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From the Director's Desk

INSIDE

The best gain of Dr. Homi Bhabha's vision and work has been the confidence to attempt and do the impossible in the country.

The Story of Indira Gandhi Centre for Atomic Research

Dr. Homi Bhabha, a visionary and founding father of Indian Atomic Energy programme, under the patronage of Pandit Jawaharlal Nehru, unfolded the vision of building a strong base in nuclear science and technology, so as to provide energy security to the country. Dr. Homi Bhabha had a clear conviction that India, in the not too distant future, would be capable of meeting its energy demands as well as national security and exploit other applications of radiations to bring better quality of life to its citizens.

Dr. Homi Bhabha, along with his colleagues, formulated a three stage nuclear programme for the country. The first stage consists of Pressurized Heavy Water Reactors (PHWRs), which are based on natural uranium resources and indigenous heavy water. The second stage is centered on Fast Breeder Reactors (FBRs), utilizing plutonium generated in PHWRs and recycled by closing the fuel cycle. The third stage would deliver energy security to the nation in a long horizon through advanced thorium reactors (Thermal & Fast), which would exploit large resources of thorium, available to India. The fissile material inputs to the third stage would come from plutonium and U^{233} produced in the PHWRs and fast breeder reactors.

The three stage programme has undergone fine tuning as demanded by the changing technology scenarios, national strategies and the emerging trends. An example is Kudunkulam Water Reactors of VVER type in collaboration with Russia. However, it remains a remarkable vision, which has fuelled the determination and commitment of the Department for more than five decades. The Department has not only met with the aspirations of Dr. Homi Bhabha but in addition has nurtured the research in frontier areas of science and technology in the country. The seeds of the activities in space, electronics, precision manufacturing industry, quality management concepts and implemtation etc, were sown as a part of the broader vision of the Department of Atomic Energy (DAE). These seeds have blossomed, over a period of time, to enable India meeting the demands of advanced technology of high relevance to the country. *The best gain of Dr. Homi Bhabha's vision and work has been the confidence to attempt and do the impossible in the country.*

Dr. Homi Bhabha was taken away from us by a tragic incident in 1966. His loss could never be fully absorbed by the country. However, India was fortunate to have another great scientist and technologist, Dr. Vikram Sarabhai to lead the atomic energy programme. He was a great visionary in his own merit. He committed himself with zeal and imagination to realize the fruits of Bhabha's ground work and took fresh initiatives, which would deliver results when the country would need them in the years to come. Founding and providing road maps for the growth of Space science & technology, fast breeder reactor science & technology, electronics research & applications, etc. are some of his most important contributions to our country.

Reactor Research Centre (RRC) at Kalpakkam was born in 1971, with a clear mission of developing Fast Breeder Reactor Science & Technology in the country for commercial exploitation. Dr. Vikram Sarabhai played a key and leading role in the establishment of this Centre and creating a roadmap for truly interdisciplinary research in reactor engineering, materials, chemistry, reprocessing, safety, instrumentation and other allied disciplines. He combined his vision with wisdom and experiences of stalwarts like Dr. Raja Ramanna, Dr. A.K. Ganguly, Shri V.N. Meckoni and Dr. P.R. Dastidar. Dr. Sarabhai's team had young and dynamic persons like Shri N. Srinivasan (the founder Director of the Centre), Shri N. L. Char, Shri S.R. Paranjpe, Dr. G. Venkataraman, Dr. P. Rodriguez, Dr. D.V. Gopinath, Dr. C.K. Mathews, Shri G.R. Balasubramanian and many others, who were motivated by him to deliver according to the roadmap but at the same time, take initiatives to sustain excellence in FBR technology with emphasis on science. It is remarkable that Dr. G. Venkataraman, Dr. P. Rodriguez and Dr. C.K. Mathews were chosen as a part of the initial team and were given full freedom to pursue basic and frontier science side by side with the pursuit of mission oriented work. The current stature of the Centre is primarily due to the clear vision and conviction of Dr. Vikram Sarabhai that technology can be delivered only in a creative and dynamic environment of rigorous science. Examples towards this can found in the programmes of Reactor Technology, Materials, Chemistry and Computer & Instrumentation, being pursued in our Centre. These programmes have enriched the basic science and supported the strategic and core sectors of the country, and at the same time, delivered the demands of the mission programme of the Centre and the Department. The Centre was moulded to a large extent, by the remarkable dynamic and visionary leadership of Shri N. Srinivasan, the founder Director of the Centre. The Centre has inherited tradition of focus on excellence and dexterity in management of R&D from his vision and values for pursuit of high technology.

In the formative years of RRC, DAE entered into MoU with CEA, France to build Fast Breeder Test Reactor (FBTR), on the lines of Rapsodie, but with a difference namely to generate steam and electricity from the fission energy in Fast Breeder core. The design work was undertaken along with the French specialists. A small team of engineers under the leadership of Shri S.R. Paranjpe worked closely with French engineers at CEN, Cadarache and at Kalpakkam to appreciate, understand and take up the design and implementation of FBTR. The design work proceeded at a high pace till about 1974. The challenge of manufacturing most of the components in India was outlined, accepted and delivered. This decision had enabled the Centre and the industries to get confidence in this complex technology. French engineers worked with Indian counterparts with exemplary collaboration and friendship.

However, after the peaceful nuclear explosion at Pokharan in 1974, the atmosphere of close collaboration could not be sustained. Right from the beginning of the collaboration, the fuel was envisioned to be indigenous uranium-plutonium mixed oxide and the French had offered enriched uranium towards fabrication of this fuel. It needs to be mentioned that UO_2 - 30% PuO_2 was a proven fuel, even at that time for Fast Breeder Reactors. After 1974, there was no possibility of getting enriched uranium from France. Indeed, even minor equipments, instruments, materials and sensors were not supplied by the western countries for Indian Nuclear Programme, particularly for Fast Breeder Reactor programme.

India had no option but to meet the challenge of developing its own Pu based fuel for starting and sustaining the Fast Reactor programme. The Department after detailed deliberations and in a characteristic bold decision, had decided to develop 70% Pu - 30% natural U carbide fuel for FBTR. This activity leading to the choice of fuel was intense and many young and experienced scientists and engineers participated in arriving at this decision. I would like to name a few, namely Shri S.R. Paranjpe, Shri S.B. Bhoje, Dr. S.M. Lee, Dr. P. Rodriguez, Dr. C.K. Mathews, myself Shri Shekhar, Shri Bir Singh, Shri S. Govindarajan, and others from RRC (then) and Dr. P.R. Roy, Dr. C. Ganguly, Dr. S.P. Garg, Shri G.L. Goswami, Dr. D. D. Sood, Shri S. Mazumdar, Shri P.V. Hegde and many others from BARC. The responsibility for fabrication of the fuel was that of BARC, while the manufacture of the fuel subassembly was the responsibility of NFC. It was a day of great joy and fulfillment when the reactor went critical on October 18, 1985. Shri C.V. Sundaram was the then Director of the Centre and Dr. Raja Ramanna was in the control room of the reactor, at the time of criticality. The presence of Dr. Raja Ramanna was most appropriate, as he had played a key role in nurturing and guiding the programmes of the Centre, including taking the bold decision of FBTR going in for Pu-rich mixed carbide fuel. Since then, the reactor had been operating satisfactorily, meeting many design criteria and providing valuable experience in fast reactor technology. Shri C.V. Sundaram played a significant role in nurturing science based technology as well as interactions with academia and research institutions and providing robust management ethics.

The Centre was renamed as Indira Gandhi Centre for Atomic Research on 16th December 1985 by Rajiv Gandhi, the then Prime Minister of India. FBTR has achieved many milestones and overcome many problems such as water purity especially with respect to SiO_2 content in once-through steam generator circuit, fuel handling incident, cooling water leak in biological shield, reactivity excursions, small sodium leak, feed water pump seizure, etc. Comprehensive experience and detailed documentation on each of the challenges mentioned above, has been a part of the learning curve and an example of setting the tradition of rigour with excellence.

It is worth mentioning that in September 2002, the Centre had celebrated the milestone of the indigenous carbide fuel reaching a burn up of 100,000 MWd/t (2400 kWh/g), a truly international landmark made possible due to interorganizational and interdisciplinary collaborative work. The sodium pumps in FBTR have operated continuously for more than 120,000 hr without failure and sodium purity has been remarkable. The experience with FBTR and the broad, multidisciplinary R & D base in the Centre has provided the confidence to launch the Prototype Fast Breeder Reactor (500 MWe) as the next step in the development of fast reactor technology.

The evolution of various programmes and achievements of IGCAR over the years is provided in a box given in page 11. It can be seen that simultaneous with the achievements at FBTR, the Centre has accomplished significant successes in many frontline R & D programmes, and also taken all steps to close the fuel cycle of FBTR. This story would be continued in the forthcoming issues of IGC Newsletter, with short essays on

1) Success of FBTR and the beginning of PFBR - R&D achievements at a glance
2) Ensuring the success for PFBR and Reprocessing of Fuels - Schools of excellence at IGCAR
3) Infrastructure facilities and the environment at IGCAR
4) IGCAR - The current challenges and future directions

Dr. Baldev Raj
(Director)

Development and Testing of Transfer Arm for PFBR

Prototype Fast Breeder Reactor (PFBR) is a 500 MWe, sodium cooled, pool type fast reactor and its construction is in progress at Kalpakkam. An in-vessel Transfer Machine, named Transfer Arm, does the fuel handling within the reactor and an inclined fuel transfer machine does transfer of the fuel in and out of the reactor. Fuel handling campaign is done once in eight months of reactor operation. The safe handling of fuel sub assemblies call for a highly reliable machine. The machines were designed in-house and to ensure its smooth performance at operating temperature of 473 K, a full scale component testing is planned in sodium.

Transfer Arm (TA) during fuel handling campaign, has to pickup the fuel sub assembly (SA), lift it and take it to a required location by suitable rotation of TA, small rotate-able plug and large rotate-able plug. The later two items are part of the top shield of the reactor assembly. After positioning at the intended location, it has to apply a load of 10 kN to ensure full seating of SA. It has many safety features and control logics. The major parts of the TA are Oval Shield Plug, Guide Tube Hoisting Mechanism, Top Structure, Tension Sensing Mechanism, Safety Brake, Linear Actuator (LA), Shielding Sleeve (SS), Gripper Subassembly (GA) and Finger Sub Assembly. Figure 1 shows the details and important components of the

Table I: Summary of various important movements of Transfer Arm

MOVEMENTS OF MECHANISMS		
Component	Movement	Drive
Inner tube	Translation 70 mm	Linear actuator
Outer tube	Translation 4600 mm	Gripper hoisting motor
Guide tube	Translation 4000 mm	Guide tube hoisting motor
TA Rotation	Rotary - 90° to + 90°	TA rotation motor
Auto orientation of FSA	Rotary <30 °	Auto

TA, while Table I summarizes various movements of mechanisms.

The safety brake is provided in the TA for protecting the gripper, in the event of failure of the wire rope or malfunctioning of the motor brake. A shock absorber is also provided to minimize the impact loading on TA under such incident.

The inner tube, 14800 mm long, is connected to the stem of linear actuator at top and to a stem at bottom to actuate the finger arm. This is the longest tube in the transfer arm. This tube is designed to transmit the required force to open / close the finger. At the bottom, a metallic bellows provides sealing between the inner space of outer tube and sodium and at top, two 'O' rings provides sealing with respect to atmosphere. A Linearly Varying Differential Transformer measures the inner tube/ linear actuator movement.

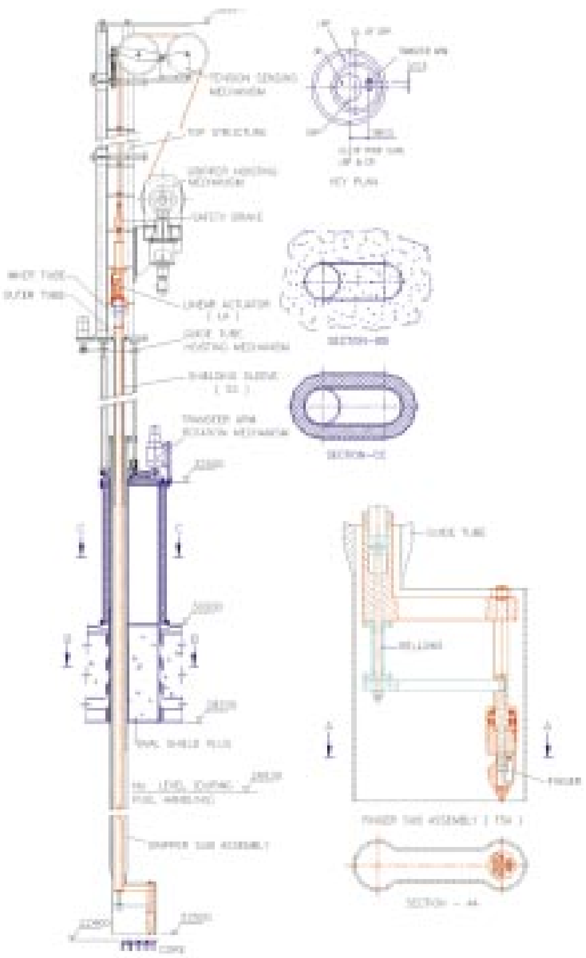


Fig.1 Transfer Arm

Finger subassembly has three gripping fingers 120° apart, which are actuated by inner tube through an offset arm and a connecting rod. Finger subassembly has two colmonoy coated taper roller bearings immersed in sodium for free rotation and for self-alignment of SA during pulling or pushing of the SA. Upward and downward movement of inner tube actuates fingers.

The transfer arm was fabricated by M/S Larson & Toubro Limited in their Hazira works and transported as subassemblies. The total height of the machine is around 23,500 mm and weighs around 235 kN(≈23.5 MT). The machine consists of slender tubes of up to 14,800 mm length moving one inside the other and heavy base with eccentric masses for providing radiation shielding. As the reliability requirement is very high, the manufacture of transfer arm has gone through stringent quality control. The machine was assembled, installed, commissioned and performance tested successfully in air at

Fig.2 Erection of Transfer Arm

Fig. 3 Gripper and Finger Sub-Assembly holding the Dummy fuel Sub-assembly

Engineering Hall-3. The subsequent testing is planned in sodium for ensuring the intended performance in the reactor.

Erection

The sub assemblies erection was done at air test facility with suitable care to protect the parts from scratches. Several handling tools were specially prepared for handling purpose. Initial problems faced in the movements of these mechanisms were analyzed and solutions obtained. Few improvements were made on finger actuating inner tube and actuator rod and gripper hoist to achieve the desired operations. Fig. 2 shows the erection of TA.

Testing

By independent testing for more than 200 times, each mechanism was qualified and found satisfactory in air. Fig. 3 shows the testing of TA. In addition, sequential cycle test as envisaged in reactor fuel handling operation was done for 10 times. The sequence is diagrammatically shown in Fig. 4. It includes the test on SA holding, releasing, lifting / lowering and seat check up. The testing in air has given enough confidence on its further operation in sodium.

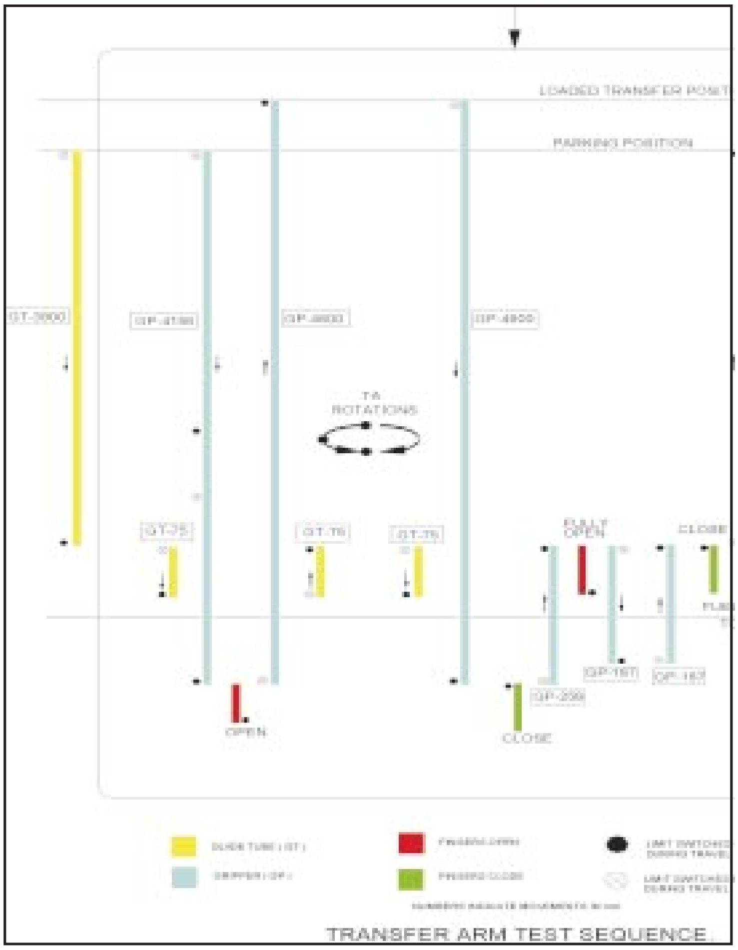


Fig. 4 Transfer Arm testing sequence

(S. Asokkumar, Convener, Taskforce for Transfer Arm Testing)

Effect of manufacturing tolerances on the design and construction of PFBR Reactor assembly vessels

The reactor assembly (RA) houses the core, entire radioactive primary circuit and other components such as core support structure, grid plate, inner vessel (IV) and main vessel (MV). The MV (Ø12,900 mm, Ht 13,200mm, Thk 25 mm) is the most critical component in the RA and forms a part of core supporting path. It carries ~1150 t of sodium along with the core and reactor internals (~920 t). In order to increase its structural reliability, its temperature is maintained at ~700 K to protect against high temperature effects including creep and temperature embrittlement. This is achieved by incorporating a cooling circuit, which consists of 24 pipes through which ~5.7% of primary cold sodium is diverted to flow through the annular space between MV and outer thermal baffle (OTB), called feeding collector and returns through the restitution collector which is the annular space between OTB and inner thermal baffle. In order to avoid complete loss of sodium coolant in the event of unlikely leak in MV, safety vessel (SV) is incorporated surrounding the MV with nominal radial gap of 300 mm. The inner vessel separates the hot and cold pools of the primary sodium circuit. These components are indicated schematically in Fig.1 and are characterized by their large R/t ratios.

In order that reliability of these vessels, especially MV, is maintained very high it is desirable that penetrations are avoided and the total weld length in the vessel kept minimum. The weld length is minimized by choosing as large a plate size as can be pressed by the manufacturer. The pressed / rolled petals are welded to form courses, which are than integrated into vessel. In such a construction, considering the large interplay of various parameters such as pressing, rolling, welding etc. it is impossible to manufacture a perfect vessel and deviations / imperfections are inevitable. The deviation i.e. the tolerance in these components is largely process related and depends solely upon the methods and procedures adopted during manufacture.

The dimensional tolerances, particularly the form tolerances of thin shell structures should be very tight so that certain functional requirements will be respected. The uniformity of gap especially between the inner surface of MV and outer surface of OTB must be restricted to ±30mm so as to maintain circumferential temperature variation in MV within acceptable limits. The variation in the inter-space between MV and SV is also to be restricted to within ±30mm to have lower duty on the remotely controlled robotic carriage, deployed for the purpose ISI and ensure its smooth maneuverability within the inter-space. Apart from these limits, tolerances should be restricted within certain values so as to protect thin walled shells against buckling, particularly under seismic induced forces and moments.

Buckling design is carried out in accordance with RCC-MR: 2002, the applicable design code for PFBR. With the liberal tolerances, higher thickness is needed to meet the codal buckling requirements, which is not preferable from point of view of thermo-mechanical behaviour, overall compactness of the RA and economy. Hence, tighter tolerance is to be achieved which in turn leads to difficulty in manufacture, affecting the construction schedule. This implies that optimum tolerance values are to be specified for all the thin shell structures to suit the design considerations and the capabilities of the Indian industries. Towards this, all the thin shells of RA are analysed to quantify the effects of imperfections on the buckling strength by carrying out detailed elasto-plastic buckling analysis using a sophisticated finite element computer code called CASTEM 3M. Analysis indicated that, among various shells, MV and TB are the critical components for which specified tolerances are critical. The summary of analysis results is presented below.

For the main vessel, shear force induced under horizontal seismic excitation causes buckling. The resultant forces acting at the mass centre and associated shear stress distribution developed during operating basis earthquake (OBE) for the peak

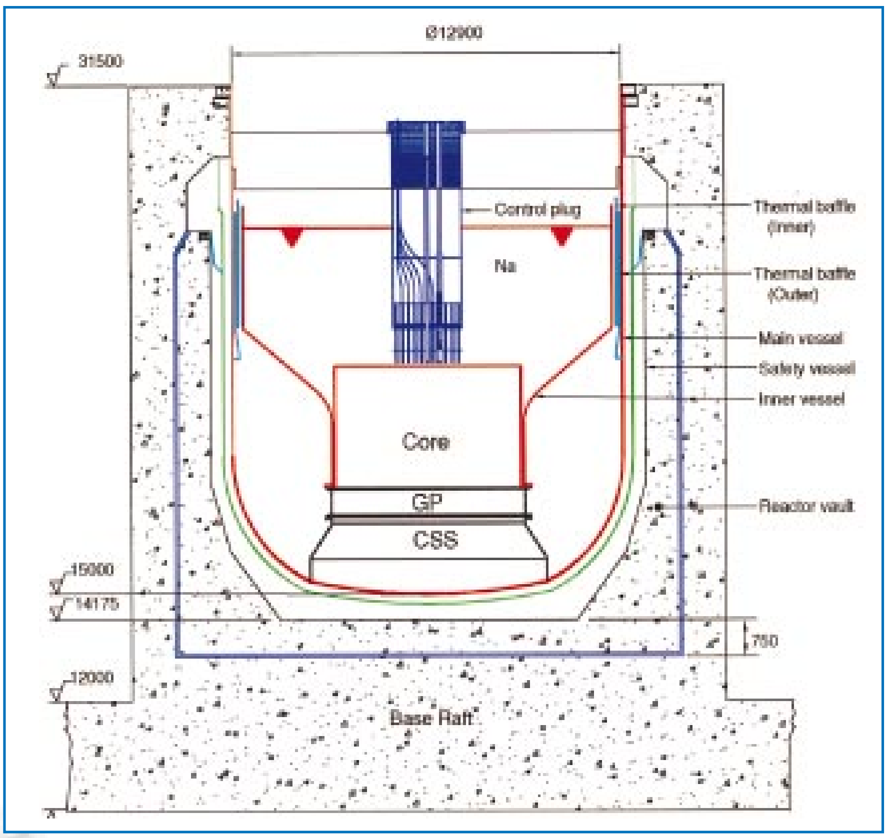


Fig. 1 Thin shell in Reactor Assembly

ground acceleration (PGA) value of 0.066g, are shown in Fig.2 and 3 respectively. By progressively increasing the imperfection, expressed in the form of out-of-roundness, PGA values that cause buckling of MV are determined. One typical shear buckling mode shape is shown in Fig.4 and effect of imperfection on PGA value is shown in Fig.5, which indicates that for the tolerance of ±30mm, PGA value of 0.075 g is acceptable.

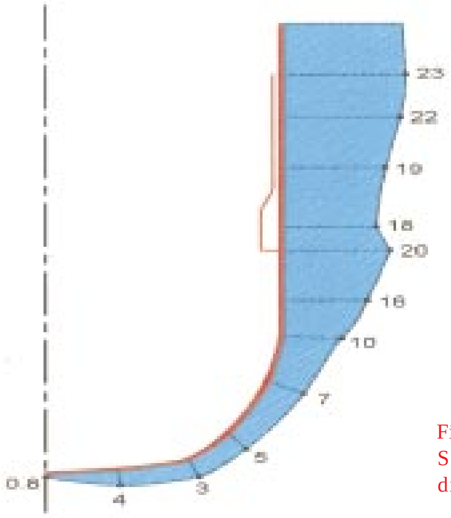


Fig. 3
Shear stress distribution

The detailed analysis has yielded a relation between the site seismicity expressed in PGA vs. tolerances of thin shells of RA. With these relations, it is observed that the vessels manufactured just to meet the functional limit can tolerate a seismic acceleration of ~0.072g for the present design of PFBR which is acceptable. However, it is preferable to achieve tighter tolerance as specified to enhance the earthquake potential of the vessels. Technology development undertaken for PFBR MV and

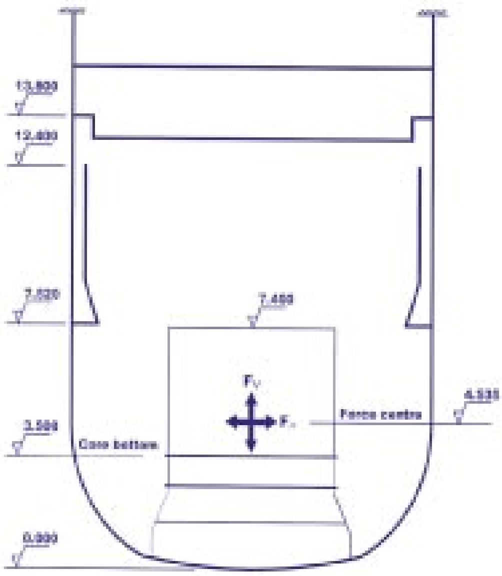


Fig. 2
Effective seismic forces

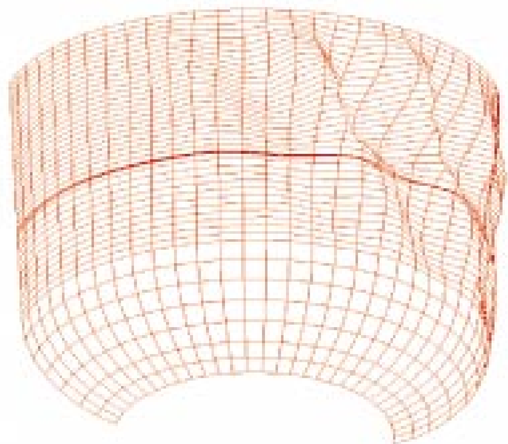


Fig. 4
Shear buckling mode shape

Analysis is repeated for the OTB, which is subjected to external pressures, developed in the feeding and restitution collectors during seismic event. The buckled mode shape under the seismically induced pressures is shown in Fig.6. The permissible PGA is arrived at as a function of manufacturing tolerance as shown in Fig.7. This figure shows that for the tolerance of ± 15 mm, the allowable PGA is 0.072g.

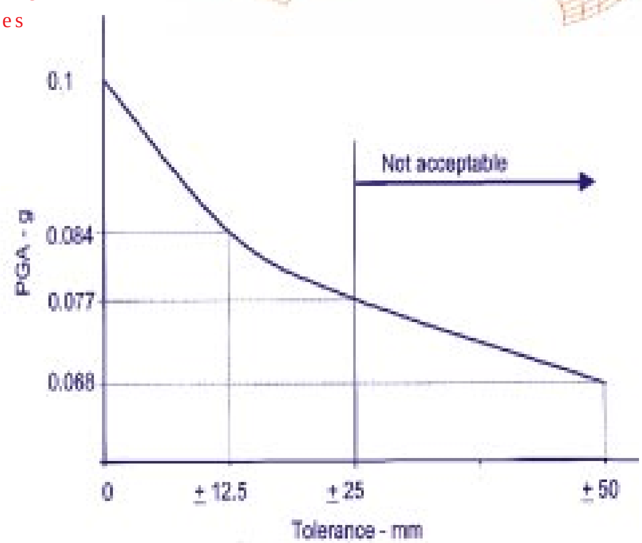


Fig. 5
PGA vs form tolerance for Main vessel

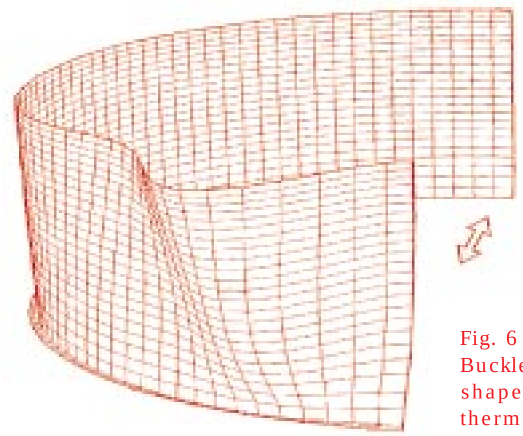


Fig. 6
Buckled mode shape of Outer thermal baffle.

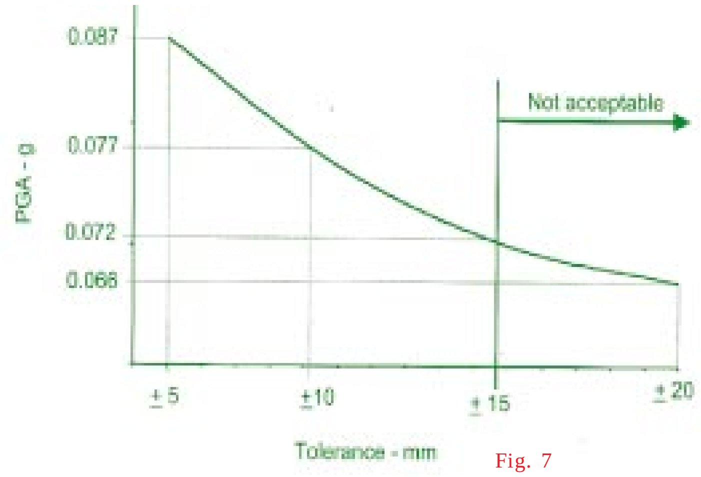


Fig. 7
PGA vs form tolerance for Outer thermal baffle.

IV indicates that achieving tighter tolerance is the most challenging task for the Indian industry, for which it has to adopt innovative manufacturing and selective assembly procedures with extensive usage of state-of-art computerized techniques. Achieving close tolerances in shells will lead to possibility of reduction in their thicknesses as well as diameter of RA. These advantages finally will translate to reduction in capital cost of future FBRs.

(V. Balasubramaniyan, P. Chellapandi and S.C. Chetal)

In-house development of remote field eddy current probes and instrumentation for in-service inspection (ISI) of steam generator tubes of PFBR

Modified 9Cr-1Mo steel is the material of construction of steam generator (SG) tubes (17.2 mm outer diameter and 2.3 mm wall thickness) of Prototype Fast Breeder Reactor (PFBR), because of its high strength and good corrosion resistance. The steam generator, with high temperature sodium on the shell side and water on the tube side, is one of the critical components of the PFBR. Wall thinning and other in-service degradations may occur in the tubes due to the severe operating conditions. Any tube leakage may lead to cascading failures of adjacent tubes due to violent sodium-water reaction. Hence, there is a need to develop a reliable non-destructive testing (NDT) method for detection and evaluation of defects during periodic in-service inspections (ISI). Remote Field Eddy Current (RFEC) method has been chosen for the ISI of the SG tubes. An RFEC system with probes has been developed in-house at DPEND.

RFEC Principle

The conventional eddy current testing cannot be applied for the inspection of ferromagnetic materials such as the modified 9Cr-1Mo steel used for the SG tubes. Magnetic saturation based eddy current testing is an alternative to this and had been used successfully during the tube fabrication. During in-service inspection, this magnetic saturation technique cannot be carried out because of the complexity of the structure, the difficulties of magnetisation and de-magnetisation. To overcome these difficulties, remote field eddy current testing technique has been chosen and developed.

Unlike the conventional eddy current probe, the RFEC probe has separate exciter and receiver coils. A monotonic decrease in signal amplitude and increase in phase lag of a receiver coil voltage are expected, as the spacing between the exciter and receiver coils inside the tube, is increased. Contrary to this, the signal amplitude initially decreases rapidly and thereafter slowly with a transition occurring at about a distance of 3 times the tube inside diameter from the exciter coil. At the same location, a sudden change in phase of the signal also occurs. The region near to the exciter is known as "direct field zone" and the region beyond the direct field zone is designated as "remote-field zone". When the receiver is located at the remote field

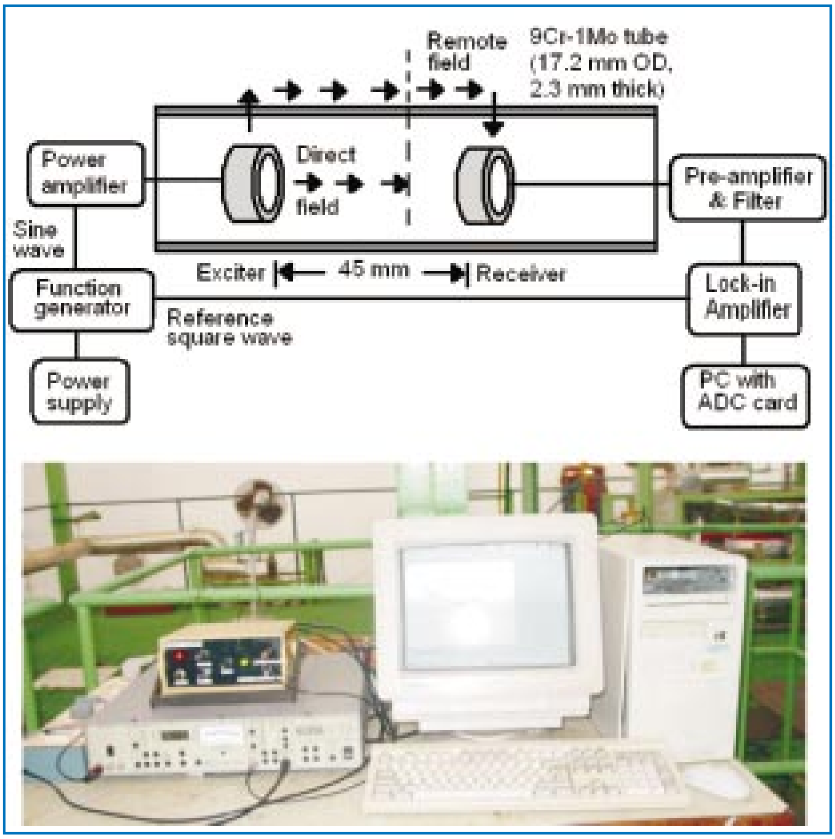


Fig. 1
Block diagram of remote field eddy current instrument and photograph of actual instrument and data acquisition system developed in-house for in-service inspection of modified 9Cr-1Mo steel tubes of steam generators of PFBR

zone, the field at the detector is the resultant of these two components. This voltage developed across the detector coil is found to be proportional to the wall thinning. The field at the detector coil of a RFEC probe is due to the indirect energy flow path, which involves the double diffusion of the electromagnetic field through the wall thickness. Because of this, RFCC method becomes a through-wall eddy current method and can tolerate large lift-off.

The excitation frequency in RFEC method is usually low (50 Hz - 5 kHz) to ensure through-wall penetration of the eddy currents. The induced voltage (~nV and noisy) in the receiver coil, subsequent to double-wall transit, is measured and correlated with wall loss. The transit of the eddy currents through the tube wall produces a characteristic double peak response for a defect, when the exciter coil and the receiver coil move over the defect. The primary advantages of RFECT technique include the ability to inspect tubes from inside with equal sensitivity to both internal and external wall loss, and good tolerance for poor electromagnetic coupling (low fill-factor).

Development of RFEC Instrumentation and probes:

High-performance RFEC instrument and probes developed at DPEND (Fig. 1) consist of a function generator (sine wave excitation and reference square wave), low-distortion 20W power amplifier, special filters and a lock-in amplifier. The amplitude and phase lag (with respect to reference square wave of the exciter) of the receiver coil voltage are measured by a lock-in amplifier. The output of the lock-in amplifier is digitised using an ADC card and stored in the computer. Any wall thinning/defects in the vicinity of the exciter or receiver coil alter the amplitude and phase of the receiver coil voltage. A calibration tube consisting of defects of 10%, 20%, 40%, and 60% wall loss OD grooves has also been fabricated and used for optimizing the test procedure, for establishing the sensitivity and basis for quantitative evaluation.

Model based approach for probe design:

The success of the RFEC method depends on the sensitivity of the RFEC probe, which in turn is related to the number of turns in the exciter and receiver coils and the inter-coil spacing. For high sensitivity detection, it is essential to ensure that the excitation frequency for a probe spacing is optimized for a given material and tube dimensions. The receiver location and excitation current have been optimized experimentally. The qualitative trends of the experimental results have been compared with a 2D axi-symmetric finite element model developed in-house. The performance of the probe has been validated using a calibration tube. Typical RFEC signals for the calibration tube with four wall loss grooves, at optimised test conditions (exciter coil width 10 mm, receiver coil width 10 mm and coil spacing 45 mm) are shown in Fig. 2. Characteristic double peaks for each of the four calibration defects are clearly seen. Wall loss down to 10% has been successfully detected using this optimised probe. A linear relationship is found to exist between the RFEC signal amplitude and the percentage wall thinning.

Problems related to bend regions of SG tubes:

There is a bend region almost at the centre of the 23 m long SG tube to accommodate the differential thermal expansion during operation. It has been

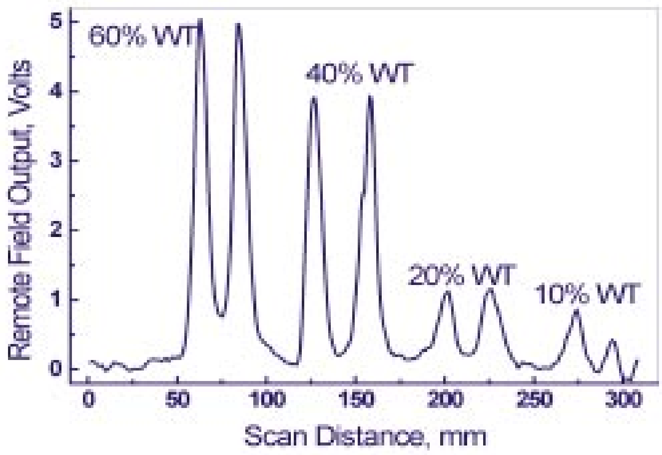


Fig. 2
Typical RFEC signals from reference OD grooves in a calibration tube

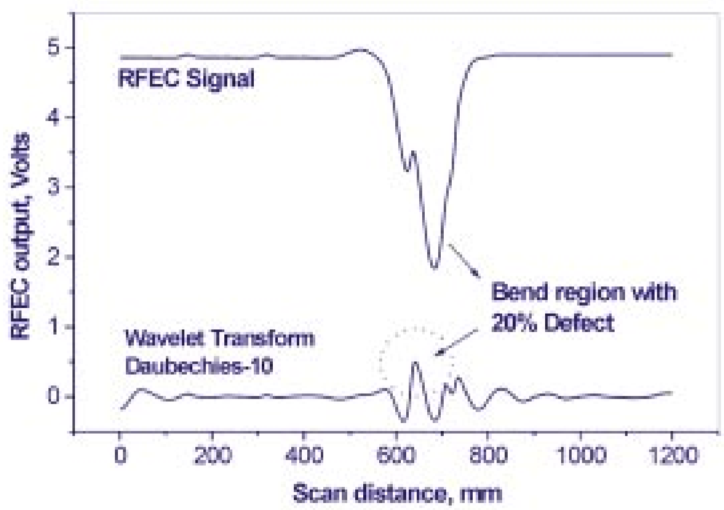


Fig. 3
Wavelet transform method applied to eliminate interfering signal from the bend regions

observed that the bend regions produce very strong interfering signals during RFEC testing, predominantly due to the misalignment of exciter-receiver coils during the passage through the bend regions and also due to the accumulated residual stresses. An advanced Wavelet transform based signal processing method has been adopted to eliminate the slowly varying (compared to genuine defect signal) strong signal. Figure 3 shows a recovered 20% wall thinning defect signal, which was masked by the dominating interfering signal from the bend region. A shift in the baseline data of the RFEC signals has been observed after bending. When an artificial defect was made in the bend region, the RFEC signal was found to be distorted. Separate experiments were carried out to understand the base line shift due to residual stresses, by loading a small tube without defects, in a tensile testing machine. The behaviour of the RFEC signal with tensile stress up to yielding has been studied. It is found that the RFEC output monotonically increases with tensile stress. The relationship between the RFEC signals and the applied stress has been established for effective interpretation of the RFEC signal.

Influence of sodium deposits on RFEC signals:

It is envisaged that during service, the sodium in the shell side would fill the defects if any formed on the OD side of the tubes. Since sodium is conducting, these deposits will have significant influence on RFEC signals during ISI and hence alter the sensitivity. Extensive studies have been carried out to understand the effect of sodium deposits on RFEC signals. Artificial defects of 20-40% wall thinning have been made in modified 9Cr-1Mo SG tubes, welded to a specially designed flange and kept in a vessel (shown in Fig. 4) where hot sodium was raised and lowered repeatedly to simulate varying conditions of sodium deposits on the external surface of the tubes. RFEC signals of the artificial defects have been obtained before and after sodium exposure. It is observed that, although the signal shape has been found to change due to sodium deposits, the height of the RFEC signal peak with respect to the base line has been found to be invariant. Hence quantification of defects is possible even with sodium deposits.

High-density tungsten carbide probe:

In order to cover the entire length of the tubes of 23 m long and to negotiate the bend regions, flexible RFEC probe with 30 m long cable has been designed and developed. Since the steam generator will be vertical, to move down the probe by gravity, a calculated weight of ~ 150 g in the form of small beads made of high-density tungsten carbide has been added to both sides of the probe. It is observed that there is an enhanced RFEC output for the probe with WC beads. Experimental observations revealed that the

Fig. 4
a) Experimental set up for sodium exposure and
b) Sodium exposed tubes
(Arrows show reference grooves filled with sodium)

tungsten carbide beads are mildly magnetic (μ_r = 2.5) and hence concentrate the flux effectively so as to increase the signal to noise ratio. It is also proposed to use high-density depleted uranium as the bead material to reduce overall length of the probe assembly.

Further developments on the anvil:

The RFEC method is highly efficient in detecting uniform wall loss defects due to corrosion. But the technique in its present form cannot detect effectively localised defects such as cracks. In order to overcome this limitation, a segmented coil RFEC probe is being developed. The segmented coil RFEC probe has an exciter and multiple receiver coils located circumferentially inside the tube. The segmented RFEC probe would also enable us to visualize the actual wall thinning variations of the SG tubes in the form of images like C-Scan. It is also proposed to use GMR sensors as receivers to enhance the detection sensitivity of defects.

(Contributed by DPEND & STD)

IGCAR milestones

1971 - REACTOR RESEARCH CENTRE (RRC) ESTABLISHED
- FBTR CIVIL CONSTRUCTION BEGINS

1972 - ENGINEERING HALLS

1973 - CENTRAL DESIGN OFFICE

1975 - REPROCESSING DEVELOPMENT LABORATORY
- CENTRAL WORKSHOP
- CENTRAL WATER CHILLING PLANT

1976 - SAFETY RESEARCH LABORATORY
- MATERIALS SCIENCE LABORATORY

1977 - RADIO METALLURGY LABORATORY

1978 - MATERIALS DEVELOPMENT LABORATORY

1980 - RADIOCHEMISTRY LABORATORY

1982 - COMPUTER CENTRE & ADMINISTRATION BUILDING

1983 - ELECTRONICS & INSTRUMENTATION LABORATORY
- PFBR FEASIBILITY REPORT
- HEALTH AND SAFETY LABORATORY

1985 - FBTR ATTAINED FIRST CRITICALITY
- RRC RENAMED AS INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH (IGCAR)

1987 - LOW POWER EXPERIMENTS IN FBTR

1989 - REPROCESSING OF IRRADIATED THORIUM RODS FOR SEPARATION OF U-233

1990 - SUBMISSION OF DETAILED PROJECT REPORT OF PFBR TO DAE / AEC

1991 - FBTR POWER LEVEL RAISED TO 1 MWt

- THREE COMPONENT SOUND DETECTION AND RANGING (SODAR) SYSTEM INSTALLED

1993 - FBTR POWER LEVEL RAISED TO 4 MWt WITH STEAM WATER CIRCUITS

- FBTR POWER LEVEL RAISED TO 8 MWt (LHR 250W/cm)

- FBTR SUSTAINED OPERATION AT 10.5 MWt (LHR 320 W/cm)

- PARTICLE IRRADIATION FACILITY (PIF) AND RADIO CHEMICAL HOT CELLS COMMISIONED

1994 - RADIO METALLURGY HOT CELLS COMMISSIONED

- FACILITY FOR TESTING LARGE REACTOR COMPONENTS IN SODIUM COMMISSIONED

- SQUID, ASIC AND DIAMOND ANVIL CELL DEVELOPED

- HIGH POWER PHYSICS AND ENG. EXPERIMENTS IN FBTR

1995 - DECISION ON TWO LOOP DESIGN FOR PFBR

1996 - FBTR FUEL CROSSES 25,000 MWd/t BURN UP

- KAMINI REACTOR CRITICALITY

1997 - FBTR TURBO GENERATOR SYNCHRONIZED TO SOUTHERN GRID

- KAMINI REACTOR TAKEN TO FULL POWER

1998 - COMMISSIONING OF STRUCTURAL MECHANICS LAB

- PFBR MAIN VESSEL SECTOR FABRICATED FOR TECHNOLOGY DEVELOPMENT

1999 - IRRADIATION EXPERIMENTS IN FBTR FOR CREEP DATA ON ZIRCALOY&Zr-Nb ALLOYS

- FBTR FUEL SET TO REACH 50,000 MWd/t BURN UP LEVEL

- SODIUM PUMP TEST FACILITY SET UP FOR ROTOR DYNAMIC STUDIES

- STATE-OF-THE-ART NEUTRONIC CHANNELS COMMISSIONED FOR FBTR

2000 - CONSULTANTS APPOINTED FOR BOP DESIGN OF PFBR

- BORON ENRICHMENT PLANT COMMISSIONED

2001 - TECHNOLOGY DEVELOPMENT FOR MANUFACTURE OF INNER VESSEL SECTORS, SG EVAPORATOR, CSRDM AND DSRDM

- HYDRAULIC DEVELOPMENT OF PRIMARY SODIUM PUMP

- FOUNDATION STONE LAID FOR PFBR ADMINISTRATIVE BUILDING

2002 - FBTR ACHIEVED A MAJOR LANDMARK OF REACHING FUEL BURN UP OF 100,000 MWd/t, WITHOUT ANY FUEL FAILURE

- 10 t SEISMIC SHAKE TABLE COMMISSIONED

- MEASUREMENT STANDARD AND CALIBRATION FACILITY SET UP

- QUALITY ENGINEERING SERVICES AND TESTING FACILITY SET UP

- PFBR ADMINISTRATIVE BUILDING INAUGURATED

- SITE EXCAVATION FOR TRIAL BLASTING AND DEWATERING STUDIES

- CONSTRUCTION OF PFBR SITE ASSEMBLY SHOP COMMENCED

- LIQUID HELIUM PLANT COMMISSIONED

2003 - CONSTRUCTION OF STEAM GENERATOR TEST FACILITY (SGTF)

- HYDRAULIC DEVELOPMENT OF SECONDARY SODIUM PUMP

- TECHNOLOGY DEVELOPMENT FOR MANUFACTURE OF PFBR TRANSFER ARM

- COMMISSIONING OF 1.7 MeV TANDETRON ACCELERATOR

- DEMO FACILITY LEAD MINI CELL [LMC] COMMISSIONED FOR REPROCESSING OF FBTR CARBIDE FUEL ON LAB.SCALE

- PFBR TEST SUBASSEMBLY LOADED INTO FBTR FOR IRRADIATION

- TECHNOLOGY DEVELOPMENT FOR PFBR STEAM GENERATOR EVAPORATOR COMPLETED

- LOW BURN UP FBTR CARBIDE FUEL PINS CHOPPED AND DISSOLVED IN LMC

- BORON ENRICHMENT PLANT ACHIEVED 62 % ENRICHMENT IN BORON-10

- HIGH PURITY (90 %) ELEMENTAL BORON PRODUCTION DEMONSTRATED

- ADMINISTRATIVE APPROVAL AND FINANCIAL SANCTION FOR CONSTRUCTION OF PFBR
- FORMATION OF NEW COMPANY “BHAVINI” FOR CONSTRUCTION OF PFBR
- FBTR CARBIDE FUEL REACHED A BURN UP OF 123,000 MWd/t

2004 - PIE OF 100,000 MWd/t IRRADIATED FBTR CARBIDE FUEL COMPLETED

- CLEARANCE FROM SARCOP FOR REPROCESSING OF 25,000 MWd/t IRRADIATED FUEL FROM FBTR IN THE LMC
- SGTF COMMISSIONED WITH SODIUM AT 2 MW, WITHOUT STEAM GENERATOR
- 25,000 MWd/t IRRADIATED FBTR FUEL PINS CHOPPED & DISSOLVED IN LMC

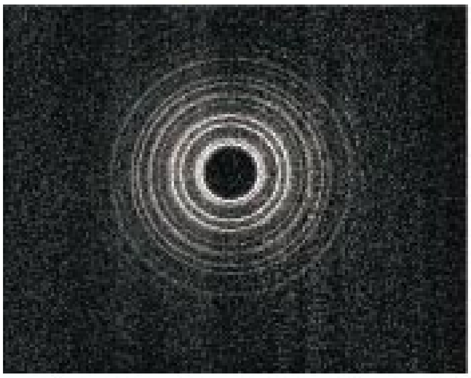
Indigenous development of an X-ray image plate scanner

“Imaging Plates” (IP) based on photo-stimulable X-ray storage phosphors establish a promising alternative to the conventionally utilized X-ray films. Upon absorption of ionizing radiation in the image plate, electron hole pairs are produced and are trapped in the immediate surrounding of their position in the crystal lattice thereby forming a latent image of the radiation falling on it. The latent image is stable until read with a laser beam. The readout of this image is done by photo-stimulation (PS) whereby the trapped electrons are liberated and recombine radiatively with the trapped holes and emit the characteristic PSL, the blue light of Eu^{2+}. The emitted light is captured, digitized and stored. The stored data is processed to view the image. The IP has several advantages compared to the conventional X-ray films. The advantages are high sensitivity; wider dynamic range, superior linearity, higher spatial resolution, data in digital form and above all the reusability of the plate after scan. Recently, an indigenously developed Image Plate scanner has been developed in the Materials Science Division.

During the readout process, the image plate is scanned point by point with a laser beam. The luminescence intensity, resulting from the photo-stimulated recombination of the defects is measured with a photo-multiplier tube, which is optically coupled to the point of emission by a light collecting lens assembly. The intensity signal is subsequently digitized and stored in a computer. After the scan, the residual information has to be bleached before the image plate can be exposed the next time. There are several IP scanner systems described in literature and some commercially available abroad. They differ in type of lasers, scanning mechanisms, techniques for the light collection and ADC converters. Therefore, the performance, especially the image quality and the readout speeds of these detectors vary and hence the total scan times are different. In our case, the scanning laser is stationary and the plate is moved to scan the entire plate to bring out the latent image.

This IP scanner is designed to scan an imaging plate of active area of 250 mm x 200 mm, which is the standard

Fig. 1 The Photograph of the Imaging Plate Scanner System and Controller



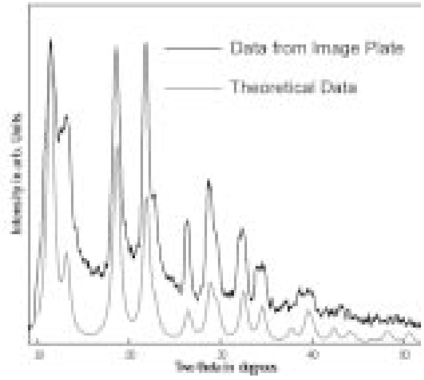


Fig. 2
The Two Dimensional XRD pattern of BaF_2 Collected by Imaging Plate and the One dimensional Converted XRD data with the Theoretical data

size of the most commercially available imaging plates. The readout laser is a focusable diode laser of 3 mW power and 635 nm wavelength. The laser is focused to 100µm spot size on a fixed position on the imaging plate by a small mirror inclined at 45º. When the laser light falls on the image plate, wherever the image is present, PSL light emission occurs. The emitted PSL light is collected and projected on to a PMT by an optical assembly. The optical assembly allows only the 390 nm PSL light and filters the 635 nm light to get the PSL signal alone. The intensity of the PSL signal gives the information of the image.

The advantages are high sensitivity, wider dynamic range, superior linearity, higher spatial resolution, data in digital form and above all the reusability of the plate after scan.

The movement of the imaging plate is achieved by means of a precision X-Y scanner. The X-movement is done by a 3-phase servomotor and the Y movement is done by a stepper motor. The maximum distance of X-movement is 250 mm along the length of the plate and the maximum Y movement is 200mm. Both the X and Y mechanical movements are along LM guide rails and use zero backlash C3 class ball lead screws. The reproducibility at the end of the X and Y-axes is ± 10µm and the total scan time is 16 minutes. An aluminum plate of 12 mm thickness with a 3mm slot is fixed on the top of the X Lead screw to fix the imaging plate with arrangement to tightly hold the plate. A photograph of the Image Plate Scanner is shown in figure 1.

The data acquisition and control is done with a 12-bit PCI Multifunction card. The data acquisition software was written in-house in Visual Basic 6.0 using the Driver Linux driver software supplied with the ADC card. At a step size of 100µm along the X and Y direction, 5 million data points are generated. The integrated Windows based software is menu driven with options to acquire data, to plot the acquired data and save it as a bitmap file. Further, there is a provision, which is useful for the X-ray Diffraction studies. The two dimensional XRD pattern i.e., Debye Scherrer rings can be converted to a one dimensional XRD pattern, i.e. Intensity Vs two-theta, which can be used for crystal structural analysis. One such XRD result of a BaF_2 sample is shown in figure 2, which shows the data from the Imaging Plate and the theoretical data, which matches well. Also, a clinical X-ray radiograph scanned in this scanner, which gave a radiograph comparable to the conventional film with three times less dose, is shown in figure 3. This scanner is proposed to be used for synchrotron beam experiments at CAT, Indore and also has potential applications for medical imaging.

Fig. 3
Clinical X-ray image

(D. Sornadurai, B. Purniah, P.Ch. Sahu and K. Govinda Rajan)

Highlights of Symposia / Seminars / Conferences

Workshop on Reliability Maintenance

May 8th 2004, Convention Centre, Anupuram.

A one day Workshop on Reliability Maintenance with an objective to expose the participants to modern maintenance practices and strategies by way of invited lectures from experts in the field of maintenance and to focus on the importance of pro-active maintenance approach was jointly organized by Institute of Engineers-Kalpakkam Local Centre and Engineering Services Group, IGCAR. About 65 delegates from various divisions of IGCAR, GSO, MAPS and BARC(F) participated in the Workshop.

Shri Y.C. Manjunatha, AD, ESG welcomed the gathering, Shri A. Sivasankaran, Chairman, IE-Tamil Nadu State Centre delivered the inaugural address, Dr. Baldev Raj, Director, IGCAR presided over the function and released proceedings (CD form), Shri S. B. Bhoje, former Director, IGCAR delivered the plenary address, Dr. Ing. B.V.A. Rao, Director, International Relations, Vellore Institute of Technology delivered the keynote address, Shri A.S. Raghu, Head, AC&VSD, ESG inaugurated the product exhibition and Shri K.C. Srinivas, Chairman, Organizing Committee proposed vote of thanks. Dr. Baldev Raj Director, IGCAR during his presidential address emphasized the importance of reliable diagnosis with minimum tests in an analytical manner at minimum cost to ensure 100% availability. He drove the point very clear with an analogy of an effective patient-doctor relationship. He also emphasized the importance of experience, training, reading and continuing education as essential factors to develop skills and expertise. He also said that all sectors of a plant, starting from design to O&M are equally important. Shri S. B. Bhoje during his plenary address spoke about the importance of human aspects and genuine spares to achieve reliability of equipment/system.

Dr. B. V. A. Rao said that the only way to increase availability is by keeping meantime of repairing (MTTR) to bare minimum. Good knowledge and skill of fault analysis to predict the fault at proper interval of inspection are essential to carryout objective diagnostic and condition monitoring to detect failure at incipient stage. Identification and assessment of failure process, operational environment, materials, transportation & handling of equipment and human performance (knowledge, skill, experience and motivation) are the vital factors for preventing failures.

Experts in the relevant field, academic institutions, R&D institutes and industries participated in the Workshop and discussed the following: (a) Increasing equipment availability with minimum maintenance, spares and cost through condition monitoring and proactive maintenance. (b) Objective diagnostic and condition monitoring techniques for early detection of on setting problems. (c) Various vibration-monitoring techniques like time domain analysis, spectrum analysis and real time analysis, to isolate defective system, since " Vibration is the language of the machine". (d) New techniques like parametric spectra, ceptrum analysis, acceleration enveloping, modal analysis, wavelet analysis, neural networks and time frequency analysis. (e) Smart sensors and materials with digital data incorporating amplification, analog to digital conversion, vibration monitoring, self calibration and self diagnostics features can be solution for vibration problems. (f) Emergence of Mechatronics. (g) Importance and implementation of Reliability centered maintenance to avoid failures.

(C. Chandran)

AWARDS & HONOURS

Congratulations

Dr. Baldev Raj, Director, IGCAR has been selected for the prestigious *International Committee on Nondestructive Testing (ICNDT) Research Award* for the years 2000- 2004. This award is given in recognition of his excellent research contributions and the impact of his contributions in the area of NDE science and technology.

Shri Anish kumar, DPEND has also been selected for the *Young Achiever Award (2000 – 2004)* by ICNDT for his NDT research contributions.

Dr. U. Kamachi Mudali, CSTD has received the *National Corrosion Awareness ONGC Award* for the year 2003. He has also been selected as a member of International Editorial Board for International Journals "Corrosion Reviews", "Surface Engineering" and "Materials and Manufacturing Processes".

". . . . When nuclear energy has been successfully applied for power production, in say a couple of decades from now, India will not have to look abroad for its experts but will find them ready at home . . . "

- Homi Bhabha

". . . . . Countries have to provide facilities for its nationals to do front-rank research within the resources which are available. It is equally necessary, having produced the men who can do research, to organise task oriented projects for the nation's practical problems . . . "

- Vikram Sarabhai

Chairman, Editorial Committee : Dr. Baldev Raj, Advisory Members : Shri S.C. Chetal.
Members : Dr. P.R. Vasudeva Rao, Dr. K. Govinda Rajan, Shri. V.S. Krishnamachari, Shri. M. Somasekharan and Dr. G. Amarendra.
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