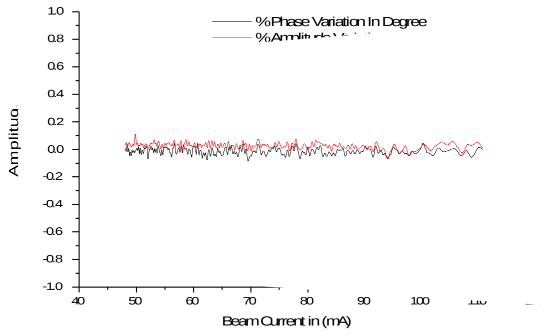

Figure 4: Amplitude and Phase stability with beam current.

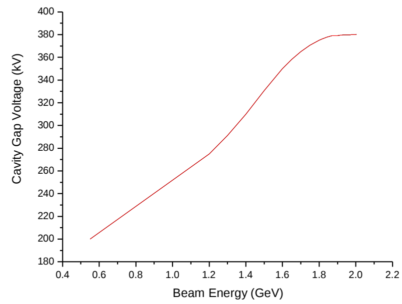

Figure 5: Auto ramp profile.

CONCLUSION

After the optimization of different RF parameters maximum 175 mA beam current at injection and 129 mA at 2 GeV has been successfully achieved. Indus-2 RF system is since then operating in round the clock shift operation and is being regularly operated at 2Gev/100mA.

ACKNOWLEDGEMENT

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REFERENCES

[1] Nitesh Tiwari, Pritam S. Bagduwal, M. Lad, P.R. Hannurkar, “Synchronization of RF fields of Indus 2RF Cavities For proper injection and Acceleration of beam”, INPAC’09, INDORE,INDIA, Feb2009