LEVERAGING DIGITAL TOOLS TOWARDS SHIPBUILDING 4.0

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SYNOPSIS

Warship construction is a complex project management exercise, involving multiple stakeholders. In the last decade, Indian Shipbuilding Industry has gone through a transformation like never before. The market has become fiercely competitive. Industry processes are undergoing a transformation with many new concepts and process improvements. The ongoing global pandemic has turned the global businesses on its head like never before. This paper aims to explore the challenges and the manner in which multiple digital processes of Industrial Revolution 4.0 were leveraged at Garden Reach Shipbuilders & Engineers (GRSE) from progressing concurrent design at remote locations to conducting Factory Acceptance Trials (FATs), Basin Trials (BT) and even during commissioning of the warship for Indian Navy and Coast Guard ships due to the severe physical restrictions imposed as a result of this pandemic.

GRSE has successfully commissioned a Naval Vessel, Landing Craft Unit (LCU) MKIV project L 58, during the global pandemic scenario where shipyard and OEMs were not physically available on site. Utilization of advanced digital tools like digital twin and virtual reality to co-ordinate with internationally located OEMs of Main Engine, Gearbox and propulsion system was critical in both successful FATS on one hand and commissioning of the propulsion system on-board on the other end of the spectrum. In addition to this, navigation system such as UHF, Satcom and MSS Terminal of the ship was commissioned with the help of remote assistance facilities.

A paradigm shift has also been institutionalised by conducting complete procurement process, from Pre-Bid meeting & Technical Negotiation meetings only through digital platforms resulting in faster overall procurement timeline. Entire Ship Design value chain from basic ship design to Production drawings between 3 stakeholders, design partner, shipyard and classification society, all located remotely was carried out entirely by leveraging the digital tools.

This paper aims to share our experience in leveraging the digital tools such as Artificial intelligence, Digital Twin and Virtual Reality. A case study is presented as a starting point, in which the digital tools were successfully utilized in shipyard environment for conducting activities involving multiple stakeholders located globally.

Keywords: Digital Shipbuilding, Shipbuilding 4.0, Industry 4.0, Digital Transformation

1. INTRODUCTION

Indian Defence Shipbuilding is a complex multidisciplinary project based industry, involving multiple stakeholders including Customer, Ship Owner and Builder, with Indian Navy as one of the biggest client right now. Indian Navy's operational footprint has increased in the past decade and has a target to achieve 200 ships fleet by 2027 from current of about 140 (as per Maritime 30-years perspective plan, 2018) as a part of the nation's modernisation and expansion of its maritime forces. This explosion of requirement of navy fleets in addition with potential in the Indian commercial shipbuilding market has resulted in increased cutting edge competitiveness in the market which is now additionally burdened with operational challenges due to the COVID pandemic. These challenges mandates the shipyards to call for an abrupt makeover of the shipbuilding processes and concepts involved.

The shipbuilding industry has embarked on the first steps towards digital transformation in the third Industrial Revolution by adoption of technologies like 3D CAD Model and Simulation, automated CNC machines, robotic steel Joining, Precise Laser Guided Measuring tools etc. all of which are aimed to achieve optimum quality with reduced time, thus increasing production efficiency. Now the Fourth Industrial Revolution is upon us. Myriad opportunities like AI capabilities, Information Management, Virtual Reality, Internet of Things (IoT) and many others are now transforming the shipbuilding Industry to modern Shipyards 4.0.

Shipbuilding is one of the oldest industry of the world, where there has been an ever increasing demand for modernization of processes involved, especially now, when various challenges like world-wide travel restrictions, factory lockdowns etc. have been imposed due to the current pandemic scenario. These challenges had a positive

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role in realization of Shipyard 4.0 goals at Garden Reach Shipbuilders & Engineers Ltd. (GRSE) and had acted as a catalyst for exploration, learning and adoption of modern and advanced processes. Over the years, several developments have been carried out across various divisions of shipbuilding at GRSE, with a target to enhance the contribution to quality and timely delivery of ships. This paper aims to elucidate the various aspects of Shipyard 4.0 and various digital tools, aligned with the concept of Industry 4.0, leveraged at GRSE to tackle the new challenges faced due to the pandemic restrictions during design, trials and commissioning of the warship for Indian Navy and Coast Guard.

The paper is organized in the following manner. The succeeding section throws some light on the historical perspective of the Industrial Revolution and its role in achieving Shipyard 4.0. Thereafter, it looks deep into the case scenarios of implementation of various tools as a follow up of Industry 4.0 toolsets adapted or projects planned to be adapted in GRSE shipyard viz, AI enabled NDT, Inspections using virtual and augmented reality, Compartment Inspection using Virtual Reality etc. It finally conclude by summing up of all benefits of achieving Shipyard 4.0

2. Industrial Revolution – A Historical Perspective

Industry around the world has been ever developing in terms of technical and technological aspects and today it has reached to a stage so named as Industry 4.0. A glance at the past might give some perspective on how this fourth revolution is different and unique in its own way.
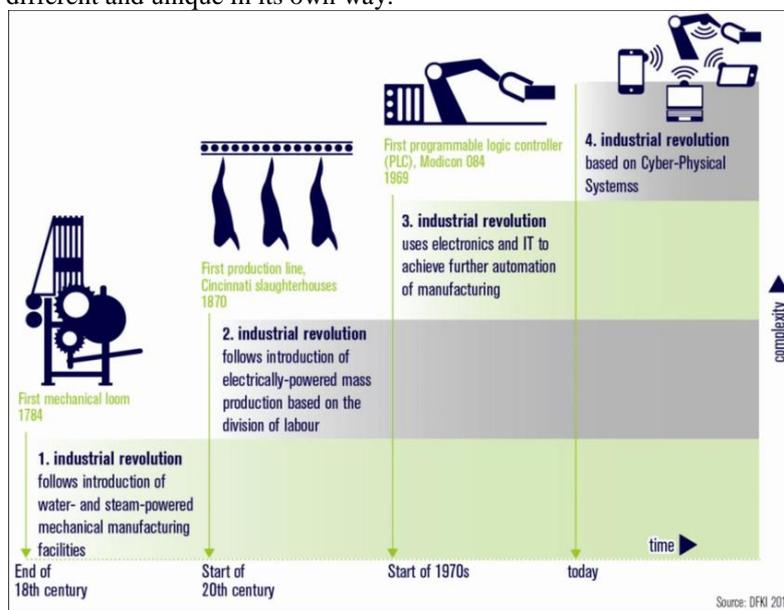

Figure 1 Stages of Industrial Revolution (Source: DFKI 2011)

The First industrial revolution came into effect from the end of 18th century and remained in force for almost a century. This was the age of start of mechanical production. The manual labour was then replaced with the usage of water and steam powered mechanical engines. The agrarian society has started becoming urbanized as factories started to emerge at every corner, and became the backbone of each industrial sector.

Nearly a century later, sparks of the Second Industrial Revolution was ignited with the emergence of newer sources of energy like electricity, gas and oil. Introduction of the concept of mass production was the essence of this phase. With the development of steel industry, this became a critical phase for shipbuilding industry, as transformation from wooden ships to steel made ships was now in progress. With the advent of World Wars, Shipbuilding processes were the focus of development with introduction of the concept of prefabrication of standard assembly/ sub-assembly, block fabrication technology for fabrication of ring joints at different location for construction of German U-boats (Submarines) and many similar developments paved the way for modern shipbuilding industrial processes adopted across the world.

The second half of the 20th Century, marked the dawn of the Third Industrial Revolution. This one is much more familiar to us than the rest as this period was inclined towards usage of digital technologies leading to coining of terms like 'Digital Revolution' and 'Information Age'. Introduction of electronics, computers and internet lead to rise of a high level of automation in all industries. The shipbuilding industry witnessed the adoption of advanced level of automation like 3D CAD modelling, CNC cutting machines, Robotic steel welding etc.

Over the period, Industry processes eventually embarking us over the present category of the Industrial Revolution, Industry 4.0. Shipyard 4.0 is a term used vis-à-vis the adoption of Industry 4.0 capabilities in designing, construction, operation, maintenance of ships and submarine construction in a shipyard. This latest revolution underpins its capabilities to enable a Digital Shipyard environment by engaging the two significant Industry 4.0

capabilities, "Cyber Physical Systems" (CPS) and "The Internet of Things" (IoT). CPS merges physical and software components together and makes the end product highly connected to the internet and its users. Robots, autonomous vehicles, smart grids and other such complex systems are examples of CPS. IoT is the collection of connected smart devices that require no human to human or human to computer interaction. These devices can range from watches to fridges to phones to weather sensors. They can communicate with each other, exchange information and work collaboratively to complete tasks and feed information back to human operators. There are a number of technologies that would be considered as Digital Shipyard enablers, some of which fit neatly under the Industry 4.0 umbrella whereas others are either recent or emerging technologies.

This vision aims at applying specific technologies to specific phases of a shipbuilding lifecycle. The three phases from the shipyard perspective being Ship Design, Ship Building and Service (Support). The idea is that these technologies will help drive the identified outcomes. Used effectively, these technologies will not only reduce the time to delivery but will also improve safety and the end quality of the platform. The cumulative efficiency of these technologies when used in collaboration with each other in a manufacturing environment can dramatically reduce the time-to-market of the platforms.

3. Key Elements of Industry4.0

The elements of Industry 4.0 enables the shipyard to pre-emptively identify defects and undertake subsequent corrective actions. The key elements for Industry 4.0 implementation in a shipyard environment are,

a. Robotic Process Automation – Utilization of robots to work in harmony with human users. Automation of repetitive tasks with optimum quality. Work efficiency can be increased with an appropriate implementation of Adaptive robots with Artificial Intelligence (AI) capabilities.

b. Additive Manufacturing (AM) – Also known as 3D printing, provides the capability to print parts, jigs, templates and pretty much anything that can be digitally modelled and loaded onto the printer. AM can be very useful in both the build and support phases of a Ship's lifecycle. An instance of AM utilization can be replacement of damaged parts, instead of having to order parts they can be simply printed in-situ reducing the turnaround time for the repair, as long as digital twin of the part is on hand, for example a CAD model.

c. Virtual and Augmented Reality (VR & AR) – VR offers a digital recreation of the physical world while, AR provides an overlay of virtual elements on real world. An AR headsets/Tablet can be preloaded with drawings or even connected directly to PLM to bring up schematics, videos and other media in front of user, thereby dramatically simplifying and speeding up the build and maintenance phases of a ship's lifecycle.

d. Data Analytics – Data has been called the "oil of the 21st century to accentuate on the potential of data when process of analysing of large, semi or unstructured data has been implemented to identify patterns, unknown correlations, ambiguities, trends etc. The core benefit of Data Analytics is in its predictive capabilities which can help to predict failures from historical performance data trends. If used at full potential, Data mining will help to analyse and predict a major impact on the project/ shipbuilding industry well in advance and will enable to plan the future business prospective accordingly.

e. Industrial Internet of Things (IIoT) – IoT is a term used to describe a collection of connected devices that can work in unison by communicating with all stakeholders to share and process information. IIoT can amplify that power by leveraging machine learning and big data technologies to utilise sensor data to expedite decision making.

f. Secured Cloud – This an innovative technology and an enabler for IIoT. It facilitates in removing border for storing, computing, processing and sharing digital information.

g. Cyber Security –With Industry 4.0 elements, enabling ease of connectivity and data sharing between all stakeholders around the world, Cyber Security becomes a critical chapter for Shipyard 4.0, especially for a defence shipyard. It is crucial to adopt appropriate measures of Cyber Security by periodical installation of security patch, updating firewall against new threat, monitoring of log & access data etc.

h. Digital Twin – The concept of Digital Twin is to literally duplicate a digital copy of its Physical Twin. The digital twin is able to simulate the physical dynamics and characteristics of its physical twin so that potential problems can be predicted and simulated in a safe environment. Due to the sheer size of a ship, a digital twin can dramatically reduce the time and effort of its subsequent physical build. Problems that would traditionally be identified once the ship is being built can be identified and addressed digitally through simulation viz, Evacuation routes, Line of site in the Bridge, Removal of machinery and equipment, Fire suppression, Compartment sealing in the event of hull breach etc.
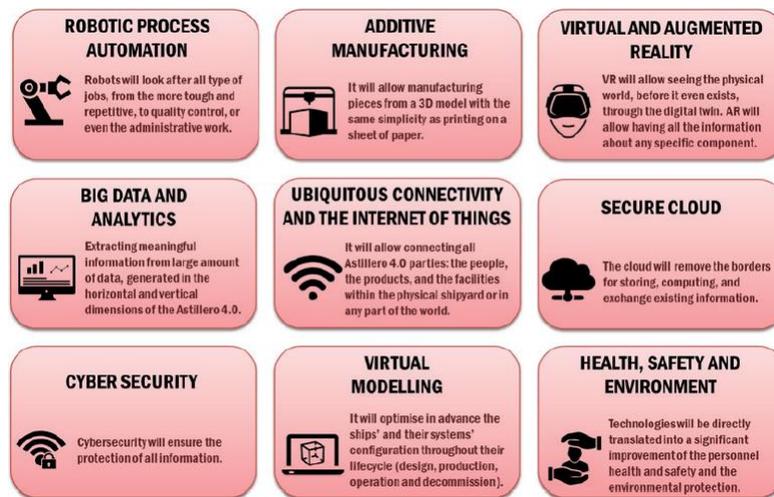
Figure 2 Key Elements of Shipyard 4.0 [8]

4. Glimpse of Shipyard 4.0 tools in GRSE

The section above articulates the dimensions of Industry 4.0. The labour intensive nature of shipbuilding poses limitations on the end to end transformation to Industry 4.0. Notwithstanding the above number of applications that have adopted Industry 4.0 tools is impressive enough to coin the phrase "*Shipyard 4.0*". GRSE initiatives till now towards shipyard 4.0 are enumerated in the succeeding paragraphs.

4.1. CASE – I

AI enabled Radiography Weld Evaluation

Welding is one of the most critical and prominent activity of the shipbuilding industry. Huge amount of welding thus carried out in turn calls for a Non-destructive testing method for verification of quality of welding joints to ensure performance and integrity of vessel. Traditionally, Radiography test uses X-Rays or Gamma Rays exposed on single use films coated with radiation-sensitive Ag-Br crystals with a gelatine layer. The exposed film is then processed in a series of chemical solutions that convert the invisible latent image of welding joint into an image that is visible as difference in optical densities or shades of grey due to difference in exposure level at the defect region.

Typically around 3000 – 4500 radiographic shots of welding for various types thickness, joint geometry and weld types is taken for each ship. The processing and evaluation of a batch of radiographic films takes about 6 ~ 8 hours for the Quality Control Inspector to give verdict. Processing and developing of RT films requires a completely dark room and also leads to down time in production as no work on the welding can be carried out on the job till the verdict on quality of weld is given, making the process a tedious and time consuming one. Typical traditional process of RT film exposure and processing is depicted in Fig 3.
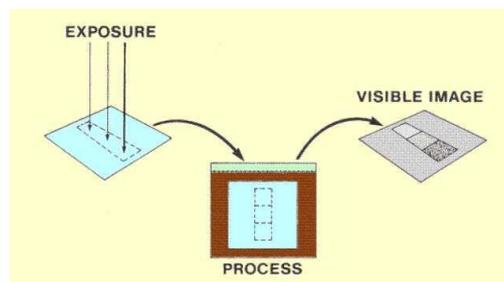

Figure 3 Traditional Radiography Process

GRSE has undertaken a project to develop and implement an AI-enabled Automated Weld Defect Recognition Software for Digital Weld Radiography Images to replace the traditional way of radiography which is a manual intensive and time consuming process to achieve an improved and reliable radiography inspection system. The intelligent system will utilize Industry 4.0 tools such as artificial intelligence (AI) and machine learning (ML) for carrying out the inspection.

In the computed radiography process, in place of traditional films, a re-usable phosphorous coated Imaging Plate (IP) is exposed to the Gamma rays or X-Rays, the energy of the incoming radiation is stored on the coating layer, thereby creating a latent image of the weld. This image is then read using a Computerized Radiography

Scanner (CRS) stimulating it with a very finely focused laser beam. When stimulated, the plate emits blue light with intensity proportional to the amount of radiation received during the exposure. This light is then detected by a highly sensitive Analog device known as a photomultiplier (PMT) and converted to a digital signal using an Analog-to-Digital Converter (ADC). The generated digital X-ray image can then be viewed on a computer monitor and evaluated. After an imaging plate is read, it is erased by a high-intensity light source and can immediately be re-used - imaging plates can typically be used up to 1000 times or more depending on the application. The complete CR process and subsequent Automated decision making result in overall time reduction, reduced down time thereby improving productivity. It is also an environment friendly process as usage of chemicals can be completely eradicated. Further, archiving of digital RT images can be done for long period without loss of image quality.

Having taken the first step towards digitisation of Radiography, GRSE is now in the process of developing AI and ML toolsets for Automated Defect Recognition (ADR), Classification and decision making. This activity was hitherto in the domain of NDT qualified personnel. A typical CR based digital Radiography process is depicted in Fig. 4. While, Steps 1-3 & 5 have already been achieved, the final piece of Automatic Weld Defect Recognition (Step – 4) is being rolled out shortly.
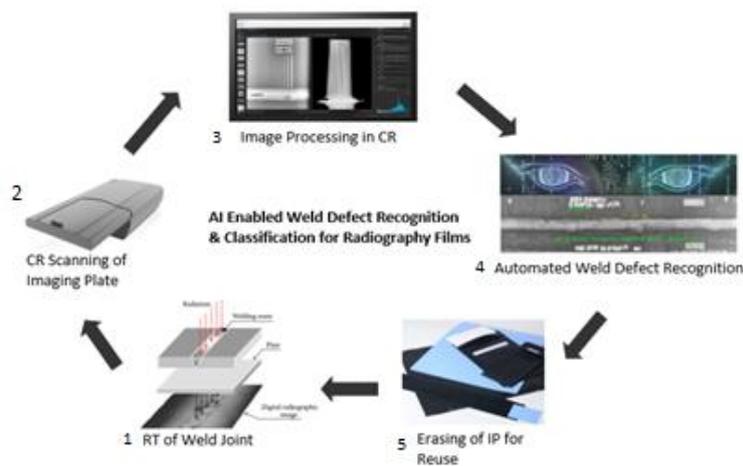

Figure 4 Typical CR based automated Digital Radiography Process

4.2. CASE - II

Remote Approval/ Optimization of 3D Models

A 3D model provides immense flexibility in transfer & sharing of data between shipyards or even with specialists at a remote location. A 3D model can be conveniently shared between two partner shipyards, involved in a common ship project. For instance, M/s MDL & GRSE are currently engaged in warship construction of the same class of ships (P17 A), and the same model is being shared & progressively updated between yards for independent production activities at 02 different locations between the shipyards.

Another key advantage of 3D model is its flexibility in sharing the model with specialist for QC, especially during the COVID times. For instance, for another Naval project (ASW SWC), whilst 3D model is being formulated locally at GRSE, Kolkata, and the QC or value addition/enhancement is being undertaken through a separate/ experienced team sitting at a distant office at Mumbai.

A 3D Model gives distinct advantages, in terms to optimization of lay-out, routing of piping/ cables, etc through two or more teams working simultaneously on the same model, to find the best design and engineering solution for the ship. 3D model in simple terms, is a stepping stone towards digital twin.

4.3. CASE - III

Online Inspection Monitoring System

Online Inspection Monitoring System (OMS) is an in-house developed rule based digital tool aimed to transform the shipyard's conventional processes with a modern approach which can gel the process's interface with elements of the fourth Industrial Revolution.

In new construction ships, various inspections of equipment and hull structure are carried out by Customer Rep (Warship Overseeing Team, WOT) and shipyard's Quality Assurance (QA) Team. Usually, hard copies of inspection reports (I-note) appended with QA comments & approval is forwarded to WOT requesting for their on-site inspection. WOT post inspection add their comment in the I-note and after final approval revert it back to production for carrying out next operation. This practice of physical movement of information results in generation of piles of physical documents; posing limitation in real-time monitoring of the progress of inspection as well as

storage/retrieval of historical inspection data. A snapshot of the platform representing the types of data captured at each transaction is shown in Fig. 5.
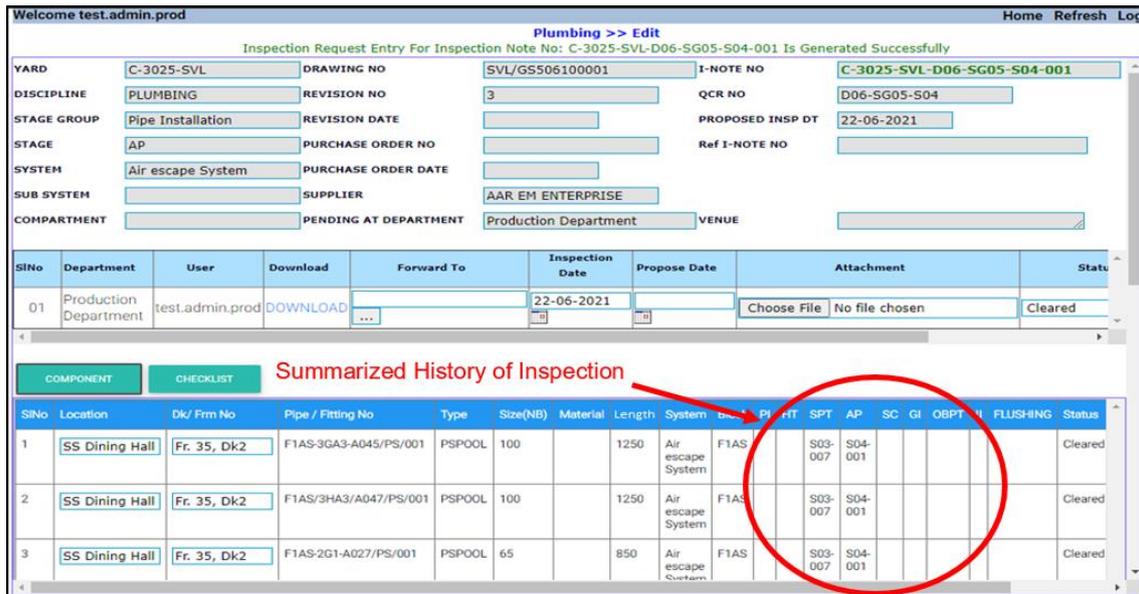

Figure 5 Snapshot of OMS platform representing Component Level Tracking

This vast amount of data, documents and information thus generated requires a firm rule based tool with multi-purpose use for attaining effective user interface having collaborative facility among the various discipline and stakeholders. This laid the framework for an in-house developed, secured JAVA based ERP platform for all new construction vessels in GRSE. OMS benefitted with,

1. <u>One point processing</u> of all inspection requisition and observations recording, thus easy storage and retrieval of the processed Inspection Notes.
2. <u>Real-time monitoring</u> of the progress of inspection and project progress percentage.
3. <u>100 % paperless transactions</u> between all stakeholders related to inspection activities, a step towards digital twin.
4. <u>Robust Vendor Base</u> creation by leveraging OMS by capturing Quality aspects of Vendor like No. of Re-offers/ Rejections, Time taken for completion etc.
5. <u>Data Analytics</u>: Continuous use of such a comprehensive platform would lead to key areas in data analytics such as,
   - <u>Predicting Weak Spots and Reduce Test Fatigue (Trials)</u> – Identifying pattern of common defects during trials. Database thus accrued will aid in the predictive maintenance activity of the system.
   - <u>Business Process Assurance</u> –The platform intelligently compares core business processes across the enterprise and plots application or services on a risk matrix.
   - <u>Vendor Evaluation</u>- Capturing vendor performance on predefined parameters for evaluation of vendor rating.

4.4. CASE - IV

System Trials leveraging digital tools

As the world was hit by waves of pandemic, travel restrictions were imposed at all places, limiting the OEM's capability to be available on-board physically for trials & commissioning. GRSE, equipped with Industry 4.0 toolsets, took these challenges head-on during system trials and commissioning of navigation system such as UHF, Satcom and MSS Terminal for Landing Craft Utility (LCU) project. During this operation, a technically sound person of the shipyard was physically present on site to perform physical checks, while receiving guidance and instructions from virtually present OEM (system expert) who was providing assistance remotely with the help of effective utilization of elements of Industry 4.0 viz. Digital twin and Remote Assistance. The OEM was constantly referring the Digital Twin model of the equipment present with them to provide necessary guidance to the shipyard rep for the trials for successful commissioning of the system.
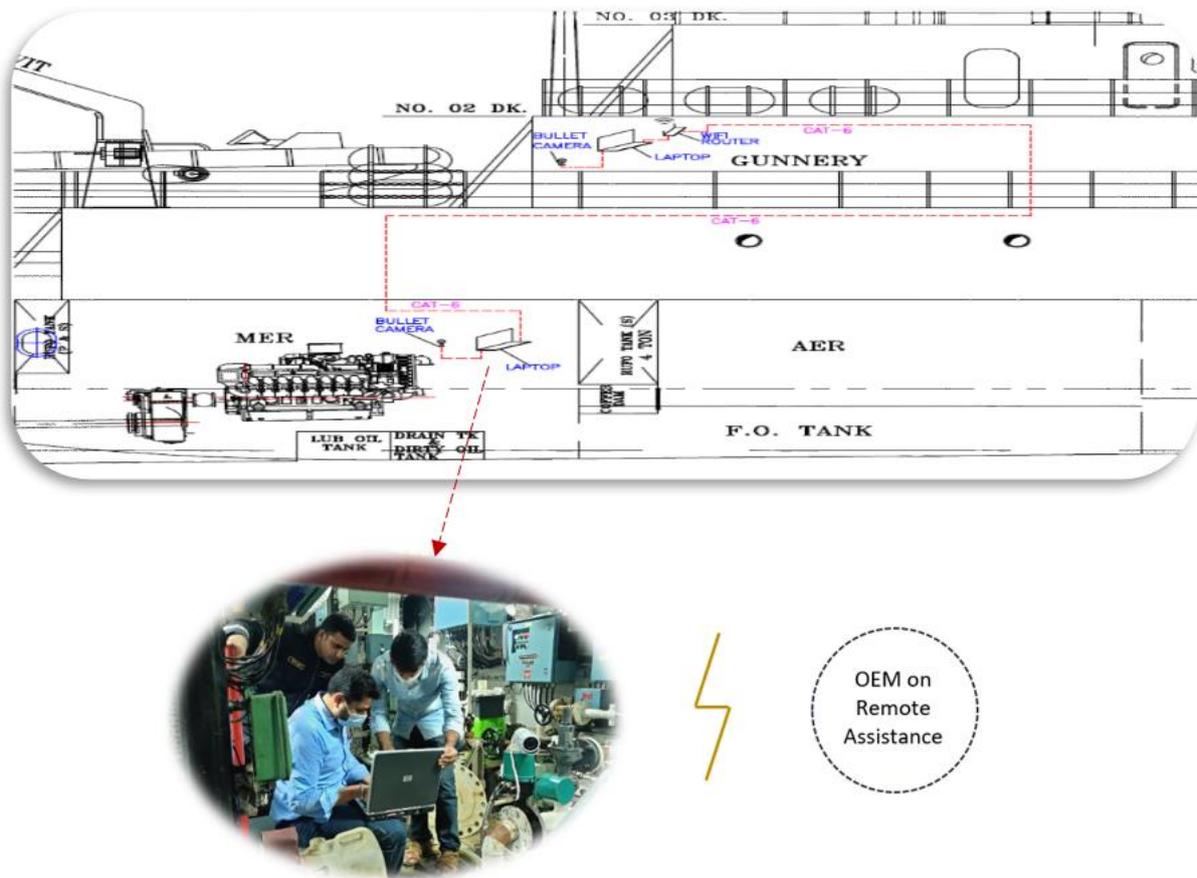
Figure 6 System trial underway without physical presence of OEM

An effective use of Shipyard 4.0 tools was seen during commissioning of Engine control system at GRSE when OEM was not physically available on board but was providing remote assistance at each step to the user performing the trials. The way out undertaken for conducting system trial without OEM is represented in Fig. 6. Following steps were required to be performed on-board for the trials,

1. Device Installation checks – Visual inspection
2. Cable loop checks – Insulation & continuity check
3. Power supply check – Polarity and Voltage check
4. Powering ON of the system
5. Software Installation
6. Safety check of the system
7. Interfacing with the third party system

Steps 1 to 4 could be easily be done with the help of system drawing by any person with basic knowledge of the equipment but having good technical knowledge of the system. Step 5, Software Installation is a critical step where OEM involvement is crucial. Any error during the installation would result in alarms blaring on the local control panel of the Engine and repairing them on-board without system expert present on-board would be a herculean task for the user. OEM, using the 3D model of the system available with them, would simulate the error scenario in the model and would then guide the user for eliminating the errors. Typical alarms which can blare during operation are shown in Fig 6.
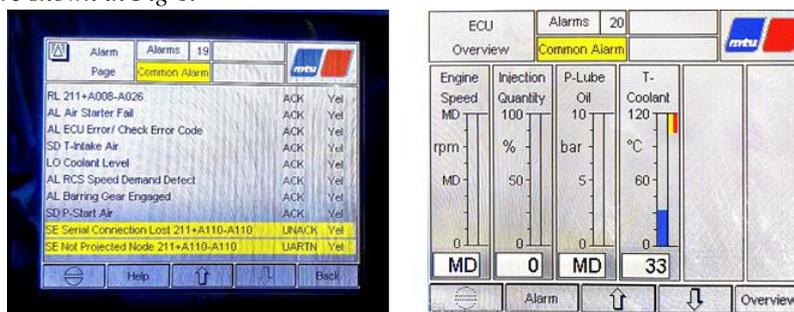

Figure 7 Typical Alarms during Engine Control System Trial

4.5. CASE - V

Compartment Inspection using Virtual Reality

Leveraging the available 3D tools helps in better appreciation of the space with associated outfit/ equipment and has a potential of drastically reducing onsite interventions, if any effort on the part of the overseer as well as time due to potential rework. Traditionally for a naval shipbuilding project, ship system/equipment drawings and 2D layouts arrangement are approved by Navy/Class. During block outfitting stage & prior commencing equipment installation, the location of items first gets marked at bulkheads/decks of the compartment for physical verification vis-a-vis approved drawings by naval overseeing teams. This critical but time consuming process is known as 'Line Out Inspection (LOI)'. With the advent of 3D modelling as the primary tool for detail design, the conventional LOI is now being replaced by review of the virtual model by GRSE & Navy for the 02 ongoing Naval projects. Whilst the 3D detail design model is being prepared by GRSE in AVEVA software, for ease of sharing/viewing the same is forwarded to Naval Overseeing teams & specialist agencies in virtual /DWF format, which can be viewed using a simple "data light" 'Navisworks Freedom Software'. This allow the user to do a 3D walk through of the compartment and make use of its measurement features. 3D model can be conveniently viewed from the existing desktops/workstations, and does not need high end workstations or high value licences. The model enables users to conceptualize and model the surfaces, decks and bulkheads. Naval teams review the model and record their observations. Based on these virtual approvals/comments, the production activities are being progressed in a well-planned & fast tracked manner.

Figure 8 Line Out Inspection being carried out at Virtual Reality lab

4.6. CASE - VI

Product Data Management and Life Cycle Management

Defence shipbuilding is a complex combination of various discipline & departments working together towards a common goal of smooth & efficient production process. To leverage the advantage of overall digitized shipbuilding process with every stakeholders on a single platform, Siemens PLM software for shipbuilding is being implemented at GRSE. This would enable digitalization of complete ship design from basic design to detail design with traceability for record of changes. As the platform would also be utilized on production floor, capturing all planning, production as well as inspection activities, enabling it to be one of the building blocks towards digital twin. PLM software would extend its usage for the ship's crew as the digital twin of the vessel would be accessible on-board.

4.7. CASE - VII

Inspection using Augmented Reality

As a novel project, GRSE has undertaken a project for digital transformation of on-board inspections using Augmented Reality. Traditionally, all the inspection activities are carried out by QA team using 2D drawings, even

though complete design process has now transitioned to 3D. This imposes various limitations during inspection and make the process tedious but also may inculcate errors during inspection due to complexity of drawing.

With the Shipyard 4.0 goals and leveraging its toolsets viz. Artificial Intelligence (AI) and Augmented Realty (AR), GRSE has initiated a project of end-to-end digital transformation of inspection process using handheld devices viz. mobile or tablets. The 3D model from AVEVA is converted for Virtual/ Augmented Reality and overlaid and aligned with the on-site conditions in 1:1 scale. This enable the user/ inspection to easily understand the design and perform visual inspection for identifying any deviation from design data.

Figure 9 Representation of Inspection using Mobile/ Tablet based Augmented Reality

5. Conclusion

This paper has presented the background of Industrial Revolution and the various building blocks of Shipyard 4.0 undertaken as novel projects at GRSE shipyard (Kolkata). As the market ready tools of promising technology grows, it becomes inevitable for the Shipbuilding Industry to transform its processes in line with the Fourth Industrial Revolution to achieve Shipyard 4.0 environment.

Shipyard 4.0 envisages a seamless collaboration of various shipbuilding process supported with various technologies viz. Automation, Virtual / Augmented Reality, Virtual Modelling, Internet of Things (IoT), Cybersecurity and others through vertical and horizontal integration of stakeholders with a focus on effective production with reduced build period, optimum quality and improved customer satisfaction. A digital shipyard affects the minutest of the day-to-day operations of design and production team, optimizing them in turn reducing costs and increasing overall safety.

While there is no doubt that the technological reforms, aligned with Industry 4.0 ideology, are being implemented in shipbuilding industry, now more than ever as the process improvement activities have become the focus for shipyards with various globally imposed restrictions and limitations due to pandemic scenario. GRSE has embarked on its journey towards Shipyard 4.0 environment with the novel projects highlighted in this paper. With complete digitalization of design process with 3D model along with its digital approval process, the inspection process which was earlier done physically using 2D drawings can now be transformed with usage of AR/VR techniques mixed with AI & ML thereby minimizing downtime and enable predictive maintenance capabilities. Digital capturing of shipbuilding process from design to production to inspections / test & trials are nothing but building blocks towards the concept of Digital Twin. However, the journey towards Shipyards 4.0 is still long, but it shows promise of an exciting one.

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