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Remote Monitoring of Fuel Tanks Onboard Romanian Naval Ships

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Abstract. The aim of this paper is the conception and design of a platform for remote monitoring of the fuel level and temperature compensation for the fuel tanks onboard the ships belonging to the Romanian Naval Forces. Considerations on how to optimize the fuel consumption of the ships is taken into account by correlating the obtained data with the operating regimes of the naval propulsion machines. Based on the data obtained from the transducer system, temperature compensation for the fuel tanks is also monitored.

1. The current state of the topic and international trends

The issue of how to create a system for measuring flow rates and levels in fuel tanks generally consists in:

- increasing the ship's operating performance with special reference to the boarding and fuel transfer installation;
- increasing the chances of the ship's survival in emergency situations.

According to data processing technology from the process there are three main types of (measurement) control systems:

- analogue, with wire-by-wire measurement and control circuits, individualized on installations or equipment;
- hybrid, which, in addition to the traditional analog system, brings in the numerical centralization of data mainly for monitoring purposes;
- digital, which starts from the interface with transducers and execution elements using numerical data processing and allowing the introduction of multifunctional consoles which permit the data bus control of all the onboard installations.

The system structure shown in figure 1 corresponds to a distributed digital architecture organized on 3 levels.
Level 1 of the system uses pressure transducers that indicate the level in the tanks by measuring the relative pressure of the liquid column. The protective separation from the environment of explosion hazard is done by Zener barriers.
Level 2 uses an intelligent interface, marked ABU 5000, which provides signal conditioning and local display.
At level 3, a specialized console is used, respectively a PC that centrally displays, through dedicated pages, the level status in the ship's tanks and performs the necessary volume calculations, etc.

The transmission from level 1 to level 2 is done in a unified current signal, 4..20 mA, and from level 2 to level 3 through a data bus using the RS-485 protocol.

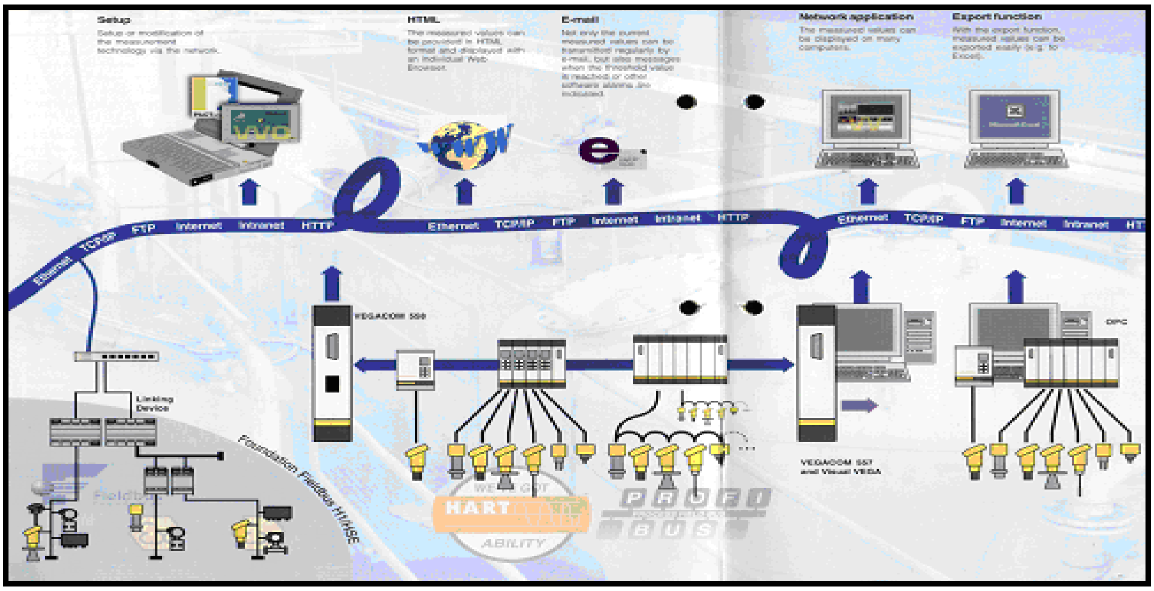

Figure 1 Tank level monitoring and control systems – VEGA Germany

This system uses proprietary (designer's) equipment and can also be developed for military applications.
VEGA manufacturer, the producer of a very wide range of level and pressure transducers, offers turnkey systems for the acquisition of measured data, local indication and their monitoring on PC-equipped consoles. For data transmission, it offers options for using various industrial-type communication protocols. It also integrates flow transducers with non-destructive assembly by FLEXIM – Germany. As the system is modular, it lends itself to further developments and has applications on naval ships as well. It still represents a proprietary-type of technical solution, but with OPC-type software facilities and Ethernet bus communications that recommend it for integration with other existing or future monitoring systems.
In order to measure the fuel flows and levels there is a series of trends generally valid for ships, supplemented by those trends that are specific only to naval ships as follows:

- manufacturers of fuel level and flow rate transducers also produce the related system for displaying the measured values as well as the monitoring system for a corresponding number of such transducers;
- the exclusive transition to digital technology with a vertically and horizontally distributed architecture, the technology which is taken from the industry and the only one that is capable of allowing a high degree of integration;
- increased structural flexibility, the system can be configured as an individual system or as a subsystem within an integrated monitoring and control system for machinery or the entire platform;
- commercial hardware and software products with naval classifications are used;
- SCADA-type integrated software platforms are used with object- and event-oriented programs, with high operating speeds that allow real-time control.

2. Analysis of the application domain and requirements

Technically, a computerized command and control system along with its infrastructure of communications and data connections constitutes what is called a *system*, respectively *Command, Control, Communications and Information*, and is part of the equipment that assists the commander in fulfilling the *Command and Control* position.

If the command and control systems of several installations are designed as a unit, they communicate and interact, we have an *integrated command and control system*.
For the integrated command and control system on the platform, it will bring together the following main subsystems:

- Propulsion Control System - PCS
- Machinery Control and Monitoring System - MCMS
- Generator Control and Power Management - GCPM
- Integrated Navigation System - INS.

According to the above-mentioned, a *"measurement system for fuel flows and levels in tanks"* functionally falls into the control and monitoring subsystem of machinery installations, physically belongs to the ship's structural elements (fuel tanks) and mainly serves the boarding and fuel transfer facility (see figure 2).

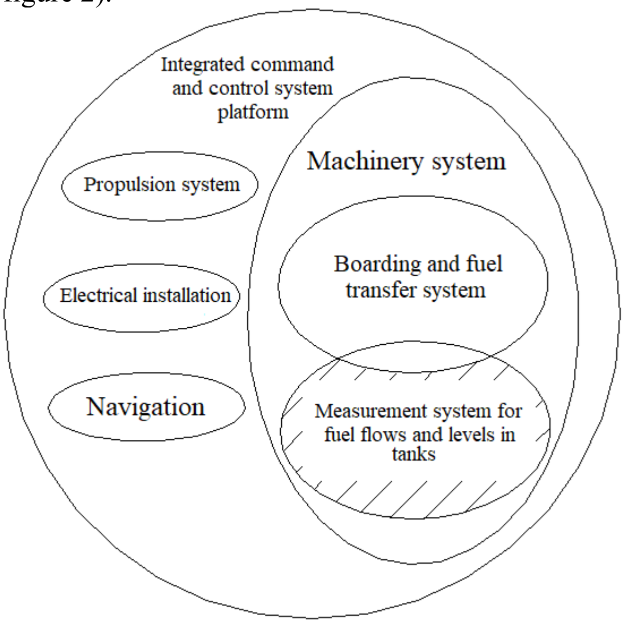

Figure 2 Application domain to the system for measuring fuel flows and levels in tanks

The system needs to ensure that the following general functional requirements are met:

- continuous measurement of fuel level in compensated and non-compensated fuel tanks
- flow measurement at the entrance to the supply tanks
- local indication of the measured value on each transducer
- digital data processing and their transmission on a data bus for centralized display through dedicated panels in the area of the supply and distribution tanks as well as in the ship's central command station.

The design of a modern measuring system capable of later integration into a control system of the entire platform demands the following hardware structural requirements:

- from the point of view of information processing, this must be an exclusively numerical (digital) system that allows practically unlimited integration of transducers
- the system architecture will be *horizontally and vertically open*, respectively:
    - horizontally, the system will have a structure *distributed* over the fuel tanks with individual PAC (Programmable Automation Controller) type signal acquisition and conditioning interfaces, supplemented by centralizing PACs, as well as numerical dialogue interfaces for LOP-type operation (Local Operation Panel)

- vertically, the system will be organized in three levels, namely:
  - level 1, local, transducer with individual PAC
  - level 2, equipped with PAC and LOP-type interface
  - level 3, equipped with a PC (Personal Computer) console located in the compartment of the PCM machine control station (MCS)
- for communication between level 2 and 3, the system will use a communication network (data bus).

The required general software functions will be:
- organization of database
- views of data in real time as well as their history evolution
- management of events and notifications
- information security on locations and access levels

Taking into account the later stages of development regarding the on-board integrated command and control systems, it is necessary to use an *integrated software platform* that allows the software integration of an array of different hardware and software equipment that is made by various manufacturers.
The system for measuring the flow rates and fuel levels in the tanks will replace and/or complement the current analogue measurement system on board.
The system will ensure the:
- ongoing measurement of the fuel level in the bow section
- ongoing measurement of the fuel level abaft
- ongoing measurement of the fuel level in the main engines
- measurement of the fuel flow
- indication of maximum levels in supply and distribution tanks, service and emergency tanks.

The existing conditions onboard the ship:
- the fuel tanks are closed, allowing for access only to the upper part and having free contact with the atmosphere
- liquid in use: diesel in non-compensated tanks, diesel and sea water in compensated tanks
- within compensated tanks, the volume of diesel consumed is continuously replaced by sea water, in both cases the level of diesel is of interest.

3. Preliminary allocation of technical requirements

3.1. Specific technical and tactical requirements
The system for measuring the flow rates and fuel levels in the tanks will ensure the following functions:
- in compensated tanks, continuous measurement of the diesel fuel level at the interface with sea water over a range of 0 – 2 m
- in non-compensated tanks, continuous measurement of the free level of diesel over a range of 0 – 2 m
- in service tanks, continuous measurement of the free level of diesel over a range of 0 – 4 m
- signalling that a maximum level of 75% of the measurement range has been reached for supply and distribution tanks, service and emergency tanks
- flow measurement at the entrance to the two supply and distribution tanks, forward and abaft, having the following characteristics: 8.5 bar, 720 m3/h, D = 200 mm
- flow measurement at the entrance of helicopter fuel tanks, having the following characteristics: 3 bar, 200 m3/h, D = 90 mm

- local indication of the value measured on each transducer
- numerical data processing and its transmission on a data bus for:
  - the centralized display of the levels, through dedicated panels in the area of the fuel tanks, as well as the calculation of the build-up in the diesel volume
  - monitoring the functional parameters in the PCM machine control station via:
    - an intuitive presentation on the control monitor in the form of a dedicated panel that will intuitively show the structure of the installation with the optical display of the functional states, the numerical values of the essential parameters associated with the dynamics of the corresponding bar graphs
    - a visual and sound alarm for maximum levels
    - damage diagnosis and alarm history
    - recording trends of acquired values.

3.2. Technical hardware requirements

3.2.1. Type of information processing. The above-mentioned functions are carried out provided that hardware structural requirements ensure a possible further development by taking over command and control functions for the boarding and fuel transfer installation.
In this respect, the suggested system must be an exclusively numerical (digital) system, which is the only current technical solution that allows it

- virtually unlimited integration of transducers
- real-time monitoring of parameters and timely decision-making and command.

3.2.2. System architecture. An open horizontal and vertical architecture will be adopted, namely:

- horizontally, the system will have a *distributed structure* composed of:
  - process transducers with output in unified signal, with safety barriers upon reaching the area of a risk of explosion
  - smart PAC (Programmable Automation Controller) process connection interfaces distributed forward and abaft, organized in modules, in order to acquire and condition a large number of signals and communication facilities
- vertically, the system will be organized on three levels, namely:
  - level 1, local, with the previously presented translators
  - level 2, located in the compartments of the filling lines at the bow and abaft, and equipped with PAC-type acquisition interfaces and LOP-type operation
  - level 3, supplied with a console equipped with a computer (PC), color monitor, keyboard, trackball, communication interfaces, which are located in the PCM compartment; the system will be designed so as to ensure a high degree of safety when running (redundant system), namely two data buses and a backup computer in the level 3 console.

3.2.3. Transducers. The system will use industrial hardware components that are available on the market. Constructive variants of anti-explosive type with certificate and naval approval are required.
Flow and level transducers:

- the electronic flow and level transducers will be “smart” on 2/4 wires, with a device for changing the measurement range
- at the transducer output, an analogue signal proportional to the measured variable is obtained, of 4...20 mA d.c. for 0...100 % of the measuring range, with the admissible limits of the output signal of 3.5 mA....22.5 mA d.c.
- the transducer will be provided with accessible terminals for “zero” adjustment, and with checking terminals intended for connecting the testing equipment
- the devices will be able to withstand exceeding the measurement range without implications on the accuracy when returning to the range

- the material of the part in contact with the fluid will be suitable for the measured medium/fluid
- the flow transducer will use non-invasive measurement techniques
- the minimum performances of the transducers will be the following:
  - accuracy: ± 0,25% of the measuring range, including the concentrated effect of linearity, hysteresis and reproducibility
  - linearity: ± 0.1% of the measurement range
  - reproducibilty: ± 0,05% of the measurement range against which it is benchmarked.

3.2.4. Smart process interfaces. The process interface equipment will have a modular construction with such types as:

- input/output modules for analogous signals
- digital input/output modules of free potential contact type, Vmin = 400 Vcc, Imin = 0,5 Acc) that will meet the following requirements:
  - the signals will not be influenced by the electromagnetic field
  - they will be protected against overvoltages (TEC 255-4 class II)
  - the A/D conversion accuracy will be at least 0.5% with a resolution of at least 12 bits
  - adjustable working range between –50% and +150% of the total measuring range
  - galvanic insulation and individual safety power supply for each transducer
- PAC-type modules with independent functions of combinational logic, data processing, Ethernet communication, watchdog and power upstate functions.

3.2.5. Communication console. The monitoring console, as the main equipment for interfacing with the human operator, will consist of the process computer, the color display, the keyboard and the printer, and will meet the following technical requirements:

- *the PC-type process computer* will be equipped with:
  - the central unit will have a state-of-the-art microcontroller with a clock frequency of at least 3.2 GHz, functioning as a multitasking operating system in real time; the maximum CPU load will be 70%
  - the central unit will be equipped with a redundant function in the event of defects; the communication module will also be redundant
- *the display* will show:
  - the process variables in several different formats for selection by the operator
  - the graphic images which will be interactive and will indicate the measurements in real time, and the current state (A / M, Closed / Open, ON / OFF, Failure)
  - the images will be obtained by operating max. 3 keys or specialized buttons
  - the response time to change the image will not exceed 1.5 s, and the duration of the update cycle will be less than 1 s
  - the lists of warning signals and events will be provided as standard images, and any elements in the system may be selected, including input / output signals
  - the screen will be of at least 53 cm, with high resolution, color
- *the printer* will meet at least the following requirements:
  - to make copies of the display, including lists, process diagrams and curves of the parameters of the installations;
  - speed: minimum 120 characters/second; 9.5 pages/min. color; 11 pages/min. black & white
- *the keyboard* will be central alpha-numeric, with dedicated keys and switches, and will ensure:
  - access to images selected on the display

- command execution on the process elements, selection of adjustment functions, changes in the reference values, selection of the operating modes, parameter tuning the parameters, etc.

3.2.6. Communications system - data bus. For horizontal and interlevel communication, the system will use a communication network (data bus) that meets the following technical requirements:

- optical fiber cable will be used redundantly arranged in the form of two separate networks: one on the starboard and the other one on the port side
- the mode of data transmission will be double channel oriented towards the transmitter
- the communication network will be provided with effective features for continuous checking, in order to avoid transmission of erroneous messages
- a standard IEEE-802 Ethernet TCP/IP protocol will be used, which will ensure the open nature of the system
- the data transmission speed will be 100 Mbit/s

3.3. Technical software requirements

Ţinând seama de posibile dezvoltări ale sistemului pentru preluarea de informaţii de la alte instalaţii, sunt necesare următoarele cerinţe software generale: Taking into account potential system developments in terms of information retrieval from other installations, the following general software requirements are to be met:

- the use of an *integrated software platform* that allows for the software integration of a wide range of different hardware and software equipment that are made by various manufacturers
- to ensure real-time control over the process
- to allow making changes easily, according to the requirements of application change or equipment replacement (such as type or supplier)
- to use a commercially accessible programming language, homologated, and of great flexibility in the development of the application
- to allow running application programs, regardless of their developing environment, and suitable for an architecture that is distributed at a high degree of security
- the possibility to modify the parameters of the control functions while running and without process interruption

On the hardware structural levels, the software requirements can be formulated as follows:

- at level 1, local, the smart process interfaces (PAC) that ensure data acquisition will use the programs made by the manufacturing companies, and will have network modules and OPC (OLE for Process Control) type programs
- at level 2, specialized SCADA (Supervisor Control and Data Acquisition) software will be used, with programming entirely oriented to objects and events that will allow the redundant connection of two computers
- this decentralized software concept is open and flexible allowing modular design and the possibility of further expansion as well as operation in greater safety.

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