Predicting The Effectiveness of Corrosion Control Measures Using Computer Simulation

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Predicting The Effectiveness of Corrosion Control Measures Using Computer Simulation

- Company background
- How did it all start
- Introduction to computer modelling of corrosion
- Applications
  - Ships and Boats
  - Offshore Oil & Gas
  - Pipelines
  - Defence
- Conclusions
BEASY Head Office Ashurst Lodge
Computational Mechanics

- Group formed in 1978
- Headquarters -
  - Southampton England
  - Billerica Massachusetts USA
- Main Activities -
  - Software
  - Publishing
  - Training
  - Research & Development
Group Activities

Engineering Software Products and Services

Scientific and Technical Information

Research & Training

Southampton UK

Billerica MA USA
BEASY Worldwide

- Clients in over forty countries
- Head office in Southampton, UK
- North American office in Billerica, Massachusetts
- Software and services partners worldwide
BEASY

- Sales and Marketing of BEASY products
- Consultancy
- Support services
- Customisation services
- Training
- Software development and R & D
Users Worldwide Include

- Chevron (USA)
- Mobil (USA)
- Conoco (Norway)
- ONGC (India)
- PSL (India)
- Anteon (USA)
- Ultra (UK)
- EMS (USA)
- Northrop Grummen (USA)
- Petronas (Malaysia)
- Petronas Gas (Malaysia)
- DSTO (Australia)
- DSO (Singapore)
- Kockums (Sweden)
- I KL/HDW (Germany)
- DSTL (UK)
- Qinetic (UK)
- Frazer Nash (UK)
- Naval Research Lab (USA)
- NSWC (UK)
- Ford (USA)
- Rotterdam Public Works (Netherlands)
- KERI (Korea)
- KINS (Korea)
- KOGAS (Korea)
- Corrocean (Norway)
- EDRD (Canada)
- GESMA (France)
Corrosion Control Applications

Maritime CP System Design
Predict how effective proposed corrosion control strategies are at protecting the vessel and how they perform over its life:
- ICCP system design
- Identify damage
- Optimise CP system design
- Validate design

Signature Management
The comprehensive solution for engineers who need to predict electric and magnetic signatures:
- Predict electric and magnetic signatures
- Optimise signatures (UEP, CRM)
- Use on board data and/or signature to predict the condition of a vessel
- Simulate ICCP control systems
Corrosion Control Applications

Oil & Gas CP System Design
Predict the performance of proposed CP system designs over the life of the structure:

- Model performance of both sacrificial and active CP systems
- Optimise design of CP systems
- Identify critical areas
- Validate design of CP systems
- Reduce post commissioning costs
Corrosion and CP Design

- Simulation of Galvanic Corrosion
- Design of Cathodic Protection Systems
- Electric Field Prediction
- Prediction of Stray Current Corrosion
- Simulation of Electrodeposition and Similar Processes
- Electrochemical Simulation
- Signature Analysis
Role of BEASY

- Computational Mechanics BEASY has made major contributions to the development of computer modelling of corrosion and other electrochemical processes.
- At the start of the 1980s it was approached by IMI Marstons to help model the performance of the impressed anodes to be used on the Conoco TLP platform for the North Sea.
- This work very quickly expanded to a model of the whole cathodic protection system of the structure.
Hutton TLP Model

The tension leg platform takes its first stride
Role of BEASY

- This work resulted in the first paper describing the application of BEASY to corrosion engineering problems by Danson and Warne at the NACE Corrosion 82 conference.
- Conoco Norway initiated a project involving Computational Mechanics (CM) and CorrOcean of Norway.
- The aim of the project was to develop a comprehensive corrosion modelling system for oil and gas offshore structures.
CM developed the modelling software based on BEASY the resulting system was called Seacorr/CP

- The software was further extended to solve a range of applications including offshore structures, pipelines and critical applications in the defence area.
- The software was then called BEASY Corrosion and CP
Role of BEASY

- New techniques were developed to model stray corrosion problems as well as to predict the corrosion related electric fields.
- New technology has been developed to predict the corrosion related magnetic fields.
Computer Simulations Are Cheaper and Faster Than Testing Prototypes
BEASY can predict the effectiveness of corrosion control measures.

For defence applications it can also predict the corrosion related electric and magnetic fields.
Corrosion Prediction

- Which Areas are Affected?
- Where are the Critical Areas?
- How Much will it Corrode after a given Time?
- How Long will it take before it is Critically Corroded?
- What will be the Effects of Environmental Conditions?
- etc....
Corrosion Prevention

- Which method of protection will be most effective?
- Which method of protection will be most economic?
- If coated, which paint impedance?
- If CP, what kind of CP system to use?
- If sacrificial system, how many anodes are needed?
- What distribution of anodes is the best?
- Life expectancy of the anodes?
- Etc....
Over a small area, the current density reaches a positive value, indicating that this area is behaving anodically.
What Modelling Can Do

- Predicts the Behaviour of Structures subject to Galvanic Corrosion.
- Simulates the Effect of Environmental Conditions.
- Simulates the Effect of Calcareous Scale.
- Allows for Multi Layer and Multi Zone Environments.
- Analysis and Design of Protection Systems, i.e. Coating, Sacrificial and Impressed CP Systems.
Corrosion Control of Offshore Structure

Predicted how well the structure is protected

Detailed prediction for critical areas
Electric Potential on the Aft Portion of the Ship
Applications

- General Analysis of Galvanic Corrosion
- Offshore Engineering
- Design of Cathodic Protection systems for ships and boats
- Corrosion of storage tanks and pipelines
- Defence (Electric and Magnetic Field Signatures, etc)
- Corrosion of concrete structures
- Underground systems
Theoretical Foundations

Electrolyte Mathematical Model

\[ k \nabla^2 E = \rho \]

Where \( E \) = Electric Field
Galvanic System

The Structure is the External Conductor (i.e. The Return Path)

Electrolyte

Anode — Cathode

Ions

Seawater

Anode

Cathode

The Structure is the External Conductor (i.e. The Return Path)
Galvanic System

- Anode
- Cathode
- External Conductor
- Ions
- Electrolyte
- Steel Vessel
- NAB Propeller

Sea Water

- Fe^{2+}
- O_2
- OH^-
It is necessary to define:

- The Electrolyte
  - Sea
  - Sea Bed
- The Cathodic Surfaces
  - Metal surface of hull
- Anodes Surfaces
  - Anodes
  - Zincs
- The Polarisation data
  - Experimental curves
Computer Model

\[ k \nabla^2 E = p \]

- **Electrolyte**
  - \( k = \) Resistivity
  - \( E = \) Voltage
  - \( p = \) Source of current

- **Mathematical Model**
  - Boundary Element Method
Electrolyte

- The Electrolyte can be any Conducting Media e.g.
  - Sea Water
  - Concrete
  - Ground, mud or ice layers
- The model can contain any Number of Regions with different Resistance e.g.
  - Sea Water and the Layer of Mud at the Sea Bed
  - Layered ground
  - Earth and concrete structures
- Only The Resistivity and the Boundary of the Electrolyte has to be modelled
Anodic and Cathodic Polarisation data can be specified for materials.
Polarisation/Electrochemical Model

The software includes a general model of the polarisation properties of the materials which can represent how the polarisation properties vary with time and the build up of calcarius deposits on the metal surfaces.

Both anodic and cathodic polarisation response is incorporated in the model. A polarisation database is provided to manage the data and to enable new materials to be easily added.
Model of a Cargo Ship

- 140m in length, only the wetted surfaces are modelled
- ICCP has 4 anodes and 2 distributed power supplies
- 2 Nickel-Aluminium-Bronze alloy (NAB) propellers, which are modelled as solid disks with equivalent areas
- 2 steel rudders
BEM Modelling Of The Ship Body
BEM Model of the Cargo Ship

- Based on the results of ship yard investigations for similar class of ships, the rudder, propeller and shafts are assumed to be uncoated because of the turbulence engendered by propeller movement.

- Certain parts of the hull, especially in the aft zone, are modelled with damaged paint represented as bare surfaces and perfect painted steel hull as insulated surfaces.

- The ICCP system consists of 4 anodes and 2 distributed centre-controlled power supplies.

- Dynamic polarisation curves are used to model the operating environment.
Electric Potential on the Ship Hull
Horizontal Electric Current Density on the Hull Surface
The Model Enables Studies To Be Performed To

- Optimise anode numbers and locations
- Change anode positions to provide better protection for the ship
- Select anode numbers and group to form a optimum ICCP system
- Identify reference cell locations that provide the best representation of the overall potential profile
Potential Profiles Along Hull Surface at a Depth of 2 Meters From Water Line
Validation Example

- Two power zone system for the USS Princeton, CG-59
- The study compared full size ship data, physical scale modelling data and computational results.

Source
- A combined design methodology for impressed current cathodic protection systems
- V.G. DeGiorgi,” E.D. Thomas II, K.E. Lucas, A. Keec
  - Mechanics of Materials Branch, Code 6382, Naval Research Laboratory, Washington, DC 20375, USA
Schematic Diagram Of The Ship And The CP System

Note only half the ship was modelled due to symmetry.
BEM Model of The Hull Used In The Study
Comparison Of Results

The total current requirements for static minimum damage conditions are:

- Experimental Computational
  - Total Amps for full ship 33.6 35.7
  - Amps to propeller 26.3 27.7
  - Amps to docking blocks 7.3 8.0

The difference between experimental and computational results is

- 6% for total current value
- 5% for Amps to the propeller and
- 10% for Amps to the docking blocks.
Figure 1a - Static flow and minimum damage conditions. Measurements taken at a depth of 10 feet.
Comparison Of Potentials Along The Hull

Figure 1b - Static flow and maximum damage conditions. Measurements taken at a depth of 10 feet.
The Study Concluded

In summary, the advantages of computational modelling include:

- Ease of model manipulation for addition or movement of anodes
- Ability to examine potential maps of the entire structure to determine under and over protection regions based on a generic polarization response
- The ability to quickly evaluate changes in anode, reference cell or damage configurations.
Summary of Conclusions

- Physical scale modelling can be an expensive and extremely time consuming method to evaluate multiple ICCP system designs.
- Computational modelling on the other hand is well suited for the quick evaluation of multiple ICCP system designs once the hull geometry has been defined.
- Conversely the accuracy of computational modelling is dependent on accurate characterizations of polarization response.
The performance of both sacrificial and ICCP systems can be predicted.
Predicting Protection Potentials

Offshore Structures
Using the offshore structures tools, the complete BEASY model can be automatically generated including the sacrificial anodes. The joints are automatically corrected by the software to enable models to be created quickly.

Special tools have been developed to simplify the task of placing sacrificial anodes on tubular members of offshore structures and pipes.
Detailed Prediction Of A Critical Joint

It is possible to zoom in on critical areas to verify that adequate protection is achieved.
Time dependent Predictions

- Two types of analyses can be performed
  - A snapshot prediction of the state of the structure under a set of assumed conditions
  - A prediction of how the potential levels on the structure will vary with time
- In order to make a time dependent prediction information on how the polarisation response varies with exposure is required
The time dependent response can be obtained from test data.

- The curves represent the polarisation response for a material held at 215 MA/M² for various periods.
In this example, the analysis of a marine pipeline which is assumed to be made of mild steel of 0.8m diameter and protected by a system of sacrificial zinc anodes is investigated.
Predicted Protection Potentials
At Time = 0
Predicted Protection Potentials
At Time = 15 Days
Predicted Protection Potentials
At Time = 40 Days
Time Dependent Predictions

- Note the minimum potential in the model has increased from approximately:
  - -700mv at time = 0 to
  - -900mv at time = 40
- Showing the polarisation of the structure
- With this type of data long term (over many years) predictions on the performance of CP systems can be made
- Information can also be obtained on the anode consumption rates
In all the above studies the condition of the vessel has been assumed to be known. However this may not be known. The following presents a tool for predicting the condition of the vessel given:

- The anode currents
- The Reference Cell Potential
- Possibly the electric field at a sensor in the sea
Condition Prediction

- The objective is to predict damaged areas on the vessel based on the known potential values at the reference electrodes.
- In this case there are three damaged areas.
- To demonstrate the effectiveness of the software in identifying the damaged areas, the number of reference cells was increased and the results shown on the following slides.
Predicting The Condition Of A Frigate

Using the data from the reference cells we aim to predict the condition of the frigate

Damaged Areas
Using One Reference Cell

1st Reference Cell = -843.4 mV
Using Two Reference Cells

1st Reference Cell = -843.4 mV

2nd Reference Cell = -898.0 mV
Using Three Reference Cells

2nd Reference Cell = -898.0mV
3rd Reference Cell = -830.9mV
1st Reference Cell = -843.4mV
Using Four Reference Cells

2nd Reference Cell = -898.0 mV
3rd Reference Cell = -830.9 mV
1st Reference Cell = -843.4 mV
4th Reference Cell = -878.9 mV
Using Five Reference Cells

2nd Reference Cell = -898.0 mV
3rd Reference Cell = -830.9 mV
5th Reference Cell = -882.5 mV
1st Reference Cell = -843.4 mV
Predicting The Condition Of The Vessel

The condition of the vessel can be predicted given:

- Anode Current Data
- Reference Electrode Potentials
- Sensor measurements of potential or electric field
- Current direction information from the anode

The more data is known the more accurate the prediction.
Impact of a Dockside on the CP system

In this application the interference between a ship and the adjacent dock is modelled to provide quantitative data on the level of interference. If the sheet piling is closer to the anode than the section of the ship hull, the current has an alternative path that it may follow. It can travel through a much shorter sea water path to the piling, through the low resistance steel of the piling until it gets close to the ship hull. It then travels through another short sea water path between the piling and the hull to complete the circuit. Unfortunately, where the current leaves the piling to enter the sea water, the steel is unprotected and susceptible to damage by the anodic currents.

The model provides a cost effective way of investigating the best corrosion control strategy without the need for expensive surveys and monitoring.
Corrosion Modelling Solutions In Defence

- Prediction of Vessel Condition
- General Cathodic Protection Modeller
- Electric and Magnetic Signatures
- Optimise ICCP System Design
- Design Orientated Modelling System
- UEP Corrosion Related Electric Field
- CRM Corrosion Related Magnetic Field
- Polarisation Database
Predicting The Corrosion Related Electric And Magnetic Fields

Electro magnetic signatures play an important role in the detection of naval vessels and in the fusing of intelligent mines.
Predicting Corrosion Related Electric And Magnetic Fields
Electric Fields

UEP below ship
**Electric & Magnetic Signature Prediction**

### Dipole Simulation

**Target Signature [meters, microvolts/meter]**

![Diagram of dipole simulation](image)

**Input ID of the sample point, position of the sample point with respect to the coordinate system and target electric field to match. Do not forget to place comma after the ID and spaces or tabs between the rest of the data. Introduce a sensor per line.**

You can copy and paste data from another application or alternatively you can use the menu on the right-hand side of the panel below.

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**Number of target values:** 200

**Button Options:**
- About TkASV
- Add
- Close
Electric Signature

Electric field along the X coordinate

Target values
- X Electric Field
- Y Electric Field
- Z Electric Field

Computed results
- X Electric Field
- Y Electric Field
- Z Electric Field

Options:
- X Coordinate display
- Distance display

Graph showing electric field along the X coordinate.
Electric Field
Magnetic Field
Predicting The Transient Dynamic Behaviour of ICCP Systems

- BEASY CP Corrosion Software...
  - Simulates the electrochemical behaviour on the metallic surfaces and the resistance of the electrolyte.
  - This provides voltages and the current densities both into the metal surfaces and throughout the electrolyte.

- ICCPSim
  - Simulates the internal workings of the control system.

- Combined
  - They provide a solution which provides prediction of the real time dynamic response of the ICCP system.
Investigate Why The System Behaves The Way it Does

- You can use ICCPSim...
- to investigate *why* a system behaves the way it does
- to find the "optimal" characteristics and layout of a system

Why does voltage at reference cell 4 never achieve the set point?
How it works - the concept

- The "classic" BEASY CP solver determines the voltages and currents in the electrolyte (caused by current flowing from the anodes in response to some CV issued by the controller).
- The BEASY CP results provide the voltage at the reference cells, and these values of PV are passed to ICCPsim.
- ICCPsim uses the SP and PV and the controller model to determine the new CV which should be passed to the generator.
ICCPSim: Applications

- ICCPSim lets you simulate real-time effects such as:
  - Start-up effects
  - Dynamic changes of the Set point (SP)
  - Dynamic changes of controller properties

Controller 1 SP and PV

![Graph showing voltage changes over steps with indicators for Ki & Kd modified and Set Point modified.](image-url)
BEASY ICCP SIM: Examples

- Example 1. Switch on of the ICCP system.*
- Example 2. Failure of a controller.
- Example 3. Anode cannot achieve set point.
  - In this case anode 2 and 4 set to:
    - TRANSIENT RESPONSE DELAY 0.16
    - TRANSIENT RESPONSE PARAMETERS FOR INCREASE 1.02
- Example 4. Hunting the set point.*
  - In this case all anodes set to:
    - TRANSIENT RESPONSE DELAY 0.1
- Example 5. Pure gain type controller.*
  - Kp= 0, Kd= 0 and Ki= 8000
Conclusions

- Computer simulation is useful for
  - The design of new CP systems
  - The analysis of systems undergoing modifications or additions
- For example
  - Ease of model manipulation for addition or movement of anodes
  - Ability to examine potential maps of the entire structure to determine under and over protection regions
  - The ability to quickly evaluate changes in anode, reference cell or damage configurations.
Conclusions

- Computer modelling provides a powerful technique for obtaining the answers required by corrosion engineers.
  - Will the design achieve the desired results?
- In the design process, especially for high value projects and complex systems, prediction and simulation essential
- The influence of design parameters as well as environments can be simulated in computer models
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