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DEVELOPMENT OF UNCONVENTIONAL TUBULAR LINEAR INDUCTION MOTORS FOR NUCLEAR REACTOR LIFE EXTENSION APPLICATIONS

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Background

Early generation 220 MWe Indian Pressurised Heavy Water Reactors (PHWR) consist of 306 horizontal coolant channel assemblies. Each coolant channel assembly consists of zirconium alloy pressure tube (PT) which contains natural uranium di-oxide fuel bundles cooled by pressurised heavy water circulating through the primary heat transport system. The length of pressure tube is approximately 5.5 meters. The nominal diameter of PT bore is 82.55 mm and its nominal wall thickness is 4.23 mm. Thin-walled zircaloy-2 calandria tube (CT) surrounds the pressure tube. The nominal diameter of CT is 108 mm and its nominal wall thickness is 1.3 mm. The annular gap between PT and CT will be 8.55 mm (when PT and CT are concentric). This annular gap serves as thermal insulation between PT and CT. The annular spacing between PT and CT is maintained by coiled spring spacers known as garter springs (GS) made of zirconium-niobium (2.5%)-copper (0.5%), a non-magnetic alloy having relative permeability approximately unity. The schematic view of PHWR coolant channel assembly showing PT, CT and GS spacers is shown in Fig.1.

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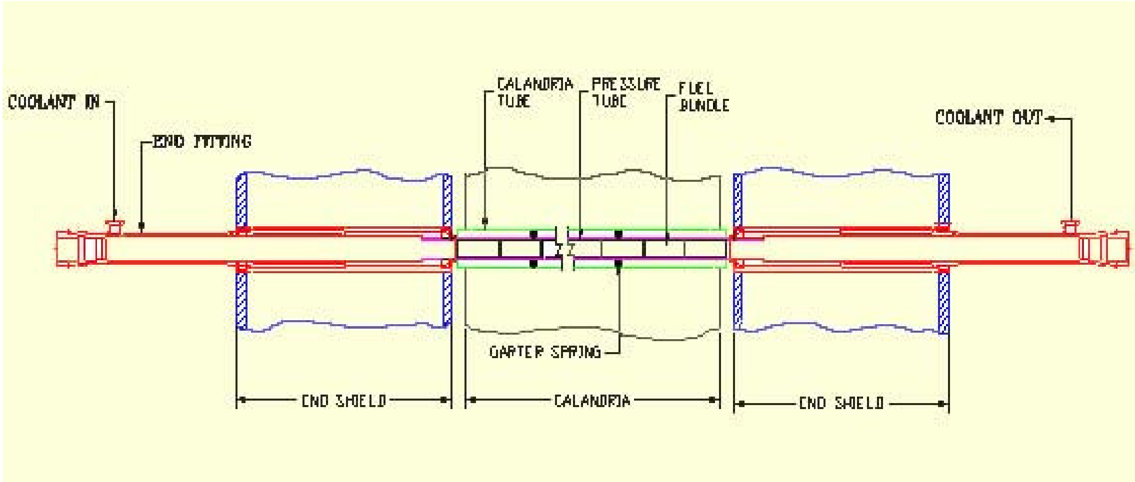

Fig. 1 Schematic of PHWR Coolant Channel Assembly

Once installed in their respective design locations (during coolant channel assembly erection/ fabrication), these GS spacers are not physically accessible from either side of coolant channel as they are confined in the annular space between PT and CT. In early generation Indian 220 MWe PHWRs, these GS spacers are loosely fixed components, meant for preventing the contact between PT and CT. There has been evidence of these loose fit GS spacers shifting from their installed locations during reactor operation.

The actual location of GS spacers in PHWR coolant channel plays a very significant role in maintaining stipulated service life of the channels. The displaced GS spacers can lead to the development of contact between PT and CT, resulting in formation of zirconium hydride blisters at the contact location over a period of reactor operation. The embrittlement and cracks caused by the hydrides (developed in the form of blisters on PT) will result in eventual failure of PT.

As such, there was a need to design and develop a device that can reposition these displaced GS spacers in highly radioactive coolant channel assemblies of operating PHWRs in order to extend their operating life. Special electromagnetic devices meant for repositioning the displaced garter spring spacers have been designed and developed by Reactor Engineering Division, BARC. These devices work on the principle of linear induction and are unconventional in nature considering their design and operational strategies. Various versions of these devices have been developed after exhaustive experimentation and design innovations.

This report gives brief overview of various unconventional tubular linear induction devices developed to serve the purpose of repositioning the loose fit GS spacers in coolant channels of operating PHWRs. Unconventional nature of the devices, design philosophy and developmental constraints are also covered in brief.

Garter Spring Repositioning by Electro-magnetic Induction Technique

The garter springs used in early generation 220 MWe PHWR's are loose fit coiled springs having 6.8 mm coil diameter and 104 mm nominal spring diameter as shown in Fig. 2. These coiled springs are not tied or hooked at free ends. A zircaloy-2 tie wire known as girdle wire is passed through the coil and spot-welded at its free ends to make the assembly in coiled form to appear like bangle. These coiled springs so called garter springs are inserted on to pressure tubes to encircle them to act as spacers. The zircaloy tie wire can act as an electrical conductor, forming close electrical circuit. As such, any linkage of time varying electromagnetic field to the girdle wire of garter spring can induce an alternating voltage in it, which in turn circulates electric current in it.

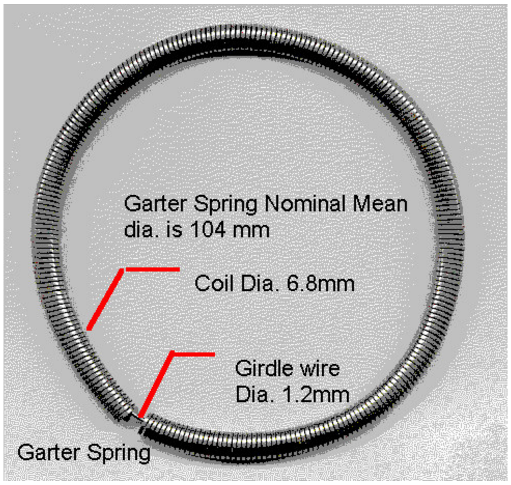

Fig. 2. Garter Spring photograph

One can impart physical movement in GS spacers (in axial direction) by inducing electric current in its girdle wire by means of electromagnetic induction device which acts as Primary Flux Device (PFD). The interaction between the magnetic flux developed by PFD and that produced by girdle wire induced current (produced by PFD flux linkage) will cause generation of mechanical force to move the garter spring in axial direction. This technique known as electro magnetic induction technique has been used in GS spacer repositioning, involving design and development of various PFD's. These PFD's, which are nothing but Unconventional Tubular Linear Induction Motors (UTLIM) can impart physical movement in GS spacers (located in the annular space between PT and CT of PHWR coolant channels) in desired axial direction

Thus, garter spring repositioning by electromagnetic induction technique involves sending a specially designed electromagnetic induction device (PFD) through the PT bore and positioning it adjacent to the target GS spacer. It may be noted that the only access available to the electromagnetic device/PFD for reaching and positioning it opposite to the GS spacers will be its insertion through the pressure tube bore through its open ends as shown in Fig 3.

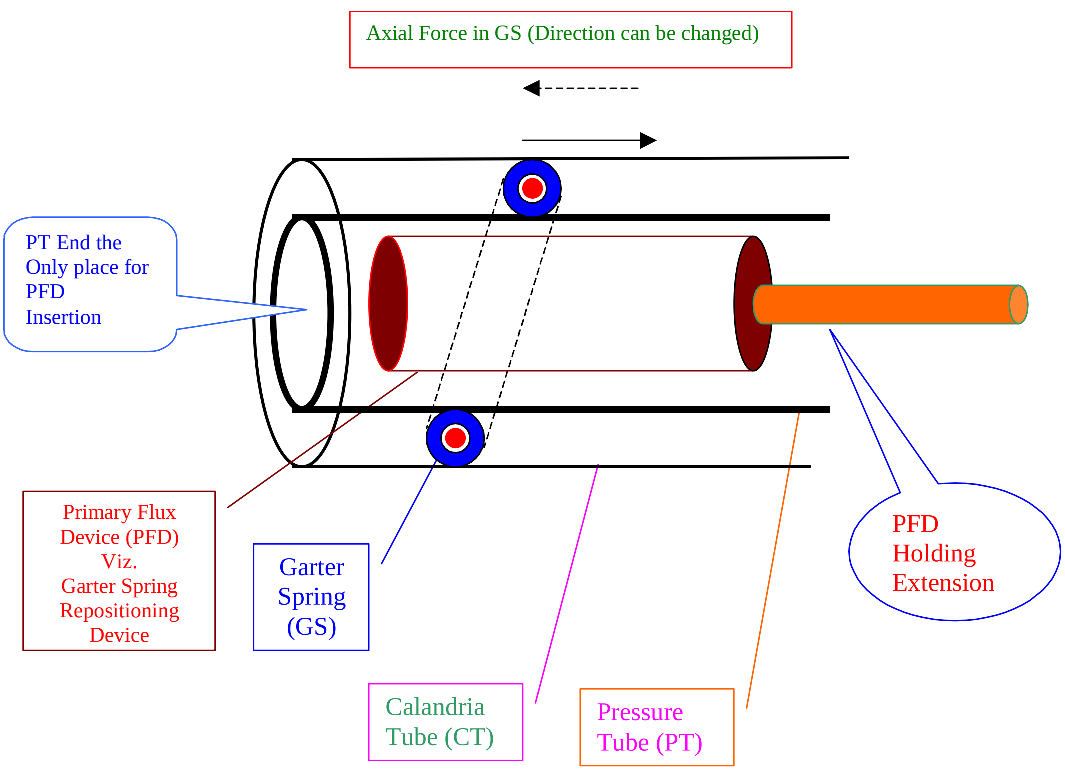

Fig. 3 Schematic of garter Spring repositioning set-up using PFD

It may be noted that the electromagnetic device (PFD) is held stationary in the PT bore (during its energisation) whereas the target GS spacer (located at the outer side of PT) is made free (by the help of un-pinching device) to facilitate its movement in the PT-CT annulus. When one energises the PFD with AC, it generates primary AC field, which in turn generates current in the girdle wire of GS by electromagnetic induction provided sufficient flux gets linked to it. The generation of alternating current in the girdle wire of GS will produce its own magnetic field (known as secondary field). The interaction between primary flux (produced by PFD) and secondary electromagnetic field (produced by girdle wire induced current) causes the movement of un-pinched GS spacers. The PFD acts as stator of Linear Induction Motor (LIM) and the girdle wire acts as its rotor, which gets pushed in axial direction resulting in physical movement of GS.

In other words, the system acts as Unconventional Tubular Linear Induction Motor (UTLIM) during its operation and essentially involves design and development of Tubular Linear Induction Device stator that imparts the driving axial force in GS spacers for their repositioning.

Primary Flux Device (PFD) Development

Linear electromagnetic induction based Primary Flux Device known as Garter Spring Repositioning Device (GSRD) has been designed and developed for GS spacer repositioning. It is basically Unconventional Tubular Linear Induction Motor (UTLIM) stator that produces magnetic flux in direction of rotor motion. In other words it is longitudinal flux motor. When excited with 3-phase AC power supply, the device generates traveling magnetic field. This device when placed inside the PT and positioned opposite to GS spacer (located in the annular space between PT and CT) will induce eddy current in girdle wire of GS spacer. Here it may be noted that the girdle wire forms electrically closed circuit since its open ends are spot-welded. Thus the girdle wire of GS spacer acts as secondary of the device viz. PFD/UTLIM/GSRD. The girdle wire induced current produces its own magnetic field, which interacts with primary magnetic field generated by GSRD resulting in generation of mechanical force in GS spacer in axial direction. This mechanical force moves the GS spacer in forward or reverse direction depending upon the phase sequence selected for energisation of GSRD winding. Fig 3. shows the schematic of the garter spring repositioning by using GSRD.

Unconventional nature of GSRD and associated system: In conventional linear induction motors, the design of stator and rotor is done to achieve optimum performance by selecting proper material and configurations. Further, in conventional system greater flexibility in design of system components is possible by choosing proper values of parameters like length of air gap, rotor and stator configuration, cooling method, operating supply etc.

In GSRD design and operation, totally un-conventional practices have been followed, which can be seen as follows:

(a) *Unconventional Rotor:* In conventional Tubular Linear Induction Motors (TLIM), secondary or rotor consists of iron core or aluminum/copper tube shrunk fitted on solid iron rod. The rotor thickness and material play very significant role in the performance of LIM. Use of ferromagnetic material as secondary or in rotor circuit has advantage of high permeability resulting in less magnetizing current drawn from mains. Further, the resistivity of secondary should be lower to help in inducing high current in its circuit for the same induced voltage. This will help in developing higher thrust/force in rotor. Thus, in conventional motor, the rotor is made up of ferromagnetic material reinforced by high electrical conductivity material to increase the magnitude of

Lorenz force developed in rotor. In GSRD (which is a single strand wire of 1.3 mm diameter having approximate length of 320 mm) acts as rotor conductor, which carries the rotor current. It may be noted that the girdle wire is made of zircaloy-2 and not that of conventional material viz. copper or aluminum. The electrical resistivity zircaloy-2 is approximately 47 times than that of copper. Further, there is non-existence of ferromagnetic core in rotor circuit as the coiled spring surrounding the girdle wire is made up of zirconium-niobium-copper alloy. This alloy is a paramagnetic material whose relative permeability is approximately 1. Thus rotor construction is totally unconventional in nature.

(b) *Presence of Large Air Gap:* Length of air gap (between stator and rotor) is very important parameter in electrical machine design. Large air-gap requires large magnetising current and results in low power factor. Also, output force and efficiency gets decreased when design incorporates large air-gaps. As such, the air-gap between stator and rotor should be as small as possible. Air-gap width in general will be between 1 to 2 mm for small Linear Induction Motors (LIM). However, in exceptional cases, conventional small LIM's can have air-gaps between 3 to 5 mm. Very large LIM's used in traction applications can have air-gaps between 5 to 15 mm.

In this case, the air gap between stator and rotor is exceptionally very large (around 8.0 mm) considering the size and rating of the motor. This air-gap is nothing but the distance of girdle wire of GS from GSRD. This enhances the requirement of magnetising current and Magneto Motive Force (MMF) needed by GSRD to establish reasonable quantity of magnetic flux in the vicinity of GS location. Further, the linkage of magnetic flux with girdle wire, which is a single turn wire/conductor, made of para-magnetic material will be very less. The system, the girdle wire of the garter spring outcome of these factors will be reduction in current induced in the girdle wire, which in turn reduces the force generation in it for axial movement.

(c) *Unconventional Operation:* In conventional motor, the stator does not act as mechanical lifting device. However, it does carry the load of winding but does not take intense mechanical loading that will lead in to generation of large bending moments. In this system, the stator of the device viz. GSRD core/former acts as load bearing element. Thus, apart from generation of intense electromagnetic flux, it is used to lift the PT in order to un-pinch GS to facilitate its movement. The load applied by hydraulically actuated Front and Rear Flexing Modules to the device (GSRD) core will be around 5.5 Ton at 16 Degree angle with respect to horizontal direction on either sides of GSRD former as shown in Fig. 4. As a result, the resultant lifting force acting on the device in vertical direction will be of the order of 1.5 Ton. This exclusive mechanical loading of device (GSRD stator) former during operation creates severe mechanical stresses in it. Further, under such large mechanical stressed condition of the stator former, the flux generation of the device gets degraded which in turn affects the force generation in GS. In conventional motors, no such phenomenon occurs.

(d) *Unconventional Application:* The PT and garter springs are made up of zirconium alloy material. The PT being closer to GSRD (as compared to GS) and being a component of larger dimensions has got the advantage of larger eddy current generation (in comparison to girdle wire of GS). This is because the PT is made of similar material as that of GS but since it is having thicker dimensions than that of girdle wire of GS, it will have low electrical impedance and hence large eddy currents will be induced in it. The magnetic field produced by PT

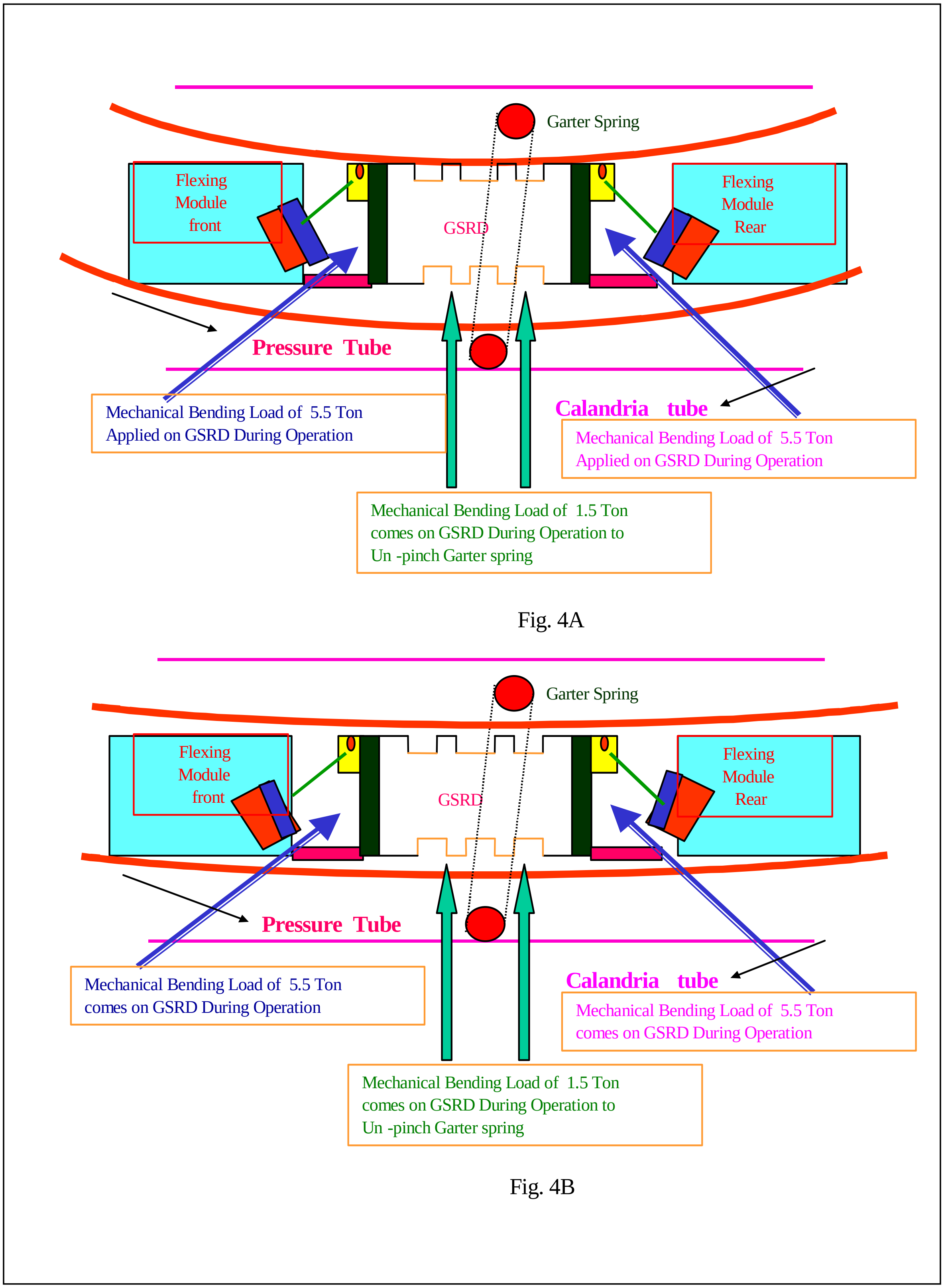

Fig. 4 GSRD acts as Load Bearing Member where extremely high mechanical stresses are imparted during operation by Mechanical Flexing Modules

induced eddy currents will oppose the main flux produced by GSRD which is the basic cause for their generation (Lenz Law), reducing flux linkage to the girdle wire of GS. As such, it acts as shield to the primary magnetic flux linkage to GS spacer. This shielding effect causes reduction in magnitude of primary flux reaching to the garter spring. To minimize this shielding effect of PT, the Primary Flux Device (GSRD) needs to be operated at such a frequency that provides optimum penetration depth for magnetic flux, to minimise shielding effect. In conventional motors, no such flux-shielding problem exists as there will be a clear air-gap between stator and rotor and no metallic components will be embedded in between to cause shielding effect.

(e) *Pulsed Mode Operation:* Large amount of magnetic flux needs to be generated in GSRD to ensure that sufficient flux links to the girdle wire of GS to produce fair magnitude of Lorenz force in girdle wire to impart axial motion for repositioning. This is needed to overcome negative effects of unusually high air-gap between stator and rotor, un-conventional nature of the device (stator) and shielding effect of PT. As such large Ampere-Turns needed to be applied to the GSRD. Further, when GSRD is operated at higher frequency to minimise the shielding effect of PT, the eddy current and hysteresis losses generated in the core will be very high besides excessive copper losses in winding. Due to this, the device former gets heated up resulting in very sharp rise in its temperature. As such, continuous operation/ energisation of the device should be avoided and the same should be powered in pulsed mode fashion by special power supply in order to minimise its temperature rise. The conventional motors on the other hand will not have such temperature shoot-up problem and are generally designed for continuous operation.

(f) *Unconventional Cooling:* In LIM, as in the case with any other rotary induction motors, active power loss occurs in primary circuit viz. primary winding loss and core loss. In case of GSRD, the operating frequency and magnetic flux density are very high. The current density in primary/stator winding in conventional LIM's in general will be between 4 to 25 Amps/Sq. mm. In case of GSRD it is around 90 Amps/sq. mm. which is nearly 3.6 times the highest value used in conventional motors. When current density is of the order of 15 Amp/sq. cms. forced air-cooling is normally adapted, where as if it exceeds further say up to 25 Amps. /sq. cms. water-cooling ducts are used in the stator for adequate cooling. In case of GSRD, due to size limitation, it is not possible to provide water-cooling ducts. As such, pulse mode operation (to limit the temperature rise of former) and natural cooling in presence of traces of heavy water have been implemented for dry channel operation of device. It may be noted that during energisation of device, heavy water evaporation (due to intense heat generation in GSRD) helps in cooling the device faster due to removal of heat in the form of evaporation (latent) heat.

Design philosophy and constraints in development of GSRD: The GSRD is an unconventional device in terms of construction, operation and end use application. Various constraints and limitations have been taken in to consideration to arrive at optimum design and its operating parameters. These are given below:

- *Compact Size:* The device should be compact in dimensions for free insertion, removal and movement in the coolant channel of PHWR in order to negotiate bends. Maximum length and diameter of the device should not exceed 350 mm and 80 mm respectively to enable it to travel through highly sagged coolant channels of operating PHWR's.

- *Unfavorable Material Properties*: The PT, CT and GS spacers are made of zirconium alloy material. This material is paramagnetic in nature besides having very low electrical conductivity. In other words, this material is having poor electrical and magnetic properties, which are unfavorable to generate higher force in girdle wire of GS for its movement. Due to inadequate force generation in GS, their repositioning becomes very difficult task.

- *Need for High Magnetic Flux Generation:* Special soft magnetic material having very high relative permeability and saturation induction should be used as core material for device. This is required in order to overcome negative affect of exceptionally large air-gap and unfavorable electrical and magnetic properties of GS so that sufficient flux links with GS spacers to produce adequate Lorenz force in GS for its movement. Further, it is not possible to use the core material in the form of laminated sheets to minimise eddy current and hysteresis losses as the core of the device acts as load member during operation. As such, selection of soft magnetic material having highest saturation induction, sufficiently higher relative permeability and very high mechanical strength for the device former is essential. Further, the core material should have higher specific resistance to minimise the iron losses.

- *Pressure Tube Shielding Effect:* During device operation, shielding-effect of pressure tube is undesirable feature, as it plays negative role in force generation on GS. This affects repositioning of GS spacers. For maximum force generation in GS, the operating frequency of the device should be selected in such a way that the shielding effect of PT is minimised.

- *Presence of Large Air Gap:* The presence of unusually large air gap reduces flux linkage between device (GSRD) and rotor (Garter Spring). This air gap is around 8.0 mm, which increases the requirement of magnetising current. As such, need of generation of very intense flux in the device is a must so that despite very high flux leakage (due to large air gap), adequate flux will link with GS in order to generate sufficient force for its movement.
- *Girdle Wire Rotor:* The system is not having conventional rotor but the GS girdle wire acts as rotor. The girdle wire being spot-welded at its open ends forms a closed electrical circuit, providing path for the electrical current circulation. This circulating current produces necessary force for its axial movement.
- *Mechanical Integrity of Former:* The device stator should use solid core as it acts as load bearing element in the system. The load on the device former will be of the order of 5.5 Ton resulting in generation of very high bending movement in it. The device should maintain its mechanical integrity during operation.
- *Hostile Operating Condition:* The device needs to be operated under heavy water environment in presence of very high radiation field of the order of 10^6 Rads. The IR value of device bound to be degraded under such intense radiation field. The IR value needs to be periodically monitored during operation due to said reason. Further, the device should be designed such that it will have some reasonable minimum in-service channel operation life.
- *Safety Features:* The device will have unbalanced phase impedances due to asymmetric primary winding and longitudinal end effects. Balanced voltage excitation will produce unbalanced phase currents. Shorter the length of device viz. GSRD, higher the impedance unbalance. As such, special power supply needs to be devised for safe

operation of device. It should be ensured that under no circumstances the device gets shorted in the channel. Features like pre-energisation checks, periodic meggering (to check IR value of device) and on-line temperature monitoring of device needs to be essentially incorporated to ensure its safe operation.

- *Uncontrolled Conditions:* Presence of muck in annulus region of PT and CT, distortion in shape of GS spacers and high electrical contact resistance at girdle wire spot weld plays significant negative role in GS movement. The device should be able to reposition GS spacers against all these odds.
- *Requirement of Moderate Operating Parameters:* The device should have features like moderate operating voltages and currents for safe power control to enhance the safety of coolant channel. This will have the advantage of minimal damage to the coolant channel in case of any accidental eventuality.

Various Devices Developed

The following Unconventional Tubular Linear Induction Motor Stator, named as Garter Spring Repositioning Device's (GSRD), have been developed for repositioning of displaced GS spacers located in highly radioactive channels of 220 MWe PHWRs.

a) ***Single Phase GSRD***: Schematic of this device and its electromagnetic flux density profile when energized by single phase 230 Volts 50 Hz AC supply are shown in Fig. 5A and 5B respectively. One can note that the flux density is maximum at the device center and nearly zero at its ends. As such, when GS is placed at the center of the device, the interaction between the girdle wire current (generated due to eddy current induced in it) and the GSRD magnetic flux interacts with each other leading to the generation of Lorenz force. This force will move GS from high flux to low flux zone. In other words, GS moves from the center to the edge of the device. Many working modules of the device have been designed and fabricated including shaded flux device by using copper rings. Heat treatment of device former is also carried out to remove the residual stresses developed in the former material during machining, as such to improve the magnetic flux generation in the device and hence to enhance force developed in GS.

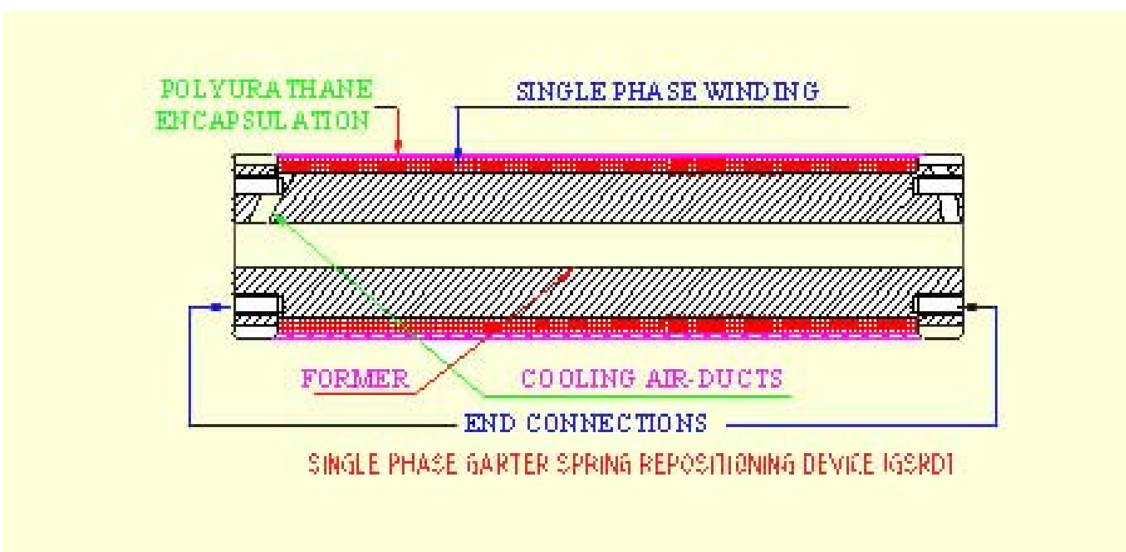

Fig. 5A Single Phase Garter Spring Repositioning Device (GSRD)

The heat-treated former becomes brittle and is not fit for the type of our application, where the former is used as load bearing element involving risk of its breakage during operation. Frequency optimisation experiments were carried out to select the best operating frequency to minimise the PT shielding effect. It has been found that beyond 200 Hz excitation/operating frequencies, the girdle wire current remains practically un-changed for same Ampere-Turns. Further, the stator core gets very hot due to eddy current and hysteresis losses as the operating frequency increases. The operating frequency has been optimised to minimise shielding effect of PT to enhance Lorenz force development in GS. However, these designs could not be implemented practically due to following reasons and limitations.

(i) The Lorenz force generation in girdle wire of GS was not very much sufficient to impart large movement in the garter spring. The device was operated in pulsed mode energisation. In each pulsed firing or energisation of device, the GS movement was found to be of the order of 5 to 10 mm per stroke, which is very low.

(ii) Commonly available Industrial power supply is 3 phase, 440 V AC at 50 Hz. Connecting Single Phase 250 Amperes highly reactive load (GSRD) between line and neutral of this power supply causes severe unbalancing of the power supply. Further, there is no control over the direction of movement of GS, as it depends upon its relative positioning with respect to device center as shown in Fig. 5B. For maximum force generation, the GS should be positioned at the center of the device. If positioning is not done properly, the GS will move opposite to the desired direction. To avoid it, if one places GS far off from the device center (to ensure the movement direction), the GS may not move, as force generation in its girdle wire will be very less at the far-off distances.

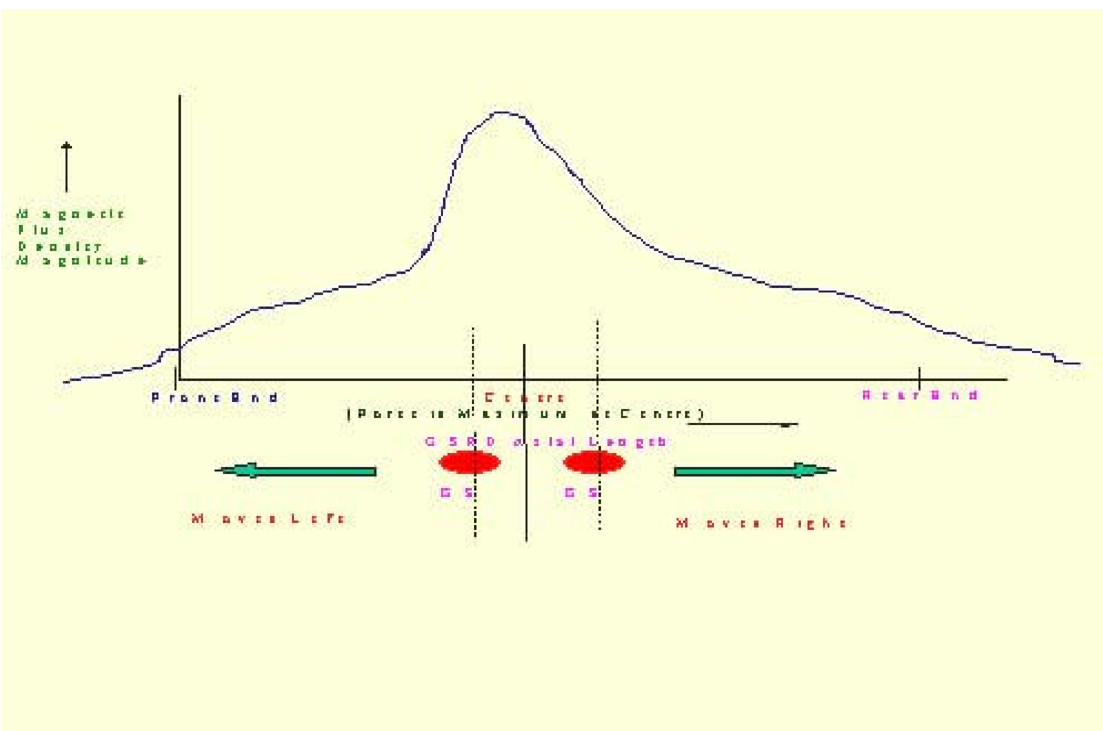

Fig. 5B Electromagnetic flux profile of Single Phase GSRD

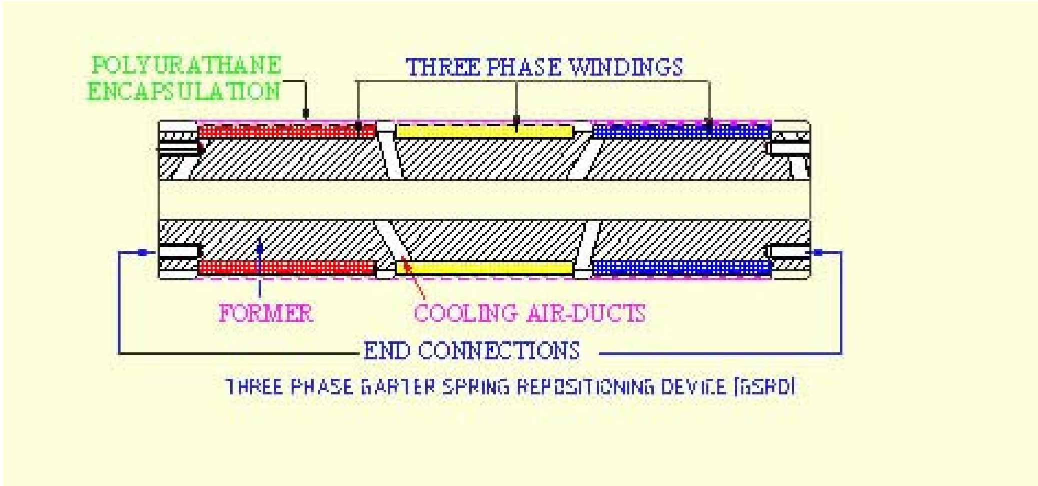

Fig. 6 Three Phase Garter Spring Repositioning Device (for dry as well as Dry- cum-wet operation)

***(b) Three Phase GSRD development*:** In order to enhance the Lorenz force magnitude and GS movement direction control, to facilitate garter spring movement in desired direction, three phase devices namely, Three Phase GSRDs have been developed. Two versions of these devices namely Dry Channel Version and Dry-cum-Wet Channel Version have been developed.

(i) *For Dry Channel Operation:* Fig. 6 shows schematic of three-phase device. The device is meant for operation in drained and virtually dried radioactive coolant channels of PHWRs. It may be noted that although this device is designed for dry channel operation, it can work in coolant channels where presence of traces of heavy water in the channel cannot be avoided due to its sagged profile. The device works at 440 VAC at 102 Hz carrying 265 Amperes through each of its phases. The operational frequency optimisation has been carried out to minimise the shielding effect of PT. The device is powered in pulsed mode fashion, where it is energised for 2 seconds during the operation and paused for minimum 5 minutes before next stroke of energisation. This is done to optimise its performance considering garter spring movement with minimum temperature rise of device per operational stroke. The winding of the device is multi-layer three-phase winding conforming to clas "C" (240 Degree C) 650/1100VAC grade insulation, carried out by using fiberglass and polyurethane compounds. The on-line winding temperature monitoring is carried out through two numbers of embedded thermocouples. In each stroke/firing cycle, which is nothing but energisation of the device for 2 seconds, free (Un-pinched) GS moves on PT around 330 to 350 mm. Reversing the polarity of supply frequency can change the direction of GS movement.

Thus, this three phase GSRD system is having the advantages of excellent force generation in GS as compared to single-phase device, fairly good balanced loading of power supply and controlled direction of garter spring movement. The power supply used for the device energisation is 300 KVA Variable Frequency Power Supply (VFPS). This power supply is provided with all necessary electrical protections for safe operation of the device. The device life in highly radioactive coolant channels has been practically found to be of the order of 1500 firing strokes having cumulative in-channel life of more than 600 hrs. The radiation life of the device is of the order of 100 Mega Rads which is quite sufficient to address more than 50 channels, assuming that per channel it takes 12 Hrs for GS repositioning operation. The device is cooled by chilled air.

(ii) *For Dry-cum-wet Channel Operation:* In order to carry out the garter spring repositioning without draining the channel, a new device has been developed. The winding of the device uses Kapton® insulation along with polyurethane encapsulation. The winding is designed for 650/1100 VAC. The device is powered by 300 KVA, 440VAC, 102 Hz VFPS. It is capable of operating under pressurised water conditions up to 5 kg/sq. cms. The garter spring movement is of the order of 350 to 370 mm per fire. The Kapton® is a polyimide film, which maintains its electrical and mechanical integrity over 1000 Mega Rads. This device is capable of operating in dry as well as wet channel conditions.

(c) ***Bunched Garter Spring Separation Device (BGSSD):*** In aged PHWRs some times the garter springs are found in bunched fashion. In other words, two garter springs comes very close to each other such that their axial separation distance will be less than 50 mm. These are called bunched garter springs. For all practical purposes, these bunched garter springs need to be separated prior to moving one of them to desired location by keeping the other one at the same position. The other GS may need shifting in an other direction. It may be noted that practically it is very difficult, sometimes impossible to move bunched garter springs however by separating them one can move the individual GS by imparting movement in desired direction by GSRD. As such, there was a need to develop a device that can separate the bunched garter springs prior to imparting movement on individual GS to reposition them in any desired location.

A device named as Bunched Garter Spring Separation Device (BGSSD) has been developed to address the problem of GS bunching. Fig. 7 shows the BGSSD. The device is capable of separating the bunched garter spring spacers and can move the selected individual garter spring in the desired direction. The device works on the principle of back-to-back linear induction concept and is capable to separate bunched GS that are located at minimum 50 mm axially apart to each other. The device uses monolithic former made of special soft magnetic material. The winding configuration and design is made in such a way that the device produces two magnetic fluxes axially opposing each other. The device is inserted into the PT of the PHWR coolant channel and positioned opposite to the bunched garter springs. It is energised in pulsed power separation mode for two seconds for separating them. After separating them, individual GS can be moved in desired direction in conventional pulse power mode of operation.

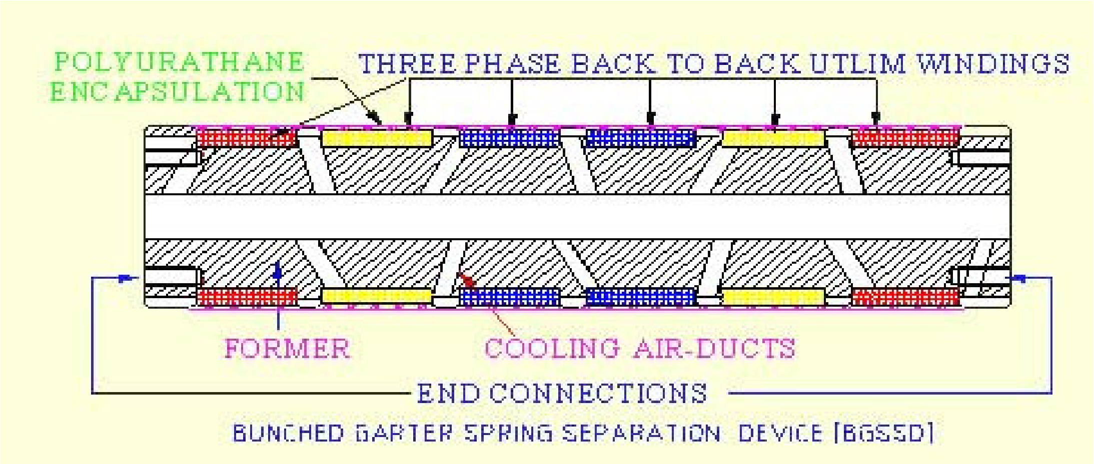

Fig. 7 Bunched Garter Spring Separation Device (BGSSD)

Conclusion

The three phase Garter Spring Repositioning Devices incorporated in INGRES (INtegrated Garter spring REpositioning System) tools have been successfully used in repositioning the garter spring spacers in highly radioactive coolant channels of Madras Atomic Power Station during the year 1995 (8 Channels of Unit-2), 1998 (5 channels of Unit –1), 2000 (28 channels of unit –1) and 2002 (29 Channels of unit-1). These devices have helped in extending the life of said coolant channels. Recently, these devices have been used at RAPS Unit-1 for life extension of 67 coolant channels. The performance qualification trials on wet-cum-dry version of three phase GSRD have been completed. This device has been incorporated in wet version of INGRES tool. It may be noted that the wet INGRES is meant for garter spring repositioning in wet coolant channels of PHWRs, viz. the coolant channels filled with heavy water under pressurised conditions (between 2 to 3 kg/sq. cms). The BGSSD development has been completed. A prototype has been fabricated and its qualification trials have been completed. This device (BGSSD) will be implemented shortly in the latest version of INGRES tools in order to tackle bunched garter spring problems.

SUPERVISION SOFTWARE FOR STRING2 MAGNET TEST FACILITY OF LARGE HADRON COLLIDER PROJECT

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Introduction

The Large Hadron Collider (LHC) is a high energy (14 TeV) particle accelerator being built at the European Organisation for Nuclear Research (CERN), Geneva. This gigantic machine uses a large number of super-conducting magnets for bending and focussing the particle beams around the 26.7 Km tunnel straddling the French-Swiss border. The magnets are cooled to 1.8°K by LiHe under vacuum. The showers of particles produced by the collision of the counter-rotating beams are detected at massive detectors located at interaction regions.

The String2 magnet test facility is built at CERN for studying and validating the individual and collective behaviour of the superconducting magnets and associated systems under normal and exceptional circumstances. It prototypes one full cell of LHC. String2 consists of 6 dipole magnets, each of ~15M long, 2 quadrapoles and a host of smaller magnets, immersed in a LiHe bath and cooled to 1.8°K in stages by multiple cooling loops. The magnet cryostat is kept under high vacuum. The superconducting current leads are also cooled in an Electrical feed box (DFB). The four major families of superconducting magnets are powered by 15 power converters. The magnet protection systems include quench detectors, switches for energy extraction, power permit logic and hardwired protection interlocks.

All the above systems are monitored and controlled from a central control room. The Supervisory Control & Data Acquisition (SCADA) software for the above was developed and installed by Control Instrumentation Division, BARC, under the framework of CERN-DAE collaboration for LHC. The project was launched in January 2000 and the first version was put on-line by March 2001. After progressive upgrades and refinements as necessitated by the phased commissioning of String2, the final version was handed over in May 2002. The system is being extensively used in the String2 test campaigns.

Scope and Objectives

The design goals of the supervision software is to facilitate integrated monitoring and supervisory control of all the main subsystems of String2, viz., Cryogenics, Vacuum, Power converters, Magnet protection (MPS), Energy extraction and interlock systems from a central control room. Being an experimental facility, the system is required to be highly configurable in terms of control loop tuning, interlock logic, alarm setting and grouping of parameters for trending and logging. The current profiles in the power converters need to be synthesizable from primitive functions and replayed for individual or gang operation. The large amount of data collected during these experiments need to be uploaded to external data bases. While it is highly desirable that the system must be integrated using commercially available hardware and software components (SCADA software, PLC, PC, TCP/IP, Ethernet, Win NT), the design must also accommodate CERN proprietary controllers and their protocols as demanded by the specifics of the accelerator system. At the same time, supervision software needs to conform to the ergonomic standards and guidelines laid down by CERN.

System Architecture

Figure 1 shows the logical architecture of the String2 supervision system as a hierarchy of layers. At a layer immediately above the process instruments reside the controllers which monitor the process variables, compute loop and logic functions and generate outputs for controlling the process equipment. A gateway controller connects a group of controllers to the next higher layer which consists of IO servers and supervision applications. The supervision applications run under PCVue32™ SCADA/MMI software and are hosted on PCs running WinNT. All the applications except Cryogenics are integrated in to a single unified database. The communication between field controllers, gateway controllers and supervision system uses a variety of protocols as described below.

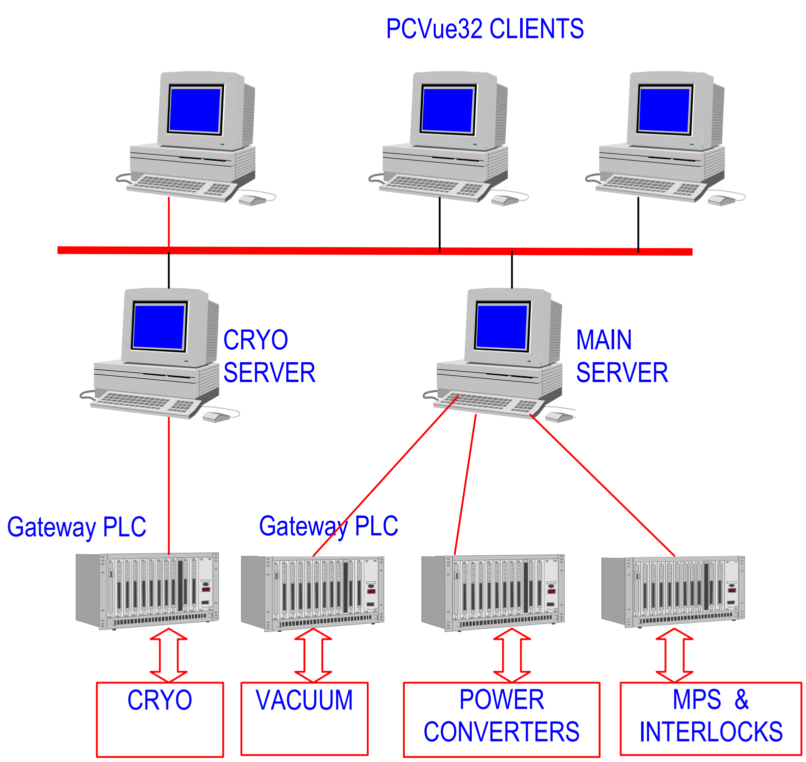

Fig.1 Architecture of the String2 supervision system

The controllers for the Cryogenic, Vacuum and Interlock systems are based on Industrial Programmable Controllers. These are connected to the respective gateway using Profibus field bus. The gateway, which itself is a high power

Programmable Controller, maintains real-time data buffers (DB) which are accessed and updated from the Supervisor's IO server over TCP/IP network using vendor defined protocol.

	CRYO	Vacuum	Power Converter	Magnet Protection	Interlocks
Variables	>5000	>500	>500	~500	~9000
PID Control loops	>120	NIL	NIL	NIL	NIL
Screens	~20	~15	~5	~20	~12

In contrast to the above, the controllers for Power Converters, Magnet Protection Systems (MPS) and their respective gateways are of CERN proprietary design. These are VME / Lynx OS based embedded software systems which communicate over World FIP field bus. The communication between the power controller gateway and supervision uses CERN proprietary protocols over TCP/IP network using socket interface. This requires a custom-made IO server. Instead of a full-fledged IO server, the solution adapted leveraged the SV manager API provided by PCVue32™, using which a driver software layer connects the PCVue32™ variables to the socket layer. However, in the case of the MPS, the IO server is implemented as an OPC server.

A dedicated PC running Win NT hosts the IO server. Due to its size, the CRYO IO server is hosted on a separate PC. The binding of the equipment variables to PCVue32 variables is done using the user friendly configuration menus provided by PCVue32.

A cluster of PCVue32 client stations located in the central control room provides the operator interface to the process groups. The supervision system provides connectivity to an external database for archiving the large quantity of acquired values.

The table above provides a measure of the system size.

Cryogenic Systems

The cryogenic system is the largest of all applications and can be further decomposed in to four main subsystems viz., DFB, CFB, QRL and Magnet cryostat.

Electrical Feed Box (DFB): In this box, the electrical leads from the power converters are cooled in a LiHe bath. There are 6 numbers of 13KA leads and 32 numbers (8 groups of 4 each) of 600A current leads. The flow of LiHe through each of the current lead as well as pressure and level in the DFB is under closed loop control using regulated valves. Each of the temperature control valve associated with a current lead is controllable using one of three possible sensors depending on the operation regime. Thus, each valve is associated with three PID loops, only one being active at a time. There are more than 120 PID loops in all.

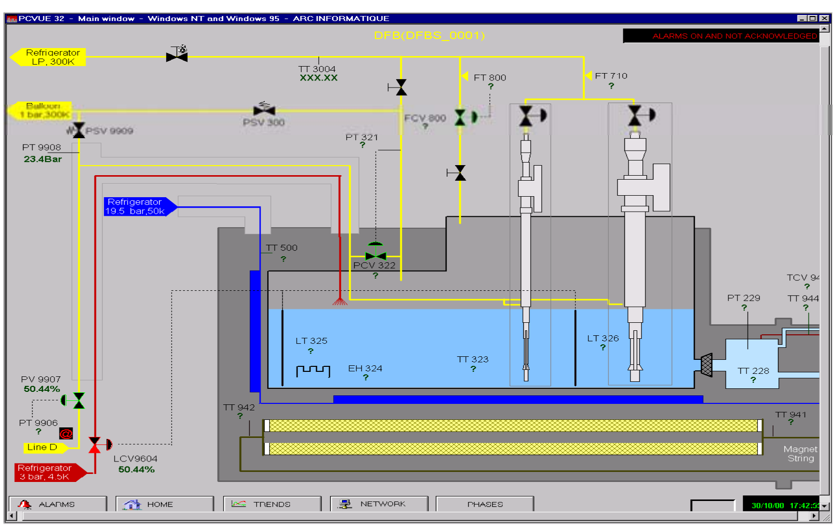

Fig. 2 DFB mimics

Magnet Cryostat: This long thin section houses the superconducting magnets and is instrumented to monitor inlet/ outlet temperatures and pressures. The cryostat is closed by a magnet return box (MRB).

Cryogenic Ring-Line (QRL): Pipes carrying He at different temperature and pressure levels around the String are connected to the magnet cryostat via jumpers. The QRL terminates at Cryogenic Return Box (CRB) and is connected to the Cryogenic feed box. QRL is instrumented with heaters, control valves and large number of temperature sensors.

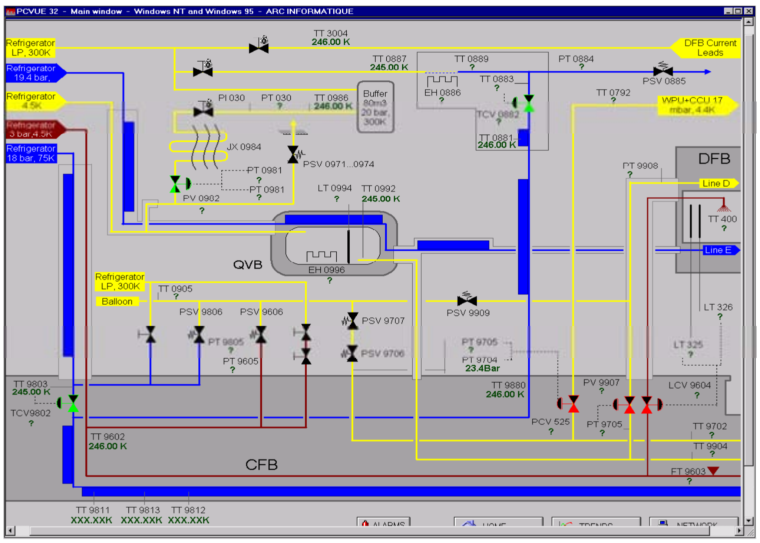

Fig. 3 CFB Mimics

Cryogenic Feed Box (CFB) : This feeds helium to QRL and DFB. The PID face-plates are designed to permit easy reconfiguration of the generic control loops. For example, the operator will be able to test a loop by substituting the process input by a forced value. He can select one of the two pre-defined set points for control and specify the permitted rate of change for the set point. Optionally, a programmable offset can be added to the set point. The controller can be manually tuned by adjusting the P, I and D constants. The actuators can be switched to manual mode and manual set point can be changed from the faceplate. The measured variable and the manipulated variable can be displayed in real-time in text and as trend graphs.

The supervision software permits the operator to set and modify the alarm threshold values which are then transferred to the PLC. The alarms can be masked, viewed and acknowledged from the alarm windows of PCVue32. Similarly, the thresholds for the large number of interlocks computed by the PLC can be programmed by the operator.

The network traffic is optimised by packing PID input and output values in buffer DBs at the gateway. A separate DB is defined to hold the corresponding time-stamp values. The supervision application includes process mimics, alarms, trends, logs, reports, alarm and interlock configurations and state (phases) view.

Figures 2 & 3 show the main mimics of the DFB and CFB subsystems.

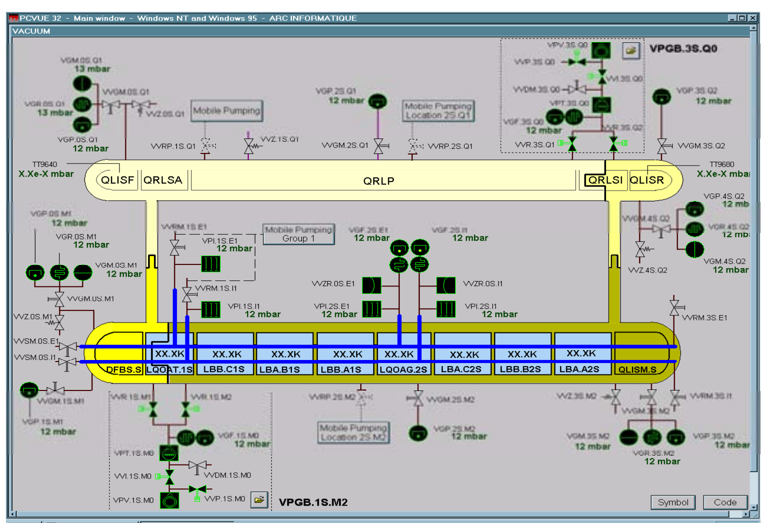

Fig. 4 Vacuum System mimics

Vacuum System

This application handles monitoring and supervisory control of the vacuum equipment for the QRL, beam-line and magnet cryostats of String2. The main equipment include pumps, valves and vacuum gauges of various types. The supervision system features animated process Mimics with popup status windows for equipment, alarm generation and annunciation, trending and archiving facilities with high degree of user configurability. The alarm generation logic is performed in the supervision application and alarms are grouped in to four priority levels.

Provision is made for automatically sending e-mails to service engineer on occurrence of predefined alarms. Figure 4 shows the main vacuum mimics.

Power Converters

This application facilitates monitoring and supervisory control of the 15 power converters which drive the four major families of superconducting magnets of String2 viz., main magnets, lattice correctors, orbit correctors and spool-piece correctors. The main magnets are powered by 13KA capacity converters while the other magnets are powered by 600A converters.

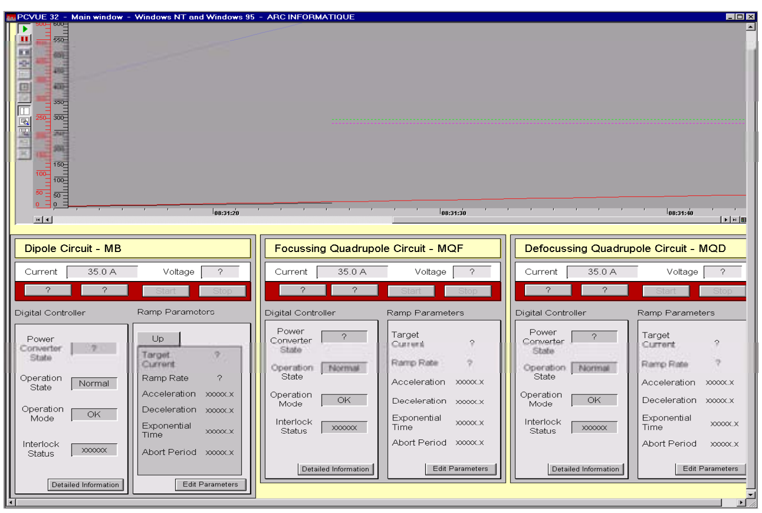

Fig. 5 Power Converter mimics

A digital controller associated with each converter regulates the magnet current under closed loop control. From dedicated PCVue32 client stations, operator can monitor the converter currents, voltages and states, control them individually or collectively and set reference currents by selecting from among predefined functions. The application provides capability for entry, play-back, editing, selection and down-loading of magnet current profiles, real-time and historical trending of currents and voltages and their archiving in a data base. Test sequences can be synthesised by the operator for individual and ganged operation of the converters. Fig. 5 shows the main power converter mimics.

Magnet Protection Systems

The aim of Magnet Protection System (MPS) is to detect the presence of abnormal behaviour in magnets, current leads, etc., in order to protect them from damage or destruction. MPS includes:

- Quench detectors and protection equipment attached to main magnets
- Quench detectors attached to current leads
- Global quench detectors
- Main magnet energy extraction systems
- Switches for corrector magnets
- Gateway between acquisition systems and the supervision.

This application presents to the operator, the general status of the Magnet Protection System (MPS). It can annunciate and log alarms and initiate command execution of several tasks. Most importantly, MPS is responsible for detecting whether a new current cycle is permitted from the MPS point of view.

Interlock Systems

The aim of the interlock management system is to protect the components of String2 (magnets, power converters, bus bars, current leads, switches) in case of quench or malfunction of one of the components. The system also allows the shutting down of the power converters in case of unauthorized access to String2 area during unattended operation.

This application facilitates display and monitoring of interlock system parameters using various screens which are organized to present information in increasing detail. Additional screens allow the operator to set power permits and clear them.

Conclusions

A fairly large supervisory control and acquisition system is integrated around off-the-shelf PLCs, custom designed controllers and SCADA/ MMI software package. This is one of the first collaborative software projects taken up by BARC under CERN-DAE collaboration for LHC. With more than 4 person-years of development effort behind it, this project represents a successful collaboration between DAE and CERN.

While bulk of the development work was carried-out in BARC, around a person-year was spent in CERN during the requirements capture and installation phases in which scores of engineers from CERN also actively participated. Internet and Web infrastructure was extensively used during this collaborative development. Being a fore runner, this project has laid firm foundations on which many later collaborations have been built.

SEPARATOR / SENSOR TIP CUTTING MACHINE

Centre for Design and Manufacture (CDM), BARC, has designed and developed a Special Purpose Machine (SPM) for cutting Hard Chrome Plated Separator / Sensor tips from a distance of 10.5 meters. During loading and unloading of fuel bundles, non-retraction of separator tips may lead to an emergency situation when fuelling machine is clamped on the channel and is having irradiated fuel bundles in its magazine. Malfunctioning of actuator or jamming of separator / sensor tips can lead to non-retraction of the separator / sensor tips.

Fig.1 Separator / sensor tip cutting machine

This situation can be handled by using special purpose cutting machine which will machine the separator / sensor tips and thus clear the channel for removal of irradiated bundles from the affected fuelling machine. After that, the guide sleeve can be cut by the same SPM but with a different tool head to disengage the affected fuelling machine from the 'End-fitting' face. The same machine can also be used to machine the side stop, if it gets jammed in its advanced position.

This SPM is designed in modular form for ease of handling, assembly and insertion to position the cutting tool at the cutting plane.

Fig.2 Feed drives and control module

It has seven modules (sub-assemblies).

i) Tool head sub-assembly,

ii) Connecting pipe sub-assembly,

iii) Axial feed & Radial feed sub-assemblies,

iv) Base frame sub-assembly

v) Hydraulic power pack,

vi) Vacuum system, and

vii) Control Console

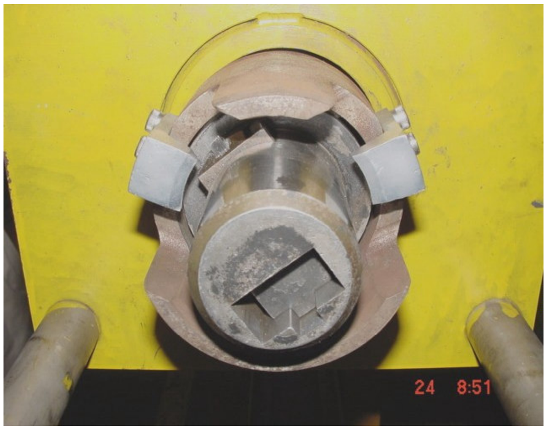

Fig.3 Position of sensor tip

The final demonstration of this SPM was carried out at CDM on October 9, 2003, in the presence of Mr G. Govindarajan, Director, A & M Group, BARC, Head, RTD, BARC, and concerned engineers from RTD and NPCIL engineers.

IAEA-RCA WORKSHOP ON "DATA VALIDATION OF AIRBORNE PARTICULATE MATTER"

BARC hosted the IAEA /RCA Workshop on "Data Validation of Airborne Particulate Matter [PM]" at the Sea Princess Hotel, Mumbai, during October 13-17, 2003. The project is part of the efforts made by IAEA to methods for assessing demonstrate nuclear analytical the elemental composition of $PM_{10-2.5\mu m}$ and $PM_{<2.5\mu m}$ size fractions from an urban and a

Mr H.S. Kushwaha, Associate Director, HS&E Group, BARC, addressing the faculty members at the IAEA/RCA Regional Training Workshop

rural site. Fourteen countries from the Austral-Asia region are actively involved in the project. The data after validation was used in source apportionment studies using receptor models.

Fourteen participants from ten East Asian countries and three faculty members from USA, New Zealand and IAEA, Vienna, formed the overseas team. One scientist each from NEERI and CPCB, as the country end-users of the study perspective and two scientists from EAD, BARC, also participated in the Workshop. The Workshop had sixteen sessions of around 90 minutes each. The program included lectures followed by practical work schedules using the computers provided for each participant. Extensive coverage on data QA/QC, use of standard reference materials, inter-comparison exercises, concept of

Group of faculty members seen at the IAEA/RCA Regional Training Workshop data outliers, data entry on excel spread sheet and use of Statgraphics package for source identification, etc. was given to participants.

The Workshop was inaugurated by Mr H.S. Kushwaha, Associate Director, HS&E Group, BARC, and was also addressed by the three faculty members, Prof. Philip Karl Hopke (USA). Dr Andreas Markwitz (NZ) and Dr Alas Fajgelj (IAEA). Dr T.N. Mahadevan, Head, EMAS, EAD, BARC, who is the country coordinator of the project, served as the Workshop Director. Certificate of participation was issued by IAEA and presented by Prof. Philip Hopke at the concluding session. The feedback information from the participants was deliberated in detail and the sheets are being communicated to the IAEA Technical Officer overseeing the project. The funding support to the overseas participants was by IAEA and DAE. BARC provided the organisational and infrastructure budgeting as in kind contribution.

TRAINING COURSE ON INDUSTRIAL HYGIENE AND SAFETY

The 23rd Course on "Accident Prevention and Promotion of Occupational Health and Safety" was conducted during October 6-17, 2003. A total of 44 participants from the middle management/supervisory level from BARC, Trombay, and BARC Facilities at outstation attended the Course.

Dr. D.N. Sharma, Head, Radiation Safety Systems Division (RSSD) BARC, while welcoming the audience, gave an outline of the course and also stressed the importance of training in inculcating safety culture in the Centre. In the introductory speech, Dr. V. Venkat Raj, Director, Health, Safety and Environment Group (HSE) BARC, explained the importance given to conventional safety in the various operations conducted in the Centre since inception. He reiterated that BARC gives equal importance to conventional safety and radiological safety. In this context, he mentioned the adoption of self-regulatory concept by the Centre for implementation of safety through the Safety Review Committees functioning under the BARC Safety Council. Mr B. Bhattacharjee, Director, BARC, in his inaugural address, emphasised on statutory compliance of safety requirements at the design stage itself. He highlighted the importance of documentation of the safe work procedures and strict adherence to them. He desired that the participants should diligently put the lessons learnt in the training course into practice.

Mr B. Bhattacharjee, Director, BARC, delivering the inaugural address. Seen on the dais (left to right) : Dr D.K. Ghosh, Head, IHSS, BARC, Dr V. Venkat Raj, Director, HSE Group, BARC and Dr N. Sharma, Head, RSSD, BARC

On this occasion, Director, BARC, has released the Catalogue containing about 125 Safety Posters prepared at the Industrial Hygiene and Safety Section, Radiation Safety Systems Division. In this function, Director, BARC gave away the prizes to the winners of Safety Slogan Contests and Safety Poster Contest. Dr D.K. Ghosh, Head, Industrial Hygiene & Safety Section (IHSS), RSSD, proposed a vote of thanks.

Mr H.S. Kushwaha, Associate Director, HS&E Group, BARC, gave the valedictory address and distributed certificates to the Course participants. This training course is conducted annually for the supervisory staff of BARC and so far more than 1000 staff members have undergone this training.

EXPORT OF TLD BADGE BASED ON BARC TECHNOLOGY

Technology for manufacturing TLD Badge for Personnel Monitoring of radiation workers was transferred to M/s Renentech Laboratories Pvt. Ltd.(Renentech Labs) on October 12, 1995 after meeting stringent quality standards set by BARC. Since then they are successfully supplying TLD badges to DAE units. As a BARC accredited laboratory, they are also issuing these badges to other institutions for Personnel Monitoring services. Foreign market for TLD badges however is dominated by the western countries for a long time.

Recently, Renentech Labs received a purchase order for 2000 TLD badges from M/s PRORAD, a Brazilian Personnel Monitoring Laboratory carrying out monitoring of radiation workers of many hospitals and industries throughout Brazil. This Brazilian laboratory was using TLD discs with 2 parts of Teflon and one part of $CaSO_4$ doped with Dysprosium ($CaSO_4$:Dy) at a concentration of 0.1 mol %. Renentech Labs had sent the samples with 3 parts of Teflon and 1 part of $CaSO_4$ doped at a concentration of 0.2 mol %, which was approved and accepted by the Brazilian laboratory. The supply has been made. Renentech Labs has also made third party exports of TLD badges to Indonesia, Bangladesh and Sri Lanka. Renentech Labs has thus set its foot in the foreign market of TLD badges/TLD discs with the help of BARC technology.

SUMMER SCHOOL ON "ELECTROCHEMICAL SENSORS – THEORY, CHARACTERIZATION AND FABRICATION"

The Summer School on "Electrochemical Sensors - Theory, Characterization and Fabrication" was a Training Programme for young researchers in the field and it was conducted during July 14-25, 2003 at the BARC Training School Hostel, Mumbai. The Summer School was inaugurated on July 14, 2003 at the Multi-Purpose Hall of the BARC Training School Hostel. The inaugural function was presided over by Dr Anil Kakodkar, Chairman, AEC and Secretary, Department of Atomic Energy, Government of India. Prof. V.S. Ramamurthy, Secretary, Department of Science and Technology, Government of India, inaugurated the Summer School.

Dr Kakodkar outlined the role played by the detectors and sensing devices in the advancement of technologies in different walks of life. Electrochemical Sensors, in particular, are the sensors of choice in a few key applications such as poisonous and toxic gas detection, bio-applications, etc. The technological know-how in the development of such Electrochemical Sensors is widely available in our country but wide-scale manufacture of such devices is yet to be achieved. He, therefore, stressed the need to 'bridge the gap' between the efforts in the laboratory and entrepreneurial endeavours in this area.

Prof. Ramamurthy, in his inaugural address, mentioned that the DST has long been

Dr Anil Kakodkar, Chairman, AEC and Secretary, Department of Atomic Energy, Government of India, presiding over the inaugural function

supporting R&D in Sensors in general and Electrochemical Sensors in particular in many laboratories in the country. The output of these efforts is that a large number of papers were published. He wished that this should be stepped up further and should culminate in large scale manufacture of sensors for various applications, thereby not only minimising the import of these devices but also making it possible to export them to other countries. The DST felt that, in order to achieve this goal, creating a large trained manpower in this field is the primary requisite and, therefore, planned to conduct training programmes in Sensors Instrumentation and Technology. The present Summer School is the first one on Electrochemical Sensors.

There were 32 lectures, each of about 90 minutes' duration, during the two-week Summer School. These lectures were delivered by specialists from BARC, IGCAR, IIT (Bombay), NCL (Pune), University of Madras, NAL (Bangalore), Raman Research Institute (Bangalore) and the Chemoelectronics Laboratory of UPL (Nahuli (Gujarat)). There were 32 participants from the various Universities across the country as well as from a few National and CSIR Laboratories. They were taken to the laboratories of the IIT at Powai for a full-day laboratory session; the different electrochemical sensors that have been developed in those laboratories over the past several years were explained to them. Also, the participants were taken to the manufacturing unit of Chemoelectronics Laboratories of the United Phosphorus Limited at Vapi (Gujarat) on July 19, 2003. The contents of the lectures were compiled into a book and was released by Prof. Ramamurthy at the Inauguration for distribution to the participants.

NATIONAL SYMPOSIUM ON "VACUUM SCIENCE & TECHNOLOGY AND VACUUM METALLURGY:IVSNS 2003"

Indian Vacuum Society (IVS), in association with Board of Research in Nuclear Sciences, Department of Atomic Energy, organised the National Symposium on "Vacuum Science & Technology and Vacuum Metallurgy (IVSNS 2003)" at the Multi purpose hall of BARC Training School Hostel, Anushaktinagar, during October 15 -17, 2003. The symposium was inaugurated on October 15 by Dr Anil Kakodkar , Chairman, AEC and Secretary to Government of India. In his inaugural address, he recalled his long association with the vacuum technology that was being developed in BARC since early days. He mentioned that BARC has the expertise in developing various vacuum equipment on the one hand and also have very demanding users on the other. He suggested that these two groups should get together to develop better and newer equipment. This will result in a significant step towards self reliance in this technology. Mr B. Bhattacharjee, Director, BARC, in his presidential address, touched upon the various vacuum metallurgical processes and outlined BARC's role in developing and using such

Dr Anil Kakodkar, Chairman, DAE and Secratry to the Govt. of India, inaugurating the symposium. Sitting on the dais are from left to right are : Dr K.C. Mittal, Convener, Mr B. Bhattacharjee, Director, BARC, Dr A.K. Ray, President, IVS and Mr A.V. Korgaonkar, Secretary, IVS

equipment for nuclear applications. Earlier, Mr A. V. Korgaonkar, Secretary, Indian Vacuum Society (IVS), welcomed the participants, dignitaries and invitees to the symposium. Dr A.K. Ray, Head, Laser & Plasma Technology Division, BARC and President, IVS, gave a brief account of the activities of IVS. IVS was established in 1970 and has been organising short term courses, lectures and symposia on various aspects of vacuum science and technology. Vacuum Metallurgy has been selected as the theme topic for IVSNS 2003. Dr K.C. Mittal, Convener, Organising Committee, proposed the vote of thanks.

The inaugural session was followed by two theme talks on 'History of Vacuum: The Indian Ethos' by Dr N. Venkatramani, Director, Beam Technology Development Group, BARC, and 'Vacuum Metallurgy- Science and Technology - An Overview' by Prof S.P. Mehrotra, Director, National Metallurgical Laboratory, Jamshedpur. The history of Vacuum Science and Technology in Indian context including the contributions of illustrious individuals and distinguished institutions was described by Dr Venkatramani. In the overview of Vacuum Metallurgy, Prof Mehrotra covered the role of vacuum in extraction of metals, refining, degassing, remelting, sintering, heat treatment, brazing and other techniques for joining metals. During the National Symposia, Indian Vacuum Society felicitates two of its members, one from industry and another from a R & D Institution, for their lifetime contribution towards advancement of vacuum science and technology. This session also included the felicitation of Mr P. Vijendran Rao, Ex-BARC (R&D), and Dr Pramod K. Naik, Ex-BARC/ Crompton Greaves & Consultant, Eaton/Cutler-Hammer, USA (Industry).

The symposium provided a forum for exchange of information among vacuum scientists, technologists and industrialists on recent advances made in the areas of vacuum production, its measurement, its role in vacuum metallurgy and its application in industry. There were about 280 registered participants from various National Institutions/Universities/ Colleges and industrial houses.

There were in all 12 sessions including inaugural, forum for industry and concluding sessions in this three-day symposium. The scientific programme had ten invited talks (apart from two theme talks) and ninety-five contributed papers. All the papers were divided into six main categories: Vacuum materials and processing, Vacuum in accelerators, Vacuum evaporation, hard coating and thin films, Vacuum production, measurements and leak detection, Vacuum brazing and welding, and Vacuum technology for nuclear fuel, industry and furnaces. Invited talks were given by the well known experts in the respective fields, namely: Prof K.L. Chopra, Dr C. Divakar, Dr S.P. Garg, Mr A.K. Jani, Mr S. Majumdar, Mr A.S. Raja Rao, Dr R.C. Sethi, Mr S.K. Shukla, Mr S.P. Singh and Dr A.K. Suri. Contributed papers were divided into oral and poster sessions. A brief summary of all the poster papers was presented by Dr D.K. Aswal before the poster session. A session named 'Forum for Industry' was organised in which delegates from industry presented the various vacuum related products.

C. Ambasankaran Memorial and Smt. Shakuntalabai Vyawahare Memorial Awards were conferred to four best contributed papers. A committee constituted by the Symposium Organising Committee evaluated the relevance, scientific content, and clarity of presentation of all the papers before deciding the award winning papers. Awards were presented to the winners in the Concluding Session.

Dr Anil Kakodkar, Chairman, DAE, & Secy. to the Govt. of India, inaugurating the exhibition. Others (from left to right) : Dr K.C. Kittal, Convener & Mr B. Bhattacharjee, Director, BARC

The industry response to this symposium has been greatly heartening too. In view of the industrial significance of the vacuum technology and vacuum metallurgy, an exhibition of vacuum and vacuum metallurgy related equipments, accessories, products, etc. by different manufacturers and suppliers was organised at the venue of the symposium hall. Thirty exhibitors participated in the exhibition. The interest shown by the exhibitors reveal that the industry has come of age and the advances that have taken place over the years is quite significant. Usually there has been a good participation from industry in exhibition. This time, six technical papers were also contributed by delegates from industry .

A souvenir was also brought out at the symposium. This was designed to provide useful information on the symposium, details about Indian Vacuum Society, abstracts of the papers and advertise-ments for vacuum products. It is hoped that the souvenir will be of great relevance and significance to the users of vacuum technology. A number of vacuum data sheets have also been included so that this will serve the purpose of a vacuum reference book.

In the concluding session, Dr A.K. Ray thanked all the delegates for the lively discussions during the three days.

भा.प.अ. केंद्र के वैज्ञानिक को सम्मान / BARC SCIENTIST HONOURED

डॉ.के.डी.सिंह मुधेर, ईंधन रसायन प्रभाग, भापअ केंद्र को सॉलिड स्टेट रसायन के क्षेत्र में प्रमुख योगदान के लिए द इंडियन एसोशियेशन ऑफ सॉलिड स्टेट केमिस्ट एंड अलाइड सांइटिस्ट 2003 के सिल्वर मेडल से सम्मानित किया गया है ।

यह सम्मान उन्हे इंडियन एसोशियेशन ऑफ सॉलिड स्टेट केमिस्ट एंव भारतीय प्रौधोगिकी संस्थान, दिल्ली द्वारा आयोजित संगोष्ठी सॉलिड स्टेट केमिस्टस एंड अलाइड ऐरियास में दिसबंर 4-6, 2003 के दौरान रसायन प्रभाग, आइ. आइ. टी., दिल्ली में प्रदान किया गया । ए.एस.सी.ए.एस. एक व्यावसायिक संस्था है, जो कि जम्मु एंव कश्मीर राज्य में पंजीकृत है और यह सॉलिड स्टेट रसायन के क्षेत्र में द्विवार्षिक संगोष्ठी आयोजित करती है ।

Dr K.D. Singh Mudher, Fuel Chemistry Division, BARC, has been awarded the 'Indian Association of Solid State Chemists and Allied Scientists Silver Medal 2003' for his significant contribution in the field of solid state chemistry. This award was given to him at the National Conference and Symposium on 'Solid State Chemistry and Allied Areas', organised jointly by Indian Association of Solid State Chemists and Allied Scientists (ISCAS) and Indian Institute of Technology (IIT, Delhi) during December 4-6, 2003 at Department of Chemistry, IIT, Delhi. ISCAS is a professional body registered with Government of Jammu & Kashmir and has been conducting biannual symposia on solid state chemistry.

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