A.1: Indus-2 achieves 150 mA beam current at 2.5 GeV

Indus-2 has been in operation in round the clock mode at 100 mA beam current and 2.5 GeV beam energy, providing stable and intense synchrotron radiation beam to the users. The emitted synchrotron radiation intensity is directly proportional to the stored electron beam current. As a further upgrade, it was decided to increase the stored beam current in Indus-2 to 150 mA beam current at 2.5 GeV. In order to achieve this target, the total RF power of the three indigenously developed solid state RF power amplifiers was increased to 175 kW, which was used to drive three RF cavities. The fourth RF cavity was driven by 50 kW klystron. Thus total RF power available was 225 kW. The energy ramping profile was also properly optimised to control the beam optics during the beam energy ramp cycle with higher stored beam current. During the beam energy ramp, the strengths of all magnetic elements were increased synchronously to maintain constant betatron tune and chromaticity. Even with the utmost care taken to maintain the synchronism between the strength of different magnetic elements during beam energy ramp, due to the various sources of errors, the tune and chromaticity may change. It was observed that betatron tune comes in the vicinity or even crosses the dangerous resonance lines, leading to partial or full beam loss. This was investigated using the online betatron tune data and its footprint on the tune diagram. In order to achieve lossless beam energy ramp it is important to keep the betatron tune away from the dangerous resonances. During the normal beam energy ramp with 100 mA stored beam current, the beam shaking was observed between 550 MeV to 700 MeV. In the beam energy ramp trials with higher beam current, the beam current gets partially lost mostly in the energy range of 550-700 MeV. After investigating the measured betatron tune data it was observed that the tunes were approaching towards dangerous third integer difference resonance of $\nu_x-2\nu_y=-3$, where ν_x and ν_y are respectively the horizontal and vertical betatron tunes. When beam comes in the vicinity of this resonance its transverse beam size increases. During the beam energy ramp, the beam is very sensitive to any perturbation and the betatron tune near this 3rd order difference resonance enhances perturbation to the beam. The transverse coupled bunch mode (TCBM) measurement supports this phenomena and the beam is found to be excited in the zone of 550-700 MeV. Also the beam shaking at synchrotron light monitor (SLM) adds another confirmation of the observed phenomena.

Based on the measured tune, beam energy ramp file was modified to keep the tunes away from the resonance. The tune was maintained at (9.265, 6.167) throughout the cycle of beam energy ramp. The currents of two families of quadrupoles were modified to keep the tune constant all along the ramp. On January 23, 2013 with the modified ramp data file, 155.8 mA was achieved at 2.5 GeV. In this trial, the beam was accumulated up to 181.7 mA at 550 MeV and beam energy ramp took ~ 14 minutes to reach 2.5 GeV beam energy. Small and undesired beam shaking at SLM was again observed. The betatron tune was varying with small amount and crossing the 5th order resonance. In the next ramp trial, the ramp file was further fine-tuned to avoid the crossing of this resonance. A lossless beam energy ramp to 2.5 GeV was achieved on January 24, 2013. During the trial operation, a beam current of 165 mA was stored at injection energy of 550 MeV and a beam current of 158 mA was achieved at 2.5 GeV after initiating the beam energy ramp. The beam could be stored for nearly 24 hours. Figure A.1.1 shows the beam current during accumulation at 550 MeV, beam energy ramp to 2.5 GeV and beam current decay in the stored condition at the final beam energy of 2.5 GeV. The betatron tune in normal ramp and ramp after tune corrections after two iterations are shown in Fig. A.1.2.

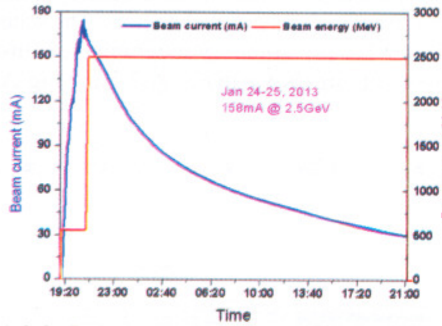

Fig. A.1.1: Beam current during accumulation at 550 MeV, beam energy ramp to 2.5 GeV and natural decay at 2.5 GeV.

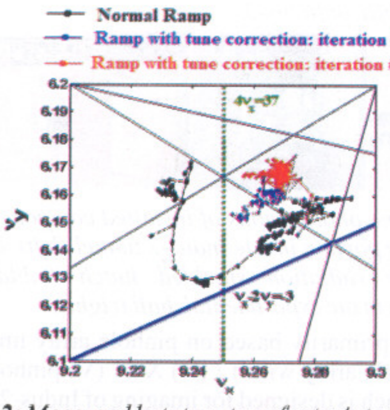

Fig. A.1.2: Measured betatron tune footprint on the resonance diagram with normal ramp and two iterations of tune correction. Bold blue lines show the 3rd order resonance, dotted green line shows the 4th order resonance and thin blue lines show the 5th order resonances.

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