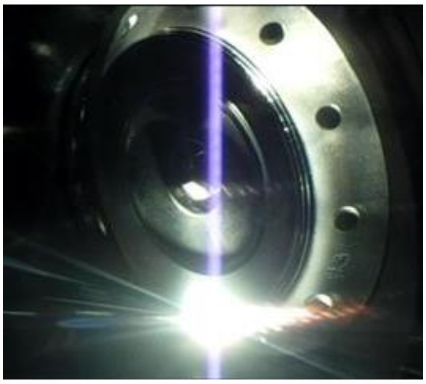
Book of Abstracts

Workshop on Electron Beam Welding for Particle Accelerators and Associated Technologies

November 8-9, 2024


- Organized by -

Raja Ramanna Centre for Advanced Technology, Indore, M.P., India

Under the aegis of Indian Society for Particle Accelerators

Book of Abstracts

Workshop on Electron Beam Welding for Particle Accelerators and Associated Technologies

Venue: Raja Ramanna Centre for Advanced Technology, Indore, M.P., India.

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Workshop on Electron Beam Welding for Particle Accelerators and Associated Technologies

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Development of Electron Beam Welding Process for Manufacture of Engineering Components for DAE Programme.

K N Karn
Bhabha Atomic Research Centre
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Abstract:

Electron Beam Welding (EBW) is a high energy density beam welding process widely applied for joining various exotic engineering material which are very difficult to be welded by conventional welding processes as the weld penetration is very deep in a single pass of weld in high thermal conductive material, the joint is nearly free from any defect as the welding is done in vacuum, weld distortion is very negligible as heat input is minimal and many more advantages. With these attractive features, EBW has been used extensively in manufacturing of very critical components and sub-assemblies for DAE programs, which were otherwise near impossible to meet the job acceptance requirements.

One of the important materials which are welding to get superconducting properties is Niobium which is being used in Department collaborative programme with Fermi Lab.
EBW has also been used for manufacture of dissimilar material joints to get very clean weld.

The talk discusses about development of EBW process for manufacture of some of Engineering Components for DAE programme.

Keywords: EBW, R-5 Project, OFHC Copper, Niobium RRR, Zirconium alloy etc.

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Basics of EBW and Anticipated Issues for the Application of Macro and Micro Scale Electron Beam Welding Process

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Indian Institute of Technology Guwahati, Guwahati-781039, Assam

Abstract:

Electron Beam Welding (EBW) is a high-precision welding technique that utilizes a focused beam of electrons to join materials, particularly dissimilar metals. Despite its numerous advantages, the application of EBW in both macro and micro-scale processes presents a unique set of anticipated challenges that stem from its inherent limitations. One significant issue is the melting and mixing of dissimilar metals, which can lead to brittle microstructures and weak joints, particularly problematic in micro-welding where material volume is limited. The requirement of precise groove preparation is crucial for effective welds, but achieving the necessary accuracy can be difficult, leading to inconsistent joint formation. Thermal dynamics also pose challenges, as rapid heating and cooling cycles can result in warping or distortion in larger components, while localized heating in micro-welding can inadvertently alter surrounding materials. Furthermore, the necessity of a vacuum environment complicates the process, as it can limit product size and design flexibility, while maintaining a stable vacuum is difficult with metals prone to vaporization. Additionally, the economic aspects of EBW, including high initial investments and operational costs, can deter adoption, particularly among smaller manufacturers. Hence, continued research and development are necessary to optimize EBW processes and expand its applications in advanced manufacturing, ensuring high-quality and reliable welds in increasingly complex environments.

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The Role of Convection and Beam Oscillation on Electron Beam Welds

Prof. G. G. Roy,
Indian Institute of Technology Kharagpur

Abstract:

Beam oscillation during electron beam welding has been reported to produce a more uniform microstructure with enhanced mechanical and corrosion properties of the weld. Such uniform microstructure is opined to derive from a churning action in the weld pool. This presentation will present a hypothesis of the author's research group for heat mixing in the weld seam under beam oscillation. The presentation starts with several case studies where beam oscillation is reported to develop enhanced weld properties, including stronger weld, higher ductility, and lower defect intensity attributed to more uniform microstructure in terms of morphology, size of the grains, porosity distribution, and texture development. Subsequently, it discusses how the uniform microstructure is generated through heat mixing, where the role of heat convection in the tiny weld pool is stressed. The presentation also depicts how strong the liquid convection could be in the tiny weld pool through several examples. Finally, the hypothesis for heat mixing is pictorially presented. Following are the conclusions from this talk. Weld seam during electron beam welding with beam oscillation is generated by intense heat and mass mixing through a complex interaction of several overlapped tiny weld pools along the weld seam assisted by strong Marangoni convection in each tiny pool. A small weld pool of 100 μm may have a very high convective strength (~ Pe=100)! Significant heat mixing improved the weld characteristics by reducing unidirectional temperature gradients in the weld seam and creating a more homogeneous microstructure and random texture. An oscillation diameter that is too large may not be beneficial. Beam oscillation improved the mechanical properties of the weld significantly. In certain instances, weld ductility has been found to be twice that of its non-oscillating counterparts.

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A Practical Perspective on using High Power Density Welding Processes in Defence Applications

P. Mastanaiah, P V Sureshu, B Hariprasad.
Defence Research and Development Laboratory, Hyderabad, Telangana

Abstract:

The two popular and widely employed advanced high-power density welding processes i.e. electron beam welding and laser beam welding, have certain unique advantages over the conventional arc and resistance-based welding processes. These high-power density processes win over arc welding processes for their relatively higher joint efficiencies, ease of joint accessibility, excellent weld quality and enabling numerous flexible weld joint designs. These features have made them very popular in strategic sectors such as defence, nuclear and aerospace. The electron beam welding process can be employed in welding of highly reactive alloys (Titanium, Niobium, Zirconium etc), as the process is performed usually under very high vacuum conditions. The present article illustrates various applications of electron beam and laser beam welding processes in the defence industry covering from miniature components to large-sized structures and high-pressure vessels. In addition, certain typical case studies correlating the metallurgical aspects of welds made with the two welding processes to achieve the functional requirements of certain practical applications are discussed in detail.

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Experiences in Electron Beam Welding of Niobium Material for Fabricating Superconducting Cavities

P N Prakash
(Formerly at IUAC, New Delhi)

Abstract:

Electron beam welding (EBW) plays a crucial role in realizing superconducting niobium cavities for use in particle accelerators due to the many advantages that it offers. Niobium cavities are expensive to design, build, process, and test, mainly due to the high cost of the Niobium materials, the complex processes which require state-of-the art facilities, stringent fabrication requirements, cavity dressing & assembly in somewhat similar to the semiconductor industry setup, the low temperature testing (2K or 4K) requiring thousands of liters of liquid helium, and expensive RF electronics systems. The cost gets further escalated if the yield, in terms of achieving the design accelerating gradient at high quality factors, remains low. The processes, particularly the parameters for electron beam welding, need to be properly developed. One of the challenges in identifying a suitable parameter for a critical joint of a given thickness for a component or sub-assembly is to search for it in the neighborhood of the basic parameter for that thickness. The percentage change in the welding current, its initial ramp up, adjustment in the overlapping region (say, in a circular weld), coupled with the heat input given in the seal pass, loss of heat between the seal pass and weld pass due to the size and thermal mass of the component and its associated fixtures, all have to be considered to produce a smooth and uniform weld bead that is suitable for good cavity performance. This is, however, non-trivial. The situation often gets aggravated further due to limited number of actual size samples available because of the high cost of niobium material. In my talk I will discuss these issues briefly vis-à-vis the electron beam welding of a few critical joints performed on actual niobium cavities developed at IUAC, New Delhi, using a couple of examples.

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Fabrication Experience of EBW at RRCAT

Sanjay Chouksey
Head, Superconducting Cavities Development Division
Proton Accelerator Group (PAG),
Raja Ramanna Centre for Advanced Technology
Indore- 452 013, India

Abstract:

RRCAT has been actively involved in developing critical technologies for next-generation pulsed and continuous wave superconducting linac-based accelerators, such as ADSS (Accelerator Driven Sub-Critical System) and SNS (Spallation Neutron Source). Superconducting Radio-Frequency (SCRF) cavities are essential for achieving high-energy beams over short distances. RRCAT has made significant strides in developing SCRF infrastructure, including facilities for fabrication, processing, dressing, and testing. One of the major challenges in SCRF technology is achieving high accelerating gradients and quality factors in cavities. RRCAT has successfully developed prototype single-cell and multi-cell cavities, including 1.3 GHz cavities, as well as 650 MHz (β=0.9) cavities. These cavities were fabricated, processed and successfully tested at RRCAT. The fabrication process involves multiple steps, and EBW plays an important role in the qualification SCRF cavities. This talk will delve into the specific experiences and challenges faced during EBW work at RRCAT.

Key areas to be discussed include EBW for SCRF Cavity Fabrication, such as challenges in welding niobium and its alloy components, quality control measures, and defect minimization strategies. Additionally, the development of EBW infrastructure, personnel training, and collaborations with other institutions will also be discussed. By sharing these experiences, this talk aims to provide valuable insights into the successful implementation of EBW technology at RRCAT. This talk will also cover potential applications in other accelerator science areas.

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Electron Beam Welding Process - Applications in ISRO

Abbaraju Nandakishore
LPSC, Bengaluru

Abstract:

The presentation details about the electron beam welding process and its evolution and basics involved in establishing the electron beam welding process. Significance of this process and its application in realizing the hardware towards various ISRO projects. Briefs about various criticalities in the process application towards realization of critical hardware to launch vehicle and spacecraft projects like Chandrayaan, Aditya-L1 & Gaganyaan etc., also briefs about the NDI techniques involved in evaluating the weld integrity / quality of the weld. Finally presents view critical hardware and associated challenges in realizing the hardware like Samudryaan through electron beam welding process.

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Practical Experiences of EBW at HAL

Shreevenkatesh Allur and team,
Hindustan Aeronautics Limited, Bangalore

Abstract:

Engine division HAL Bangalore was set up in 1957 to manufacture Orpheus turbo jet engines for Kiran MkII application under license from M/S Rolls Royce. Since then, aero-engine design and manufacturing technologies have evolved multi-fold. The division has continuously adopted to the technological changes progressed around the world through collaborations with aero-engine OEMs. Currently the Division is engaged in the manufacture, repair & overhaul of various types of Aero Engines. The division has to manufacture very complex and critical parts in high precision and cost-intensive work centers using state-of-the-art technology.

Engine division has got very good experience in EBW machines since 1982. As on date Engine division has four EBW machines.

1) Techmeta Sciaky EBW, 60KV, Beam current up to 500mA
2) Techmeta Genova EBW, 60KV, Beam Current up to 500mA
3) Steigerwald EBW, 100 KV to 150KV, Beam current up to 100mA
4) Pavac EBW, 80KV to 150 KV, Beam Current up to 100mA

The machines are being used for welding of the following various materials

1) Titanium and its alloys (thickness range 2mm to 7.35mm)
2) Aluminum and its alloys (thickness range 5mm to 7.5mm)
3) Nickel and its alloys (thickness range 3.5mm to 12mm)
4) Steel and its alloys (thickness range 0.1mm to 40mm)

These EBWs are SPM having complex technology like special motors, High voltage tank etc. The following are few challenges which we faced during establishment of new parts and which we have over come

1) Welding of lengthier parts were run out needs to be controlled due to machining constraint.
2) Parts having high thickness and less diameter. e.g. Thickness is 5mm, Diameter is 20 mm and material is titanium.
3) Parts with varying thickness. Ex: Nozzle guide vanes with variable thickness from 3.5 mm to 11.0 mm

Few challenges which we were faced in up keeping the machine and which we have over come

1) Regular failure of chamber light.
2) Cooling water contamination.
3) Frequent failures of diffusion pump heaters.
4) Upgradation of NC controller and frontend HMI
5) Upgradation of old out dated Rotary and booster pumps.
6) Identifying the Vacuum leakages.

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Indigenous Development of Electron Beam Welding Machines for Industrial Applications

M. N. Jha[1,2], B. Prakash[1], S. Gupta[1], P. Malik[1], R. I. Bakhtsingh[1] and Martin Mascarenhas[1]
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[2]Homi Bhabha National Institute, Mumbai
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Abstract:

Electron Beam (EB) Welding is an autogenous welding process where heat required for melting and joining of metals is obtained from the impingement of high energy electrons on to the target surface. The high power and high efficiency of the EB heat source, beam maneuvering capability such as generation of various beam oscillation patterns at very high scanning speed, welding of large thickness in single pass, high depth to width ratio, low heat affected zone, low distortion, low residual stresses, welding of dissimilar (e.g. Cu-SS, SS-Al etc.) metals and capability to operate in high vacuum environment, are some of the salient features of the EB welding and melting technology which makes it most suitable for the joining of reactive, refractory and difficult to weld materials. However, EB Welding could not gain much popularity in the manufacturing industry due to its complex nature and high initial cost. The exploration of EB technology is not within the reach of many industries in India due to its high import cost and poor quality of post-sale services by international manufacturers. Some of the MSME industries are compelled to be away from this process due to non-availability of customized machines as per their specific application requirements such as power ratings and foot print. The indigenization of this complex technology can overcome it. The industries like nuclear, automobile, aerospace and space research organization can harness the benefit of EBW to upgrade their product quality and simultaneously can reduce their cost.

The EB Melting and EB Welding technologies are indigenously developed at Bhabha Atomic Research Centre (BARC), Mumbai for welding and metallurgical processing of refractory, reactive and dissimilar metals in high vacuum environment. The EB Welding Machines with power rating ranging from 1kW, 25kV to 12kW, 80kV and EB Melting Machines with power ranging from 10kW, 15kV to 150kW, 40kV are already developed and are being used for production purpose at various units of Department of Atomic Energy (DAE). The technology and know-how of EB Welding and EB Melting Machines developed at BARC is available for Transfer of Technology (Tot) to private Industries. The interested parties may contact Head, Technology Transfer and Collaboration Division, BARC to access the information regarding Tot or the Private Industries to whom the Technology of EB Machines have already been transferred.

Keywords: Electron Beam Welding, Electron Beam Melting.

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Controls and High Voltage Engineering of EBW Machine: Operation

Dr. D. V. Ghodke
ISDDS/PLDD/PAG, RRCAT, Indore
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Abstract:

Electron Beam Welding (EBW) is a highly efficient and precise welding technique that melts and fuses metals using a focused beam of high-energy electrons. This technology is especially useful for applications that require deep penetration and minimal heat-affected zones, making it ideal for the research, accelerator, aerospace, automobile, and medical industries. The control and high-voltage engineering features of EBW machines are crucial for maximizing performance and maintaining welding process dependability.

The control system of an EBW machine plays an important role in regulating factors such as beam current, voltage, beam size, travel distance, beam deflection and speed. Advanced feedback systems and automation enable real-time modifications, improving weld quality and consistency. Modern EBW systems frequently incorporate computer numerical control (CNC) to provide complicated welding patterns, seam tracking, online power management, and improved process repeatability. This presentation covers into detail on the controls for the RRCAT EBW machine.

Furthermore, high-voltage engineering in EBW includes dealing with issues such as high voltage insulation, thermal management, and the possibility of glow and arc discharge instability, which may affect weld quality. The RRCAT EBW machine has undergone innovative upgrades and changes, which include: (1) a single solid ceramic high voltage insulator, (2) dry nitrogen purging for the main working chamber, electron gun, high voltage deck, roughing pumps. (3) enhanced vision system with upgraded CMOS camera, (4) rearrangement of CPU, displays, and other components to prevent EMI interference during arc discharge, (5) Moisture control system for high voltage insulators for electron guns, (6) HVAC system for an EBM machine. (7) Increased insulation for the biasing power supply. (8) modified cathode assembly for easy maintenance, making high voltage cable connections, and reducing the high voltage glow discharge by removing sharp edges and silver coating to prevent surface oxidation. (9) Longer creepage distances for high voltage insulators, cables, and fiber optic cables. (10) Clean air in the work environment minimizes dust collection on the surface of high voltage and fiber optic cables, (11) An extra insulator for high voltage and fiber cable with silicon and glass tubing. (12) Replaced the current plastic roughing line with SS tubing; these are significant upgrades, among other things.

To summarize, the control and high-voltage engineering of electron beam welding equipment are critical to the technology's reliability and capabilities. By upgrading / improving the hardware's high voltage systems, electron gun, vacuum systems, vision system, laser and fibre optic system, enhancing controller hardware and algorithms, the EBW machine can achieve superior welding results, ensuring EBW's wider adoption in various high-tech accelerator component applications. Future upgrades are planned to focus on further integrating digital technologies, as well as increasing the high voltage systems' safety.

References:

"Electron Beam Welding (EBW) Programing Guide", PAVAC Industries INC. Version 1.0.
"Electron Beam Welding (EBW) Operator Guide", PAVAC Industries INC. Version 1.0.
Internal discussions and communications with PAVAC Industries INC.

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Electron Beam Welding for Superconducting Radio Frequency Components

C. Grimm
Fermi National Accelerator Laboratory, USA

Abstract:

To participate in RRCAT's "Workshop on Electron-Beam Welding for Particle Accelerators and Associated Technology", Fermilab (FNAL), will describe their experiences with electron-beam welding (EBW) of Superconducting Radio Frequency (SRF) components. I will discuss the equipment used, mainly details in Low Voltage Sciaky EBW machines, which are also used at Thomas Jefferson National Lab and C F Roark Welding & Engineering Inc. for SRF applications. I will describe in detail the steps we perform to generate EBW weld parameters prior to welding the actual components, using titanium adapter rings welded to 1.3 GHz cavities as an example. We will look at some of the tooling and how that is used to keep pressure on the weld joints. Finally, we will look at various SRF components that were EB welded by me at Sciaky, examples include single-cell cavities, helium tank integration welds and work FNAL is involved with in developing conduction cooled cavities with cooling rings welded directly on cavity half-cells.

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Fundamentals of Electron Beam and Laser Welding Techniques

Prof. Mohd Zaheer Khan Yusufzai,
Indian Institute of Technology BHU, Varanasi

Abstract:

Electron beam welding is a high energy beam fusion welding process that offers several advantages over the conventional fusion welding processes. Although fusion welding process should essentially involve melting of material at the interface only, however most conventional fusion welding processes melt a substantial amount of material near the interface during the process. The amount of material melted is quite large when the plates of larger thicknesses are being welded. The issue is mostly because the energy density (energy per mm^2) of conventional fusion welding processes is quite low and the primary mode of melting is by heat transfer through conduction. The high energy beam welding processes like electron beam welding and laser beam welding have a significantly higher energy densities (10^8 W/cm^2 in LBM and EBW in comparison to 10^5 w/cm^2 in arc welding processes). The melting can also be carried out by key hole technique of welding. These factors lead to the reduction in the total amount of heat input during welding and the melt weld pool being significantly smaller in size. The smaller weld pool reduces the chances of defects in the weld region and the reduction in total amount of heat input reduces the size of the heat affected zone. The rapid heating and cooling cycle also improve the weld microstructure and prevents the coarse grain heat affected zone from forming.

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Laser Beam Welding for Accelerators applications

B. N. Upadhyaya[1,2]
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[2]Homi Bhabha National Institute, Training School Complex, Anushakti Nagar, Mumbai
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Abstract:

Laser welding has wide range of applications in industries and nuclear field due to flexible fiber optic beam delivery, localized heat input resulting in minimal heat affected zone (HAZ), thermal distortion and metallurgical damage to the material. There are two modes of laser welding: CW mode and pulsed mode. CW mode laser welding is deployed to weld high thickness material with high welding speed, however, distortion and HAZ are high as compared to pulsed laser. In case of pulsed laser, heat source is not continuous resulting in less distortion and is advantageous for low thickness welding of up to few mm and applications where minimum thermal damage is of prime concern. There are two operational regimes of laser welding based on process parameters, which are conduction mode welding and keyhole mode of welding. In conduction mode welding, there is no vaporization and depth of penetration is governed by the rate of energy input from the laser beam and rate of energy taken out through the thickness of material by means of conduction. In conduction mode, the shape of liquid molten pool is decided by the thermos-capillary convection, whereas in the case of keyhole welding, material vaporization takes place resulting in formation of deep hole inside the molten pool causing full trap of laser beam. Conduction mode welding is limited to low depth of the material due to its poor absorption coupling. In keyhole mode, keyhole cavity is created directly by vaporization of the material from weld poo and melt displacement rate is very less as compared to vaporization rate. This talk will cover laser material interaction, basics of laser welding and laser welding results for some of the accelerator components.

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Laser Welding of SCRF Cavity Components: India's Successful Novel Technology

Khare Prashant*, Upadhyay Brahmanand,
Raja Ramanna Centre for Advanced Technology, Indore-452013, INDIA
*email: prashant@rrcat.gov.in

Abstract:

Novel technique to fabricate Superconducting Radio Frequency (SCRF) cavities with the help of laser welding process without using vacuum environment has been developed for the first time in the world, at Raja Ramanna Centre for Advanced Technology (RRCAT), Indore, Department of Atomic Energy, India. The first single cell cavity was fabricated and tested to give an accelerating gradient of 31.6 MV/m with quality factor of 1E10 at 2K. This performance matches with internationally accepted performance levels expected from a well fabricated SCRF cavity. This technique has advantages like 25 times lower capital cost and very significantly lower operating cost. This talk describes the technique and advantages associated with it. A pulsed Nd: YAG laser was used and high purity argon environment (less than 3 ppm), is maintained during welding.

Subsequently, a multi-cell (5-cell), 1.3 GHz SCRF cavity has also been fabricated using this technique. This talk describes the technique, infrastructure developed, method of fabrication and experience in fabrication of multi-cell cavity by laser welding route. The experience of fabricating a multi-cell cavity unveiled many advantages of this technique which were hitherto unexplored during fabrication of a single cell cavity.

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Protocol for Clean and Sound Electron Beam Welding: SCRF Cavity as a Case Study

Dr. Vikas Jain
Raja Ramanna Centre for Advanced Technology, Indore-452013, INDIA
*email: vikas@rrcat.gov.in

Abstract:

Electron Beam Welding (EBW) is a high-precision welding technique that offers several advantages over traditional welding methods, including deep penetration, narrow heat-affected zone, and high welding speeds. However, the successful implementation of EBW requires stringent control of various parameters, especially cleanliness and vacuum conditions. This presentation describes a detailed protocol for clean and sound EBW, focusing on the specific case of superconducting radio frequency (SRF) cavities, a critical component in particle accelerators.

The RRCAT's SCRF development program has been instrumental in advancing the state-of-the-art in SRF technology. The 15 kW EBW machine at RRCAT plays a crucial role in fabricating complex SRF cavity components. To ensure the quality of the welded joints, meticulous attention is paid to the preparation of the niobium (Nb) surfaces. Chemical cleaning processes, such as alkaline and acid etching, are employed to remove surface contaminants and oxide layers. The vacuum level in the electron gun and welding chamber is maintained at ultra-high vacuum (UHV) conditions to minimize the impact of residual gases on the welding process.

The successful qualification of the 650 MHz cavity at RRCAT highlights the importance of a well-defined EBW protocol. By adhering to stringent cleanliness standards and optimizing welding parameters, it is possible to achieve high-quality welds with minimal defects. This presentation provides valuable insights into the critical factors that influence the success of EBW for SRF cavities and can be extended to other applications requiring precision welding.

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Issues in EBW Technology and Its Mitigation Procedures

Y. K. Arora[1], R.N. Mardhekar[1], A. A. Shinde[2]
[1]Central Workshop, Tata Institute of Fundamental Research
[2]PLF, Tata Institute of Fundamental Research

Abstract:

Advanced manufacturing technologies (AMTs), including electron beam welding (EBW), are being explored by academic, industrial, and regulatory entities for their technical feasibility, cost-effectiveness, and safety in fabricating components for various research activities. EBW is considered one of the cleanest welding processes, with fewer defects than conventional arc welding. TIFR's central workshop houses a PAVAC Lastron 100 EBW machine, where various critical welding jobs are carried out. Recently, work has been initiated to fabricate low beta Nb superconducting QWR. To evaluate the electromagnetic design and optimize mechanical fabrication steps, stainless steel (SS) and oxygen-free high-conductivity copper (OFHC) prototype fabrication with electron beam welding is being undertaken in parallel at both TIFR and BARC. Here, we present the issues faced while operating the machine, such as electrical, instrumentation, vacuum, and software problems. We present how these problems were diagnosed and addressed. Additionally, we explore how we have optimized parameters during SS prototype fabrication, customized fixture design and fabrication to achieve accurate alignment of various QWR components, and minimized warping and distortion during welding. However, the figures presented here are specific to the TIFR machine

Keywords- QWR, EBW

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EBW relevance in Fusion Technologies; Experiences and Lessons Learnt

Jaydeep Joshi
ITER, Institute for Plasma research, Bhat Gandhinagar

Abstract:

Components relevant to fusion environment require a control not only in terms of the material composition but also from the perspectives of ensuring their longevity when operating in harsh nuclear environments with minimal chances of repair even through remote operations. ITER under construction in south of France with a global collaboration of seven participating nations is a first of kind machine to demonstrate fusion power of 500 MW with a Q factor of 10. The components in the machine, especially those forming the first vacuum boundary, are required to adhere to French nuclear codes of safety. Diagnostic Neutral beam (DNB) is one of the eight in kind deliverables from Indian domestic agency to ITER. The beam line consists of components like an RF based ion source capable of producing and accelerating 60 A of H- beams at 100 keV with inbuilt optics control, a neutralizer to convert accelerated ions to neutrals, an electrostatic residual ion dump and a calorimeter for beam optimization and control. These components are housed in a vacuum vessel which in turn is connected to a duct through a set of front-end components to deliver 20 A of H^o at 100 keV into the ITER plasma 21 m away from where the beam origin point. Considering the high heat loads, 1 – 10 MW/m^2 expected on the components during operation, most of the components are made of copper or its alloys like CuCrZr which are water cooled through in-built circuit of water-cooling channels. These channels are either deep drilled or milled during the production process. The closing of these channels and their subsequent transition to SS employs electron beam welding process in various configurations, sizes, and depths up to 18 mm. The process required a careful phase of development considering that the components are made of copper for which no previous data base or expertise existed and all the joints needed to qualify a leak rate specification of 10^{-9} mbar l/s. The other important application of the electron beam welding is in the fabrication of heat transfer elements used in the calorimeter. Several prototypes had to be developed in scaled versions to optimize the process and relevant parameter before its deployment in actual manufacturing. This presentation discusses the component and their welding configurations, the optimization process through prototype development phases and the lessons learnt thereby leading to manufacturing of the actual components certified for their use at ITER.

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Hands on experiments- RRCAT Electron Beam Welding Machine.

Raja Ramanna Centre for Advanced Technology, Indore-452013, INDIA

Abstract:

Superconducting Radio Frequency (SRF) cavities are the pivotal/core/fundamental components of modern Linear Accelerators. It is now widely acknowledged that SRF cavities must be fabricated from high purity niobium. This process involves using deep drawing of half-cells from sheet material followed by Electron Beam Welding (EBW) in high vacuum. EBW is highly effective technique used to achieve high quality welds maintaining the material's high purity required for saving the niobium superconductivity. The EBW parameters must ensure a full penetration of the joints and smooth weld seam of a few-millimeters width at the inner cavity surface. The weld bead top and underbed is required to have smooth profile to minimize the peak electric and magnetic fields in order to achieve the maximum accelerating gradient. The objective of the Hands-on experiment session is to provide live demonstration of 3mm and 4mm thick Niobium samples focusing on the optimization of welding parameters along with detailed discussions related to Welding Procedure Specifications (WPS) and Procedure Qualification Record (PQR) welding documents. The weld zone & HAZ cross section are investigated by optical microscope with further assessment of weld joint qualification like RRR measurement, UTS, face & root bend test. Inner RF weld bead is plan to examine by optical inspection bench. The setup can measure the features up to 40 mm/pixel and record the images to analyze the defects on the inner weld bead. EBW generates potentially harmful radiation, such as X-rays and other types of radiation. Therefore, strict safety measures must be implemented to ensure the safety of operators and mitigate any health-related risks associated with the process. Safety poster is demonstrated for risk associated with X-ray radiation and operator safety.

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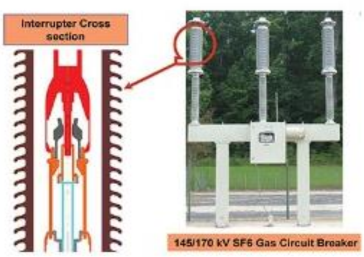
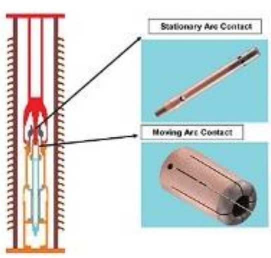


SF6 Circuit Breaker - Contacts



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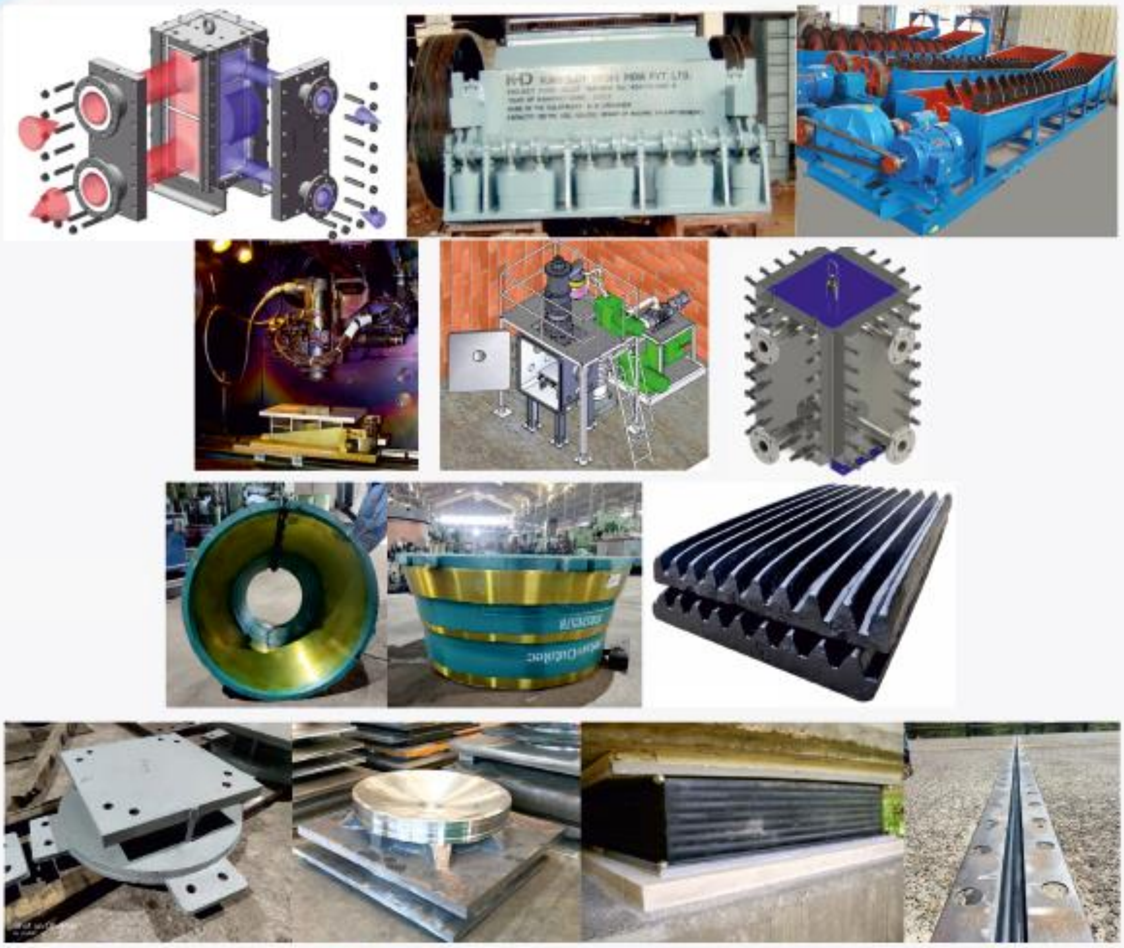

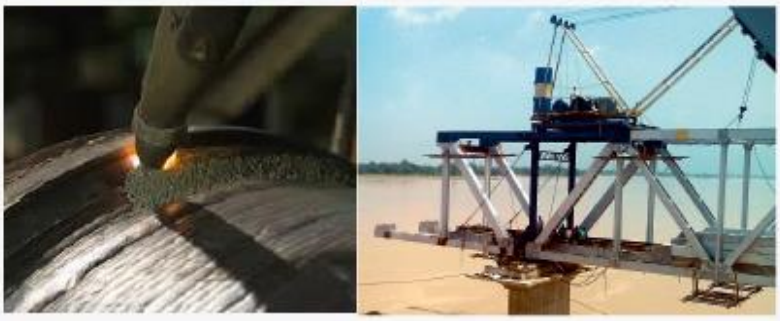

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