Condition Assessment Scheme for Ship Hull Maintenance

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Abstract

The goals of the CAS Project (Condition Assessment of aging ships for real-time Structural maintenance decision), which is concluded in spring 2008, were to increase ship safety through improved hull condition monitoring. The first step, and also the particular focus of the project, was an increased efficiency and quality of the thickness measurement process. The main results from the project are a standard exchange format, called the Hull Condition Model (HCM), and a suite of prototype tools which use this HCM format. Commercial tools are being derived from CAS: although they use the same HCM format, they involve different implementation principles. Validation of the underlying concept has been achieved by a real demonstration, at the Lisnave shipyard, in Portugal. We are exploring ways towards HCM acceptance as a maritime standard. The use of a Robot in the thickness measurements process is considered. Risk Based Inspections "RBI" and associated predictive tools would be of a great added value for HCM based processes.

1. Introduction

Inspection and maintenance of a ship's hull structure are vital to ensure its integrity. Such inspections are performed by surveyors of classification societies, by crew or owner's superintendents, by vetting inspectors and by thickness measurement companies. Hull inspections typically cover: the state of coating, the assessment of possible structural defects and, most prominently, the remaining thickness of plates and profiles. For many years, there have been clear procedures for measuring and assessing thickness values (IACS URZ). Nevertheless, despite the large number of measurements which have to be taken during class renewal for aging tankers or bulk carriers (see IMO MEPC.94(46) and Resolution A.744(18)), measurement preparation, reporting and assessment are all typically performed manually, or with minimal IT support (e.g. Excel tables).

Although the lack of IT support for handling thickness measurements seems obvious, no previous successful attempt for an integrated electronic support for this process is known to the authors. A prerequisite for the electronic exchange and interpretation of thickness measurement data is a data model covering all required elements of hull structural inspections. Such a model would then also form the basis for the development of tools for preparation, recording, reporting and assessment of thickness measurements. The EU project CAS focussed on comprehensive IT support for hull inspection and maintenance in general – and the thickness measurement process in particular. In the project, major stake holders of the thickness measurement process cooperated to devise an enhanced process, design a data model for the exchange of measurement data and implement prototype tools to examine possible benefits of the new procedure.

2. Business context

2.1 Virtual company

The CAS project was defined in the light of the "virtual company" concept, where several independent companies act together as a single company, sharing the same information and using standard exchange formats. It was also inspired from the industrial ISO STEP exchange standards. In this particular project, all along the condition assessment process, involved companies (Owner, Thickness measurement Company, Classification society, etc) behave indeed as a single "virtual company".

2.2 Client driven developments

2.2.1 Software differentiation

The CAS project is now very close to its official end, so we have the resulting basic tools, which fit the specifications of the project. However those basic tools are already being transformed into commercial applications which are quite different because they cater with the needs of different types of clients.

2.2.2 Ship-owners

For ship operators, it is of the utmost importance to reduce off-hire periods and to keep repair cost under control. In that respect, a clear view of the current status of the hull structure is required so that areas in need of further investigation could immediately be identified. Furthermore, decisions on necessary repairs must be taken without delay and be communicated unambiguously to repair yards. The electronic thickness measurement support devised in CAS largely supports these requirements, through reduction of manual copying of data, clear visual display of measurement results directly on a 3D model of the ship and fast generation of final reports.

2.2.3 Oil companies

Floating Production Storage Offloading units (FPSOs) operators are showing interest for HCM type tools, as a means for the follow-up of their units. They especially do not want to miss any future degradation, which could potentially lead to the interruption of oil production. Prevention of production interruption, through timely repairs, is their main objective. Therefore, the history of all inspections on the FPSO (by the classification society and the owner's people) should be recorded and updated in the tool, enabling at any time the drafting of an exhaustive specification of the due repairs. Predictive tools, extrapolating from the past inspections, would also help anticipate the need for repairs.

2.2.4 Charterers

Charterers would like to protect themselves against bad surprises regarding the structural condition of the vessels they charter, which could lead to environmental disasters and long litigation procedures. Thus, as a condition for chartering a vessel, they may require an HCM file, providing a transparent view of the structure condition.

3. Goals and State of the Art

3.1 Goals

The specific goals of the CAS Project were to increase ship safety, by providing a permanent easy and transparent access to all ships structural data. This was a means of protecting the coasts of Europe from oil spoilage disasters, as well as protecting crews of bulk carriers from sudden sinking. The CAS project was a three-years EC funded project, gathering partners involved in all aspects of the condition assessment process.

A standard exchange format, called Hull Condition Model "HCM", was to be developed in order to support the full condition assessment process. A standard exchange format is especially needed in this process, because Thickness measurement companies work with all Classification societies, and ships sometimes change their Classification societies.
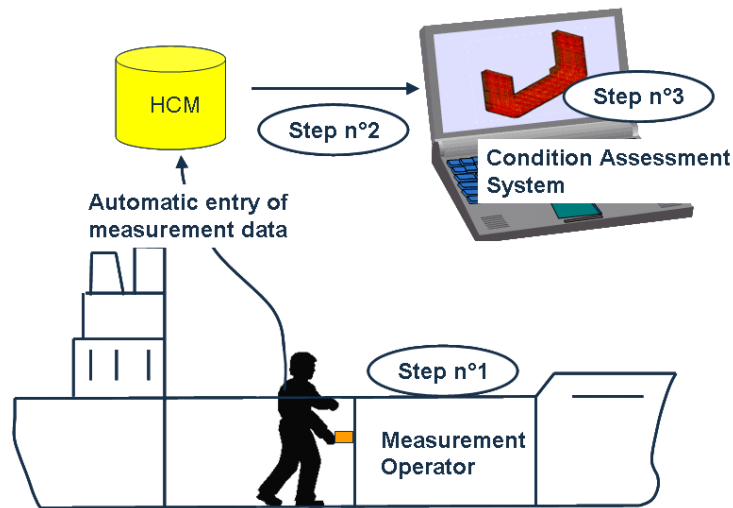
Fig.1: Condition assessment workflow

A by-product was the increase of the process efficiency, because measurement reports are made available at any time during the measurement campaign, and in particular they can be delivered after 2 or 3 weeks only, which means before the ship leaves dry-dock, easing the undertaking of repairs resulting from those measurements. Coherence of measurements between successive measurements campaigns can be ensured, because the measurements are in a structured electronic format.

3.2 State of the art

The main results from the project are: the standard Hull Condition Model (HCM), a suite of prototype tools using the HCM format and supporting the condition assessment process in all its phases, including data interfaces to and from classification software. The following phases of the process are particularly supported:

- Creation of the ship's 3D-model,
- Entry of the measurements into the model, either by a robot or human operators,
- Assessment of the structural condition.

HCM was written in XML language and is made publicly available on the project web file: http://www.shiphullmonitoring.eu

Validation of the tools, concepts and methodologies developed in the project has been successfully achieved by a real demonstration in the Lisnave shipyard in Setúbal / Portugal. This demonstration has been documented by a video film that is shown at the end of this presentation. The ship chosen for thickness measurements tests was an oil tanker, 150 000 DWT, L = 274 m, 5 years old.

A portion of the ship's outside shell was measured by a robot. The inside of some water ballast tanks and cargo tanks was measured through rope access. Both groups of measurements were recorded together into the HCM model, and analysed through visualisation and condition assessment tools.

After the end of the CAS research project, a Consortium is expected to take care of the updating of the HCM standard. The Consortium will initially consist of all partners of the project, but will be open to additional candidates. Therefore this paper is entitled to consider the potential developments and applications expected in the next years.

4. IT Tools

4.1 Developing around the HCM standard

Commercial tools are being derived from the CAS project. Although they use the same HCM format, they involve different implementation principles and have been used for different types of marine clients.

4.2 IST tool

4.2.1 Hull Modeling Software Tools

In the scope of CAS, prototype software tools were implemented by Instituto Superior Técnico (IST) to produce in a short period of time a product data model in accordance to the HCM standard.

The main concept of CAS, of a paperless data collection for a faster and more efficient processing, requires the existence of a 3D product data model, to assist planning of the measurement campaigns, to visualize the data collected and to provide support to its subsequent analysis. For the intended use, a set of requirements were specified. From the geometric point of view, the model does not need to have high accuracy because a simplified geometric description, based on linear approximations of both curves and surfaces was adopted on the HCM. From the structural point of view, all the plates and stiffeners to be inspected during a campaign must be present and identifiable on the model.

In future business scenarios, 3D models of the ship hull may be available during the operational life of the ship, as a result from the engineering analysis carried out during the design process. However, currently and in the near future, a large majority of existing ships will not have such models.

One of the issues of creating the hull models for existing ships is the eventual lack of information. Whenever the only data available are the drawings available onboard the ship, the model must be developed from a reduced set of data and also in a short period of time, due to the time constrains on the repair yards. So, for the required purpose it was assumed that the simplified model should be able to be developed from the information on the drawings commonly existing on board the ship, such as the general arrangement, body plan, docking plan, midship section, shell expansion, transverse and longitudinal bulkhead.

Sometimes, in an existing ship, neither the body plan nor an offset table is available. In this case, a rough hull shape must be defined using the existing data. For instance, some aspects of the hull shape can be obtained from the available drawings, such as some cross-sections from the docking plan, the stern and bow contours from the general arrangement, the bilge radius, the rise-of-floor, and deck camber from the midship section drawing.

For the purpose of creating a ship 3D product data model, compatible with the HCM, two new prototype software tools were developed and implemented in CAS, one for the generation of a simplified hull form and the other for the modeling of the ship hull structures.

4.2.2 Parametric Definition of the Hull Shape

An approximated hull shape can be generated from the main dimensions, some form coefficients, and a set of main curves, each defined by a set of shape parameters. The parameters consist of a set of distances and angles that can easily be obtained from the general arrangement and structures drawings. The main curves used are the flat of bottom, the flat of side, the midship section, the stem and stern contours, Fig.2. The sectional area curve is also obtained parametrically and used to generate additional cross sections in the aft and fore bodies, in compliance with the required displacement and form coefficients.

From these curves a set of surfaces is generated. The intersection of those surfaces with transverse planes produces the set of cross sections needed to define the hull in a way similar to the traditional body plan.

The purpose of this tool is not to generate a fair hull form but only to provide an acceptable external boundary for the development of the structure generation tasks. In this context, by acceptable it is meant that the strakes of plates and the stiffeners existing on the ship can be entirely mapped into the 3D model.
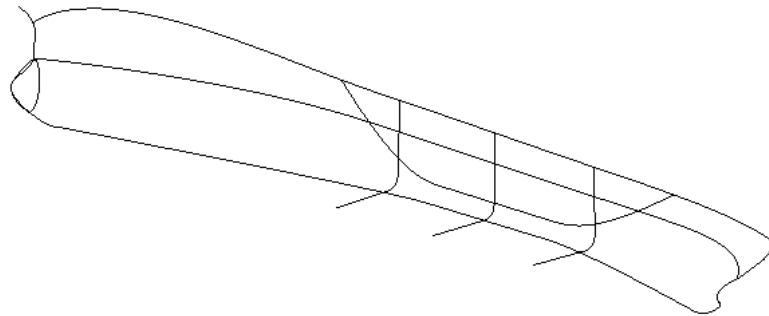
Fig.2: Main hull curves

The application has a modular structure composed by two main modules, a NURBS kernel and a set of naval architecture functionalities.

The NURBS kernel provides the basic functionalities for parametric curve and surface modeling, such as curve fitting and approximation, surface generation, curve/curve intersection, curve/plane intersection, surface/plane intersection and surface/surface intersection.

The naval architecture module provides the specific functionalities for the parametric generation of curves, alteration of the section area curve, computation of areas.

4.2.3 Hull Structures Product Data Modeller

The modeller system developed is not just a geometric modeller but a product data modeller. The system must be able to manage not only the geometry but also the data specified in the HCM model, which contains information such as as-built plate thicknesses and stiffener scantlings, the associated structural systems and compartments, as well as the acceptable diminutions in accordance to the structural safety criteria adopted by the classification society.

The arrangement of the internal structures is kept separate from the hull form to allow a larger flexibility during the modeling activity: slightly different hull shapes can use the same internal structural arrangement or different internal arrangements can be evaluated for the same hull form.

For modeling purposes, the hull structure is considered divided into two main groups, the external hull and the internal structural systems. The external hull can be composed of one or more shells and may have planar or curved regions that depend directly of the hull shape and the main deck. The internal structures are planar, and their boundaries can be partially obtained from the outer hull and main deck shapes.

The structural systems considered are the bulkheads, the decks, the web frames, the bulkheads and the girders. For each of these systems, generating templates can be defined. These templates have two main parts, corresponding to the two stages of the modeling process: first the shape of the base molded surfaces is obtained and next, the geometric description of plates and stiffeners is determined.

The first part defines the geometry identifying the external boundaries, a set of shape parameters and some form features specifications, such as openings, if any. The second part defines the associated stiffened panels. Each generating template defines a family of structural system members, with similar shape and scantlings. The scantlings are defined by one or more plate sets and stiffener sets, which describe sequences of adjacent groups of plates/stiffeners, identifying the quantities, dimensions, spacings, scantlings and materials. These generic definitions are designated by templates because they do define explicitly neither the shape nor the exact arrangement of the associated plates and stiffeners. Wherever the boundaries or the scantlings of the system change, a new template must be defined.
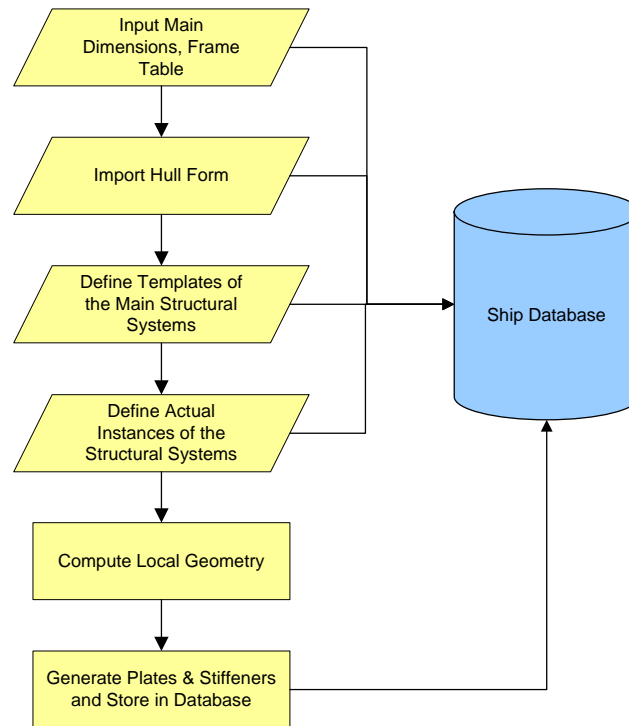
Fig.3: Structures Modeling Sequence

To obtain the actual system members, the templates must be instantiated to a precise location on the hull. Then, the plane or planes associated to the system are first trimmed by the outer hull (shell and main deck) and next by all the boundaries enumerated. The result of this process is the actual external shape of the member, defined by a closed polygonal line. Then, from the application of the specified plate sets to the member shape, a set of seam lines is obtained, defining the contours of the plates. From the application of the stiffeners sets, a set of trace lines is obtained. The typical modeling sequence is presented in Fig.3.

The system has a modular structure and is composed by seven main component layers.

The simplified geometry kernel provides the functionalities to process polygonal lines and surfaces, including some elementary modeling and intersection operations.

The structural modeling functions provide the capability to process the input shape parameters to generate the 3D representations of the mentioned structural systems. The ship data storage is a relational database, implementing standard SQL language. The scripting engine is based on the Python language and a number of extensions were developed to allow the generation, storage and retrieval of data from the database. The XML processor provides capabilities to import and export data from measurement campaigns in accordance to the HCM data model. The graphical interface provides the 3D visualization of all the entities generated by the modeller.

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In compliance with the simplified geometry adopted, plates and stiffeners are represented only as surface meshes without thickness, Fig.4, Fig.5, although the product data stored in the database can provide the information for a solid model representation.
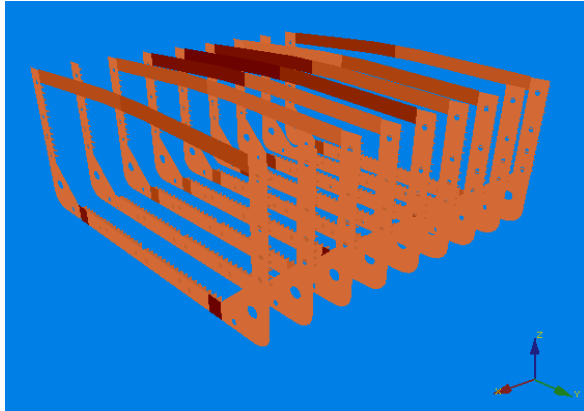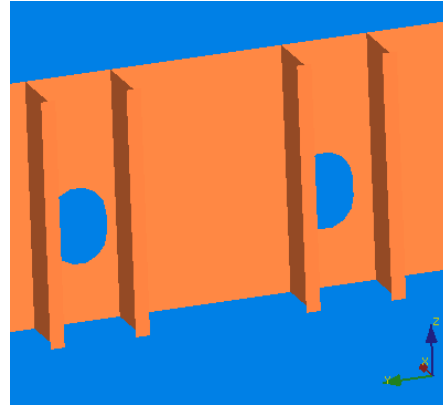

Fig.4: Web frames   Fig.5: Simplified plate and stiffeners

The shell can also be displayed in a 2D expanded view. The user interface is based on dialog-boxes for data input and editing.

4.2.4 Validation and Testing

To validate the methodology implemented, one cargo hold of an existing Suezmax oil tanker was modelled, based on a set of structural drawings. The system was able to produce a model on which, in spite of some irregularities on the distribution of the plates on the shell, all the plates and stiffeners were correctly mapped, Fig.6. An XML data file was exported in accordance to the HCM. The information was used by the surveyors to associate the measurements obtained during the campaign carried out on the ship, in a shipyard dock.
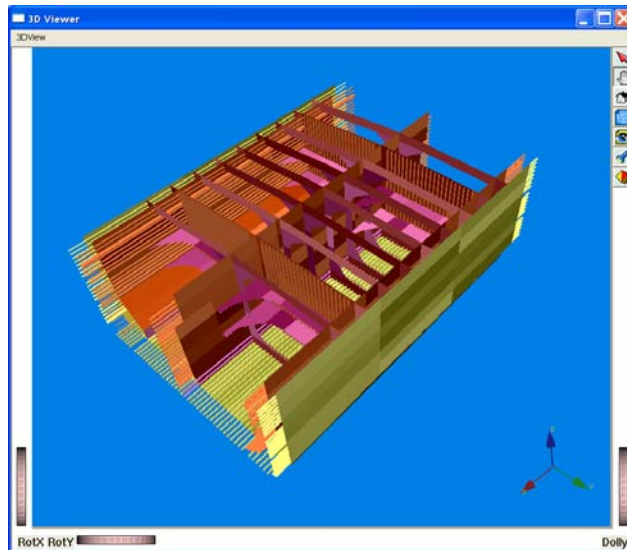

Fig.6: Suezmax cargo tank

Finally the file with the campaign measurements was imported back into the system. The points were correctly assigned to the shell plates and able to be compared to the as-built thickness values.

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4.3 GL-Pegasus

4.3.1 Principles

The concept of the CAS Project aimed at the development of methodologies, data formats and software prototypes to validate the developed ideas/solutions around Hull Condition Monitoring and Assessment. Due to the urgent necessity for adequate computer tools for data collection, visualisation and assessment of Thickness Measurements (TM) to be used operatively, for Germanischer Lloyd the exploitation of the results of the CAS project have been reflected in the development of a commercial tool – GL Pegasus – to support the whole TM Process. Within this context, GL Pegasus has been developed in parallel to the CAS project, providing additional input for the refinement of user requirements and for the development of the data model itself.

GL Pegasus utilises HCM as its main data format. According to the new defined TM workflow, Fig.7, the initial HCM file is created in POSEIDON, GL's software system for ship structural design and scantling calculations. For this purpose and as part of the activities of the CAS project, the corresponding data interfaces from POSEIDON to HCM have been developed. However, as HCM has been developed as a neutral data format and with interoperability in mind, it should be possible to utilise any HCM file created with other Ship Structural CAD systems in a similar way. This has been demonstrated within the CAS Project by using GL Pegasus with 3D Models that have been generated from the FORAN system of SENER and from the CAS-Tool prototype of IST (see section 3.2).
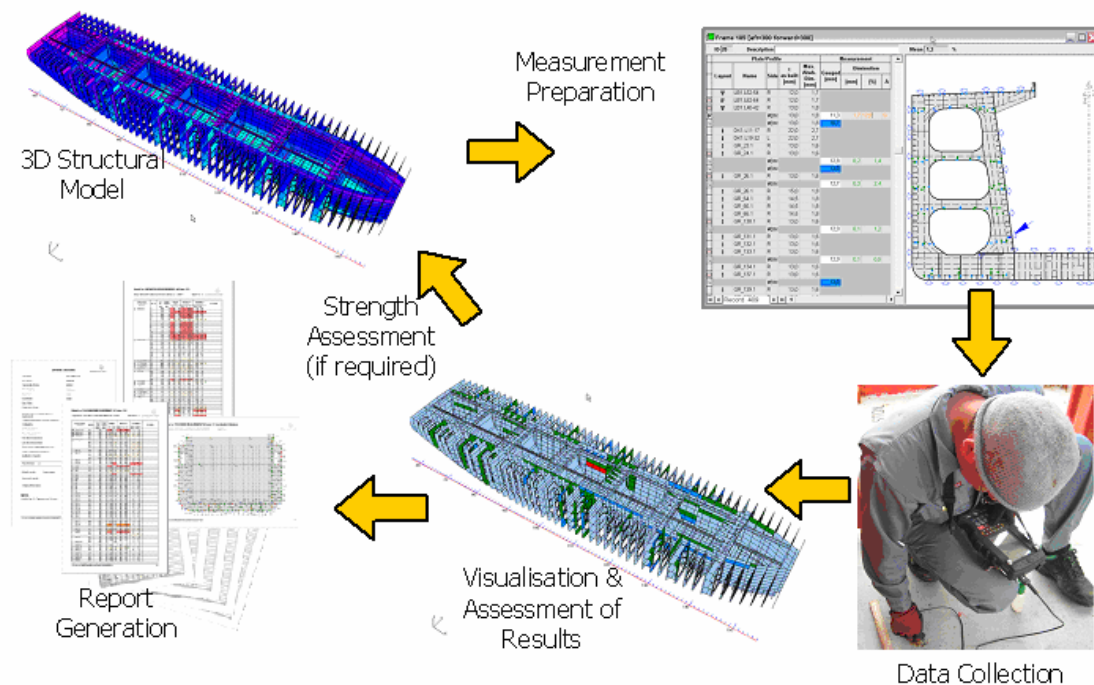

Fig.7: TM Workflow with GL Pegasus

Once the initial HCM file is generated from POSEIDON, it is loaded into GL Pegasus and used for the different phases of the TM process:
- Campaign preparation
- Data collection
- Visualisation and Assessment
- Reporting
- Structural assessment

4.3.2 Campaign Preparation

Based on the requirement to display the 3D model in the traditional 2D representation for TM purposes, *Jaramillo et al.* (2006), GL Pegasus generates corresponding views (TM configurations) as typically shown in the sketches of the structural areas. Basically two different types of TM configurations are used for this purpose, which correspond to the IACS recommended procedures for reporting of Thickness Measurements:

a) **Strake oriented**: In this case the plate strakes of a single structural element are arranged in tabular form together with a corresponding sketch (e.g. a deck or shell expansion view)

b) **Cross section oriented**: for so called *ring measurements,* transverse sections of longitudinal structural parts at specific frame positions are considered. However, this type of view is also applicable for transverse structural parts at the corresponding frame position.

A TM configuration displays a tabular and a graphical view of the relevant structural parts. Both views are interconnected to each other as they show a different representation of the same data as contained in the HCM file. Fig.8 and Fig.11 show a cross section oriented and a strake oriented TM configuration, respectively.
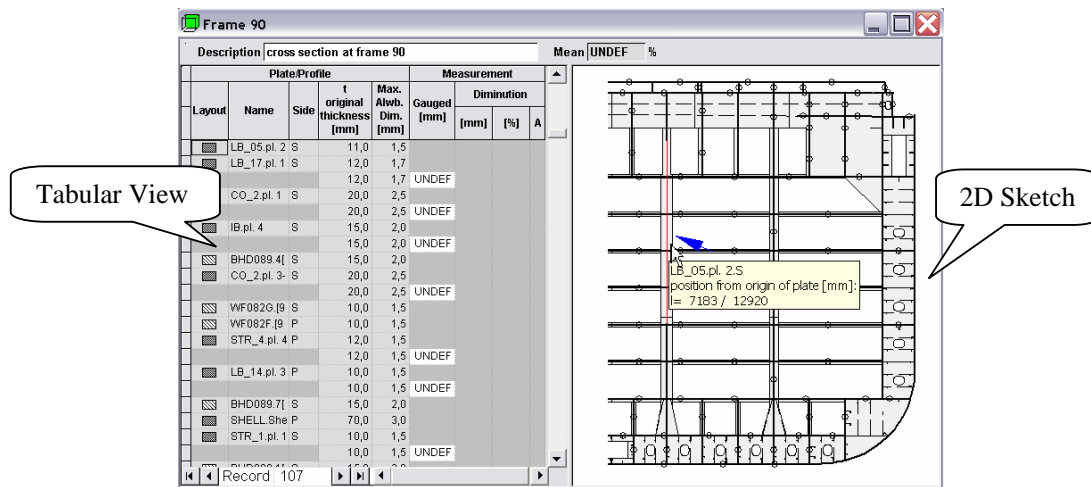

Fig.8: Cross section oriented TM configuration

Depending on the scope of the measurement, the user creates the required TM configurations and positions the points manually or automatically on the corresponding structural components, either before or after the data collection. Furthermore, for a better organisation of the measurement campaign, GL Pegasus introduces the concept of measurement sequence. A measurement sequence is a set of numbered points arranged at a specific TM configuration that can be used to interface with an UTM Gauge. The definition of measurement sequences can be achieved prior or during the data collection. This provides additional flexibility and adaptability to different working procedures of TM operators.

Measurement sequences play an important role for the interfacing mechanism with UTM gauges. Most data interfaces of UTM gauges are based on different types of arrangements of points (often called files) in form of lists and arrays. GL Pegasus communication with UTM gauges has been achieved by mapping between the proprietary file format defined by the UTM Gauge vendor and the measurement sequences. Fig.9 shows an example of a measurement sequence that has been transferred to a GEIT DMS-2 UTM Gauge. This is one of the most sophisticated UTM gauges on the market and is equipped with a large alpha-numeric display allowing for a tabular representation of the data. The bidirectional data transfer possibilities of such an UTM Gauge makes it possible to define complete measurement tasks, transfer them to the UTM Gauge, perform the measurement and send the results back to GL Pegasus.
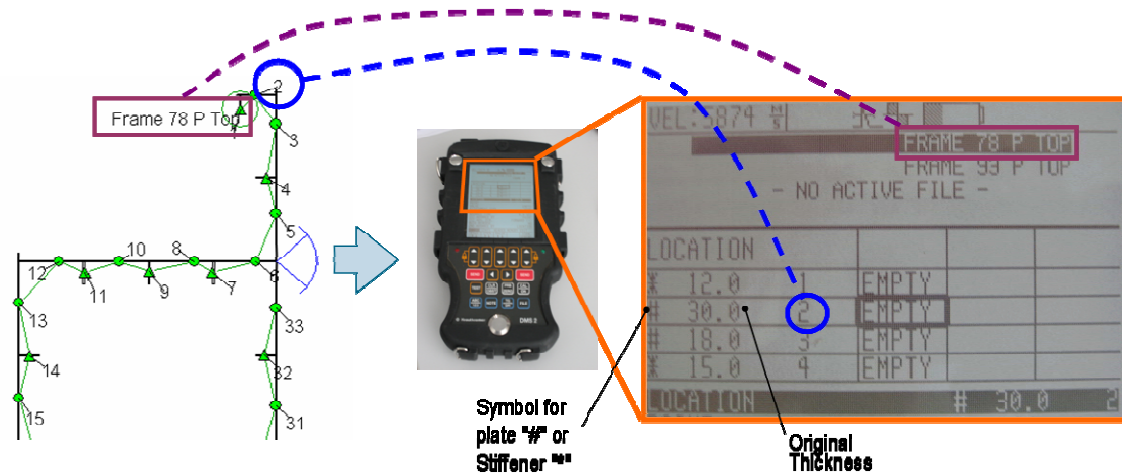
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Fig.9: Data Transfer with UTM Gauge using a measurement sequence

4.3.3 Data Collection

Principally, the actual data collection procedure is not changed by GL Pegasus, as the TM operator must take the readings one by one ensuring that they are correctly assigned to the corresponding positions. However, GL Pegasus provides support in different ways. In particular, it is possible to establish an optimised combination of the sketches and the lists of points being measured. The corresponding print outs for use on board are generated from GL Pegasus prior to the measurement task.

The entry of the data into the system can be achieved in different ways, adapting to the individual way of working of the TM companies and the equipment available. Basically, the following possibilities for data entry are supported by GL Pegasus:

- Manual entry: this reflects the conventional procedure and represents the support for simplest UTM devices that do not support any kind of data transfer with the computer.
- Semiautomatic entry: for UTM Gauges supporting a one-way data transfer to the computer. This a typical configuration for devices equipped with a simple data logger such as the GEIT DM4-DT. Measurement sequences are marked manually on the printed sketches and are later entered into GL Pegasus. The corresponding measurement values are then associated automatically during data transfer from gauge to PC.
- Automatic entry: For UTM Gauges supporting a bi-directional data transfer with the computer such as the GEIT DMS-2. This allows for an easy identification of measurement points on device and eliminates the creation of additional measurement configurations in the UTM Gauge.
- Direct connection: this requires two operators involved during measurement, which are wire connected. The measurement equipment and the computer running GL Pegasus remain on deck (e.g. within a container) and the operator inside the ship structure only has the probe in the hand sending the reading values. Coordination for correct assignment of the readings in GL Pegasus is ensured by voice/video communication. Fig. 10 depicts how data collection is performed using a direct data communication between UTM equipment and GL Pegasus. This procedure has been used by MME during the demonstration measurements in the CAS project.

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- two wire-connected operators
- cable supplies power (light), voice, video, US-signal
- operator in structure only has probe in the hand
  → increased safety
- TM readings directly entered into GL Pegasus

Fig.10: Data collection using a direct connection between UTM equipment and GL Pegasus

4.3.4 Visualisation and Assessment

As soon as the measured values are entered into GL Pegasus by any of the options explained above, the results can be visualised in the tables, in 2D and in 3D. For this purpose, a colouring scheme has been defined reflecting the degree of corrosion with respect to the specified corrosion margins. The colouring schema is displayed in the tabular representation and in 2D as per measurement point. In 3D, the colouring schema applies additionally per plate/stiffener making it easier to identify hot spots and areas that require special attention.
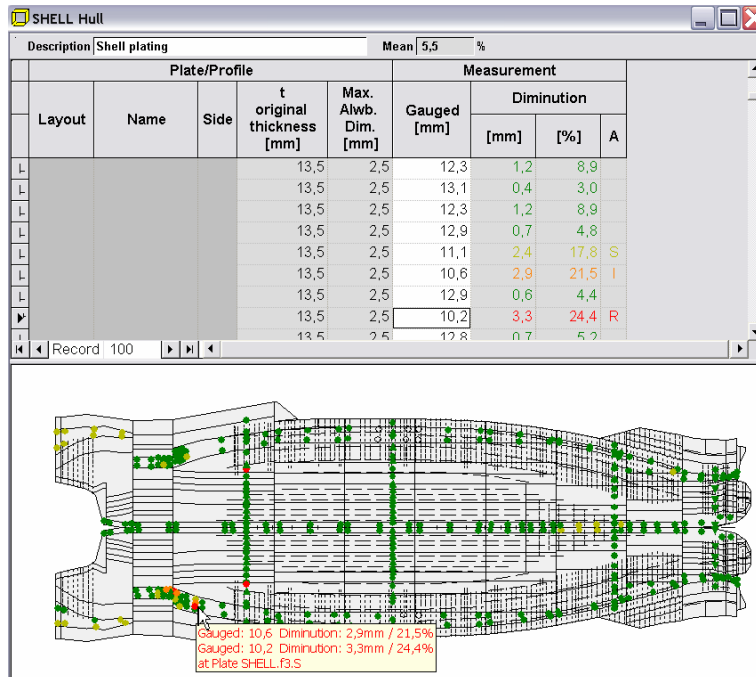
Fig.11: Visualisation of results on a strake based TM configuration

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The visualisation in 3D makes it possible to obtain an overview of the TM results in a consistent way. Structural parts can be hidden or displayed as required, applying different mechanisms and criteria such as the type (plate/stiffener), the functionality, the resulting degree of corrosion, etc.
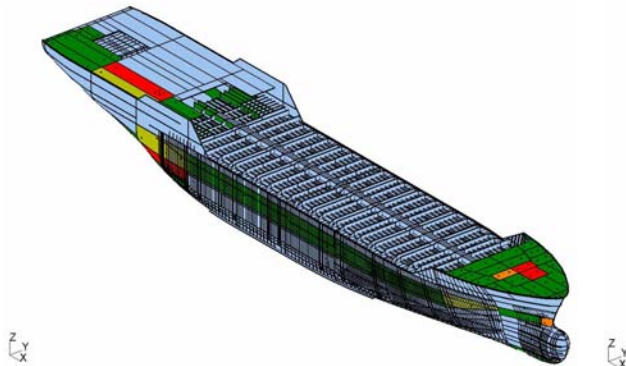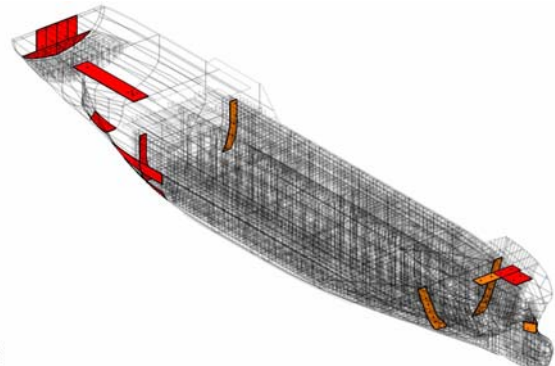

Fig.12: Overview of the TM results

Fig.13: Easy identification of hotspots

Standard functionality for 3D visualisation such as rotate, pan and zoom are available. It is also possible to limit the area being displayed by interactively applying a user defined clipping box as shown in Fig.14.
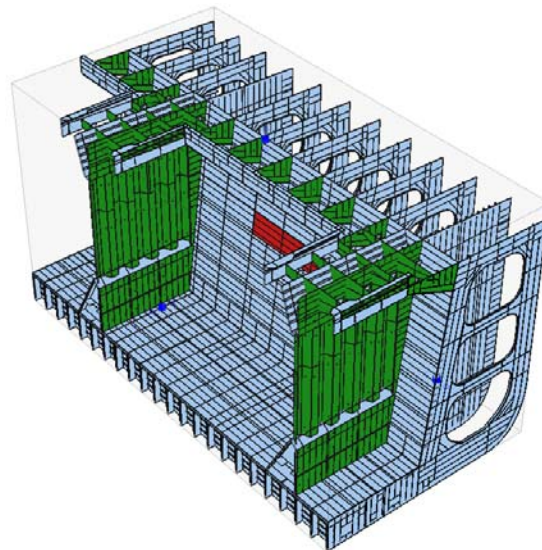
Fig.14: limitation of the 3D display by a clipping box

4.3.5 Report generation

Addressing one of the highest prioritised user requirements concerning the reduction of the time needed for the elaboration of the final TM report, see CAS Report D-1-2-1, *Jaramillo et al.* (2006), GL Pegasus provides the functionality to automatically generate a TM report in compliance with IACS requirements. The time for availability of the final report is therefore reduced to a matter of minutes in contrast to days or even weeks as for large TM campaigns utilising conventional procedures.

The generated report contains a cover page with information about the vessel and the corresponding measurement campaign, a list of contents and the documentation of the each measured area (TM configuration) including the tables and the corresponding sketches.

Additionally, a summary of hotspots can be included in the report. For each individual item in the list of hot spots, a link to the corresponding section in the report is available for easy reference. The summary of hotspots is a valuable instrument for the TM assessment. The technical expert and surveyor can concentrate on the areas requiring special attention and reflecting the actual result of the measurements in terms of possibly required measures to be initiated.
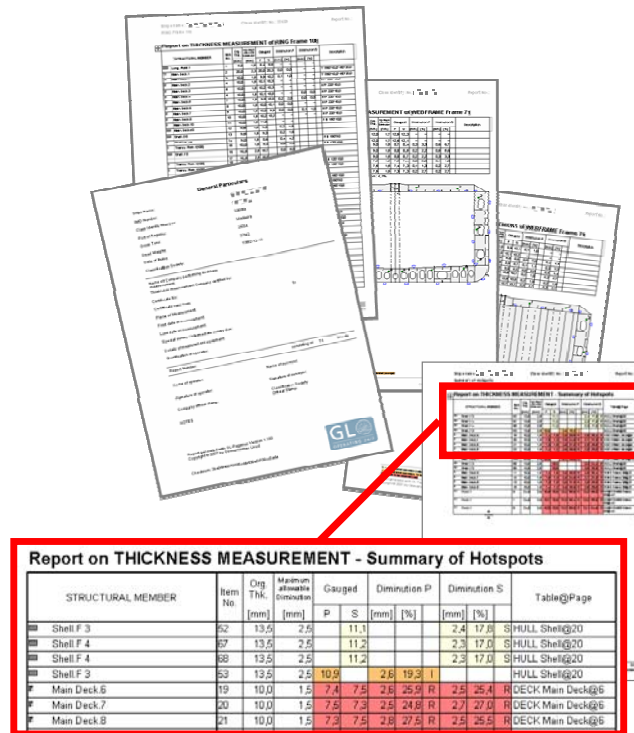

Fig.15: Automatic generated TM Report

As the scope of documentation in the generated report can be adjusted by the user, the reporting functionality can also be used for the generation of partial reports (e.g. reports at the end of each campaign day). In Fig. 15 some sample pages of a TM report generated by GL Pegasus are shown.

4.3.6 Structural Assessment

Depending on the resulting hull condition with respect to corrosion degradation it might be necessary to perform strength calculations to verify the integrity of structural components locally or globally and to eventually determine the required scope of repairs. For this purpose and within the scope of the CAS Project, corresponding data interfaces from HCM to POSEIDON have been developed. HCM files can be imported directly into POSEIDON. The measurement values are associated automatically to the respective plates and profiles of the POSEIDON model and the following longitudinal strength assessment refers to the actual measured values.

4.4 VeriSTAR HLC

4.4.1 From theory to practice

A great deal of adaptations and ergonomic developments are required to move from the research projects prototype to any derived commercial tool. In particular a commercial tool must be appealing to operational people, typically to the ships' superintendent or offshore oil fields operational people. Although it can be used for ordinary vessels, the tool developed by Bureau Veritas is currently oriented towards the offshore oil industry, because those clients have, in the first place, expressed their interest. Therefore, the tool was associated with an existing asset management tool (AIMS), which

was designed for the planning and reporting of all inspection and maintenance tasks for a given unit, whether required by the classification society of the owner's operational teams. The tool is understood as the first module of a new series of customer oriented tools, providing a initial 3D geometric model that will be used later on for finite element analysis, tonnage calculation, hydrodynamics, etc.
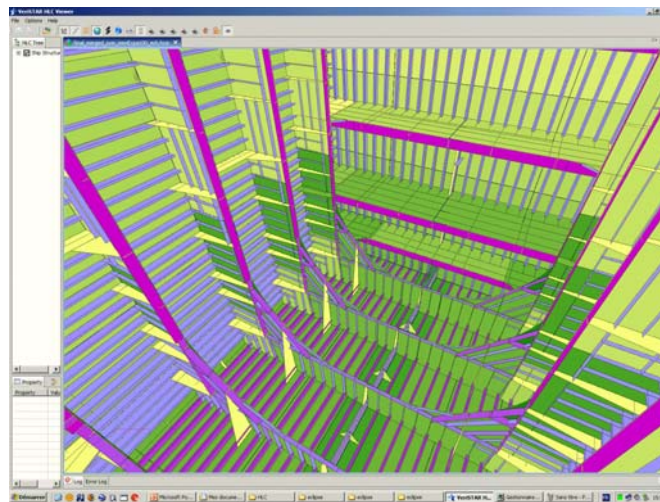

Fig.16: 3D View

4.4.2 Coarse modeling

The tool includes a function that allows starting up with a coarse model of the ship and later on the addition of details, by super-imposition of smaller elements. For instance, only the area in way of one single cargo tank may be initially needed for the first renewal survey, so this area must be modelled in details, but the rest of the ship's model may be fairly well represented with a good enough coarse modeling. At the next renewal survey, other areas of the ship will have to be modelled in details, which will be achieved by super-imposing smaller structural elements above the coarse structural elements.
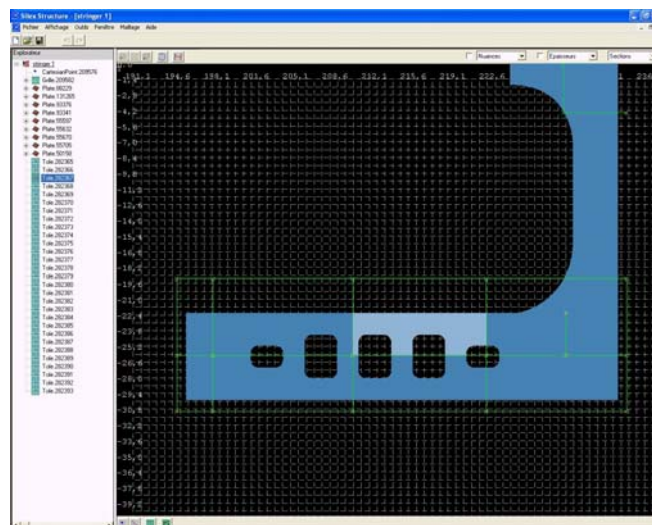

Fig.17: Super-imposition of smaller elements

4.4.3 "2D" views for data input

To ease the input of measurements into the 3D-model, the tool provides "2D" views, which are technically 3D views, but perpendicular to the structural elements to be measured. So the 2D views are

automatically derived from the 3D model and there is no need for drawing additional 2D views for the purpose of data input.
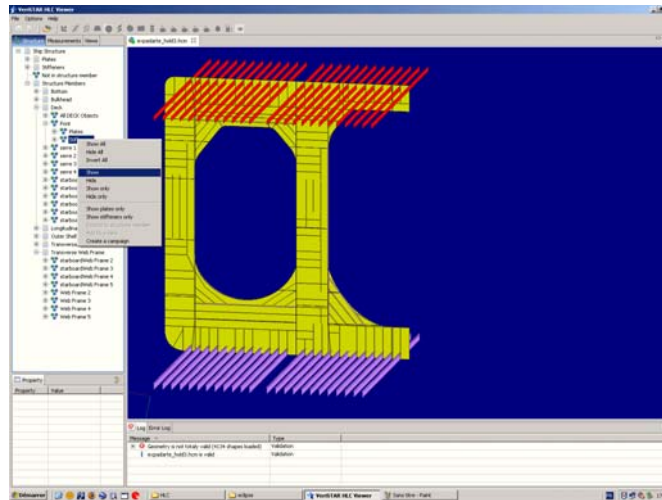

Fig.18: "2D" view for measurements input

4.4.4 Visualisation means

A set of visualisation means has been added, for instance:
- to erase selected structural elements, in order to get a better view of previously hidden structural elements,
- to extend a selected structural element to all similar elements on board or to larger structural assemblies including this element.
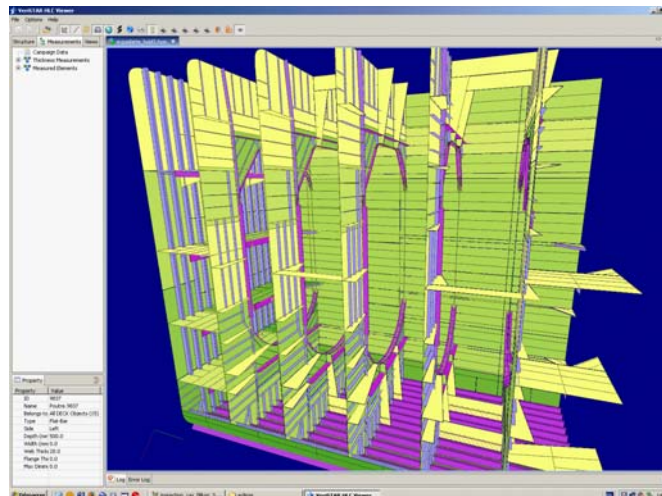

Fig.19: Erasing elements

4.4.5 Google Earth

All inspection data (thickness measurements, coating condition, cracks, inspection reports, pictures, video films), can be visualised on the 3D-model. Flags are displayed with a "look and feel" similar to "Google Earth" pictures. The user adjusts the level of details to be shown on the screen, and the type of information he wishes to see.
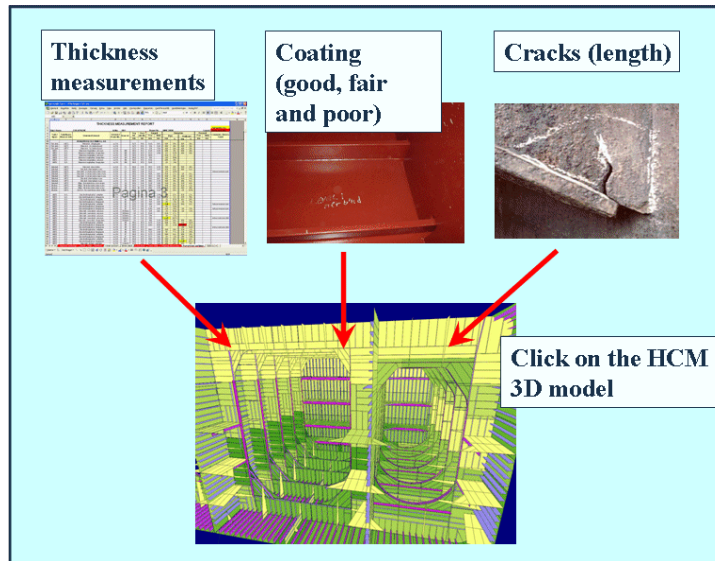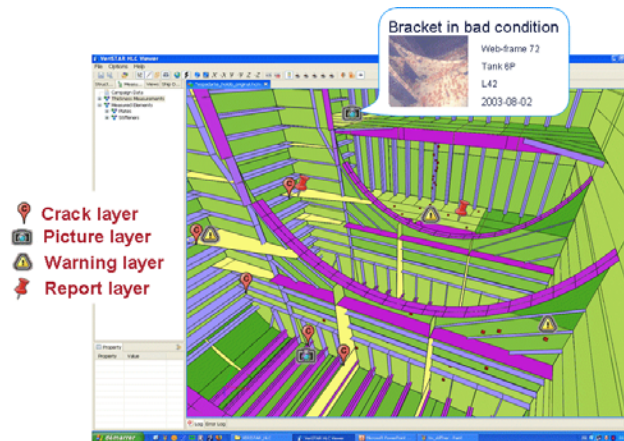
Fig.20: Easy storage of inspection data

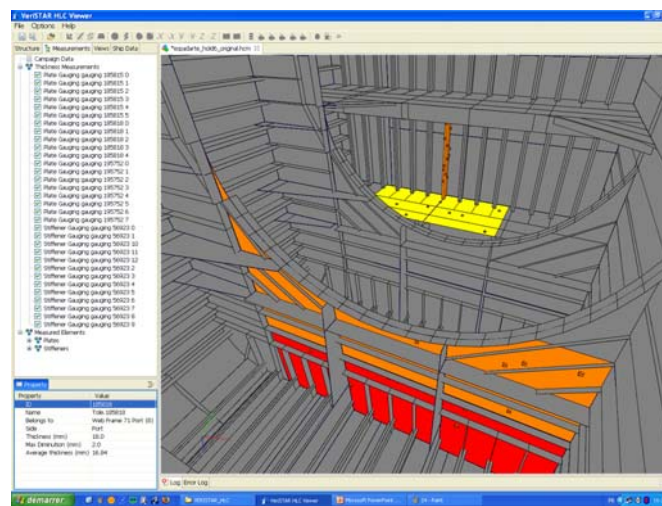
Fig.21: Google Earth look and feel

Fig.22: Repair preparation (what is wrong in the structure)

4.4.6 Repairs preparation

The superintendent is expected to check the tanks, one by one, inside the virtual ship, which is a convenient alternative to visiting the real ship, as a preparation of the repairs. But, it helps the superintendent very much to have access to a dedicated view, which focuses on what is wrong with the structure, for instance the plates to be repaired and the pictures and reports related to damages or degradation.

5. Outlook and further development

5.1 Level of detail

The guideline for defining the proper level of detail of the 3D-model is expected to be clarified during the real-life implementations which are to be carried-out in the next future:
- for new-building ships and for offshore units which always stay with the same owner at a fixed location, a detailed model can be expected,
- at the contrary, for many ships in service, changing owners frequently and sailing around the world, simpler models should be considered as an alternative.

5.2 Using a Robot

The Robot used in the project was a Magnetic Hull Crawler, designed for inspection and maintenance of steel surfaces. A permanent magnet enables the Robot to crawl on a ship's outer shell in dry-dock. This robot is able to operate both in air and underwater (50 m). It is Joystick or PC controlled. Dimensions are 610 x 460 x 400 mm and the weight is 60 kg.

Fig.23: Measurements Robot

In the air (as it was the case in the demonstration), the positioning of the Robot is done by 3 odometers (each odometer consisting of a steel cable rolled around its coding device) which transmit in real time the motion of the Robot as x, y, z coordinates to the Cybernetix software "Robolocalisator". This software is searched by the "Hullmap" software which merges the values of the position and the steel thickness. The "Hullmap" software, from the position of the Robot in the 3D environment of the 3D-model, detects automatically the reference of the plate, using an invisible video camera, always perpendicular the plates. This reference is displayed on the "Hullmap" screen and is automatically added to measurements and positions in the HCM file.
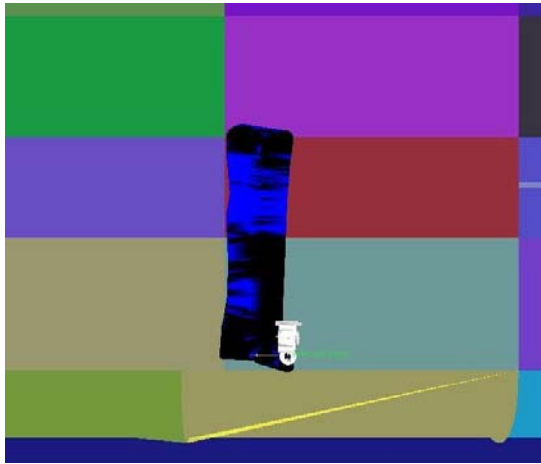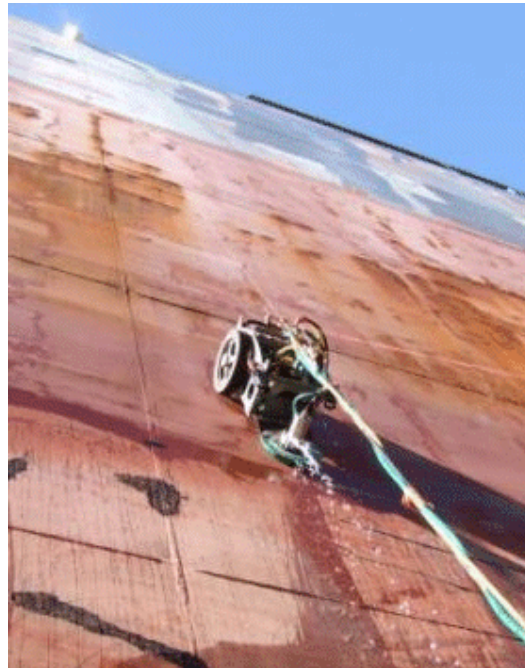
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Fig.24: Robot scanning outer shell   Fig.25: Robot crawling on outer shell

The role of a Robot in the thickness measurements process is now clarified. The Robot is well adapted to flat surfaces, such as outer shell and flat cargo bulkheads. Surfaces should be in a clean condition. It is very good at scanning doubtful plates. Close-up survey, implying the physical proximity of the surveyor, is not required for the outside shell, so that the robot can be left alone. The robot could even be programmed to take, say, all bottom measurements alone and unattended. The Robot could also be useful for naval vessels at sea, because they have clean hulls and consequently ultrasonic gauging can be done without a prior cleaning of the hull. For FPSOs, which do not dry-dock, and therefore have underwater hull covered with fouling, the Robot could be used, if it could be found a way to remove the fouling (high pressure nozzles) or to take measurements through the layer of fouling.

In the future, other types of robots might be developed:
- for underwater NDT inspection of hull of vessels at harbour (hull thickness measurement and cathodic protection inspection).
- to measure stiffened plates, for instance inside the ballast tanks.

In narrow double skin ballast tanks, where human access is difficult, a swimming robot could perform the gauging. However, under current IACS rules, a close-up survey is required in this case, for instance for web frames in ballast tanks, so that the surveyor must also be present, close to the robot, at the time of measurements. Therefore, the advantage of the Robot is reduced, if anyway the presence of a human surveyor is required in those locations.

5.3 RBI developments

Risk Based Inspections "RBI" and associated predictive tools would be of a great added value for HCM based processes. The use of degradation models and extrapolation from several measurement campaigns for planning of repairs is examined in this paper and can be combined with an evaluation of the severity of resulting damage, to finally provide RBI based inspection schemes.

The main reasons for implementing a risk based approach in inspection planning are:
- to ensure that the "Base Line Risk" does not exceed the risk acceptance criteria, as set by the operator, at any time;

- to focus the inspection effort on items where the safety, economic or environmental risks are identified as being high, whilst similarly reducing the effort applied to low-risk systems;
- to identify the optimum inspection or monitoring methods to match the identified degradation mechanisms.

A risk assessment has to consider all relevant failure modes and mechanisms, however, in a first approach the focus is on corrosion. Starting point for a risk based inspection strategy is

1. a screening of the current ship condition, to identify areas of high risk as well as medium and low risk level; followed by:
2. an estimation of a risk value on a consistent methodology and the development of a risk matrix;
3. the prioritisation of the different areas;
4. the development of an appropriate inspection program.

The screening of the ship to identify the areas of high risk starts with the segmentation of the ship structure. As not every part of the structure will have the same risk, segmentation is necessary. For each segment, the risk can be estimated by evaluating the probability of failure and the consequence of failure. The combination of both leads to the risk. The probability of failure can be estimated by using different methods, such as: qualitative methods (e.g. questionnaire, simple risk matrix), semi-quantitative methods (e.g. index procedure) and quantitative methods (fully probabilistic approach).

Qualitative methods deal with few essential data and lead to a rough estimation of the failure probability. The semi-quantitative methods use more information and some calculations are carried out, which result into a more accurate failure probability. The quantitative methods consider fully probabilistic approaches and lead to an accurate estimation of the existing failure probability.

The semi-quantitative approach presents a good medium, because the fully quantitative approach requires a lot of data which are normally not available for existing ships and the semi-quantitative approach gives a more detailed failure probability than the pure qualitative approach. A combination of index procedure, which leads to a general result for the probability of failure, and the remaining life, which is related directly to the corrosion, is appropriate for the assessment of the threats due to global thinning based on corrosion. The assessment of the consequence of failure for each segment considers the consequences for safety, the environment and the economical consequences.

The combination of the failure probability and the corresponding consequence leads to the current risk of the ship segment regarded. The joining of all segments leads to a risk value for the ship. The merging of the local segment risk to a global risk is not considered, however this aspect should be covered in a further study. Several different approaches exist in the literature, e.g. reliability block diagram, fault tree analysis, reliability networks.

After the estimation of the risk related to each segment, an appropriate inspection strategy should be developed. The inspection effort and interval should be determined taking into account the current and the future risk of the segment regarded. The possible risk based improvements of the existing inspection methods can be carried out in two ways:

- adjustment of the inspection effort,
- adjustment of the inspection schedule.

Both possibilities and a mixture of both are conceivable. The aim of the adjustment is to investigate the vessel with the higher risk more intensively than the vessel with the lower risk. This could also lead to a modification of the date for the next class inspection. It is thinkable that for ships where the risk assessment was carried out and show a low risk level, the inspection intervals could be extended. On the other hand, for ships with a high risk level, the inspection intervals should be reduced in order to avoid unacceptable risks.

Beside the modification of the inspection interval, the effort could also be modified. This is implicitly already covered in the specific codes, as the inspection effort increases with the age of the ship. Using the risk based approach would extend the current procedure to other effects than only regarding the age. Based on the risk assessment, it is possible to identify areas of the ship with higher and those with lower risk. The inspection amount taken at the higher risk areas should be larger than at the lower risk areas. The procedure given above could be a starting point for a development of a risk based inspection program.

5.4 IACS standard

There is an on-going action versus IACS to add the HCM-based reporting of thickness measurements into the IACS Uniform Requirement UR Z10, as an alternative to the existing Excel-based reporting formats. It is believed that a few real-life implementations of HCM by ship-owners are a pre-requisite to having HCM accepted as an IACS standard.
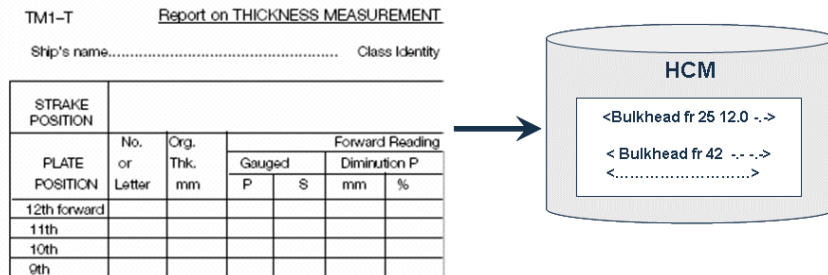

Fig.26: Towards an IACS standard

5.5 Export of HCM from shipyard

All big enough shipyards center their shipbuilding process around a very complete CAD model of the ships, which contains not only the ship's detailed hull structure, but also mechanical systems, fluid systems, ventilation and electrical systems. These CAD models are very detailed, because they must provide enough information for the building of the real ship. They incorporate a lot of the shipyard's experience and know-how and are generally, for that reason, not handed-out to the ship Owners after the delivery. The easiest way to have ships equipped with HCM files would be that the building shipyard generates the HCM file directly out of its CAD model. We can expect that this would be acceptable for shipyards, because HCM only covers hull structure and is so simplified that it cannot be used by a competitor to build a sister-ship.
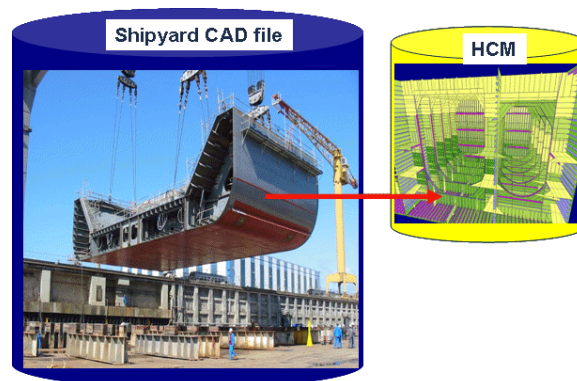

Fig.27: HCM from shipyard

5.6 Regional Waters Authority scheme

5.6.1 Definitions

A "Regional Waters Authority" (RWA) can be defined as the Official Body having the law enforcement powers over an extent of sea waters (the "controlled" waters), surrounding a given region of the world. Regional Waters Authorities could typically be the EC Maritime Administration, the US, Canadian or Japan Coast Guards.

5.6.2 Technical approach

We examine hereafter the new technical possibilities offered by the HCM technology to an RWA, however the legal aspects and the associated repartition of maritime actors' responsibilities, would have to be analysed as well, if we had to draft a complete proposal for implementation.

5.6.3 Continuous follow-up versus status control

The only way for the RWA, to make sure that the condition of a vessel, sailing in its controlled waters, is safe, is to have a direct access to the current structural condition status of the vessel, at the time of its entry into the controlled waters. Thus, the RWA does not need to examine the history of the vessel (past owners, flags, classification societies, damages, detentions, etc), which may include some missing or subjective aspects, but only needs to concentrate on the objective structural condition status of the vessel, at this precise point in time.
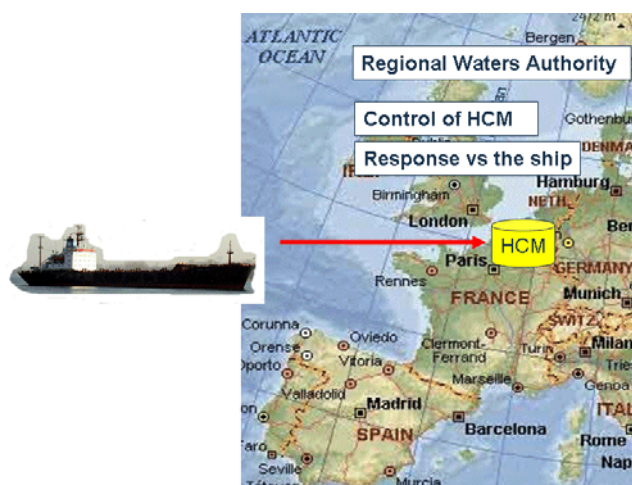

Fig.28: Regional Waters Authority scheme

5.6.4 RWA scheme major steps

Therefore the following tentative scheme can be considered:

- all "risky" ships entering the controlled waters are required to have an updated HCM file.
- at the entry into the controlled waters, those ships must send their HCM file to the RWA. In practice, this file would be complemented by a set of administrative and cargo-related information.
- on the basis of the HCM file, the RWA will activate the proper response:
    * continuous follow-up of the ship and communication to shore stations,
    * request of an inspection by the Port State Control authority at next port of call,
    * access refusal to the ship in the controlled waters.

- in a bad weather period, the RWA would require all "risky" vessels trading inside the controlled waters to send their HCM to the RWA. Vessels deemed weak would be required to reach the nearest port of call, to wait safely for the improvement of weather conditions.

5.7 Extension of ship status file

Following the same line of thoughts, in order to provide the RWA with a complete ship status, we could develop a complementary tool, to reflect the condition of the machinery equipments.

Both structural and machinery status should indeed be taken into consideration, because:

- structural failures occur seldom, but usually cause serious consequences;
- machinery equipments failures (steering gear, diesel generators or main engine) are frequent, but usually cause relatively less serious consequences, in relation with collision or grounding.

By opposition to the structure, where the condition is easily and obviously reflected by the thickness of steel plates and stiffeners, some research is a pre-requisite to establish a list of the parameters describing the condition of the machinery equipments.

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