Remote monitoring of Ballast Water Treatment System quality by using flow cytometry and satellite communication technologies

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Abstract - Remote monitoring and flow cytometry were lately significantly developed. Ballast water treatment systems (BWTS) are in use on lot of ships today and new systems are still in research projects worldwide as well. So fast development requires control and monitoring of installed systems. International Maritime Organization (IMO) regulations and Ballast Water Convention 2004 include inspection of treated ballast water (BW) if needed. That could initiate lot of legal, beside to operational, problems in maritime industry. That implicates the need of a monitoring treated BW before the ship enters a port. It has been described in this article how to monitor treated ballast water to make sure the BW and BWTS on a ship is in proper condition, but before the port entrance. The monitoring system and its parts flow cytometer and satellite communication system together with remote operation system from the land office have been explained. Auto-monitoring of treated BW on board by using newest sensor technologies and satellite communications are included in the model of three sub-systems and remote operation from the land office, but to be autonomous from the ship's crew. Main goal of the research is that a ship enters the port with the BW cleanliness confirmation. In this way there is no need to sample the BW and no time is lost for analysing the samples.

Keywords - Ballast Water Treatment System, IMO Convention, flow cytometry, satellite communication system, remote operations.

I. DEFINITION AND BALLAST WATER PROBLEM

The problem and the base of the research explained in this article exists long time in maritime industry (observed 1903. in North Sea). The definition of ballast water says that is the water taken up or released by a ship to provide static and dynamic ship's stability. It is usually taken into ballast tanks when cargo is being offloaded and discharged when cargo is being loaded. Ballast water quantities are adjusted on the open ocean to compensate for weather, fuel consumption and for the overall safety of the ship and crew in any place and time.

When ships take in water for ballast in port, they also take in whatever organisms present in the water. These organisms are then transported and potentially introduced into the waters of the ports along the vessels' routes as ballast tanks are emptied each time when cargo is loaded. Ballast water taken on in one ecological zone and released into another, may introduce aquatic invasive species and non-indigenous organisms. This can drastically disrupt fragile marine ecosystems.

The problem is that the ability of modern ships to cover long distances in a short amount of time, provides a means for non-native marine species, including algae, invertebrates, and pathogens **[1]**.

The International Maritime Organization (IMO) commenced problem solution legally. At first it was, on 1991. launched *Guidelines for Preventing the Introduction of Unwanted Organisms and Pathogens from Ships' Ballast Waters and Sediment Discharges*. Then, it has been launched the *International Convention for the Control and Management of Ships' Ballast Water and Sediment*, on 13.02.2004. It states that:

- Ballast water must be treated before it would be released into another ecological zone
- Vessels built during or after 2009 have to install a type approved Ballast Water Treatment system, immediately once the convention enters into force
- Vessels built before 2009 must install a certified Ballast Water Treatment system by 2014 or 2016 (depending on ballast water capacity of the vessel)

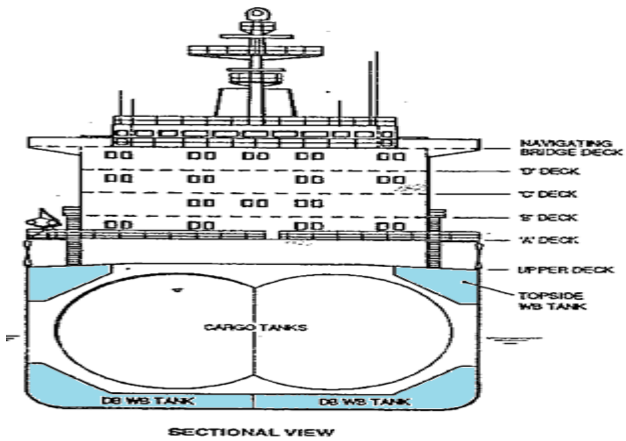

Fig. 1. Gas carrier - Ballast Water Tank Drawing, not installed a BWTS [2]

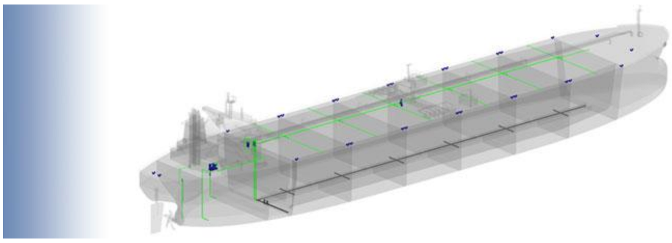

Fig. 2. Installed Inert gas BWTS with bottom dispersion deployment

The Convention requires from certified inspectors to do their best efforts to avoid *not needed stoppage caused by potential sampling* of all the ships (p.12). That means the advantage is usually given to respect the contracts of transportation, instead to protect the seas **[2]**.

The inspector can give an order to a designated institution or certified laboratory to take samples and to analyze water ballast that any crew intents to discharge into the sea. That inspection in a laboratory includes analyses to find whether any microorganisms were in ballast water and to find out salinity and kind of salt in the way to determine where from is the ballast water. If the analyses find out no microorganisms or not any other reason that would prevent ballast water discharge, all the expenses would be paid by the Ministry that the inspector represents. Those expenses are very big expenses and that time loss could even cause loosing the cargo in next port of call and staying at anchorage for a few months. Then is needed *cheaper* and faster BW inspection or detection. New technologies would help to find better ways for that.

II. MONITORING

The monitoring of the quality of a BWTS is usually done just in the institutes only while the tests of any candidate systems are performed. Sampling is usual method of the monitoring and the newest sampling technologies shorten the time needed for good analyses. Samples on arriving ships were taken just in researching time to find out the potential dangers to domicile waters.

Experience from the sampling cargo quality on different product tankers and chemical tankers prove the problems related the quality of the liquids. There are lot of legal trials that prove guilt of the ship company owners or the cargo providers in loading ports when the quality of a liquid cargo was found in improper condition.

The time needed for a good liquid cargo analyses in the lab is 3 to 7 hours, sometimes even longer time period.

Related to BWTS quality monitoring, the time needed for a good analyses of ballast water samples in any laboratory is expected to be same. All of that is the time loss that could be avoided with new technology use.

All providers and sellers of new BWTS models (21 BWTS model inventors have confirmation of IMO approval certificate till August 2011.) say that their models are resistant to sea salt water and to heavy seas condition. But, there are no proofs of that resistance during 10 or 20 years period. Other experiences prove that all ship pipelines and running machinery systems get damaged by time being exposed to the seas and ship's life conditions during the years. That is also a reason why the monitoring is needed, beside to other treatment quality reasons.

Flow cytometry is the technology that provides electronic detection and sampling of ballast water, followed by data collection, filtering thru ordered filter and transmitting. That technology is well developed today. It is in use in clinical medicine, biochemistry and in fresh water sampling in lakes, accumulations and natural sources.

Fig. 3. Flow Cytometer exhibit by Fluid Imaging Co. on GloBallast R&D Forum in Istanbul, Oct., 2011. [7]

Other applications are in researching possibility of ballast water detection and sea harmful algae blooms and other unwanted sea organisms detection. It has already been suggested by this author to use flow cytometry for ballast water detection. A good research flow cytometer has been successfully tested and finalized as a product for use.

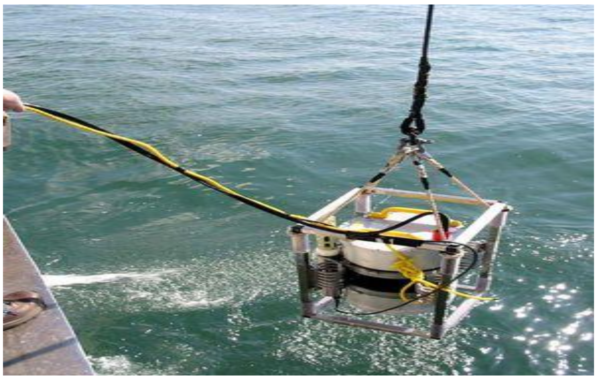

Fig. 4. Submerging Research flow cytometer [3]

It works while the data and power transport between the submerged instrument and the computer on the ship runs through a high quality submersible cable. A cable has the advantage of continuous control over the instrument and direct interactive data acquisition.

The instrument can be equipped with an onboard computer. If a long (extra) cable for connecting the ship based computer with the instrument is not desired, a solution is offered based on an embedded computer for control and data storage and a battery pack for powering: the submerged cytometer with embedded computer runs on fully preprogrammed operation with samplings at preset times or depths ,using the pressure sensor.

Samplings can also be initiated by an external trigger from another device or from an existing cable. After surfacing again, the measured data files can be conveniently transferred to the shipboard computer through a wireless link (using a high pressure antenna housing on top of the CytoSub) **[3]**.

This implicates the use of flow cytometry technology in the way as explained in the following proposed model.

Fig. 5. Embedded computer inside the housing with flow cytometer [3]

III. MONITORING MODEL

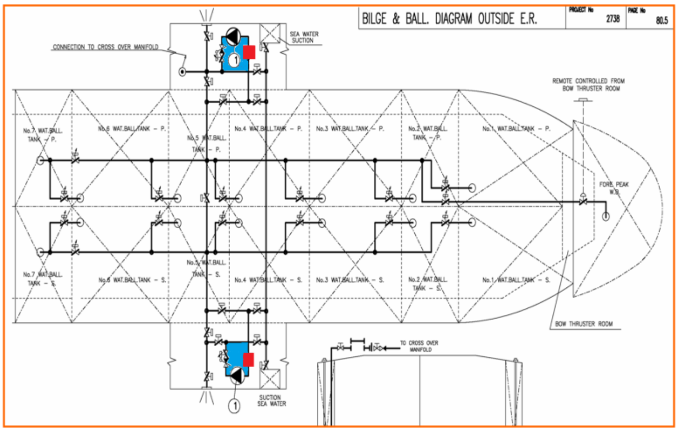

Fig. 6. Blue color: recirculation beam units; red color: flow cytometers

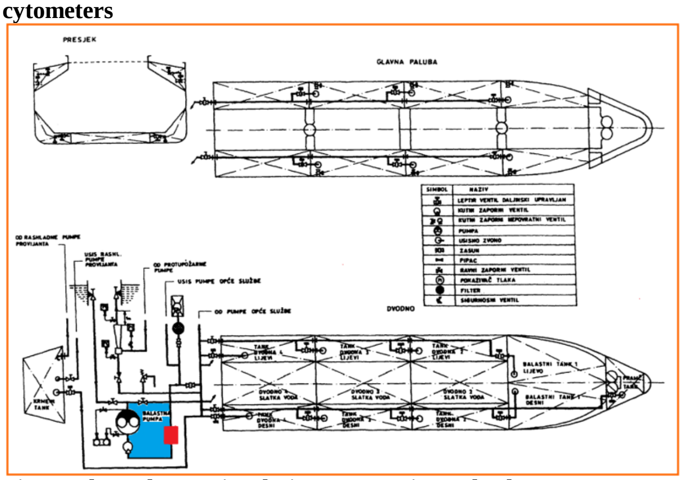

Fig. 7: Blue color: recirculation stern unit; red color: cytometer

The monitoring model includes a ballast water system, ballast water treatment system, flow cytometer with ballast water recirculation unit, ship's transmitting unit, ship to shore transmitting system and remote communication system shore to ship. There are a few options of installing cytometer in line.

It is important to connect the flow cytometer recirculation unit with a good transmitting unit that forwards detected data to a land remote office. People in that office would remotely start the system on the ship and stop the operation when the detection is completed. Captain of the ship or Chief Officer would supervise the operation on the monitor in Cargo control room or on the Navigational Bridge if the indication exists over there. Ship's stability remains in good condition during the test performing time, since the BW tanks don't remain filled with less than 98% of the total tanks capacity. All mentioned activities would be well and easily pre-calculated in usual way that is computerized as well.

The possibility for that kind of satellite communication between a ship and a remote office already exists and it is in use worldwide for Remote Maintenance. Remote maintenance is explained in following projects: ICAS, JRC and SCADA.

IV. REMOTE OPERATIONS OF THE SYSTEM

Project Integrated Condition Assessment System remote monitoring (ICAS) has commenced the monitoring programs installation on submarines and aircrafts, then on the ships. Monitoring software is installed on the ships to detect failures of the engines before the failures make damages. This is a Commercial Off the Shelf (COTS) software product for which the US Navy holds License Rights. Presently, ICAS is installed on approximately 100 US Navy ships. The ship may have no knowledge of the problem and the shore infrastructure informs the ship of the problem.

The Maintenance Engineering Library Server (MELS) is a common shore side database where statistical analysis can be accomplished to further maintenance savings and to gain a better knowledge of equipment operation. Integrated Performance Analysis Reports (IPARs) is part of projected plan of getting the data to the Regional Maintenance Center's (RMC's).

Regional Maintenance routinely provide feedback to the ships via the Integrated Performance Analysis Reports. Data automatically collected on these ships has saved thousands of man-hours through the automation of performance monitoring as well as time saved through the automated diagnostic features of the software **[7]**.

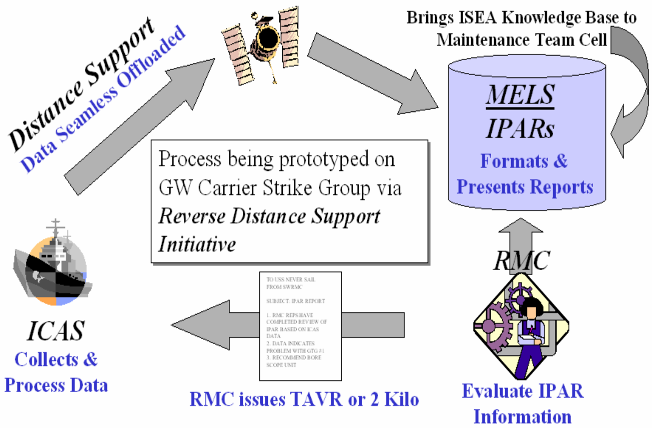

Fig. 8. ICAS Remote monitoring vision [7]

Project (Japan Radio Co., Ltd.) JRC is based on sale of their products (units in communication chain system) and maintenance of those products from the land maintenance stations. Required equipment that JRC obligates the ship to be equipped with is Remote Maintenance Server that operates via INMARSAT satellite. It is necessary to connect only one JRC Fleet product to get into the Remote Maintenance System.

Those products are Fleet F77(JUE-410F) and Fleet Broad Band (JUE-500) .

The educated service team connects to ship systems using satellite communication and analyzes failure. Accredited technician can remotely link onboard the vessel to inspect, analyze, resolve and take follow-up action for next port attendance.

JEG system is present all over the world and their technicians are able to come to each port and resolve the failure or just to resolve the problem.

The strategy of Japan Radio is to keep all of this activity cost effective. For better understanding of this cost effective maintenance system is important to say that remote maintenance teams are located in Canada(2), USA(9), South America(6), Africa(6), Europe(17),Australia and Polynesia(5), and in Asia(18). A representative office is located in Croatia.

There is just one emergency phone number to call from anywhere to get their support. Over 270 fully trained and qualified partners and agents, assisting 24 hours a day and 365 days a year. It is more economic to have a remote maintenance then other, usual way of maintenance on ships. The table below shows costs data researched **[4]**.

Table I. Table of maintenance costs

Costs in USD	**Local expert**	**Supplier expert**	**Remote maintenance**
Pure problem solving	1 hour	0.5 hour	0.5 hour
Busy time	5 hour	2 days	0.5 hour
Expert salary	500.-	1600.-	50.-
Expert travel expense	0.-	2000.-	0.-
SatCom costs	0.-	0.-	240.-
Total USD	500.-	3600.-	290.-

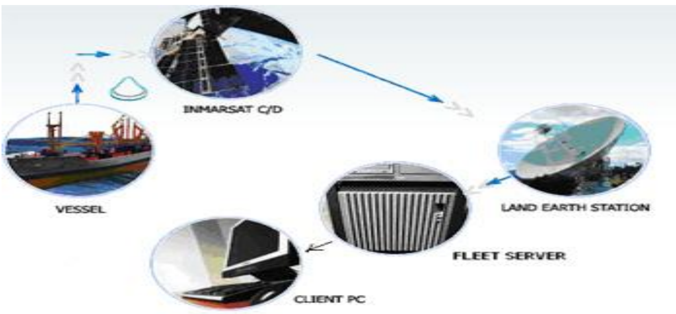

Fig. 9. Concept of remote monitoring SCADA system [8]

The following block diagram illustrates the concept and principle of **Vessel Monitoring SCADA System**. Using SCADA systems to monitor and control the Vessel equipment, it is also able to control the action of vessel systems by locally as well remotely. The vessel monitoring SCADA system constitute of total ship alarm status, warning alert, vessel fuel bunkering management, tank level management and engine management.

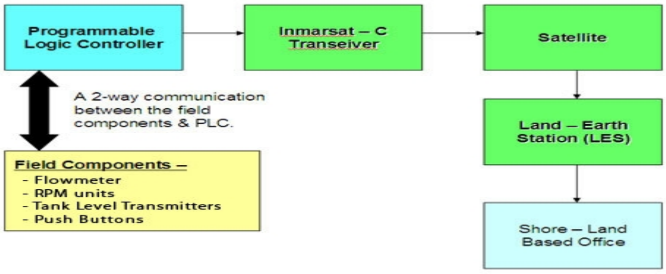

Fig. 10. Principle of remote Vessel monitoring SCADA [8]

The above mentioned system data can be monitored from any particular location to any land office at any specified time of interval without delay[3]. SCADA system is a system with quality that could be used for the model explained in this article. Also the method that is implemented in JRC system could include remote operation of the model explained in this article **[8]**.

V. CONCLUSION

Remote operations on the ships are in use more and more every day. In this project the people from the land office remotely operate ship's ballast system (ballast pump and ballast water tank valves), then they (also remotely) run fixed flow cytometer on the ship that analyses treated ballast water by recirculation. Flow cytometer data are then, transfered from embedded computer thru local ethernet connection to remote computer and/or straight to the Land Remote Office for evaluation. The data of the cytometry scans are transmitted straight and momentaly thru a good bandwith by INMARSAT satellite communication system. It is possible to do this project becouse of technology development. Well developed remote operations and flow cytometry, followed by satellite communications, would improve the life on the ships, maritime industry and sea ecology. Ships would enter ports with confirmed ballast water cleanliness and no time will be lost for any ship's ballast water sampling and analyses.

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