DEVELOPMENT OF THE SYSTEM FOR LONGITUDINAL COUPLED BUNCH MODES MEASUREMENT AT INDUS-2

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Abstract

In a circular accelerator, beam instabilities are intensity-dependent collective effects that arise because of the electromagnetic wake fields generated by the beam as it interacts with its environment. These instabilities limit the high current operation in the accelerator and degrade the performance of synchrotron radiation beam. Indus-2 is a synchrotron radiation source at RRCAT, Indore having design beam current of 300 mA and 2.5 GeV beam energy. Beam intensity signal obtained from wall current monitor (WCM) is used to measure the longitudinal coupled bunch modes (CBM). To study the beam instabilities, an automated software has been developed which acquires the beam intensity spectrum for measurement of coupled bunch modes. The software has option of complete CBM scan, scanning near the significant RF cavity higher order modes (HOM) and scanning of user-selected modes. The scanning time for complete 291 modes is ~5 minutes. In this paper, we describe the measurement system, features of the developed software and some measurement results on Indus-2 machine.

INTRODUCTION

To achieve high luminosity and brightness in a circular accelerator, intense particle beam with number of bunches is required. Collective effects or collective instabilities must be taken into the account where higher beam intensity is desired. Indus-2 is a synchrotron radiation source at RRCAT, Indore, India having design beam current of 300 mA and 2.5 GeV beam energy. Presently Indus-2 is being operated at 100 mA beam current and 2.5 GeV beam energy. Study and detailed understanding of the nature and cause of collective instabilities with corrective measures are important for the successful operation of accelerator. Coupled bunch collective effects include the effects which are associated with electromagnetic fields generated by the collection of all particles in a beam [1]. In a circular accelerator, if the interaction of particle beam with the environment increases the collective effects, the particle beam becomes unstable and these instabilities are called as coupled bunch instabilities. The effects of coupled bunch instabilities on synchrotron machine performance are increased emittance of beam, increased beam size, possibility of beam loss, saturation of maximum beam current and lifetime reduction etc.

Collective instabilities can be measured by the amplitude of transverse and longitudinal oscillations of charged particle beam by analyzing the beam spectral components. The transverse (betatron) and longitudinal (synchrotron) oscillation are normally damped by natural damping mechanism. The equation of motion of particle in circular accelerator is given as

$$\ddot{x}(t) + 2D\dot{x}(t) + \omega^2 x(t) = 0 \qquad (1)$$

Where, D is the natural damping factor and ω is synchrotron or betatron frequency. The solution of the above equation is a damped oscillation for ω >> D as shown in the Fig.1. This is the condition of a stable beam.

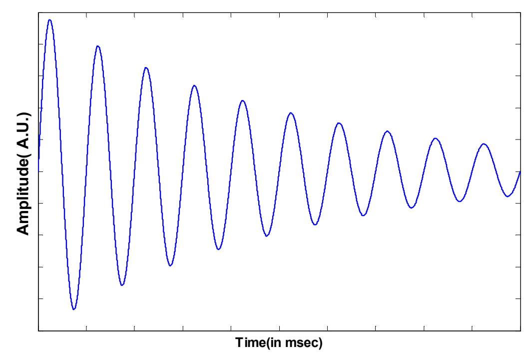

Figure 1: Natural damping of beam oscillation.

The electromagnetic fields created by the interaction of bunches of charged particle with metallic surroundings in an accelerator are called wake fields. The wake fields act back on the bunches and increases growth of longitudinal and transverse oscillations. In the presence of wake fields the equation of motion of particle in circular accelerator can be written as

$$\ddot{x}(t) + 2(D - G)\dot{x}(t) + \omega^2 x(t) = 0 \qquad (2)$$

Where, G is growth rate factor because of wake fields and D is the natural damping factor. The solution of the equation in the presence of wake fields depends on the growth rate. If growth rate is less than damping rate the resultant oscillation will be damped as shown in Fig.1. If growth rate is higher than damping rate the resultant oscillation starts growing and the beam becomes unstable [2]. Figure 2 shows the condition of unstable oscillations. These instabilities can be observed by longitudinal and transverse oscillation frequency in the beam spectrum.

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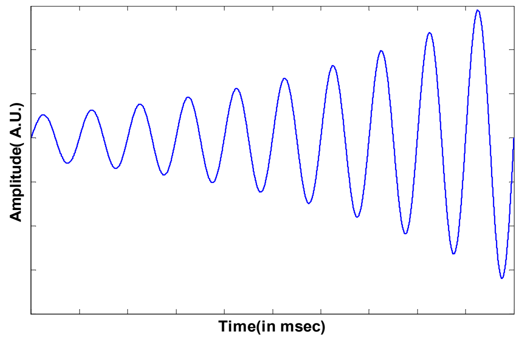

Figure 2: Beam oscillation growth because of instability.

The longitudinal oscillations of beam create angle modulation in the beam pickup signal. The modulating frequency is decided by the longitudinal mode of oscillation. In longitudinal dipole mode, modulating frequency is given by synchrotron frequency of machine and harmonic of revolution frequency. In longitudinal quadrupole mode, modulating frequency is given by twice of the synchrotron frequency and harmonic of revolution frequency. Figure 3 shows the typical beam spectrum with the longitudinal dipole and quadrupole oscillation around a revolution harmonic.

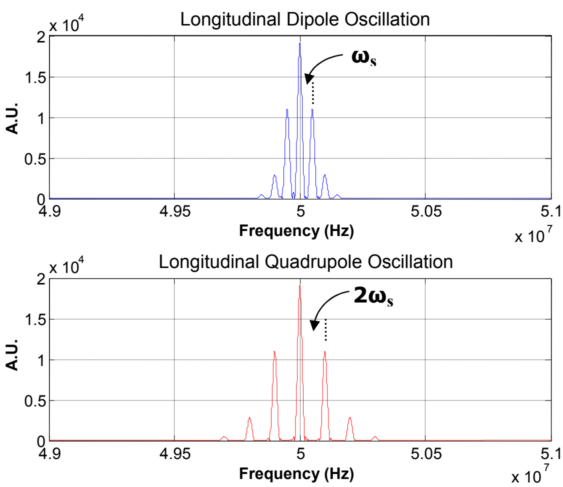

Figure 3: Beam spectrum with longitudinal oscillation.

SYSTEM DESCRIPTION

The block diagram of longitudinal coupled bunch measurement system is shown in Fig.4. For observation of longitudinal CBM, the wall current monitor (WCM) of Indus-2 ring is used to pick up the beam intensity signal. The pickup signal of WCM is fed to a spectrum analyzer for producing the beam spectrum. Spectrum analyzer has been chosen for this purpose because the dynamic range required for measurement is more than 50 dB. GPIB interface is used for acquiring the beam spectrum data from spectrum analyzer to PC for extracting the information about CBM. The PC is also connected with the machine control system to acquire the beam information namely beam current and beam energy.

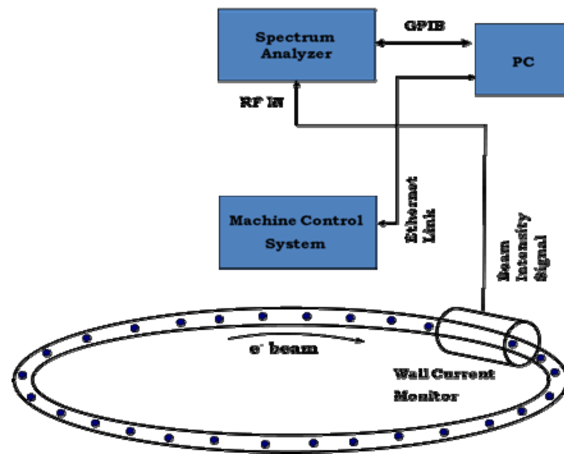

Figure 4: Scheme of longitudinal coupled bunch measurement system.

SOFTWARE DESCRIPTION

Due to excitation of coupled bunch modes, frequency components generated in the beam spectrum can be given by

$$\omega_m = \omega_{rev}\,(rN \pm (m + \nu_s)) \qquad (3)$$

Where, ω_m is frequency present in the beam spectrum due to coupled bunch mode no. m, r is the harmonic number, N is total no. of buckets in circular accelerator and ν_s is synchrotron tune value [2]. For Indus-2 total no. of buckets (N) is 291 and m is 0 to 290. The RF frequency of Indus-2 is 505.812 MHz. The frequency range of scanning of all 291 modes is taken as 505.808 MHz to 757.84 MHz.

Manual measurement takes long time to scan wide bandwidth with the fine frequency resolution, hence it is not practical to analyse all coupled bunch modes at identical beam conditions. For automation of this process, a MATLAB based software has been developed to interface the spectrum analyzer and acquire the beam spectrum data from spectrum analyzer into PC. Following features are available in the software:

- Scanning of beam spectrum for all 291 the coupled bunch modes.
- Scanning of beam spectrum for selected frequency range.
- Scanning of beam spectrum near the measured HOM frequency of RF Cavities.
- Saving of the images of beam spectrum where coupled bunch modes are excited.
- Saving of the frequency and amplitude of coupled bunch modes in MS-excel file.

After acquisition of the data, software locates the peaks in beam spectrum corresponding to the coupled bunch

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modes and calculates the amplitude of coupled bunch modes. The mode number, frequency of coupled bunch mode and the amplitude of excitation are displayed on graphical user interface of software. Three different options are provided in the software to scan the coupled bunch modes (CBM). In the first option, software scans all 291 CBM in beam spectrum. Scanning time is ~280 seconds in this mode. In the second option, software scans the CBM in given frequency range. The scanning time depends on the frequency span. In the third option, software scans the CBM in the vicinity of HOM frequency of RF cavities. The eight numbers of significant longitudinal HOM frequencies are selected for this scanning. Scanning time is ~80 seconds in this mode.

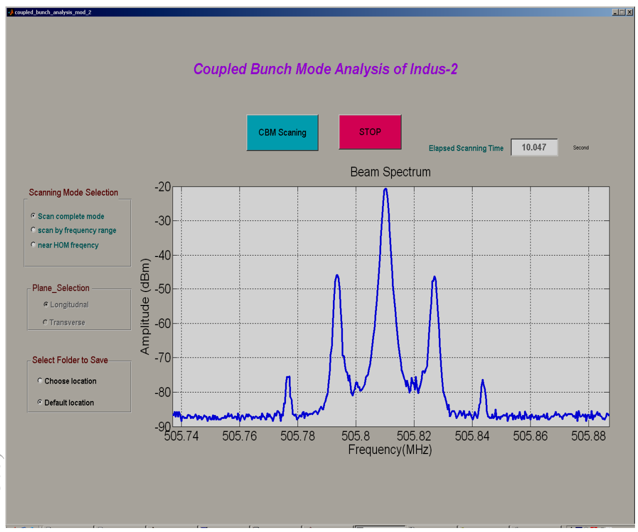

Figure 5: Snapshot of graphical user interface for longitudinal CBM measurement.

Figure 5 shows the snapshot of graphical user interface for longitudinal CBM measurement. The scan results are saved in the form of MS-Excel file. The software saves the spectrum image if the excitation level of coupled bunch mode is above -70 dBm. The software is interfaced with the Indus-2 machine control system over TCP/IP network to acquire the beam current and beam energy information.

RESULTS

The longitudinal coupled bunch modes were measured at different beam energies during the beam energy ramping from 550 MeV to 2.5 GeV. The typical CBM measurement results at beam energies 550 MeV, 2 GeV and 2.5 GeV at beam current ~100 mA are shown in Fig. 6.

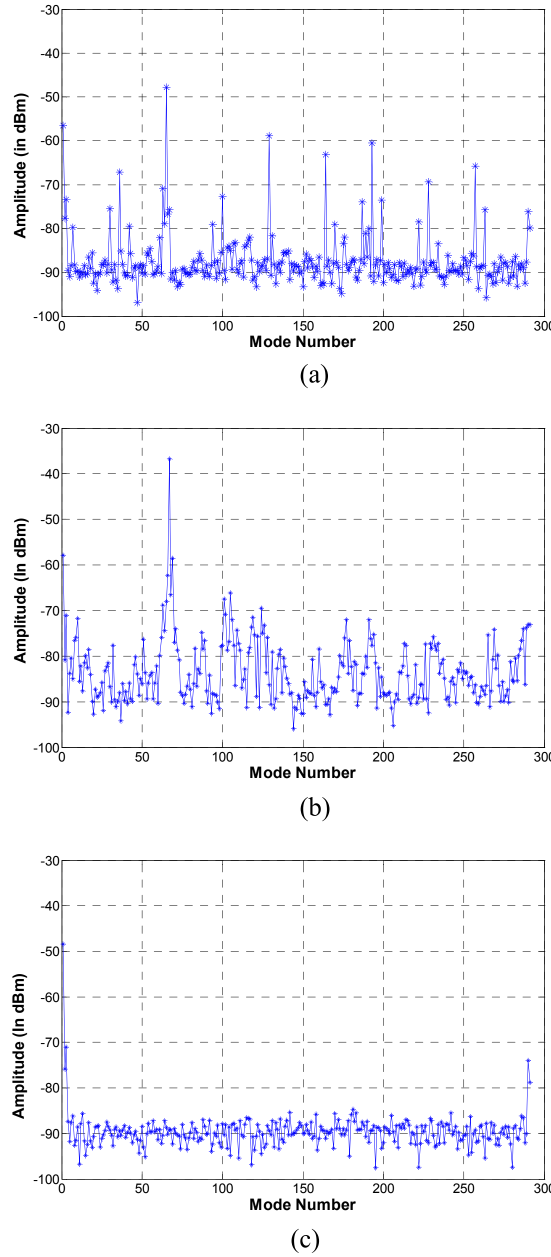

Figure 6: Typical measurement results of CBM measurement with energy (a) 550 MeV (b) 2 GeV (c) 2.5 GeV.

The excitation level of CBMs is observed to change with the beam energy. To confirm this behaviour, the measurement of synchrotron tune has been performed during beam energy ramping. The measured synchrotron tune variation with beam energy is shown in Fig. 7.

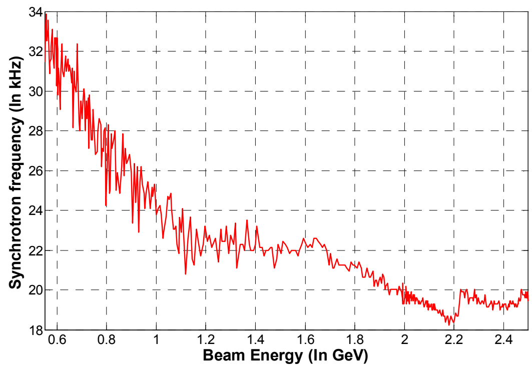

Figure 7: Typical measurement result of synchrotron tune with beam energy.

In view of the observed synchrotron tune variation with beam energies, there is a need for Indus-2 to control the narrow band impedance resonances during beam energy ramping.

CONCLUSION

A system of longitudinal CBM measurement has been developed and installed in Indus-2 synchrotron radiation source. Measurement of CBM will be very important for achieving design goal of Indus-2 i.e. operation at 300 mA, 2.5 GeV. The measurement system can be use to find optimum bunch filling pattern in Indus-2 to increase the instability threshold[3]. The study of transverse CBM is also required to understand coupled bunch mode instability in Indus-2. The change in CBM level with energy gives an indication of requirement for dynamic correction of CBM and HOM during beam energy ramping.

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