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The Development of Expert-System for Corrosion Protection of Ship Structures

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Abstract: *Corrosion of steel structures in the ships brings about various problems such as reduced life of the structure, loss of money, material etc and may cause accidents. It is important to adopt methods to eliminate, lessen the effects, or prevent corrosion of ship structures. Expert System for Corrosion Protection of Ship Structures is a user-friendly computer interface using suitable software. The Expert-System consists of three components: a knowledge base, inference engine and a working memory. It helps the user to find remedies for corrosion related issues of the steel structures in a ship. The user can input the defects seen and the Expert-System will return the possible cause and remedies for the problem found-as the output- from the knowledge base of the Expert-System.*

Keywords: *expert-system; knowledge base; corrosion; ship structures; protective coating*

I. Introduction

"At US$1.8 trillion, the annual cost of corrosion worldwide is over 3% of the world's GDP. Yet, governments and industries pay little attention to corrosion except in high-risk areas like aircraft and pipelines. " -George F Hays : Director World Corrosion Organization[9]. The proper material selection, protection and corrosion control can help to reduce this wastage due to corrosion. Wastage on corrosion includes wastage of materials, energy and money. It is so important to study the causes of corrosion and introduce methods to avoid it or reduce its effects. The effective use of protective systems and corrosion resistant materials can reduce or sometimes entirely eliminate corrosion problems. There are different sources of attack on structures, ships and other equipments which will result in corrosion of it in seawater. For the success of the corrosion prevention efforts, the proper monitoring of corrosion rate and wastage of vessel should be done. Regular scheduled inspections should be done giving good attention to most corrosion vulnerable areas of the ship. The inspections include visual inspection, measurement of shell plate thickness etc.

Steel is the most used metal in ship construction and it is so much corrodible. Due to long voyages in corrosion causing service conditions and long-interval maintenance, ship structures are very much affected by corrosion. Expert System for Corrosion Protection of Ship Structures is a user-friendly interface for implementing corrosion protection of ship structures using a computer software. During solving a corrosion related problem, there may be unavailability of an expert who has knowledge in that specific field to solve that problem. Here comes the importance of an Expert-System. An expert system is a high performance problem solving (software) computer program, capable of simulating human expertise in a narrow domain[13]. The Expert-System for Corrosion Protection of Ship Structures will help the user to get the proper advice as from the expert to solve the issues related to corrosion of steel structures in a ship.

II. The Expert-System

A typical expert system consists of three components: an inference engine, a knowledge base and a working memory. The key element to expert system performance is the embodied domain expert's knowledge and not any kind of formalisms or inference methods[13]. Knowledge in a specific domain consists of declarative descriptions, relationships and procedures. Declarative descriptions refer to a collection of facts, constrains, dependencies and laws about the domain. Procedural descriptions include a series of steps or actions to be performed, to achieve a specific goal. Expert system contains knowledge about their own structure and operations; thus they may also reason about their function eg., provide information on how and why they perform in a certain way[13]. Expert systems instead of following a deterministic sequence of actions; use a few general procedures to find the solution of a problem. Expert Systems use specific information about the domain which can guide through the state space and reduce the search time. This information is called heuristic information and these search methods are called heuristics[13]. Expert systems cannot solve simpler versions of the problem they are designed to solve; they lack common sense knowledge. Many of the problems addressed by Expert Systems may be formulated as search problems through a state space to find a suitable solution.

2. 1. Knowledge Base

Declarative descriptions of expert level information, necessary for problem solving, are stored in the knowledge base. At the data level, declarative factual knowledge is represented by tools like first order predicate logic, frames, semantic nets etc[13]. At the knowledge base level, inferential knowledge is represented by tools like logic programming (e.g. PROLOG) and production systems(OP5). The control knowledge defines the interference mechanisms which is responsible for interpretation of the other pieces of knowledge[13].

For the implementation of an Expert-System for Corrosion Protection of ship structures, the knowledge base includes the knowledge about the various types of corrosion which occurs in a ship. It also includes expert knowledge about the various coatings which are used for corrosion protection. The knowledge base includes the various rules and guidelines which a ship should comply with. There should be knowledge about the various inspections and maintenance procedures for corrosion prevention and protection. The current Expert-System specifically studies about the corrosion of steel structures in a ship.

2.1.1. Types Of Corrosion

Ship structures are always exposed to corrosive environment. The different corrosions include uniform corrosion, intergranular corrosion, galvanic corrosion, crevice corrosion, pitting corrosion, cavitation, erosion corrosion, stress corrosion cracking, stray current corrosion, fretting corrosion and biologically influenced corrosion etc.

2.1.1.a. Uniform Corrosion

In Uniform corrosion the corrosion will be uniform throughout the metal. It mostly occurs while metal is exposed to atmosphere. It shows uniform thinning without any localised attack[1]. The corrosion products will be spread on the entire metal surface. The initial corrosion product thus formed will prevent further corrosion by acting as a physical barrier between the metal surface and environment.[1]

22.1.1.b. Galvanic Corrosion

Galvanic corrosion occurs when two metals with different electrochemical potentials or with different tendencies to corrode are in metal to metal contact in a corrosive electrolyte. A cell in which the chemical change is the source of energy is called a galvanic cell. The driving force of corrosion is the potential difference between different materials[1]. Between the two different materials connected through an electrolyte, the less noble will become the anode and tend to corrode. In the galvanic series, the metal tends to corrode when connected to a metal which is more cathodic to it. The farther apart the metals or alloys are in the series, the more rapid will be the corrosion of the more anodic (baser) metal.[1].

21.1.c. Intergranular Corrosion

Intergranular corrosion occurs when corrosion occurs on the grain boundaries than the grain. The electrochemical potential difference between the grain body and grain boundary causes the formation of a galvanic cell. In stainless steels, the chromium depleted alloy sets up passive-active cells of applicable potential difference, the grains constituting large cathodic areas relative to small anodic areas at the grain boundaries[2]. Electrochemical action results in rapid attack along the grain boundaries and deep penetration of the corrosive medium into the interior of the metal[2].

2.1.1.d. Crevice Corrosion

It is a localised form of corrosion, caused by the deposition of dirt, mud, dust and deposits on a metallic surface or by the existence of voids, gaps and cavities between adjoining surfaces[1]. Crevice corrosion is also called cavernous corrosion or corrosion under deposit[3].Crevice corrosion occurs in cases where the crevice is sufficiently large to permit the entry of the corrosive solution, but narrow enough to form a stagnant state and hold a solution with the desired charachteristics. The crevices can be of the order of 50-200µm[3].

2.1.1.e. Pitting Corrosion

It is a form of localized corrosion of a metal surface where small areas corrode preferentially leading to the formation of cavities or pits , and the bulk of the surface remains un-attacked . Metals which form passive films, such as aluminium and steels are more susceptible to this form of corrosion[1].Sites which are more susceptible to pitting are grain boundaries[1].

2.1.1.f. Cavitation Damage

Cavitation occurs wherever the local pressure in a flow field falls below a certain critical value. Cavitation corrosion is a form of localized corrosion combined with mechanical damage that occurs in a rapidly moving liquid and takes the form of areas or patches of pitted or roughened surface[1]. Cavitation corrosion is a conjoint action of corrosion and cavitation. Cavitation damage is the degradation of a solid body by cavitation. There will be continuous loss of material by the impact of cavitation under the influence of erosion[1]. Cavitation occurs wherever irregular water flow takes place, particularly if high pressures and vacuum are involved in the flow systems[1]. It takes place when the velocity becomes so high that its static pressure is lower than the vapour pressure of liquid[1].

2.1.1.g. Erosion Corrosion

Generally all types of corrosive media can cause erosion corrosion[3]. In most cases erosion corrosion is due to the turbulence of the flow and this influences the chemical and mechanical stability of the surface films. The corrodent can be a bulk fluid, a droplet or a substance adsorbed or absorbed on another substance[3]. In impingement type erosion corrosion, the liquid is in turbulent flow, containing bubbles of air and suspended particles that can hit the metallic surface strongly and destroy its protective film. The wear takes the shape of a directional progress of the attack[3].

2.1.1.h. Stress Corrosion Cracking and Hydrogen Embrittlement

Stress corrosion is the failure of a metal resulting from the conjoint action of stress and chemical attack. It is the failure caused by initiation and propagation of a high aspect ratio crack[1]. Stress corrosion can be caused by stresses, either residual, thermal or applied or a combination of all[1]. Stresses introduced by thermal treatments are due to dilation and contraction of metal or indirectly by the modification of the microstructure of the material. Cracks can be initiated at surface discontinuities, corrosion pits, or grain boundaries. In corrosion fatigue and SCC, a surface pit constitutes a stress raiser, especially in the initiation process. Corrosion fatigue can help initiation of the fracture while SCC and/or hydrogen embrittlement could assist more or less intensively, the crack propagation. Hydrogen embrittlement is a phenomenon whereby hydrogen is absorbed which exert local stresses and leads to embrittlement of the material, such as high strength steels. It results in brittle fracture throughout the material. Here, instantaneous final fracture occurs and the failure will be mostly intergranular[1]. Stress corrosion crack growth rates are usually $10^{-11}$and 10^{-6} m/s. Here the failure occurs without any previous warning[3].

2.1.1.i. Fretting Corrosion

Fretting corrosion is a combined wear corrosion process in which material is removed from contacting surfaces when motion between the surfaces is restricted to very small amplitude oscillations. It occurs where low amplitude oscillatory motion in the tangential direction takes place between contacting surfaces, which are nominally at rest[3]. Fretting is a form of abrasive wear. It is characterized by discoloration, local surface dislocation and deep pits. The initiation of the fretting fatigue crack starts at the boundary of the fretting scar at the fretted zone[3].

2.1.1.j. Microbiologically Influenced Corrosion

Heavy fouling micro-organisms decreases the amount of dissolved oxygen at the interface and act as a barrier on structural steel in the splash zone and shields the metal from damaging effect of wave action[3]. In most cases the films are not continuous and an oxygen preferential cell is created. Microbial films are suspected of being capable of inducing pit initiation on stainless steels and copper alloys in marine environments. Microbial films will affect the general corrosion rate only when the film is continuous. A single bacterium can produce a mass of over one million microorganisms in less than seven hours. The bacteria as a group can survive from -10^{o}C to 100^{o}C , pH~0-10.5, dissolved oxygen(0 to saturation), pressure(vacuum to >31MPa) and salinity (parts per million to about 30%). A scatter of individual barnacles on a stainless steel surface creates oxygen concentration cells. Uncovered areas will have free access to oxygen and act as cathodes, while the covered zones act as anodes[3].

2.1.1.k. Stray Current Corrosion

Stray currents are uncontrolled currents which originates mostly from DC systems and cause corrosion at the point of leakage from the system i.e. site of exit of Fe++ ions[1]. The major stray current corrosion problems now results in cathodic protection systems. Stray current corrosion can show penetration along the grain boundaries or a selective attack of the ferrite within the matrix of grey cast iron [1]. Stray current flowing along a surface will not cause damage because of the high conductivity of the electric path compared with the electrolytic one. The damage occurs when the current re-enters the electrolyte and will be localized on the outer surface of the metal. Stray current causes accelerated corrosion when they leave the metal structure and enter the surrounding electrolyte. These can be hundreds of meters away or more[3].

2.1.2. Protective Coatings

Protective coatings act as barriers to prevent the corrosive medium reaching the metal to be protected. There are specific protective coatings for different spaces in a ship based on their properties. The proper application of the coatings will be a main factor which will decide if the coating system will complete the target useful time. Protective coating should have the specified Dry Film Thickness(DFT)[8]. The knowledge about the coating systems are very important in the development of the Expert-System for corrosion protection.

2.1.2.a. Corrosion Susceptible Areas

The corrosion susceptible areas include outer hull, ballast tanks, fuel tanks, fresh/ grey/ black water tanks, bilges, pipe works and cooling systems, holds and storage tanks, boiler and engine, rudder, propellers, bearings, flanges, valves, pumps, void spaces, seachests, stabilizers etc,.
Critical areas to be considered in single hull tankers are[15]:

- Main deck plating and internals.
- Bottom plating in way of bilge and internals.
- Upper part shell plating and internals.
- Middle part shell plating and internals.
- Lower part shell plating and internals.
- Upper part side skin plating and internals.
- Middle part side skin and internals.
- Lower part side skin and internals.
- Forward Transverse bulkhead upper part.
- Forward Transverse bulkhead middle part.
- Forward Transverse bulkhead lower part.
- Aft transverse bulkhead upper part.
- Aft transverse bulkhead middle part.
- Aft transverse bulkhead lower part.

2.1.2.b. Coating Defects

There are different types of coating defects. The common types of coating defects are, sags, runs, cissing, orange peel, cracking or mud cracking , holidays, over thickness, under thickness , overspray, grit inclusions and human error. Coating defects also include in-service coating failures. The common in-service coating failures are shop primer failure, through-film breakdown, blistering, edge breakdown, weld corrosion, calcareous deposit induced coating failure, poor surface preparation, reverse impact damage, mud cracking, stress related coating failures[12].

The fabrication processes after the primer is applied causes shop primer failure. Through film breakdown occurs at ullage spaces at the top of the ballast tanks. Blistering are either liquid filled or dry hemispherical bubbles at the paint or metal interface. The ionic contamination on the substrate prior to coating itself and migrating to the interface with the substrate causes blistering. Edge breakdown occurs at edge of stiffeners and around cut outs, due to surface tension effect of wet film, high coating velocity etc.Weld Corrosion at either side of the weld bead and HAZ is due to poor surface preparation after welding. Calcareous deposits induced coating failures orginates partially from the reaction of carbon dioxide with the hydoxyl ions (from sacrificial anodes) and partly as the result of semisoluble carbonates being deposited from the seawater. Mud cracking is a result of a very high build up of coatings, or due to excessive thinning. Stress related coating failures is initiated at heavily stressed areas within tanks. It is observed that the same failure occur at the same place repeatedly along the length of the structure.[12]

2.1.2.c. Coating Systems

There are three class of coating systems based on their respective target useful life. Systems I,II and III have their target useful life of 5years(±3 years), 10years(±3 years), 15years(±3 years) respectively. The classification societies have defined the three main coating conditions. Coating conditions with only minor spot rusting is classed as “good”. Condition with local breakdown at edges of stiffeners and weld connections and/or light rusting over 20% or more of areas under consideration, but less than as defined for poor condition is classed as “fair”. Condition with general breakdown of coating over 20% or more of areas or hard scale at 10% or more of areas under consideration is classed as “poor”[12].

Table.1 Grading of coating conditions[12].

Rating/Condition	Good	Fair	Poor
Spot rust Light Rust	Minor	<20%	-
Edges and Welds	-	Local Breakdown	-
Hard Scale	-	-	≥10%
General Breakdown	-	-	>20%

2.1.3. Coating Maintenance and Inspection

Assessment of coating breakdown should be done to help the grading of coating conditions of ballast tanks. Ballast tanks of all ships except of oil carriers, are required to be maintained at least 'fair'. There are assessment scales for scattered, localized and linear coating failures. The areas to be included in the assessment scale are those of actual corrosion, and not rust staining[12].

Table.2 The frequency of inspections for ballast tanks, other than double bottom tanks (ABS Steel Vessel Rules Section 7-3-2/1.1.19 and 1.1.10 and IACS Z10.2 and Z10.5).

Coating Condition	Ballast Tank Internal Inspection During Periodical Survey															
Good	S			I		S			I		S			I		S
Fair	S			I		S			I		S	A*	A*	I	A*	S
Poor**	S	A	A	I	A	S	A	A	I	A	S	A	A	I	A	S
Vessel age	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
S	Special Survey															
I	Intermediate survey															
A	Annual Survey															
A*	Annual survey on minimum 3 ballast tanks (one forward, one amidships, one aft within the cargo hold area other than double bottom tanks) and fore and aft peak															

** Double bottom tanks with hard coatings of vessels over 5 years of age found in POOR condition and with substantial corrosion are to be surveyed annually(ABS- SUR- 2007, 7-3-2/1.1.10(ii)).

2.1.4. Guidelines For Corrosion

IMO PSPC MSC.215(82) standard provides technical requirements for protective coatings in dedicated seawater ballast tanks of all types of ships of not less than 500 Gross tonnage and double-side skin spaces arranged in bulk carriers of 150 m in length and upwards for which the building contract is placed, the keels of which are delivered on or after the dates referred to in SOLAS Regulation II-1/3-2 as adopted by resolution MSC.216(82). There should be a Coating Technical File (CTF). It shall be reviewed by Administration. The No.34 IACS Procedural Requirement on Application of the IMO Performance Standards for Protective Coatings (PSPC), Resolution MSC. 215(82), under IACS Common Structural Rules for Bulk Carriers and Oil Tankers procedural requirement is to be read in conjunction with the IMO Performance Standards for Protective Coatings(PSPC), Resolution MSC. 215(82). Application of the referenced international standards is mandatory under this procedural requirement for maintenance and inspection of coatings[12].

2.2. Inference Engine

The inference engine solves a problem by interpreting the domain knowledge stored in the knowledge base. The interference engine also records the facts about the current problem in a special purpose workspace, called working memory. Inference engines generally utilize “backward chaining”. Backward chaining is a goal driven decision making process[13].

Inference engines in rule based systems can use different strategies to derive the goal (i.e. new fact), depending on the types of applications they are aimed at . The most common strategies are forward chaining and backward chaining. Forward chaining is essentially data driven. That is, the system starts with the initial set of elements in the working memory and keeps on firing rules until there are no rules which can be applied or the goal has been reached. Here, the system is moving forward from the state of the goal state. Backward chaining is a goal driven strategy. It involves decomposing a problem into sub-problems and solving each one of them. That is the goal is reduced further, and so on, until they are solvable directly[14].

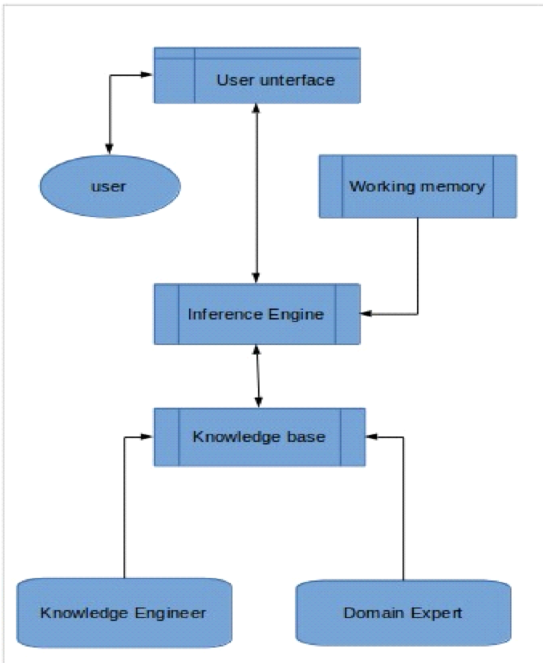

Fig 1. Architecture of an Ideal Expert-System[15]

2.3 Working Memory

Designing a good knowledge representation is the key to solving difficult problems. Most problem solving knowledge can be represented in the form of quanta called structures. Usually these structures are propositions, rules and frames. Any rule in an Expert System is a pattern invoked program. Such a program is not called by other programs in the ordinary way but is instead activated whenever certain conditions hold in the data. A rule will have a situation recognition part and an action part. A frame is a structure that ties together knowledge about a variable[14].

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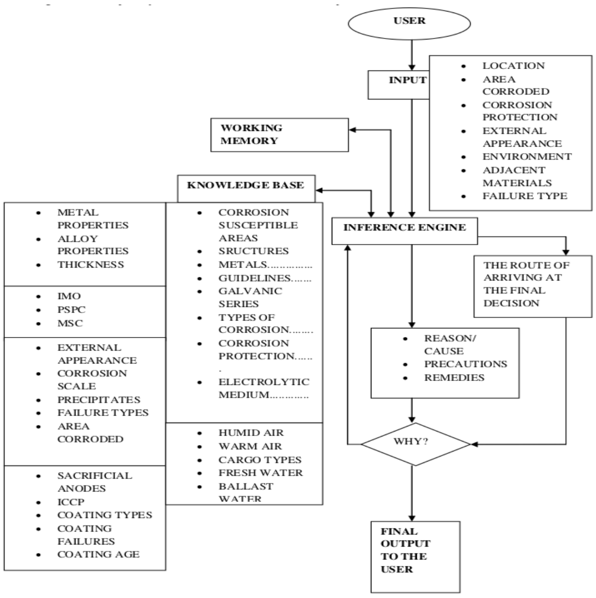
The fundamental use of a programming system is not to create sequences of instructions for accomplishing tasks but to express and manipulate descriptions of a computational process and the objects on which they are carried out. Since knowledge imparted to the system is largely empirical and because knowledge in the domains is developing rapidly, systems need to make changes easily and in an incremental or modular fashion[13]. Logic programming allows the manipulation of evaluated facts even in the absence of rules[14].

The knowledge base uses a database to store information. A database stores a collection of structured data shareable between different parts of the Expert-System. They are data independent i.e. databases are immune to changes in the storage structure and access strategy of data[15].The database should be a collection of data which has no unnecessarily duplicated or unused data(Howe,1983).

Fig 2. Expert-System for Corrosion Protection of Ship Structures



The inference engine make use of the working memory and the knowledge base of the expert system. The inference engine uses the 'object-attribute-value'(OAV) triples which are stored in the working memory to fire the IF-THEN rules. The inference engine uses the IF-THEN rules to make a decision from the data available in the knowledge base.

The IF-THEN rule works as shown below:

Let there be conditions 1,2,3,4,5 and 6 and conclusions U,V, W, X,Y and Z.
Let the rule be: IF condition 1 AND condition 2 AND condition 5 among the conditions 1,2,3,4,5,6 are true; then the conclusion/ decision should be conclusion Y.

IF CONDITION 1
AND CONDITION 2
AND CONDITION 5
THEN CONCLUSION Y

Thus all the knowledge about corrosion in the knowledge base will be structured in the form of rules from which suitable conclusions/decisions can be derived by the inference engine. Most expert systems include a facility by which the user can ask the expert system to explain why it recommends that particular decision[14]. Thus the Expert-System will display the conditions which came true that resulted in the final conclusion/decision. Thus the user can know the reason of the decision made.

III. Conclusion

Corrosion always causes various damages to the ship structures. In this context, it is vital to find and implement methods which will help to eliminate corrosion or to minimize its effects. There are situations when there is a non-availability of a Corrosion Expert to solve a related problem. Expert-System for Corrosion Protection of Ship Structures is a easy to use computer interface for the user to find the solution for corrosion related issues of ship structures. It consists of a knowledge base, interference engine and a working memory. The knowledge base includes the expert knowledge on types of corrosion, protective coatings, maintenance procedures of coatings and the guidelines regarding corrosion in ship structures. The implementation of Expert-System for Corrosion Protection of Ship Structures will help to reduce the problems due to corrosion in ship structures.

References

[1] A. Zaki, “Principles of Corrosion Engineering and Corrosion Control,” 2006.
[2] H.U. Herbert, R.R Winston, “Corrosion and Corrosion Control, Third Edition,”1907.
[3] V.S. Sastri, E. Ghali, M.Elboujdaini, “Corrosion Prevention and Protection,” 2007.
[4] SOLAS, “Consolidated Edition, Chapter II-1,” 2004.
[5] “Requirements Concerning Survey and Certification,” International Association of Classification Societies, 1990.
[6] “Corrosion Inspection and Maintenance of Oil Tankers, Herbert Engineering Corp,” 2012.
[7] “Condition Assessment Programme,” DNV,2000.
[8] “Corrosion Protection of Ships,” Recommended Practice, DNV, 2000.
[9] “The Feasibility of a Corrosion Resistant Ship”, BMT Defence Services Limited, 2009.
[10] “Ship Hull Coating Systems Simplified,” Hydrex Underwater Technology, 2011.
[11] “Guidelines for Corrosion Protection and Coating Systems,” Rules for Classification and construction, GL, 2010.
[12] “Guidance Notes on the Inspection, Maintenance and Application of Marine Coating System,” American Bureau of Shipping, Third Edition, 2007.
[13] T. Spyros(Editor), “Expert-Systems in Engineering Applications,” Springer-Verlag,1993.
[14] V.N. Constantin, “Expert-Systems and Fuzzy Systems,” 1985.
[15] P.B.DAVIES, “Expert Database Systems- A Gentle Introduction,” 1991