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Development of Piezoelectric crystal based frequency tuner for superconducting quarter wave resonator

The commissioning of a superconducting (SC) linear accelerator (linac) based on niobium quarter wave coaxial resonator (QWR) is approaching completion. Silicon and Oxygen beams from Pelletron accelerator have already been accelerated by the first accelerating module of linac and beam was delivered to conduct experiment. The quarter wave resonator of IUAC, is made from bulk niobium sheet and enclosed in a SS-jacket. Near the high voltage end of the central conductor, a pneumatically operated niobium bellows is placed to tune the resonator frequency as shown in figure 1. The frequency fluctuations have got two components, one happens in slow time scale (seconds) and the other happens in faster (a few tens to hundreds of sec) time scale. The fast drift of the frequency is controlled electronically by the well known dynamic phase control (DPC) loop. By flexing the niobium bellows acting as the mechanical tuner, the slow drift of the frequency is controlled. The two tuning mechanisms working simultaneously are able to lock the phase and amplitude of the resonators with respect to master oscillator and beam was accelerated through the linac. However, since helium gas is used to flex the bellows sitting at a very low temperature (~ 40-60 K), the gas line got chocked a few times in the past, by traces of moisture during cold tests. In addition, the slow tuning mechanism requires continuous supply of high purity helium gas inside the SS-bellow, for its operation. With the recent growing usage of piezoelectric crystal in the tuning mechanism of SC resonators, efforts are on to make the tuning mechanism of our resonators more reliable and cost effective. A piezoelectric tuning mechanism was developed and tested with our existing fast tuning control scheme based on DPC method for the phase locking of the resonator.

Fig. 1. Niobium quarter wave resonator with slow tuner bellows at IUAC

Before connecting the niobium bellows loaded with piezoelectric tuner with the resonator, its effect on the niobium bellows was checked outside by measuring the deflection with dial gauge as shown in fig 2. One side of the piezoelectric tuner is connected to the back of the niobium convolution of the tuner bellows and the other side is clamped by fixing it on an aluminium flange. Biasing the piezoelectric actuator (Physik Instrumente (PI) make) between its two voltage limits (-19 and 100 volts), the total deflection measured by the dial gauge was 85 m. The whole assembly shown in fig 2 was connected at the open end of a resonator (shown in figure 3) to test the performance at room temperature and cold condition. At room temperature, for a fixed distance between the top convolution of the slow tuner and the end of the central conductor, the frequency range of the resonator with full bias of the piezoelectric actuator (-19 to 100 Volts), was measured to be ~ 2.5 KHz. When the resonators were cold at 4.2 K, the frequency range had been reduced to 626 Hz. The hysteresis observed in the frequency change for increase and decrease of the bias voltage of the piezoelectric actuator is shown in figure 5.

Fig. 2. Measurement of the deflection of niobium bellows after powering the piezoelectric actuator

To keep the superconducting resonator phase locked with reference to the master oscillator in the dynamic phase control loop, the piezoelectric voltage should vary with phase error of the resonator controller. To achieve this, a Proportional and Integration (PI) based control scheme has been used.

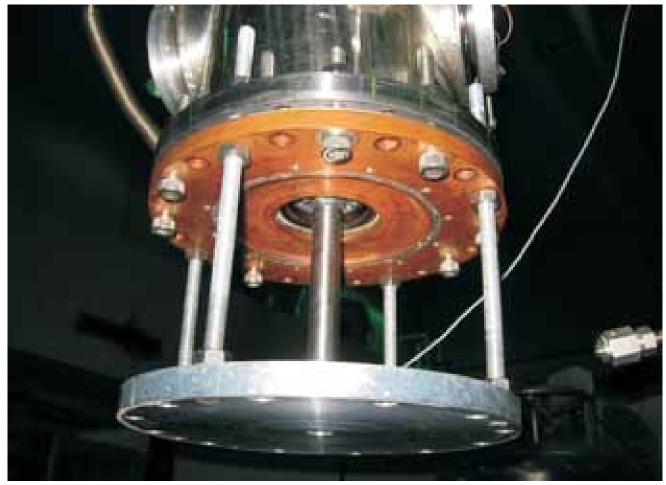


Fig. 3. The mechanical tuner (hiding inside the resonator) along with the piezoelectric actuator prior to a cold test

During the first test of a superconducting resonator in test cryostat along with the fast tuner and piezoelectric actuator acting as slow tuner, the overall locking mechanism worked very well. In this test, no mechanical arrangement for coarse tuning was available to tune the resonator frequency at 97.000 MHz. At a resonance frequency of 96.920 MHz, piezoelectric was kept at + 40 Volts to keep the phase error signal equal to zero by adjusting the reference of the P-I control. Then the control of phase and amplitude was put in close loop. It was observed that for both, large and small variation of resonance frequency from its central value, the piezoelectric voltage kept on varying between a few volts to tens of volts. When the cryostat was shaken to generate large vibrations, the resonator's frequency started fluctuating widely (>100 Hz), the controller drew high power (>250-300 watts) from RF amplifier and eventually the phase lock was broken. But within 510 seconds, the lock was recaptured with the help of piezoelectric tuner. During this extreme operation, the output from the high voltage amplifier to the piezoelectric actuator had gone up to a few tens of volts. The stability of the lock was observed for an hour at a moderate accelerating field of 2.2 MV/m.

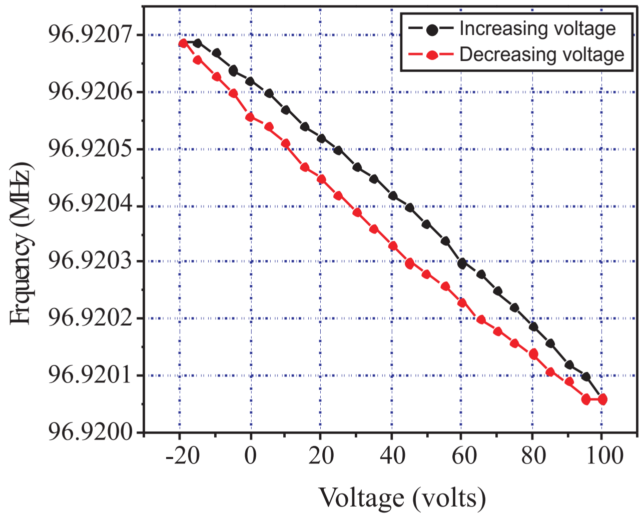


Fig.4. Hysteresis curve of the piezoelectric actuator

The amplitude and phase lock stabilities were measured to be 0.1% and 0.4 degree respectively at this field level. The resonator was locked at 3.0 MV/m for a short duration, but due to lack of time, stability test at this field could not be accomplished for longer period. A mechanical arrangement to bring the resonance frequency of the QWR at 97.000 MHz with the piezoelectric actuator is under construction. This will be tested along with the piezoelectric and the fast tuner in future. The mechanical tuning scheme, if required, can be integrated in the closed loop. After successful test of the complete tuning and locking mechanism using piezoelectric tuner in future, it is planned to implement this new scheme on the resonators in all the cryostats of the superconducting linac of IUAC.

X-ray Bremsstrahlung from PKDELIS ECR plasma

X-ray Bremsstrahlung measurements from typical ECR plasma can give an idea of the performance of the ECR source in terms of confinement properties of the plasma. The emission of these spectra gives an indication of the possible energies of electrons that are available for producing highly charged ions and can further help as a tool to optimize the source performance. Very recently, the x-ray Bremsstrahlung from the PKDELIS ECR source was measured using a 3"x3" NaI detector set-up configured as shown in figure 1a.

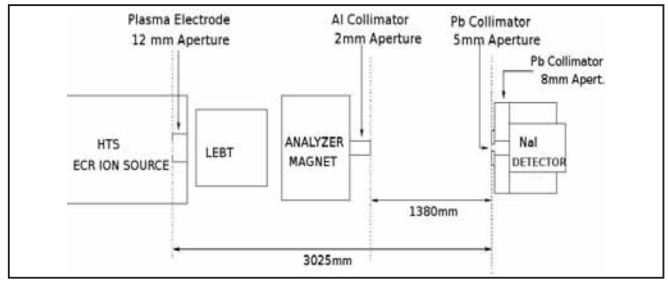


Fig.1a. Schematic of X-ray Bremsstrahlung measurement set-up

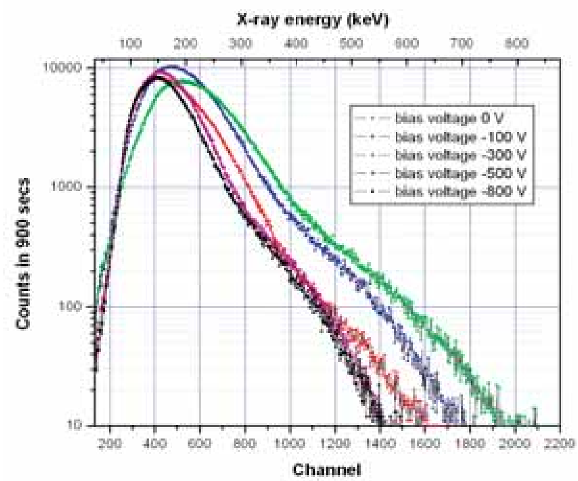


Fig.1b. Typical measured spectra

X-ray Bremsstrahlung was measured from the ECR plasma along the extraction side through the 0° port of the analysing magnet. Due to the high count rate, the distance between the detector and the source had to be increased. The x-ray spectra were measured as a function of negative bias voltages keeping the extraction voltage OFF with each measurement taken for 900 seconds (figure 1b). Negative bias voltages repel/inject cold electrons into the ECR plasma. The other parameters relevant for this measurement are shown in the table. From these measurements, it can be observed that as the bias voltage was increased up to -300 V, maximum effect on the x-ray Bremsstrahlung occurred at a value of -300 V in terms of increased x-ray energy (data plotted in green colour) and shift of the peak of the distribution. From the value of -500 V and that at -800 V, the effect was of reducing the x-ray Bremsstrahlung. So it can be inferred that the negative bias effect was best at the value of -300 V.

However, in the beam optimisation experiments for argon (Ar^{8+} and Ar^{11+},see figure 2 below) , the best beam currents at this value assuming similar vacuum conditions, Rf power and magnetic fields were not observed. The best value was -134 V for optimising on Ar^{8+} and -110 V for Ar^{11+}. The explanation for this behaviour is not available at the moment. The errors involved in these measurements are quite small and do not significantly influence this behaviour. It should be pointed out that when the extraction voltage was raised to 20 kV, the slope of the distribution had a bump from 150 keV onwards. Most probably the emission of this additional Bremsstrahlung is due to change of the electron trajectories inside the source. A quick estimate of the mean electron temperature can be obtained from the slope of the distributions.

Table: Parameters set for X-ray Bremsstrahlung measurements

parameter	**value**
RF absorbed power	400 W
Extraction voltage	OFF
Injection vacuum	1.0×10^{4} mbar
Post analyser vacuum	3.2×10^{7} mbar
B_{min}/B_{ecr}	0.58
Injection / extraction field	1.4 T / 095 T

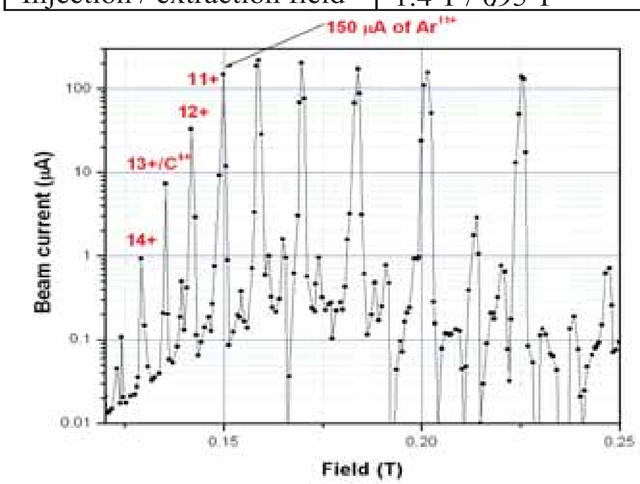
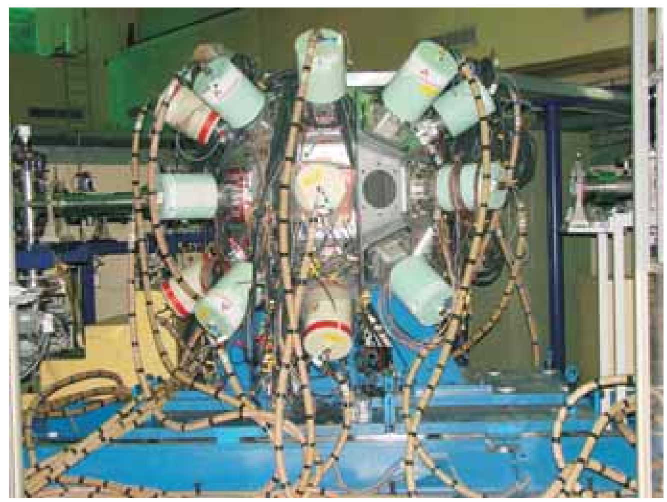


Fig 2. Charge state distribution optimized on Ar^{11+}

Indian National Gamma Array in Beam Hall II

The installation of the Indian National Gamma Array facility (INGA) at Beam Hall II of IUAC was completed by Nov. 2007 and the detectors and equipments from the collaborating institutions TIFR, UGC-DAE-CSR, SINP, VECC and BARC started arriving by Dec. 2007. In-beam testing of the augmented facility was carried out during Jan-Feb. 2008 followed by regular experiments from Feb 28, 2008.

A total of fifteen experiments were carried out during the first cycle of INGA operation (Feb-Jun. 2008). The number of clover detectors used in individual experiments during this period varied from 18-20. The typical data rate was 3-4 kcs in triple γ–γ–γ coincidence mode. To minimize the dead time, the data were read in parallel from three CAMAC crates. Suppression of readout from ADCs with no data was carried out in hardware.



INGA Set up at IUAC

Some of the experimental studies carried out during this period are:

High spin structure in ^{112}In and search for chiral bands

Role of proton and neutron orbits in magnetic rotation for A ~ 137 nuclei

Search for band termination in Magnetic rotation band in A~140 region

Spectroscopy of magnetic rotation bands near Z~64 N~82 shell closure

Spectroscopy of neutron-rich nuclei near ^{132}Sn produced by heavy-ion induced fission

Spectroscopy of trans-lead nuclei $^{210-212}$Ra, $^{209-211}$Fr

Study of octupole correlation in $^{239-241}Pu$, $^{237-240}Np$

The second cycle experiments are planned during the first half of 2009.

SERC School on Nuclear Physics, 2008

The Science and Engineering Research Council (SERC) of the Department of Science and Technology (DST), Government of India, have instituted a five-year program of holding annual SERC Schools on nuclear physics. Primary objective of these Schools is to elevate the academic standard of students and young faculty members engaged in research in nuclear physics. The Fourth School in the third cycle of the program was held at Inter University Accelerator Centre (IUAC), New Delhi during 1 - 20 September, 2008. The theme of the School was **"exploring symmetries in nuclei using the national accelerator facilities"**.

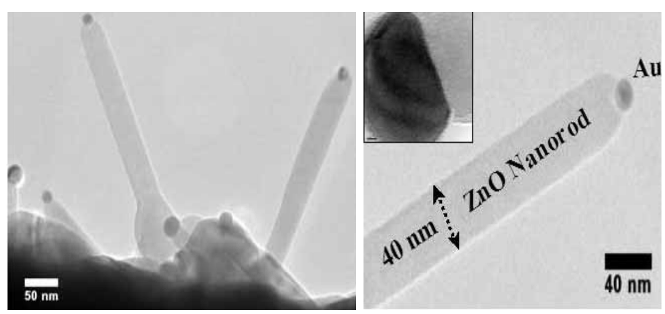
Distinguished teachers and researchers, drawn from the universities and research laboratories in India, conducted the lectures and tutorials. The topics covered included nuclear structure using large arrays, spectroscopy of heavy nuclei, giant resonances, dissipative collision and advances in nuclear structure models. About forty students from various universities and institutions attended the courses. Besides advanced topics, preliminary courses were also taught in the School. A few special evening lectures were delivered by eminent experts in various related fields. The main speakers, staying at IUAC campus for the duration of the course, had intensive interactions with the participants. Extensive laboratory sessions were conducted by IUAC staff for the benefit of the students.

Indo-US School on Cryogenics, Superconductivity, Vacuum and Low Temp. Measurement Techniques (Nov., 2007)

A five day School on "Indo-US School on Cryogenics, Superconductivity, Vacuum and Low Temperature Measurement Techniques" was organized at IUAC during November 19- 23, 2008 with the support of Indo-US Science & Technology forum. There were about 100 participants from University, Scientific labs of DAE (IPR, RRCAT, VECC, BARC) and other academic Institutes. Faculty members were from international laboratories like Jefferson Lab, Fermi lab of USA, CERN in Switzerland, ITP in Germany and National laboratories. In total, there were 10 sessions in five days and 27 lectures were delivered by 12 faculty members. Dr. T. Ramasami, Secretary DST inaugurated the School and the keynote address on "Activity of Cryogenics in Department of Atomic Energy" was delivered by Dr. Anil Kakodkar, Chairman, Atomic Energy Commission and Secretary, DAE. In addition to regular course lectures, two general evening talks on ITER and ILC were also arranged.

Activities on Nanocomposite thin films

There have been rigorous research activities on synthesis of metal dielectric nanocomposites by atom beam co-sputtering, using 1.5 keV Ar atom beam. Recently the Au nanoparticles embedded in ZnO nanocomposites were synthesized. The annealing of the same at 600ºC yielded the ZnO nanorods with Au on tip of the nanorods as shown in figure below.



A project titled 'Nanostructuring by energetic ion beam' has recently been approved under Nano Mission programme of Department of Science and Technology. The facilities of field emission SEM, close cycle refrigerator for in-situ XRD in beam line and high current neutral beam source will be procured to boost the research programme in the field of thin film metal-dielectric nanocomposites. Another project on

'Synthesis and characterization on functional oxide materials' has been approved by Department of Science and Technology.

Workshops /Schools/Acquaintance Programs (April - October, 2008)

A three day school on "Optical **Characterization"** was organized from 30th June-2nd July 2008. The school stressed on the fundamentals of optical properties and the potential use of the facilities of optical characterization like UV-Vis, Photoluminescence, Raman, Fourier transform infra-red and thermo luminescence spectroscopy for materials characterizations, synthesized and/or modified by swift heavy ion irradiation. Approximately 85 participants attended the school and 14 lectures were arranged besides the experimental demonstrations of the existing facilities at IUAC.

A one day workshop on **"Accelerator based research on Polymer Science"** was organized on 25th August 2008 at IUAC. The workshop covered various themes like swift heavy ion effects on metal polymer nano-composites, metal/ceramic dispersed polymer composites, conducting polymers, fabrication of nano/micropores in polymers, grafting of polymers, energy loss and straggling in polymers. The workshop was attended by about 80 participants from various universities and institutions. The workshop included 9 invited talks, 4 oral presentations and about 20 poster presentations.

A two day workshop titled **"Heavy Ion Radiation Biology at the molecular level: current trend and future prospects",** was also held on 13th and 14th October, 2008 at IUAC. About 30 participants including 15 from out station cities participated in the workshop.

The Deptt. Of Physics, **NIT Silchar,** Assam, and IUAC, New Delhi jointly organised a one-day workshop on "IUAC **acquaintance programme"** at NIT Silchar on 8th February, 2008. Faculty members and research scholars of various scientific disciplines from different colleges, universities and Institutes of North East India participated in this workshop. The workshop was inaugurated by Dr. D K Avasthi, IUAC who later discussed in details the technological importance and advantages of swift heavy ion irradiation in material science research. The inaugural session was presided over by Prof P K Banik, Director, NIT Silchar. The key note address was delivered by the coordinator of the workshop Dr. S S Nath, lecturer, Deptt. Of Physics, NIT Silchar. The participants warmly interacted with the resource persons and expressed their interest on ion irradiation research work.

A one day **acquaintance programme** of IUAC at **North Maharashtra University, Jalgaon** was also held on 30th April 2008, which was locally organized by the Department of Physics of the University. Prof. P.P. Patil, NMU co-ordinated the overall programme. Approximately 60 participants comprising of faculty members from various colleges and nearby institutions and research scholars attended the programme. Topics related to Materials Science and Radiation Biology were discussed which generated a lot of enthusiastic response from the participants.

Another IUAC **acquaintance programme** was organized at **Pondicherry University** on 21st October 2008. Physics and Earth Science Department of Pondicherry University participated in the programme. Dr. S. Balakrishnan was in charge of the overall programme. Besides, there were participants from nearby colleges and Geology Department of Bangalore University. Topics on Accelerator, AMS and Materials Science were discussed via talks and informal discussions which resulted in a favorable response from the participants.

TESLA Technology Collaboration (TTC) meeting (20-23 October, 2008)

The mission of the TTC is to advance Superconducting RF technology R & D and related accelerator studies across the broad diversity of scientific applications, and to keep open and provide a bridge for communication and sharing of ideas, developments, and testing across associated projects. Now TTC has a membership of 52 accelerator laboratories and presents the largest expertise in the field of superconducting RF accelerator R&D activities worldwide. Several Indian institutions, like RRCAT, BARC, IUAC and DU have joined TTF collaboration last year. A meeting of this collaboration took place at IUAC during October 20-23, 2008 supported by the Indo - US Science & Technology Forum. The meeting was attended by 47 researchers in superconducting technology from different laboratories in USA, Japan, Germany, France, Italy, U.K. and from 35 different laboratories in India. The deliberations on details of resonator performance, high field gradients, fabrication and surface treatment methods and cryomodule fabrication were intense and lively. One full session was devoted to discussion of the Indian efforts in this field.

Status of 15 UD Pelletron (April 1 to October 31, 2008)

Operation of Pelletron was quite satisfactory from 1st April to 31st October 2008. There was only one scheduled tank opening maintenance of Pelletron in July 2008. Routine maintenance jobs like terminal foil stripper loading, column support post & accelerating tube resistors maintenance, charging system maintenance and in-tank ion pump maintenance & rotating parts were carried out in this maintenance. Problems related to the fluctuations in the charging chain #2 current and corona probe were also solved. One of the separator box was severely damaged and was replaced by a new assembly. A solenoid valve used in the operation of earthquake RAM was also replaced. Full operation of earthquake RAMs was checked which performed quite satisfactory. Apart from this, maintenance of sublimator pump in post acceleration section (SP 03-1) was carried out and an ion pump in the same location (IP 03-1) was also replaced by a new one. In ion source maintenance, routine maintenance of MC-SNICS was carried out and 5g of fresh cesium was loaded. Einzel lens also required cleaning. HV conditioning of deck was also carried out during this scheduled maintenance.

Few modifications and development work were also carried out in July 2008 scheduled maintenance. Position read back system for stripper foils at high energy dead section (FS D2-1) was modified to read the exact position of stripper foils FS D2-1. A 50 position foil stripper assembly procured from NEC, USA has been installed in vault area (after analyzer magnet). Use of this stripper foil assembly is multi purpose. This can be effectively used to reduce ME / Z^2 by increasing the charge state after acceleration. This will help to switch the beam to the beam line where ME / Z^2 is low. The controller for it was developed in house and can control the movement of foil strippers either locally or remotely from control room. CAMAC crate in vault area was modified for remote control of this newly installed foil strippers. The foil stripper assembly along with its controller was tested after its installation and is working fine. Apart from this, a new port aligner for offset faraday cup was installed in vault area. The port aligner will be used to align the position of offset faraday cup according to the direction of beam, so that beam current falling in the cup can be read precisely. This is essential to read ^{17}O current in case of Beryllium AMS work.

Maximum terminal voltage achieved during high voltage conditioning was 13.66 MV. ^{19}F beam (125 MeV) was delivered to user at the maximum terminal potential of 13.6 MV and ^{32}S beam (45 MeV) was delivered to user at the minimum terminal potential of 7.48 MV. Out of total beam time of 2634 hours, 1124 hours of beam time was used by INGA users and 466 hours were used for pulsed beam runs using multi harmonic buncher (MHB) along with low energy chopper and traveling wave deflector.

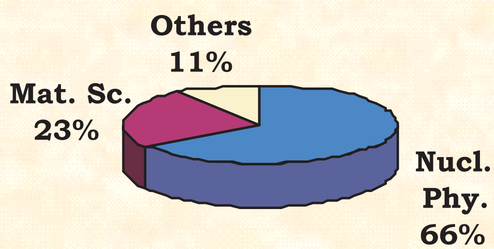
^{16}O, ^{28}Si and ^{32}S beams were bunched for different experiments. 70 hours of ^{16}O, 100 MeV bunch beam run was utilized for the stability testing of MHB and High energy sweeper (HES). All the pulsed beam runs were quite stable.

The uptime of machine for this period was 96.27%. The beam utilization time was 66.03%.

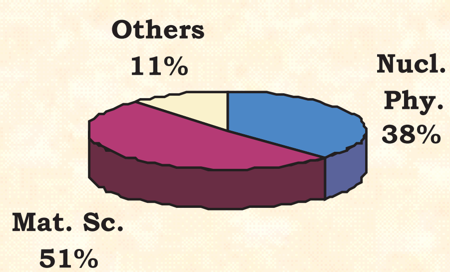
Statistical Summary

Total Chain Hours	=	3989 Hrs.
Beam utilization time	=	2634 Hrs.
Beam change time	=	8 Hrs.
Machine Breakdown time	=	109 Hrs.
Machine scheduled maintenance	=	1142 Hrs.
Accelerator conditioning	=	1055 Hrs.
Beam tuning time	=	192 Hrs.
Experimental setup time	=	108 Hrs.

FIELDWISE BREAKUP OF UTILIZED BEAMTIME (APRIL - OCTOBER, 2008)



USERWISE BREAKUP OF UTILIZED BEAMTIME (APRIL- OCTOBER, 2008)



User List: April to October, 2008

University / Institute / College	Shifts utilized
Allahabad University	08
AM University, Aligarh	06
Andhra University	12
Anna University, Chennai	02
Bangalore University	03
BARC, Mumbai	06
BH University, Varanasi	02
Dayalbagh Institute, Agra	03
Delhi University	24
GNDU, Amritsar	05
GSI, Germany	18
Guwahati University	02
HNB Garhwal University	03
IIT, Delhi	06
IIT, Kharagpur	08
IIT, Roorki	08
ISRO	03
IUAC, New Delhi	40
IUC, Kolkata	16
JNU, New Delhi	02
Kalyani University, W.B.	02
Kurukshetra University	03
Manipur University	02
MSU, Baroda	21
Mumbai University	06
Padova University, Italy	15
PRL, Ahmedabad	09
Punjab University	23
SINP. Kolkata	30
TIFR, Mumbai	08
Utkal University	03
VECC, Kolkata	08
W.Bengal Univ. of Terchnology	02