ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 5, Issue 1, January 2016

Development of Methodology for Managing Effects of Marine Corrosion using FE Approach

D.Rajasekhar, Ananthakrishna, P.S.Deepaksankar, D.Narendrakumar, K.Ramasundaram

Abstract: Maintenance and renovation of rotating ship component requires accurate knowledge in order to develop cost effective programs to extend their useful life. An innovative and successful technique used to manage effects of corrosion is discussed here. Crevice corrosion was observed on bearing area of propeller shaft of research ship Sagar Purvi due to the ingress of sea water through sea tubes/shaft seals, thereby making excessive pitting leading to reduced strength and durability with chances of cracking under rotation. This paves the way for replacement of propeller shafts once in every two years which is costly. Technical study established two alternate solutions viz., metal cladding on less corroded area and clad welding by MIG welding on largely affected area. FE analysis using ANSYS is used for design optimization and fatigue strength determination. Radiographic and DP tests on shaft and fatigue test on prototypes proved perfectness of welding. The shaft has been reused since two years and it is working well like the original one. Cost of rebuilding is about 10% of cost of new propeller shaft with same performance and it provided an innovate idea to manage corrosion and its adverse effects.

Index Terms— **crevice corrosion, corrosion fatigue, shaft welding, weld design, heat-treatment.**

I. INTRODUCTION

Sagar Purvi is a coastal research vessel (CRV) of National Institute of Ocean Technology an autonomous body under Ministry of Earth Science, Government of India, operated and maintained by Vessel Management Cell. The vessel is primarily used for various scientific programmes and provides a platform for many scientific activities. The vessel rendered services to various institutions as a national facility and carried out operations in different fields of research. Sagar Purvi is having overall length of 30.15m, breadth of 6.5m, draft of 1.8m and tonnage 187 GRT. The vessel's cruising speed is 6 knots with maximum speed of 8 knots. Figure-1 shows the CRV Sagar Purvi.

Fig.1. Sagar Purvi

A. Objective

- To study effects of corrosion on ship's propeller shafts.
- Develop an engineering solution to reuse pitted propeller shafts for saving considerable cost and time and to ensure efficient management of corrosion.
- To evaluate the quality of work.
  - Transient thermal analysis using ANSYS to prove the quality of weld.
  - Fatigue analysis using ANSYS to determine fatigue strength.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 5, Issue 1, January 2016

Erosion corrosion occurs as a result of combination of an aggressive chemical environment and high fluid-surface velocities. Protective scale on the metal surface wears as ship's propeller churns in the ocean. Pitting and crevice corrosion is due to the presence of warm salt water stagnant for long periods of time. Corrosion observed on stern tube, bearing or seal seating area and it cannot be detected until the shafts are removed.

II. CORROSION

A. *Corrosion Theory*

Water on the metal surface dissolves CO_2 and O_2 from the air.

$H_2O+CO_2 \rightarrow H_2CO_3$ --- (1)

$2H_2O \rightleftharpoons 2H^+ + 2OH^-$ --- (2)

$H_2CO_3 \rightleftharpoons 2H^+ + CO_3^-$ --- (3)

$Fe \rightarrow Fe^{2+} + 2e^-$ --- (4)

Electrons lost by Fe are taken by H^+

$H^+ + e^- \rightarrow H$ --- (5)

$4H + O_2 \rightarrow 2H_2O$ --- (6)

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ --- (7)

Dissolved O_2 can take electrons

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ --- (8)

$2Fe_{(s)} + O_{2(g)} + 4H^+_{(aq)} \rightarrow 2FeCO_3 + 8H^+$ --- (9)

Fe^{2+} reacts with dissolved O_2 and water

$4Fe^{2+} + O_2 + 4H_2O \rightarrow 2FeCO_3 + 8H^+$ --- (10)

$FeCO_3 + X4H_2O \rightarrow Fe_2O_3.XH_2O$ --- (11)

B. *Causes of Corrosion*

The factors that cause corrosion are

- Reactivity of metal
- Presence of impurities
- Presence of air, moisture, gases like SO_2 and CO_2
- Presence of electrolytes

C. *Hot Water Corrosion*

It is usually observed on Boiler systems; Turbines etc., where the parts are subjected to very high temperature. Dissolved oxygen and CO_2 are the common causes. The member will be under mechanical stress and fatigue cracking. In present scenario, a small amount of sea-water entered through shaft seal. During shaft rotation, temperature of water increases which is prone to hot water corrosion [1] and surface pitting.

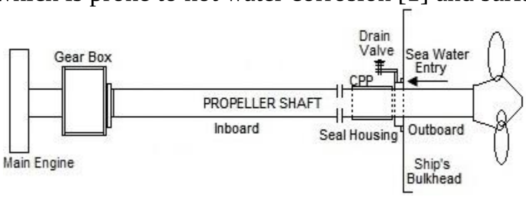


Fig.2. Schematic representation of propeller shaft assembly

Though there is a drain system in place to vent out stagnated hot water and in-spite of anti-corrosive measures taken; the shaft is vulnerable to corrosion because of stagnated water. Figure-2 shows the schematic representation of propeller shaft assembly.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 5, Issue 1, January 2016

III. METHODOLOGY ADOPTED

A. Engine Details

Two main engines with controllable pitch propulsion system are used for propulsion. Two auxiliary engines are used to drive generators. Main engines are having a displacement of 495inch^3, which transmit a power of 105kW at 1800RPM.

B. Material Specification

Propeller shaft is made with EN1.4418 material, which has high strength, toughness, good weld-ability and good resistance in slightly-moderately corrosive environments. These qualities make EN1.4418 to use for many applications such as shafting, propeller bolting, water turbine parts, and equipment for hydro power stations etc. The physical properties are density 7700kg/m^3, modulus of elasticity 215GPa, thermal conductivity 15W/m^{0}K, specific thermal capacity 430J/kg^{0}K and electrical resistivity 0.8Ωm.

Table-1. EN1.4418 compositions

Element	%		Element	%
C	0.03		Mn	1.5
Cr	16		Pb	0.035
Ni	5		S	0.015
Mo	1		N	0.02
Si	1		Fe	Balance

Table-2. Mechanical properties

Mechanical Property	Value
Tensile strength	950-1000N/mm^2
Proof strength	Min 750N/mm^2
Reduction in area	Min 40%
Elongation	Min 16%
Hardness	280-340HB

C. Problem Definition


Fig.3. Corrosion in propeller shaft


Fig.4. Deep pitting on bearing area

Crevice corrosion was observed on propeller shaft in bearing area due to ingress of sea water through failed or partially failed seals. Fine sand particles would have also entered inside the seal area during vessel's operations in shallow water region. These sand particles act like an abrasive, in turn during prolonged use will wear the shaft. The combined effects of corrosion and wear made the shaft to replace once in every two years. Figure-3 and 4 shows corrosion in propeller shaft.

D. Corrosion and Prevention Methods

Cathodic protection, Impressed Current Cathodic Protection and Lubricants Anti-corrosion Grease etc., are the measures to minimize marine corrosion [2, 3]. Even in ships fitted with ICCP or sacrificial anode, propeller shafts are vulnerable to corrosion. This is because propeller shafts are electrically insulated from hull by lubricating oil film in bearings and by the use of non-metallic bearing materials in tail shaft.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 5, Issue 1, January 2016

IV. SOLUTION TO MANAGE CORROSION EFFICIENTLY AT LOW COST

A. Design Criteria

Primary load carried by the drive shaft is torsion. Shaft must have enough torsional strength to carry torque without failure [4]. Corrosion on the shaft reduces strength by two reasons. Directly it reduces cross sectional area, which in-turn increases shear stress. Corrosion also creates uneven surface, which in-turn increases stress concentration factor, thereby reducing life span of shaft. Equation 8 illustrates the relationship between Torque-T, Polar moment of inertia-J, Shear stress-τ and Radius of shaft-R.

$$\frac{T}{J}=\frac{\tau}{R} \text{ --- (12)}$$

The relationship between Power-P, number of revolutions-N and Torque-T is given by;

$$P=\frac{2\pi NT}{60} \text{ Watts --- (13)}$$

The shaft has to transmit a power of 105kW at 600RPM; substituting these values in equation 12; the shear stress on shaft becomes,

$$\tau=\frac{T.R}{J}=\frac{60\times105\times1000\times35\times32}{2\pi\times600\times\pi\,(70^4-20^4)}=24.97\text{N/mm}^2 \text{ --- (14)}$$

B. Metal Cladding

Cladding is covering of one material with another, is often achieved by extruding two metals through a die as well as pressing or rolling sheets together under high pressure, which adds corrosion resistance to steel.
Procedure of metal cladding:

- Cleaning and degreasing using solvents.
- Apply a suitable release agent where cladding is not needed.
- Taking rough V groove in depth of 1/3 of thickness of pitting wherever worn out areas to be rebuilt.
- Apply metal clad on worn out surface with maximum thickness and leave for 24 hours curing time.
- Smooth machining till required uniform thickness is obtained.

The metal clad on shaft results in bond with following strength components; Compressive strength 92.7N/mm^2, Flexural strength 65.23N/mm^2 and Shear strength 24.72N/mm^2 etc. By comparing the strength of original shaft in table-2 and from equation no-3 it is clear that metal cladding is not a feasible solution.

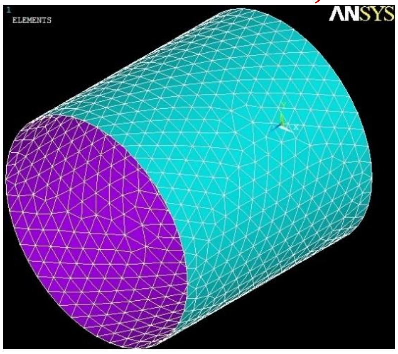
C. FEA Approach for Design Optimization

Quality of weld is decided by many parameters viz., Heat input, welding temperature, inter-pass temperature, pre-heating temperature, welding current, voltage, type of welding, type, size and composition of electrode, heat-treatment type so on. FE [5] approach is used for optimizing these parameters. Temperatures distribution at weld section were determined, which in-turn decides the parameters such as the composition, phase, thermal stress and strain and residual stress so on.

Strength of the shaft depends on thermal, electrical, mechanical and metallurgical parameters. Thermal, metallurgical and electrical parameters were optimized by transient thermal analysis. Residual stress [6] is one of the predominant factors that determine mechanical strength. Heat input (welding current and voltage), heat-treatment decides the residual stress retained in a shaft. An analysis on residual stress indicate the strength and there by the life of shaft. FE approach used for design optimization, virtual manufacturing, and testing saves cost, time and efforts. The stress gradient near fusion zone is usually higher as compared to other areas, which leads to cold cracks. By minimizing thermal stress through proper heat input results in minimal residual stress.

Shell element is taken for the present thermal analysis. Material properties viz., thermal conductivity, density, specific thermal capacity, pre-heating temperature so on has given as input. Heat input is varied by changing the travel speed of electrode and its effect on temperature distribution [7] in both fusion zone and heat affected zone are studied. Heat input is optimized to get peak mechanical properties, since the shaft is subjected to a fatigue load during its operation. Figure-5 shows finite element model of the shaft.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 5, Issue 1, January 2016



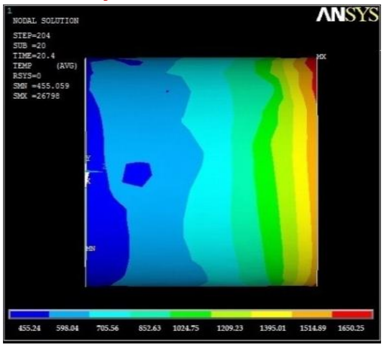


Fig.5. FEA model of shaft **Fig .6.Nodal temperature of FE model**

From present analysis, it is clear that the temperature at welding zone is 1650 ^{0}C. Melting point of Steel is 1538 ^{0}C. Welding temperature is above melting point and it prevents excessive evaporation of molten metal. Temperature distribution is shown in figure-6. It is clear from the analysis that proper fusion between parent metal and weld is achieved by utilizing optimum heat input.

D. Clad Welding by MIG Process

MIG welding [8] on corroded area is an alternate solution to metal cladding, since EN1.4418 has better weld-ability. Welding is done on corroded area post machining. A DC current with 225A and 25V is used with an electrode of Ø 1.2mm. The electrode composition is given in table-3, which offers good weld-ability and a safety against cracking. Equation 11 shows the relation between heat input-H [9], welding voltage-V, welding current-I and welding speed-S (mm/min). The efficiency (η) of MIG welding is usually 0.9.

$$\text{Heat input } H = \frac{V.I.60}{S.1000}.\eta \quad KJ/mm \text{ --- (15)}$$

A mixture of Argon (68%), Helium (30%) and Oxygen (2%) is used to protect the molten metal from atmospheric contamination. Addition of Oxygen provides good arc stability and Helium will increase the energy of arc, in-turn gives improved fluidity and wider weld. A gas flow rate of 14 litres/min is maintained for the current welding. An Inter-pass temperature of 140°C is maintained [10] to minimize cracking, to maintain good wetting of molten pool and to provide fine grain structure. Figure-7 and 8 shows prototype preparation stages.

E. Heat-treatment

Steel's mechanical properties are largely determined by its microstructure, which in-turn is determined by its chemical composition. Carbon is the key to obtaining a martensitic microstructure. With addition of certain other alloying elements, strength of martensitic stainless steels [11, 12] can be enhanced through precipitation of inter-metallic phases. In producing these precipitations hardening heat treatment must be carefully controlled. Post cleaning, the shaft is pre-heated to 110°C to prevent any possible shrinkage [13, 14].

Fig.9. Portable heat-treatment oven

Annealing at 590°C for 4 hours followed by air cooling, increases the toughness, stabilizes the structure and minimizes martensite. Grinding, brushing, polishing, blasting and pickling is done to remove defects, welding oxide, organic and carbon steel contamination from weld and parent metal surfaces. Figure-9 shows heat-treatment oven.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 5, Issue 1, January 2016

V. TESTING

A. Fatigue Test

Due to oscillating load caused by waves, fatigue is substantial importance for metals in ocean application. Fatigue [15, 16] is thought to begin at an internal or surface flaw where the stresses are concentrated and consists initially of shear flow along slip planes. Fatigue strength of welded joint is dependent on components shape, welding method and type of joint. Combined addition of chromium and nickel makes EN1.4418 capable of withstanding 10^8 cycles [18] with 350MPa stress in sea water and 10^8 cycles with 550MPa stress in air. Fatigue specimen is prepared according ASTM E-468 standard and is tested in RR Moore fatigue testing machine [19, 20]. Figure-10 shows test fatigue specimen.

B. Shaft Straightness Test

Shaft linearity is one of the important aspects to be considered. Propeller shaft is used to transmit torque between engine and propeller through gear box. In a bent propeller shaft, the axis of shaft is different from its axis of rotation, which causes vibration, in-turn results in a premature wearing of bearings and seals. Bent shaft also causes material fatigue, equipment vibration and shaft misalignment so on. It is important to do shaft straightness test before it is reused, since the various thermal loads viz., welding heat, pre-welding and post weld heat treatment may cause shaft bending.

Since heat straightening method may cause local hardening which results in hard spot and thermal cracking, mechanical straightening method is used for the present application. It relaxes stresses in the material fibers that initially caused shaft to bend. Shaft bend is typically measured in terms of total indicator reading. Straightness tolerance of shaft ranges between 0.013- 0.083mm/m of length of shaft.

Fig.10. Fatigue test specimen

Fig .11 Machining and shaft straightening

Shaft is held between two centers of lathe and marked at regular intervals. Using dial indicator, note down the total indicator reading. Shaft deflection is half the value of TIR. The highest deflection point is considered for shaft straightening. The shaft is fixed in a press and highest deflection point is placed directly under the ram. Slowly actuate the press and measure the dial indicator reading. This process is repeated until the desired shaft straightness is obtained. Figure-11 shows the arrangement for shaft machining and shaft straightening.

C. Dye Penetrant Test

Penetrant sprayed to properly clean welding surface. Standard dwell time is maintained to allow penetrant to fill the defect and excess penetrant is then removed. A white developer is then sprayed over welded area which draws penetrant from defects out onto the surface to form a visible indication, which indicate the location, orientation and possible types of defects on the welded surface. A visible light of 10 foot candles intensity was used after a one minute development time to allow the blotting action to occur. Figure-12 shows DP test arrangement.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 5, Issue 1, January 2016

Fig.12. DP testing of welded shaft

Fig.13. Shaft ready for reuse

D. Radiographic Test

To check presence of sub surface defects, a radiographic test was subsequently carried out. Welded specimen is placed between source of radiation and film, in a light tight holder, and radiation is allowed to penetrate the part for 6 minute. The result is a two-dimensional projection of the welded area onto the film, producing a latent image of varying densities according to the amount of radiation reaching each area. A developing time of 5 minute is used in the current testing.

E. Fatigue Analysis of Shaft Testing by FEA approach

Apart from above mentioned non-destructive tests, a FE analysis of shaft using Ansys [21] is carried-out to determine the fatigue strength. Tet 10node 187 solid element is used for the present analysis. Torsion load at shaft end and other boundary conditions are specified as per the present condition. Resulting shear stress and strain at different elements were analysed. Figure-14 shows a FE model of the shaft and figure-15 shows shear stress distribution.

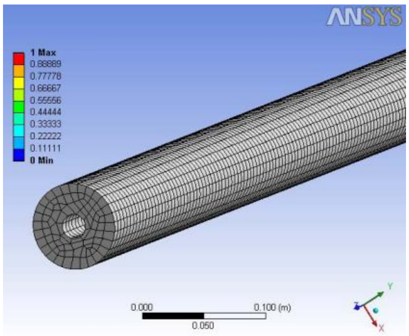


Fig.14. FE model of shaft

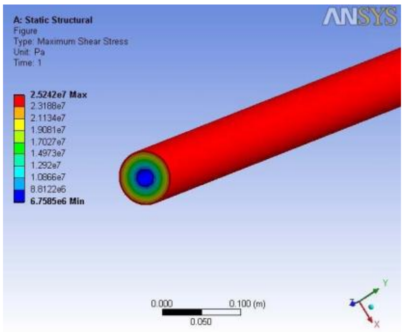


Fig.15. Shear stress distribution

VI. RESULTS AND DISCUSSION

Since shaft is a rotating member and it is not possible to do fatigue test on it, a prototype is prepared and tested to find its life. The prototype didn't break till 10^8 revolutions, which showed that perfectness of welding. DP showed that welding is very much acceptable and confirmed surface quality of welding. From Radiographic test, it has been proven that quality of welding is good. Sub surface defect are not found. Only fine defects were found which is well within the acceptable limit. The repaired shaft has been used over a period of two years and performance is satisfactory.

VII. CONCLUSION

Right approach to the problem really gives best solution; this is proved in our work too. Industry needs transformation of innovative ideas into successful experiment. Fatigue specimen was rotated for 10^8 revolutions and it didn't fail. Non-destructive tests on the shaft confirmed the quality of weld. The takeaways of this successful work are basically

- Task of managing effect of corrosion resulted in an innovative engineering solution to efficiently manage corrosion.
- FEA analysis saves cost, time and efforts, in-turn useful for design optimization.

- The work was completed in about 15 days and consumed 10% actual cost of propeller shaft, which saved huge cost and 6-8 months of lead time for import.
- The cost towards prolonged dry-dock (due to import) is also saved.
- Lateral thinking and application of prevalent tools to requisite situations is the norm. Similar work can be done in future too.
- The propeller shaft is reused in CRV Sagar Purvi and achieved original performance.
- This procedure has been approved by third party surveyor from classification society IRS.

ACKNOWLEDGMENT

The authors would like to acknowledge the contribution and support given by **Mrs. D. Bernardin Marina**, of **National Institute of Ocean Technology** for her valuable suggestion and recommendation that helped in enriching this paper.

REFERENCES

[1] T. Tzevelekoua, A. Flampouria, A. Rikosa, A. Vazdirvanidisa, G. Pantazopoulosa, D. Skarmoutsos, "Hot-water corrosion failure of a hard-drawn copper tube", Engineering Failure Analysis, vol. 33, pp. 176-183, October 2013.

[2] M.A. Malik, M.A. Hashim, F. Nabi, S.A. AL-Thabaiti, Z. Khan, "Anti-corrosion Ability of Surfactants: A Review", International Journal of Electrochemical Science, vol. 6, pp. 1927-1948, 2011.

[3] I. Lyuben, G. Wang, A.S. Kuan A.S., "Evaluating Corrosion Wastage and Structural Safety of Aging Ships", International Maritime Conference -PACIFIC 2004.

[4] M.A.K. Chowdhuri, R.A. Hossain, "Design Analysis of an Automotive Composite Drive Shaft", International Journal of Engineering and Technology, vol. 2(2), pp. 45-48, 2010.

[5] A. Capriccioli, P. Frosi, "Multipurpose ANSYS FE procedure for welding processes simulation", Fusion Engineering and Design, vol. 84(2-6), pp. 546-553, 2009.

[6] L. Yajiang, W. Juan, C. Maoai, S. Xiaoqin, "Finite element analysis of residual stress in the welded zone of a high strength steel", Bull. Mater. Sci., vol. 27(2), pp. 127-132, April 2004.

[7] V.T.B Kiran, M. Krishna, M. Praveen, P. Niranjan, "Numerical Simulation of Multilayer Hard facing on Low Carbon Steel", International Journal of Engineering and Technology, vol. 3, no. 1, pp. 53-63, February 2011.

[8] X.C. Li, D. Farson, R. Richardson, "Weld Penetration Control System Design and Testing", Journal of Manufacturing Systems, vol. 19, no. 6, pp.383-392, 2001.

[9] M.A. Gaodi, D.I. Sangotra, "Review Paper On Effect Of Varying Welding Heat Inputs On Microstructure, Mechanical Properties And Corrosion Behaviors Of Ferritic Stainless Steel & Mild Steel", International Journal of Modern Engineering Research, vol. 4, no. 1, pp. 105-109, 2014.

[10] S. Murugan, S.K. Rai, P.V. Kumar, T. Jayakumar, B. Raj, M.S.C. Bose, "Temperature distribution and residual stresses due to multipass welding in type 304 stainless steel and low carbon steel weld pads", International Journal of Pressure Vessels and Piping, vol. 78, pp. 307-317, 2001.

[11] T. Wang, L. Li, X. Li., X Yang, "The Numerical Simulation and Control of Microstructure in Heat-affected Zone in GMAW", Journal of Modern Applied Science, vol. 3, no. 5, pp.162-166, May 2009.

[12] A.M. Paradowska, J.W.H. Prince, R. Ibrahim, T.R. Finlayson, "The effect of heat input on residual stress distribution of steel welds measured by neutron diffraction", Journal of Achievements in Materials and Manufacturing Engineering, vol. 17, no 1-2, pp. 385-388, July-August 2006.

[13] J.U. Park, S.C. Park, C.H. Lee, "Control of Longitudinal Bending Distortion of Built-Up Beams by High-Frequency Induction Heating", Welding Journal, vol. 88, pp. 29-34, 2009.

[14] E.M. Qureshi, A.M. Malik, N.U. Dar, "Residual Stress Fields due to Varying TackWelds Orientation in Circumferentially Welded Thin-Walled Cylinders", Journal of Advances in Mechanical Engineering, pp. 1-9, 2009.

[15] G.V. Karpenko, G.N. Filimonov, R.G. Pogoretskii, M.M. Matseiko, V.G. Kryzhanovskii, Y.M. Sirak, "Corrosion-Fatigue Strength of Steels used for the Fabrication of Ship Propeller Shafts", Fiziko-Kimicheskaya Mekhanika Materialov, vol. 4, no. 6, pp. 627-633, 1968.

[16] S. Beretta, M. Carboni, G. Fiore, A.L. Conte, "Corrosion–fatigue of A1N railway axle steel exposed to rainwater", International Journal of Fatigue, vol. 32, pp. 952-961, 2010.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 5, Issue 1, January 2016
[17] S.K. Bhaumik, R. Rangaraju, M.A. Parameswara, M.A. Venkataswamy, T.A. Bhaskaran, R.V. Krishnan, “Fatigue failure of a hollow power transmission shaft”, Engineering Failure Analysis, vol. 9, pp.457-467, 2002.

[18] C.M. Bollenhagen, M. Zimmermann, H.J. Christ, “Very high cycle fatigue behaviour of austenitic stainless steel and the effect of strain-induced martensite”, International Journal of Fatigue, vol. 32, pp. 936-942, 2010.

[19] D. Rozumek, Z. Marciniak, C.T. Lachowicz, “The energy approach in the calculation of fatigue lives under non-proportional bending with torsion”, International Journal of Fatigue, vol. 32, pp. 1343-1350, 2010.

[20] M. Knez, S. Glodez, M. Ruzicka, J. Kramberger, “A rotating bending approach for determination of low-cycle fatigue parameters”, International Journal of Fatigue, vol. 32, pp. 1724-1730, 2010.

[21] Ravikant, G. Krishna, M. Didwania, “Modal analysis of drive shaft using FEA”, International Journal of Engineering and Management Research, vol. 3, no. 1, pp. 4-7, February 2013.

AUTHOR BIOGRAPHY

First Author: D.Rajasekhar, Scientist-F, Head-Vessel Management Cell, National Institute of Ocean Technology.

Education Details: B.E., Mechanical Engineering, M.S., M.I.E (Marine), F.I.E (Marine), Chartered Engineer.

Publications:

- A Finite Element Approach to Renew underwater shell plate of a dumb barge sans dry docking: an innovative and cost effective model, *Journal of Ships & Offshore Structure, Vol. 1, January-June 2008, Pages 35-40.*
- Fuel Cell Technology for Propulsion and Power Generation of Ships: Feasibility Study on Ocean Research Vessel Sagarnidhi, *Journal of Shipping and Ocean Engineering 5 (2015) 219-228.*
- Indian Research Ships: Features and Future, *Science Reporter, August-2014, pp 32-37.*
- Data Mining Modelling Techniques and Algorithm Approaches in Privacy Data, *National Conference on Data Mining on National Security* at SCSVMV University, Kanchipuram, Chennai, Sponsored by: DST, Delhi.
- Failure Analysis and Reliability Assessment of Ship’s Dynamic Positioning System, *International Conference on Recent Advances in Mechanical Engineering* at Dr. M.G.R Educational and Research Institute University, Chennai, 21-22 April 2011.
- Sagar Nidhi: Braving the Antarctica Waters, *Science Reporter, SR Vol.47(11) November-2010, pp 30-32*
- An Analysis on Various Ballast Water Treatment Techniques for ORV Sagar Nidhi, *Indian Journal of Geo-Marine Sciences*, Vol 43 (11) November 2014.
- A study of reliability and safety on dynamic positioning system of ORV Sagar Nidhi, *National Conference on Ocean Society of India*, at National Institute of Ocean Technology, Chennai 25-29 July, 2011.
- Rescue on the High Seas-ORV Sagar Manjusha the Saviour, *Science Reporter, November-2015, pp 34-37.*

Research Work and Achievements:

- Worked on concepts to improve the reliability of the Dynamic Positioning System on Sagar Nidhi and has won the **National Maritime Award from the Ministry of Shipping** for **Technological Innovation**.
- Received **National Maritime Search and Rescue Award** by the **Ministry of Defence** for saving a fishing vessel-**Kesavan** in distress condition (almost sunk) and saving the **lives of 12 fishermen** during the dark hours of 24 January 2014.
- Received appreciation from PMO for the successful recovery of sunken torpedo **Varunastra** using **Sagar Nidhi.**

Membership:

Qualified ISO 9000 lead auditor

Marine Surveyor / NDT Expert

Technical expert in Expert Committees of GSI/NCAOR/NIO/Indian Coastguard

Member - Ocean Society of India

Fellow of the Institution of Engineers (India)

Member of the Institution of Engineers (India)

Second Author: Ananthakrishna, Scientist, Vessel Management Cell, National Institute of Ocean Technology

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 5, Issue 1, January 2016

Education Details: B.E., M.Tech-Material Science and Technology- Mechanical Engineering.

Publications:

- Effect of Alternate Solution Treatment on Microstructure and Mechanical Properties of Modified Vibrated Cast Al-Si-Mg Alloys, *International Journal of Mechanical Engineering*, Vol. 1, January-June 2008, Pages 35-40.
- A Finite Element Approach to Renew underwater shell plate of a dumb barge sans dry docking: an innovative and cost effective model, *Journal of Ships & Offshore Structure, Vol. 1, January-June 2008, Pages 35-40.*
- Indian Research Ships: Features and Future, *Science Reporter, August-2014, pp 32-37.*
- Fuel Cell Technology for Propulsion and Power Generation of Ships: Feasibility Study on Ocean Research Vessel Sagarnidhi, *Journal of Shipping and Ocean Engineering 5 (2015) 219-228.*
- Influence of Silicon Content and Heat Treatment Parameters on Mechanical Properties of Modified Vibrated Cast Al-Si-Mg Alloys, *Indian Foundry Journal*, Vol. 54, October 2008, Pages 21-29.
- An Analysis on Various Ballast Water Treatment Techniques for ORV Sagar Nidhi, *Indian Journal of Geo-Marine Sciences*, Vol 43 (11) November 2014.
- A study of reliability and safety on dynamic positioning system of ORV Sagar Nidhi, *National Conference on Ocean Society of India,* at National Institute of Ocean Technology, Chennai 25-29 July, 2011.

Research Work and Achievements: Worked on concepts to improve the reliability of the Dynamic Positioning System on Sagar Nidhi and has won the **National Maritime Award from the Ministry of Shipping** for **Technological Innovation**.

Membership: NIL

Third Author: D.Narendrakumar, Scientist, Vessel Management Cell, National Institute of Ocean Technology

Education Details: B.E., Mechanical Engineering, M.Tech-Nanotechnology.

Publications:

- Indian Research Ships: Features and Future, *Science Reporter, August-2014, pp 32-37.*
- Fuel Cell Technology for Propulsion and Power Generation of Ships: Feasibility Study on Ocean Research Vessel Sagarnidhi, *Journal of Shipping and Ocean Engineering 5 (2015) 219-228.*
- A Finite Element Approach to Renew underwater shell plate of a dumb barge sans dry docking: an innovative and cost effective model, *Journal of Ships & Offshore Structure, Vol. 1, January-June 2008, Pages 35-40.*
- A study of reliability and safety on dynamic positioning system of ORV Sagar Nidhi, *National Conference on Ocean Society of India,* at National Institute of Ocean Technology, Chennai 25-29 July, 2011.
- An Analysis on Various Ballast Water Treatment Techniques for ORV Sagar Nidhi, *Indian Journal of Geo-Marine Sciences*, Vol 43 (11) November 2014.
- Failure Analysis and Reliability Assessment of Ship's Dynamic Positioning System, *International Conference on Recent Advances in Mechanical Engineering* at Dr. M.G.R Educational and Research Institute University, Chennai, 21-22 April 2011.

Research Work and Achievements: Worked on concepts to improve the reliability of the Dynamic Positioning System on Sagar Nidhi and has won the **National Maritime Award from the Ministry of Shipping** for **Technological Innovation**.

Membership: NIL

Forth Author: P.S.Deepaksankar, Scientist, Vessel Management Cell, National Institute of Ocean Technology

Education Details: B.E., Mechanical Engineering, Diploma in Marine Engineering, Class 4 MEO (motor).

Publications:

- Indian Research Ships: Features and Future, *Science Reporter, August-2014, pp 32-37.*
- Fuel Cell Technology for Propulsion and Power Generation of Ships: Feasibility Study on Ocean Research Vessel Sagarnidhi, *Journal of Shipping and Ocean Engineering 5 (2015) 219-228.*

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 5, Issue 1, January 2016

- An Analysis on Various Ballast Water Treatment Techniques for ORV Sagar Nidhi, *Indian Journal of Geo-Marine Sciences*, Vol 43 (11) November 2014.

Research Work and Achievements: Worked on concepts to improve the reliability of the Dynamic Positioning System on Sagar Nidhi.

Membership: NIL

Fifth Author: K.Ramasundaram, Scientist, Vessel Management Cell, National Institute of Ocean Technology

Education Details: M.E., Mechanical Engineering,

Publications:

- Indian Research Ships: Features and Future, *Science Reporter, August-2014, pp 32-37.*
- An Analysis on Various Ballast Water Treatment Techniques for ORV Sagar Nidhi, *Indian Journal of Geo-Marine Sciences*, Vol 43 (11) November 2014.

Research Work and Achievements: Worked on concepts to improve the stability of the vessel Sagar Manjusha. **Membership: NIL**

Authors Photographs:

				
D.Rajasekhar	Ananthakrishna	D.Narendrakumar	P.S.Deepaksankar	K.Ramasundaram