A.1: Indus-2 synchrotron radiation source successfully operates at 175mA beam current at 2.5 GeV

The indigenously developed Synchrotron Radiation Source Indus-2 had been in routine operation at 2.5 GeV beam energy with ~125mA beam current in round the clock mode for providing the stable and intense synchrotron radiation beam to the beam line users. In order to provide more intense synchrotron radiation, it was decided to increase the stored beam current to 175 mA at 2.5 GeV. For achieving this, the installed RF power capacity of indigenously developed solid state RF amplifiers feeding four Indus-2 RF cavities were increased up 200 kW providing total RF power of 250 kW. During initial trials for the high beam current operation, longer accumulation time due to beam current saturation and partial beam loss during beam energy ramping posed initial challenges. Subsequent effort to reach higher beam currents encountered new challenges like increase of temperature at few locations in the vacuum chambers and vacuum deterioration in few sections mainly in the RF cavities, which led to trip the main RF system followed by the beam dump.

In order to achieve the continuous and fast beam accumulation, the bunch filling patterns, Higher Order Modes (HOM) in Indus-2 RF cavities as well as the betatron tunes were optimized. Out of total 291 RF buckets, only 194 buckets ($2/3^{rd}$) were filled to mitigate the problem of ion trapping. Indus-2 RF cavities are equipped with precision water cooling system and Higher Order Mode Frequency Shifter (HOMFS) to avoid interaction of beam with these harmful HOMs. The temperatures of precision chillers of RF cavities were optimized to 50.0°C (cavity #1), 47.5°C (cavity # 2), 51.0°C (cavity# 3), 57.5°C (cavity #4) for suppressing longitudinal modes L4 and L5. This helped in accumulation of higher beam current at injection energy. During ramping, the amplitude of L1 mode was also observed to be more than its normal value causing partial beam loss, this was suppressed by optimizing HOMFS positions in two RF cavities. With this optimization, the beam loss was reduced. Theoretical Frequency Map Analysis (FMA) for the operating tunes was carried out to study the lattice sensitivity to the nonlinear components of magnetic forces in terms of tune diffusion rate. It was found that for the old operating tune point [9.268, 6.147], there was a higher tune diffusion rate at horizontal aperture ~18mm, due to the fourth order resonance. The operating tune point was changed to [9.272, 6.157] at which, the tune diffusion rate was comparatively small, resulting in more suitable operating tune point for better beam injection and the lifetime. With this optimization, Indus-2 ring was smoothly filled with the stored beam current of 240 mA at injection energy on 15^{th} December-2013. During beam energy ramping, significant beam loss was observed from injection energy up to 700MeV. In order to minimize partial beam loss, tune point was adjusted using two families of quadrupoles, namely Q2F and Q3D, to keep them away from the harmful optical resonance lines as shown in Fig. A.1.1. The partial beam loss was further minimized by applying the Bunch by Bunch Instability Feedback Control in the vertical plane. During further beam energy ramping trials, at higher beam current, the temperature at the vacuum chamber at the septum magnet location was found increasing rapidly which tripped RF when the beam energy reached ~ 2.1 GeV.

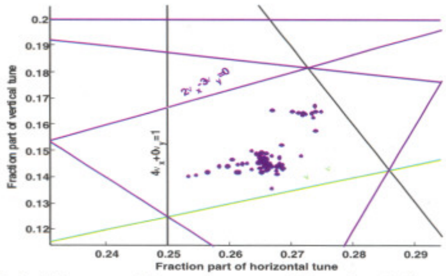

Fig.A.1.1: Measured betatron tune (blue dots) during beam energy ramping.

Careful analysis of the orbit data gathered during ramp revealed that, the vertical closed orbit was shifting at the location of the septum. However, rise in temperature was found to be within limit for the acquired orbit position at 1.7 GeV beam energy.

To arrest the temperature rise, vertical orbit position of beam, throughout the circumference, attained at 1.7 GeV was maintained up to 2.5 GeV by optimizing the strength of all vertical steering magnets. On reaching at 2.5 GeV beam energy during the stored beam condition, the temperature was found to be increasing due to the heating generated by intense synchrotron radiation. To minimize the temperature rise, the closed orbit was minimized throughout in the ring. During switch over to the minimum orbit, vacuum at various locations in Indus-2 ring deteriorated due to the exposure of synchrotron radiation to the new unexposed surfaces of the vacuum chamber which generated the trip signal to the RF for beam dump. Therefore, instead of going to minimum orbit everywhere in the ring, a local vertical bump at the location of septum was applied, which resulted in controlling the temperature rise of the vacuum chamber in the septum location without increase in the residual gas pressure. Additionally relative phases of RF cavity voltages and gap voltages were also optimized at injection energy and during ramping so as to provide optimum resultant voltage for beam at 2.5 GeV with higher stored current. Incorporating all these efforts, Indus-2 ring was filled with the maximum beam current ~213mA on 26^{th} December-2013. Beam energy ramping was started with ~212mA and finally, 179mA stored beam current was achieved at 2.5 GeV. This trial was repeated on 20^{th} January 2014, in which maximum beam current of 181mA was successfully achieved at 2.5 GeV as shown in Fig. A.1.2.

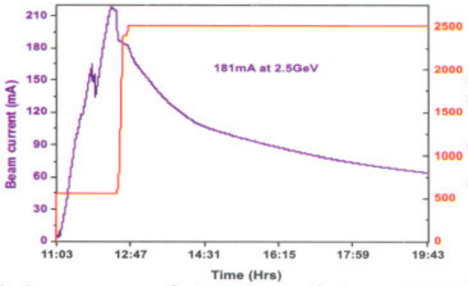

Fig.A.1.2: Beam current during accumulation at 550MeV, beam energy ramp to 2.5GeV and natural decay at 2.5GeV.

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