COMMISSIONING AND OPERATIONAL EXPERIENCE WITH INDUS-2 RF SYSTEMS

M R Lad[#], M K Badapanda, Pritam Singh Bagduwal, Ashish Bohrey, R.K.Deo, P R Hannurkar, Akhilesh Jain, M K Jain, Narendra Kumar, Ramesh Kumar, Moonuku Prasad, Vikas Rajput D.Sharma, Nitesh Tiwari, R.Tyagi,
Raja Ramanna Centre for Advanced Technology (RRCAT), Indore-452013, India

Abstract

Indus-2 is a 2.5GeV/300mA third generation Synchrotron Radiation Source being commissioned at Raja Ramanna Centre For Advanced Technology, Indore. RF system provides sufficient voltage for boosting electron energy from 550 MeV to 2.5 GeV in addition to compensate for Synchrotron Radiation losses. 505.8 MHz Indus-2 RF systems is in operational state since April 2005. The beam injection into Indus 2 from Booster Synchrotron started in Aug. 2005.First beam accumulation was achieved on Dec.1st, 2005 with injected beam of 450 MeV.The injection energy was subsequently increased to 550 MeV. After achieving beam accumulation at the injection energy, the beam energy was ramped to 2 GeV. So far 38 mA of beam current has been stored at the injection energy and accelerated to 2 GeV at 26 mA.

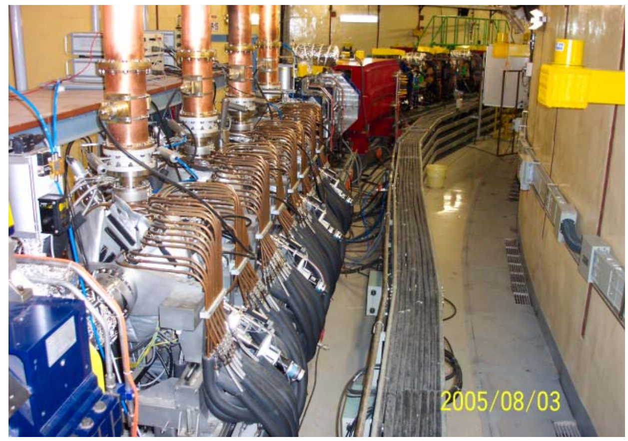
During First commissioning phase of Indus 2 the RF system was switched on with one RF cavity and then for 2 GeV operation two RF cavities were energized. Modular RF system has been operating satisfactorily during machine operation. The low-level control system has been completely installed with optimization of phase & amplitude loop to the desired stability in progress; the tuning loop was installed in the beginning phase. For the stored beam of 38 mA.at 550 MeV no dangerous HOM frequencies were observed.

INTRODUCTION

Full description of Indus-2 RF system can be found in [1], but briefly it is composed of four numbers of bell shaped elliptical cavities (Fig.1) to generate 1500 kV accelerating RF voltage. 64 kW RF amplifier system powers each RF cavity. Each power plant can run independently of others. The power from Klystron amplifier is transmitted to RF cavity through 6 1/8” co-axial line. Two racks of low level & control electronics are installed for each plant. The RF module comprises of 64 kW klystron amplifier, 20 kV/5A HV power supply, 10 W solid-state driver amplifier, and low-level control. For fine regulation & stabilization of the cavity fields frequency, amplitude and phase loops are installed on each RF station. High precision cavity temperature control system is incorporated to control HOM. Protective equipment’s interlock unit act directly to the RF switch, which cuts driving power to RF amplifier chain. The RF system is completely remote controlled from both RF & main control rooms

ladm@cat.ernet.in

Figure 1



OPERATIONAL ASPECTS

RF cavity gap voltage requirement is 75 kV for injection and 375 kV at 2.5 GeV; correspondingly the wasted power on the cavity surfaces is 900 watts and 22 kW respectively. The power transferred to the beam is of the order of 50 kW per cavity at full beam current. Table1 shows the main parameters of Indus-2 RF system.

Initially with injection energy of 450 MeV few thousand turns were achieved without RF.Then the RF system was switched on by the end of Nov.2005.On 1st Dec 2005 first time SR was observed with **RF ON**. Only one RF cavity (Station 4) was switched on at 60 kV gap voltage. Later on injection energy was increased to 550 MeV & beam accumulation was observed in Feb 2006 with only one RF cavity at 60 kV gap voltage. Phase of RF signal was optimized for proper injection. With low beam currents stored the ramping trials were carried out. On 18th may 2006 the beam was ramped to 1.9 GeV at very low currents with only one RF cavity at around 350 KV of gap voltage. At 1.9 GeV the losses to restore were only ones due to bending magnets (no ID used at present) which are 210 keV, the beam power was very low. For these 3 months the machine was operated with RF cavity no.4 only. The cavity resonant frequency was set to 1.5 kHz below the generator frequency to avoid Robinson instability where as the remaining 3 cavities were detuned 100 kHz or more in order to avoid harmful interaction with the beam. The vacuum trip level was set at 10^{-7} mbar. The injection was tried at different gap voltages; at higher gap voltage injection rate was slightly lower.

Table 1: Main RF Parameters

	Stage-I	Stage-II	
Operating Energy	2	2.5	GeV
Injection Energy	550	550	MeV
Beam Current	300	300	mA
Frequency	505.81227	505.81227	MHz
Energy Radiated per turn at Final Energy			
Bending magnets	255.02	622.613	keV
Wavelength shifter	14.33	22.390	keV
Multipole wiggler	17.33	27.080	keV
Total energy radiated per turn			
At injection energy	2.0635	2.0635	keV
At final energy	286.68	672.083	keV
Total Beam Power	86.03	201.62	kW
Total Voltage across cavities			
At injection energy	300	300	kV
At final energy	1.1	1.5	MV
Over-voltage factor (q)			
At injection energy	145.4	145.4	
At final energy	3.84	2.232	

For ramping to 2 GeV or above two cavities were switched on (Station no.4 & 1) in May 2006. Initially the gap voltages of both cavities were kept at lower values. The station phase of each plant were optimized for best injection. The cavity resonant frequencies were set to 1.5 kHz below the generator frequency & the remaining 2 cavities were detuned 100 kHz or more. In Aug-Sept.2006 beam was ramped to 2 GeV at 26 mA, Cavity #1 was operated at 500 KV max. (40 kW) & Cavity #4 was operated at 450 KV max. (30 kW). The cavity tuner loop was operative since start of commissioning, however the phase loop optimization was done for two stations to achieve +/- 1 deg.stability.Phasing between two RF cavities was performed by balancing the input power to cavities at max. gap voltage & full beam loading during operation. The operation was carried out in different combinations of gap voltages and sometimes with only one independent cavity; injection rates were also noted. Max. beam accumulation of around 38 mA was achieved. In the initial phase of commissioning low beam current operation was planned hence cavity main coupler coupling was adjusted to 1.09 (critical coupling) without beam for all four RF cavities.Each RF plant is independently controlled hence machine could be operated with any of two RF plants or with one RF plant also at lower beam energy.

At higher beam currents the beam induced voltages were measured & calibrated in RF control room. Also the HOM signals monitoring was done at each energy & current levels, no dangerous HOM were observed.

During the shutdown of the machine from Oct onwards the main coupler coupling was adjusted to 2.0 without beam for all four RF cavities. This will allow higher beam current operation in the machine.

Many components like Synthesized signal generator, fast electronic phase shifter, RF limiter, RF power monitors have been developed indeginously.

RF SYSTEM OPERATION

RF Power Amplifier

NDUS-2 RF amplifier (fig-2) is based on 64 kW multi-beam, integral-cavity type klystrons. The auxiliary power supplies for its filament, ion pump and modulating-anode are floating at beam supply voltage of 20 kV. The current and voltage signals floating at beam voltage are monitored through optical fibre interface. The RF power transmission system is realized using $6^{1}/_{8}$" EIA lines and coaxial-line components, which operate at normal atmospheric pressure. The power amplifier has operated well during operation. Initially the problem of cross talk between two amplifiers was there which was later on solved. The amplifier was operated from remote & calibration of analogue signals like Klystron beam voltage, beam current, body current was done.

The problem of spurious circulator arc trips happening during early phase of commissioning was observed & was solved.

Figure 2

RF Cavities

Once installed in the ring, the cavities were baked and RF conditioned. The careful procedures were followed during conditioning of the cavities and slowly power was increased for each cavity. With many hours of operation at high RF power and also beam current good conditioning of the RF cavity occurred; hence cavity vacuum interlock trips happening during the first months of commissioning are not occurring. Vacuum in the cavities is now normally $2\text{-}10^{-9}$ mbar without beam at nominal RF power and with beam at higher energies vacuum degraded sometimes and also trips were observed (level of $1.0\text{-}10^{-7}$ mbar).

Low Level Electronics

The low level electronics has proved to be very reliable. It is of modular construction, which is easy for installation and maintenance. Except initial problems like signal level, signal noise and operation with remote no further problems came from this part of the RF system. All the required specifications have been met after the fine settings of the loops parameters. The frequency loop keeps the cavity resonant frequency to ±500Hz or ±100 Hz . Actually the frequency loops sensitivity is normally set to ±500 Hz, while the cavity resonant frequency is kept –1 to –1.5 kHz below the generator frequency to avoid Robinson instabilities. The amplitude loop keeps the cavity gap voltage stable to ±1% low beam loading, while the phase loop keeps the phase of the input power to the cavity within ±1.0 degrees (at 505 MHz) at any power level. During commissioning sometimes when phase error was higher the injected beam was getting lost. All the other components of the low level electronics (interlock switches, station phase shifter, Cavity RF signal distribution, power monitoring at all stages in amplifier chain etc.) have performed well within the required specifications.

Klystron Bias power supply

SCR primary controlled 20 kV, 5.5 Amp power supply has been built. It is designed to operate with wide input variation of –30 % to +10% to deliver rated power with output variation within 0.3%. An 800 kVAR-detuned filter is employed, not only to keep the input power factor near unity but also to keep the line harmonics within certain limit. A spark gap based crowbar protection system is used to protect the expensive klystron tube, which diverts the energy stored in the filter capacitor of the high voltage power supply. Except some trivial problem no major faults has been experienced in HV power supply during operation.

Solid State Driver Amplifier

Solid-state amplifiers operating at 505MHz have been developed to drive the klystron power amplifiers. Each of these solid-state amplifiers is capable of providing 10 Watt of RF power with a gain of 40dB.Except initial problems Solid-state amplifiers have worked satisfactorily. 1-Watt solid-state amplifier has also been used in main distribution rack.

CONCLUSION

All the RF cavities have been tested & two were set into operation. The whole system has worked reliably. For higher beam current operation remaining cavities will be energised depending on the requirement A study on the working temperature of the activities and its relation with HOM has been carried on. This will allow operating the system with no excitation of HOM by the beam.

For the moment the operation of the whole system is satisfactory but complete tests have to be performed on the mutual interaction among all the control loops of the plants at higher beam currents. On each RF plant four loops, the control of the reference temperature, the turning loop, the amplitude loop and finally the phase loop would be optimised for high beam loading.

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