Method or System for Optimizing Fuel Efficiency in a Vessel

TECHNICAL FIELD

[001] This invention concerns a method or system for optimising fuel efficiency. Particularly, the invention provides for method or system for optimising fuel efficiency in a marine vessel.

[002] The invention has been developed primarily for use in a marine vessel and will be described hereinafter with reference to this application. However, it will be appreciated that the invention is not limited to this particular field of use.

BACKGROUND ART

[003] In recent years, the price of crude oil has soared to record highs, leading to greater emphasis on fuel saving measures, particularly in marine vessels where significant quantities of fuel are utilised for each operation. It is well known that a vessel travelling with a less than optimal draft, trim or heel, generally consumes more energy than one with travelling at optimal or close to optimal draft, trim or heel and thereby requiring more fuel for consumption. There has therefore been a greater emphasis in manipulating these parameters to provide optimum draft, trim and heel that will provide greater fuel efficiency but yet acceptable safety level leading to significant cost savings in fuel consumption.

[004] Currently, one of the known methods of optimizing fuel efficiency in vessels utilise the lowest constant speed of the vessel for a specific delivery schedule. However, this method does not factor in the physical loading condition of the vessel which may differ between voyages. For example, the cargo may be loaded in various areas of the vessel such that the weight distribution differs, leading to the vessel having a positive or negative trim or an uneven heel. To counter this uneven weight distribution, vessel operators normally adjust the ballasting tanks in a vessel to ensure stability of the vessel. Proper ballasting of the vessel is largely based on the experience of vessel operators and it is common for vessel operators to factor in a large safety margin to ensure the vessel is stable and safe at sea. This leads to the vessel consuming more than the optimum level of fuel required for the specific delivery.

[005] It is known that the fuel consumption of a vessel is directly related to the resistive friction of the hull, against the surrounding water. The resistive friction of the hull is related to the amout of surface area of the hull in contact with the surrounding water. The amount of surface area of the hull in contact with the surronding water is related to the draft of the vessel. Thus to reduce the fuel consumption, it is therefore ideal to reduce the draft of the vessel.

[006] Most vessels, particularly those designed for carrying large amounts of cargo, may be fitted with a computer program such as a loading computer software specifically for calculating the stability of the vessel. These calculated stability may be in the form of parameters like VCG, TCG, draft, trim and heel from amongst others. These calculations are based on the cargo loading and tank

volume levels of the vessel, amongst others the ballast tank levels in a vessel. Manipulating ballast tank levels in a vessel, for example, by reducing the amount of liquid within certain ballast tanks in the vessel, will lead to a decreased draft, and thereby less fuel consumed. However, while a decreased draft will lead to greater fuel efficiency, safety of the vessel may be compromised as it is now less stable and more prone to capsize. Although optimal draft curves of specific hull forms based on international standards are widely available, due to the varying loading condition of the cargo leading to uneven weight distribution throughout the vessel and the dynamic variation of the optimal draft and trim values with the vessel loading , it is difficult for vessel operators to accurately and safely manipulate the ballast tank levels to achieve an optimal draft or trim.

[007] Relying on experience of the vessel operators and providing a large safety margin to counter this is unlikey to lead to fuel consumption efficiency. There is therefore a need to provide for improved methods for increasing fuel efficiency by effectively manipulating these above-mentioned parameters.

[008] Any discussion of the prior art throughout the specification should in no way be considered as an admission that such prior art is widely known or forms part of the common general knowledge in the field.

SUMMARY OF DISCLOSURE

[009] It is an object of the present invention to provide an improved method for optimising the fuel consumption of a marine vessel.

[010] It is an object of the present invention to provide an improved method for increasing the efficiency of fuel consumption in a marine vessel.

[011] It is an object of the present invention to overcome or ameliorate at least one of the disadvantages of the prior art, or to provide a useful alternative.

[012] Other objects and advantages of the present invention will become apparent from the following description, taken in connection with the accompanying drawings, wherein, by way of illustration and example, an embodiment of the present invention is dislcosed.

SUMMARY OF THE INVENTION

[013] According to a first aspect of the invention, there is provided a method for optimising fuel efficiency in a marine vessel comprising the steps of:

(a) Retrieving first operational data of the vessel from a main processor;

(b) Comparing first operational data with first optimum data to obtain a first variance;

(c) Automatically adjusting one or more ballast tank pairs of the vessel based on the first variance to obtain a computed draft of the vessel;

(d) Proceeding with step (a) if the computed draft is not equivalent to optimum draft;

(e) Retrieving second operational data based on the computed draft obtained in step (c) from the main processor;

(f) Comparing second operational data with second optimum data to obtain a second variance;

(g) Automatically adjusting one or more ballast tank pairs of the vessel based on the second variance to obtain a computed trim of the vessel;

(h) Proceeding with step (e) if the computed trim is not equivalent to optimum trim;

(i) Outputting suggested criteria to the user for optimising the fuel efficiency of the vessel.

[014] According to an embodiment of the invention, the method further comprises the step of verifying that the computed draft and the computed trim is within safety limits of vessel stability and stress.

[015] Preferably, the suggested criteria of step (i) includes a recommendation to adjust the volume of liquid of the one or more ballast tank pairs selected.

[016] Preferably, the recommendation to adjust the volume of liquid includes increasing or decreasing the volume of liquid to the one or more ballast tank pairs selected.

[017] Preferably, the suggested criteria of step (i) includes percentage in terms of power saved based on the recommendation to adjust the volume of liquid to the one or more ballast tank pairs selected.

[018] Preferably, the first operational data includes current vertical center of gravity of the vessel.

[019] Preferably, the first optimum data includes the allowable vertical center of gravity of the vessel.

[020] Preferably, the first optimum data includes a predetermined range of vertical center of gravity that is close to the allowable vertical center of gravity of the vessel.

[021] Preferably, the first optimum data includes the maximum vertical center of gravity of the vessel.

[022] Preferably, the first optimum data includes a predetermined range of vertical center of gravity that is close to the maximum vertical center of gravity of the vessel.

[023] According to yet another embodiment of the invention, the first variance is the absolute difference between vertical center of gravity and allowable vertical center of gravity of the vessel.

[024] According to yet another embodiment of the invention, step (b) further comprises:

(i) Sending an alert to user if the first variance is negative; or

(ii) Comparing the first variance with a first predetermined range if the first variance is positive.

[025] Preferably, the optimum draft is achieved if the first variance is within the first predetermined range.

[026] According to yet another embodiment of the invention, step (c) will initiate if the first variance is positive and falls outside of the first predetermined range.

[027] Preferably, the first predetermined range is within the range of 5% of the maximum allowable VCG curve.

[028] According to another embodiment of the invention, step (c) further comprises the following steps:

(a) retrieving second operational data of the vessel from the main processor;

(b) Comparing second operational data with a second optimum data to obtain a second variance;

(c) Identifying one or more ballast tank pairs for deballasting based on the second variance so that the computed draft is equivalent to the optimum draft.

[029] According to yet another embodiment of the invention , the second operational data includes the current trim of the vessel.

[030] According to yet another embodiment of the invention, the second optimum data includes the optimum trim data at a specific speed and displacement.

[031] According to yet another embodiment of the invention, the second variance is the absolute difference between the current trim of the vessel and the optimum trim.

[032] According to yet another embodiment of the invention, identifying one or more ballast tank pairs for deballasting further comprises the following steps:

(a) Selecting the aft quadrant tank pairs when the second variance is positive; or

(b) Selecting the fore quadrant tank pairs when the second variance is negative.

[033] According to yet another embodiment of the invention, selecting the aft quadrant tank pairs further comprise the following steps:

(i) Selecting available aft wing tank pairs; or

(ii) Selecting aft double bottom tank pairs; or

(iii) Selecting a combination of aft wing tank and aft double bottom tank pairs, wherein the selection of any of the above (i) to (iii) depends on the contribution of each of the above (i) to (iii) to the first variance.

[034] According to yet another embodiment of the invention, selecting the fore quadrant tank pairs further comprise the following steps:

(i) Selecting available fore wing ballast tank pairs; or

(ii) Selecting fore double bottom ballast tank pairs; or

(iii) Selecting a combination of fore wing ballast tank pairs and fore double bottom ballast tank pairs, wherein the selection of any of the above (i) to (iii) depends on the contribution of each of the above (i) to (iii) to the first variance.

[035] According to yet another embodiment of the invention, the selected ballast tank pairs are stored in a second main processor.

[036] According to yet another embodiment of the invention, step (g) of the above further comprises the following steps:

(a) Identifying one or more ballast tank pairs for deballasting based on the results of the second variance; and

(b) Selecting forward wing ballast tank pairs when the second variance is negative; or

(b) Selecting aft wing ballast tank pairs when the second variance is positive.

[037] According to yet another embodiment of the invention, selecting forward wing ballast tank pairs includes deballasting the forward wing ballast tank pairs or ballasting the aft wing ballast tank pair.

[038] According to yet another embodiment of the invention, selecting aft wing ballast tank pairs includes deballasting the aft wing ballast tank pairs or ballasting the aft wing ballast tank pairs.

[039] According to yet another embodiment of the invention, the computed trim is computed by the main processor from the ballasting and deballasting of the wing ballast tank pairs of step (g).

[040] According to yet another embodiment of the invention, the selected wing ballast tank pairs are stored in the second main processor. Preferably, a further step of comparing the computed trim with the optimum trim is made to determine if the computed trim value is close to or equal to the optimum trim.

[041] Preferably, if the computed trim is not close to or equal to the optimum trim, step (e) will be initiated.

[042] According to a second aspect of the invention, there is provided a system for optimising fuel efficiency of a marine vessel, the system comprising a controller configured to electronically retrieve operational data of a vessel from a main processor, said controller configured to electronically compare the operational data with optimum data, said controller configured to automatically adjust the ballast tank pairs of the vessel based on the comparing to optimise the fuel efficiency of the marine vessel.

[043] According to a third aspect of the invention, there is provided a program storage device readable by a machine, embodying at least one program of instructions executable by the machine to perform a method of optimising fuel efficiency of a marine vessel according to the above.

LIST OF ACCOMPANYING DRAWINGS

[044] For a better understanding of our invention, we shall refer to the following drawings and their detailed description that follows as exemplary of a specific embodiment of our invention, in which:

[045] FIGURE 1 is a block diagram of a system for optimising fuel efficiency in a marine vessel in accordance with the present invention;

[046] FIGURE 2 is a maximum and allowable Vertical Center of Gravity (VCG) curve against the draught of a specific hull form in accordance with the present invention;

[047] Figure 3 is a optimum trim curve of a specific hull form in accordance with the present invention;

[048] Figure 4 is a flow chart diagram of a method for optimising fuel efficiency in accordance with the present invention;

[049] Figure 5 is a side view of a marine vessel showing the ballast tanks divided into quadrants in accordance with the present invention;

[050] Figure 6 is a top view of a marine vessel showing the ballast tank pairs in accordance with the present invention;

[051] Figures 7a, 7b, 7c are representations of trim conventions used based on current conditions of a vessel in accordance with the present invention;

[052] Figure 8 is a flow chart diagram for optimising draft of a vessel in accordance with the present invention;

[053] Figure 9 is a flow chart diagram for selecting forward ballast tank pairs for optimising draft in accordance with the present invention;

[054] Figure 10 is a flow chart diagram for selecting aft ballast tank pairs for optimising draft in accordance with the present invention;

[055] Figure 11 is a flow chart diagram for optimising trim of a vessel in accordance with the present invention;

[056] Figure 12 is a flow chart diagram for ballasting wing ballast tank pairs in accordance with the present invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[057] The present invention discloses a method and system for optimising fuel consumption in a marine vessel. Accordingly, the elements and steps have been represented by conventional elements and steps in the drawings, showing only the specific details that are pertinent to the present invention so as not to obscure the

disclosure with structural details that will be readily apparent to those skilled in the art having the benefit of the description herein.

[058] The system of the present invention comprises a controller that integrates one or more marine vessel systems to improve the fuel effiency of the marine vessel. A main processor provides data processing and software execution functions for performing the analysis and recommendation to the end user for improvements in the fuel efficiency. In a preferred embodiment, the main processor may comprise any of the known microprocessor devices, for example, a Pentium or Celeron processor. In one embodiment, the main processor may be provided with a Windows based functionality although a plurality of other operating systems (such as LINUX) could also be used. Additionally, the main processor includes the necessary associated devices such as non-volatile and volatile memory, a graphics processor, an audio processor, device drivers and bus protocol interfaces. The main processor can also function as a general purpose computer for executing software programs.

[059] The main processor can operatively communicate with one or more marine vessel systems over one or more communication buses to be described further below, receiving operational data from the vessel system for processing, manipulation and analysis. The main processor can also communicate with another main processor of the same described above which in turn communicates with the marine vessel systems. Examples of these marine vessel systems may include system tank gauging, remote control valves and pumps and draft sensors.

The results of the data processing operation by the main processor produces control signals provided as control inputs to the relevant vessel system over the one or more communication buses. Alternatively, the results of the data processing operation may be communicated via a display interface on either the main processor or a second main processor which allows the end user to view information regarding the status of the marine vessel and to thereafter make the necessary adjustments to improve the fuel efficiency of the vessel.

[060] A preferred embodiment of the present invention utilises communication between a main processor and a second main processor, as shown in **Figure 1**. The second main processor has similar characteristics and functions of the main processor. A preferred embodiment of the main processor uses a loading computer program which obtains operational data of the vessel through one or more of the vessel systems. The operational data may be obtained through operational data sensors located at strategic locations of the vessel through input-output devices or manually input by a user into the loading computer program. The communication devices of the operational data sensors with the main processor will not be discussed in detail for the purposes of this invention. Some examples of the operational data used in the preferred embodiment of the present invention include the draft, trim, vertical centre of gravity (VCG), heel and/or bending moment data. A preferred embodiment of the loading computer program used in the main processor may be Easeacon, which is known and readily available, and calculates and plans the loading of the cargo or stores of the vessel. The loading

computer program performs calculations and analysis to ensure the stability of the vessel at varying cargo loading conditions at each port of call.

[061] The main processor communicates bi-directionally with the second main processor over a communication bus with one or more serial communication ports for providing signal paths over the bus. A preferred embodiment of the present invention uses a duplex serial RS232 communication cable. This allows the operational data to be bi-directionally communicated from the main processor to the second main processor.

[062] The second main processor also contains a controller capable of receiving and transmitting information to and from the loading computer program stored in the main processor. The controller provides instructions to the loading computer program to perform calculations on operational data obtained from the main processor or means of comparison with data embedded in the memory.

[063] It is well known that hull forms of vessels are not of uniform shapes. As a result, it is difficult to calculate the surface area of a hull form, particularly the surface area of a hull form in contact with water. The optimisation of fuel efficiency of a vessel in the present invention utilises the optimum draft and trim curves data for a specific hull form as basis for optimising the fuel efficiency.

[064] **Figure 2** shows a maximum and allowable Vertical Centre of Gravity (VCG) curve against the draught (or draft) of the vessel (in metres) of a specific hull form. In a preferred embodiment of this invention, the maximum VCG

(VCG_{max}) curve and the allowable VCG curve (with damage stability requirement) are based on International Maritime Organization (IMO) standards and are specific to a hull form. The maximum VCG curve and allowable VCG curve provides indication of safe operation and stability of a vessel. A VCG that lies below the maximum and allowable VCG curves will provide an indication of safe operation and stability. However, the use of this curve is not limited to the present invention and is simply an example of the various types of maximum and allowable VCG curves available. Generally, a user who wishes to improve the fuel or power efficiency of the vessel performs calculations based on the curve data such as that shown in figure 2 and will use the allowable VCG curve data as a basis for improving fuel efficiency. The allowable VCG curve is used because it takes into account the safety limits of the vessel and a reading that is close to this curve will generally indicate to the user that the vessel is running at close to optimal efficiency.

[065] **Figure 3** shows an example of a preferred embodiment of the optimum trim curve data. The optimum trim curve data is based on results of model tests performed in a wave laboratory at various speeds for a specific hull form. The results of these model tests for a specific hull form provides an indication of the optimum trim at the corresponding displacement and current or planned speed. These model tests are performed by running a scaled down hull form through various simulated sea conditions at various speeds. The optimum trim in this case is the minimum trim to reach within 0.5% of the optimal power usage of the vessel.

[066] The optimum trim curve is plotted with the trim (in degrees) against the displacement (in tonnes). Each curve shown in the graph indicates the optimum trim at a specific speed and displacement. For example, if the displacement of the vessel is 14,500 tonnes and the current or planned speed is 19 knots, the optimum trim obtained from this curve would be approximately +0.1 degrees.

[067] A method for optimising fuel efficiency in a vessel in accordance with the present invention is depicted in **Figure 4**. The method involves, firstly, performing a draft optimisation of the vessel. This is shown in figure 4 as checking the vertical center of gravity (VCG) of the vessel at current loading condition. This is followed by adjusting one or more ballast tank pairs of the vessel by deballasting the selected one or more ballast tank pairs. The VCG of the vessel after deballasting the selected ballast tank pairs are computed and compared with the optimum draft. If the computed draft (from the VCG of the vessel obtained earlier) is not close to the optimum draft, the draft optimisation steps will be repeated until it reaches the optimum draft or to a predetermined range close to the optimum draft. Further details on the draft optimisation will be discussed hereinafter.

[068] Once the optimum draft or a predetermined range close to the optimum draft is attained, trim optimisation of the vessel will be initiated using the computed draft (as obtained from the VCG of the vessel) attained from the draft optimisation step. The purpose of the trim optimisation is to further optimise efficiency of the vessel by optimising the trim. The current trim of the vessel is retrieved from the main processor based on the computed optimum draft from the previous step. A

process of selecting ballast tank pairs for deballasting or ballasting is initiated. If the computed trim is not close to the optimum trim, the trim optimisation step will be performed until it reaches the optimum trim or to a predetermined range that is close to the optimum trim. Once the computed trim has been optimised to a desired level, the controller will initiate checking of the computed optimum draft and trim to ensure that they meet the safety criteria. Upon meeting the safety criteria, the controller will provide a recommended solution based on the optimisation process above. Details of the checking will be discussed hereinafter.

[069] The final step initiates ouput to the user suggested criteria for optimising the fuel efficiency. In operation, this involves suggesting to the user via a display interface, the final ballasting condition of the ballast tanks of the vessel in terms of the volumes to ballast the tank vessels to increase the fuel efficiency of the vessel. This can take the form of a graphical mimic of the ballast control panel or a tablular display of the ballasting condition. The user will then implement the suggested ballasting conditions on the vessel.

[070] In the context of this invention, the use of the words 'optimisation', 'optimise' or 'optimised' refer to the steps required to bring a certain key parameter to an optimal value or a predetermined value or range which is close to the optimum value.

[071] The draft of a vessel is related to the volume of liquid in the ballast tanks. As mentioned before, the draft of the vessel refers to the depth of vessel hull

beneath water which is related to amount of surface area of the hull which is in contact with the water.

[072] A plurality of input devices or draft sensors may be located at various locations on the perimeter of the hull of the vessel for measuring the draft. Typically, marine vessels above a certain capacity or loading contain a plurality of ballast tanks located in various locations of the hull of the vessel to maintain stability of the vessel. It is to be understood that the type of material or fluid used for the ballast tanks is not limited to liquids. For simplicity, the level of fluid in the ballast tanks will be referrred to as the ballast level hereinafter. An input device or sensor may be attached to each of the ballast tanks so as to allow the control unit of the vessel to determine the existing ballast levels at a given cargo loading condition of the vessel.

[073] **Figure 5** shows a side view of a typical vessel showing the ballast tanks divided into 4 quadrants. For the purposes of the present embodiments, the term 'ballast tanks' and 'tanks' are the same and will be used interchangeably. For simplicity, quadrant A refers to wing tanks in the aft portion of the vessel or aft wing tanks, quadrant B refers to double bottom tanks in the aft portion of the vessel or aft double bottom tanks, quadrant C refers to wing tanks in the fore portion of the vessel or forward wing tanks and quadrant D refers to double bottom tanks in the fore portion of the vessel or forward double bottom tanks. It is known that adjusting tanks on the the fore and aft of the vessel will have different effects based on the loading condition of the vessel. **Figure 6** is a top view of a typical

vessel showing how the tanks may be separated. For the purposes of optimising fuel efficiency, port and starboard ballast tanks in pairs are used for performing fuel optimisation. This is because adjusting the port and starboard ballast tank in pairs has less effect on the heeling and hence the stability of the vessel. This results in less changes to the loading condition at the final stage where heeling optimisation takes place to achieve stability of the vessel.

[074] In operation, reducing draft of the vessel is performed by simulating the removal of as much ballast liquid as possible to simulate a vessel with a lighter draft and hence lower the contact area of the surface of the hull with the surrounding water. This is done by setting the volume of the required tank to "0" or emptying the ballast tank pair.

[075] **Figures 7A, 7B and 7C** establishes the trim conventions used based on a current condition of a vessel. The trim of a vessel refers to the condition of the vessel that is loaded and balanced properly with respect to the waterline. The trim also refers to the angular displacement of the vessel about the waterline. **Figures 7A, 7B and 7C** show an overview of the various types of trim of a vessel. The optimum trim line as shown on **Figures 7A, 7B and 7C** is the trim of the vessel where the vessel operates at optimum efficiency due to its trim condition. It is to be understood that the optimum trim of the vessel differs from vessel to vessel and is dependent, amongst others, on the loading condition, speed of travel, hull form and weight of the boat. As explained above, the optimum trim curve as provided in Figure 3 is a representation of the optimum trim curve data for a specific hull form. If the current trim of the vessel is more than the optimum trim, as shown on **Figure**

7B, this indicates that the trim value is positive (or it is trim aft) and the vessel stern is submerged deeper than the bow in relation to the optimum trim line. If the current trim of the vessel is less than the optimum trim, as shown on Figure 7C, this indicates that the trim value is negative (or it is trim fore) and the vessel bow is submerged deeper than the stern in relation to the optimum trim line. The term 'current trim' in the context of this invention defines the trim at the current loading condition of the vessel.

[076] **Figure 8** shows a detailed overview of the flow chart for optimising the draft of the vessel according to an embodiment of the present invention. The objective of this step is to reduce or to optimise the draft of the vessel. This is done by obtaining the current or planned loading condition of the vessel from the loading computer program. The current or planned loading condition of the vessel may be obtained by retrieving this data from the main processor. The current or planned loading condition of the vessel preferably includes operational data such as the draft, trim, vertical center of gravity, heel, bending moment and/or ballast tank information data.

[077] The first step is to obtain the current VCG (from the operational data) of the vessel. In operation, the current VCG of the vessel is obtained from the loading computer program in the main processor. The current VCG is the VCG of the vessel at the current loading condition. The controller will next compare the current VCG obtained with the allowable VCG (damage stability requirement) at the same draft (as shown in Figure 2) so as to obtain a variance. The variance is the

absolute difference between the maximum VCG and the current VCG at the same draft.

[078] Depending on the variance obtained, one of 3 scenarios will occur. If the variance is negative, this indicates that the value of the current VCG is numerically higher than the value of allowable VCG curve. Such a situation would indicate that the vessel is not stable and this will prompt or alert the user to replan the loading condition of the vessel. If the VCG variance is positive and within a predetermined range that is close to the optimum at this draft, this will prompt the controller to initiate end of the draft optimisation process as the objective of the process has been achieved. The predetermined range, in the context of this invention, is within 5% of the maximum VCG curve. If the variance is positive and is out of the predetermined range close to the optimum VCG, draft optimisation will continue to further bring the draft closer to the optimum.

[079] The next step is to identify suitable ballast tank pairs or combinations of ballast tank pairs for deballasting. The term deballasting refers to the removal of liquid from the ballast tank. Once the suitable tank pairs have been identified and adjusted, this information or ballast tank data is sent to the main processor containing the loading computer program whereby the vessel's data such as VCG is recomputed based on the information sent. The vessel's data such as the current VCG and draft data will be sent back to the controller and subsequently compared with the optimum VCG curve as provided in **Figure 2**. Using the draft of the vessel obtained from loading computer in the deballasting step, the optimum VCG data at that draft is– obtained from the allowable VCG (damage stability

requirement) and compared with the current VCG of the vessel. This process of obtaining the vessel's VCG and draft, comparison with the optimum VCG curve , computation of the optimum VCG and variance is iterative until the current VCG is equivalent to the optimum VCG or a predetermined range close to the optimum VCG The optimum draft value at the optimum VCG is then stored in the main processor's database as an optimum draft to be used for further calculations.

[080] When the variance is positive and out of range of the predetermined optimum draft range, the next step is to identify suitable ballast tank pairs for deballasting so as to adjust the selected ballast tank pairs and to bring the computed draft to the optimum draft or within the predetermined range close to the optimum draft. The ballast tank pairs may for example be numbered from the front of the vessel to the aft of the vessel, the first tank set may be the fore peak tank, the first port and starboard tank pair and the second port and starboard tank pair, etc. To identify suitable ballast tank pairs for deballasting, the current trim is used and compared with the optimum trim. As mentioned above, the current trim is part of the operational data obtained from the loading computer program of the main processor. The optimum trim data is obtained from the optimum trim data curve of **Figure 3**.

[081] Since the displacement of the vessel (and therefore current draft) is known previously, the variance of the current trim and optimum trim will result in two scenarios. As described above, a positive trim indicates that the aft of the vessel is heavier and a negative trim indicates that the fore of the vessel is heavier. Each of these two scenarios will be explained in detail in hereinafter.

[082] **Figure 9** shows a flow chart detailing the steps which are taken when a positive trim is obtained from the draft optimisation process. To identify suitable ballast tank pairs for deballasting, a check is first performed on the aft wing tank quadrant (i.e. quadrant A of **Figure 5**) of a vessel since the aft of the vessel is the heavier end. The controller will next decide if there are any aft wing tanks available for deballasting. If no aft wing tanks are available for deballasting, the controller will proceed with the next step of performing checks on the aft double bottom tank pairs (quadrant B of Figure 5) as described in the next section. If yes, and there are aft wing tanks available for deballasting, the ballast tank pairs at the furthest end of the aft portion of the vessel will be deballasted first, followed by the next ballast available ballast tank pair till it reaches the center of the vessel. The deballasting step simulates the removal of as much liquid from the ballast tank pair to simulate a vessel with a lighter draft. The simulation is performed by setting the volume of the required ballast tank pair to "0". Once this is done, the aft ballast wing tank pair's contribution to the VCG is obtained and compared with a predetermined range. The contribution to the VCG, which will be used hereinafter in the context of an embodiment of this invention, refers to the variance which is the absolute difference between maximum VCG and the current VCG at the same draft. Once all the ballast tank pairs' contribution to VCG has been obtained, the ballast tank pair having the greatest contribution to VCG and within the predetermined range will be selected and stored in the memory or database. The ballast tank pair selected will in effect be the pair that brings the draft to the

optimum draft or within the predetermined range close to the optimum draft once it has been deballasted.

[083] If none of the aft ballast wing tank pairs are able to bring the draft to the optimum draft or within the predetermined range close to the optimum draft when deballasted, the controller will proceed to perform the same check as described in the preceding paragraph on the forward wing tank pairs (Quadrant B in Figure 5). If no aft double bottom tank pairs are available for deballasting, the controller will proceed with performing the check on a combination of aft wing tank pair and aft double bottom tank pair for draft optimisation. If aft double bottom tank pairs are available, the controller will allow the aft wing tank pair set which have been selected from the previous step to remain deballasted. It will then proceed to simulate the deballasting of the aft double bottom tank pairs in a similar way to the aft wing tank pair, that is, to start from the furthest to the aft portion to the central portion of the vessel. Once this is done, each of the aft deballasted double bottom tank pair's contribution to the VCG is obtained and compared with a predetermined range. Once all the deballasted aft double bottom tank pairs' contribution to VCG has been obtained, the aft double bottom tank pair having the greatest contribution to VCG and within the predetermined range will be selected and stored in the database.

[084] In the previous step when no aft double bottom tank pairs are available and a combination check is performed on the aft wing tank pairs and aft double bottom tank pairs, a combination check is performed for the purpose of finding a

better solution in which the draft can be optimised when 2 or more tank pairs are simultaneously adjusted. The combination check of the tank pairs that can be deballasted together is performed by first storing the available tank pairs for combination checking in a one dimensional programming memory array. For example, if the first wing tank, third wing tank, seventh wing tank and aft peak tank can be deballasted, the array becomes a one dimensional array containing 4 values. The next step is a binary combination check on these four available tanks, emptying the combinations of tanks and sending this information to the loading computer program to obtain the vessel parameters which are then compared with the optimum data as described earlier.

[085] This is followed by a check on the fore wing tank pairs and fore double bottom tank quadrants (i.e. quadrants C and D of **Figure 5**) from the heavier end of the vessel to the lighter end of the vessel. The reason for performing the check first on the heavier end of the vessel to the lighter end is to adjust the draft and trim simultaneously in as few steps as possible in the optimisation process. The reason for first performing the ballast tank pair check on the fore wing tank quadrants is that adjusting the wing tanks result in less destabilization of the VCG than emptying a double bottom tank. This also results in bringing the draft closer to within a safe VCG range. After all the possible combination tanks are checked and no further suitable tank pairs can be deballasted, the current vessel condition having a draft value that is equivalent to the optimum draft or within a predetermined range close to the optimum draft will be stored in the controller and the next step will be to perform trim optimisation as shown in **Figure 11**.

[086] **Figure 10** shows a flow chart detailing the steps which are taken when a negative trim is obtained from the draft optimisation process. To identify suitable ballast tank pairs for deballasting, a check is first performed on the fore wing tank quadrant (i.e. quadrant C of **Figure 5**) of a vessel since the fore of the vessel is the heavier end. The controller will next decide if there are any fore wing tanks available for deballasting. If no, the controller will proceed with the next step of performing checks on the fore double bottom tank pairs (quadrant D of **Figure 5**). If yes, the ballast tank pairs at the furthest end of the fore portion of the vessel will be deballasted first, followed by the next ballast available ballast tank pair till it reaches the center of the vessel. The deballasting step simulates the removal of as much ballast water from the ballast tank pair to simulate a vessel with a lighter draft. The simulation is performed by setting the volume of the required ballast tank pair to "0". Once this is done, the fore ballast wing tank pair's contribution to the VCG is obtained and compared with a predetermined range. Once all the ballast tank pairs' contribution to VCG has been obtained, the ballast tank pair having the greatest contribution to VCG and within the predetermined range will be selected and stored in the database as an optimum solution. The ballast tank pair selected will in effect be the pair that brings the draft value to the optimum draft or within the predetermined range close to the optimum draft once it has been deballasted.

[087] If none of the fore ballast wing tank pairs are able to bring the computed draft to optimum draft or within the predetermined range close to the optimum draft

when deballasted, the next step will be to perform the same check as described in the preceding paragraph on the fore double bottom tank pairs (Quadrant D in **Figure 5**). If no fore double bottom tank pairs are available for deballasting, the controller will proceed with performing the check on a combination of fore wing tank pair and fore double bottom tank pair for draft optimisation. If fore double bottom tank pairs are available, the controller will allow the fore wing tank pair set which have been selected from the previous step to remain deballasted. It will then proceed to simulate the deballasting of the fore double bottom tank pairs in a similar way to the fore wing tank pair, that is, to start from the furthest to the fore portion to the central portion of the vessel. Once this is done, each of the fore deballasted double bottom tank pair's contribution to the VCG is obtained and compared with a predetermined range. Once all the deballasted fore double bottom tank pairs' contribution to VCG has been obtained, the aft double bottom tank pair having the greatest contribution to VCG and within the predetermined range will be selected and stored in the database as an optimum solution.

[088] In the previous step when no fore double bottom tank pairs are available and a combination check is performed on the fore wing tank pairs and fore double bottom tank pairs, the combination check is performed for the purpose of finding a better solution in which the computed draft can be optimised when 2 or more tank pairs are simultaneously adjusted. The combination check of the tank pairs that can be deballasted together is performed by first storing the names of the available tank pairs for combination checking in a one dimensional programming memory array. For example, if the first wing tank, third wing tank, seventh wing

tank and aft peak tank can be deballasted, the array become a one dimensional array containing 4 values. The next step is a binary combination check on these four available tanks, emptying the combinations of tanks and sending this information to the loading computer program to obtain the vessel parameters which are then compared with the optimum data as described earlier.

[089] This is followed by a check on the aft wing tank pairs and aft double bottom tank quadrants (i.e. quadrants A and B of **Figure 5**) from the heavier end of the vessel to the lighter end of the vessel. The reason for performing the check first on the heavier end of the vessel to the lighter end is to adjust the draft and trim simultaneously in as few steps as possible in the optimisation process. The reason for first performing the ballast tank pair check on the fore wing tank quadrants is that adjusting the wing tanks result in less destabilization of the VCG than emptying a double bottom tank. This also results in bringing the computed draft closer to the optimum draft. After all the possible combination tanks are checked and no further suitable tank pairs can be deballasted, the current vessel condition having a computed draft that is equivalent to the optimum draft or within a predetermined range close to the optimum draft is stored in the controller and the next step will be to perform trim optimisation as shown in **Figure 11**.

[090] **Figure 11** shows the trim optimisation flow chart according to a preferred embodiment of this invention. The computed draft from the draft optimisation process in the first operation is used for this trim optimisation step. If the current VCG is less than the maximum VCG, this will be indicated as anywhere below the

maximum VCG curve of Figure 2. This will also indicate that the controller will proceed to optimise the trim. If the current VCG is more than the maximum VCG, this will alert and prompt the user to return to the first step of draft optimisation (**in Figure 8**). The ballast tank pair condition from the first draft optimisation operation is checked to evaluate if the fore or aft is heavier by checking the current trim of the vessel against the optimum trim (against the optimum curve of **Figure 3**).

[091] For trim optimising, once the heavier of the fore or aft portion of the vessel has been identified, the trim optimisation will proceed with with the heavier end of the vessel. The reason for doing so has been described above. In contrast to the draft optimisation process, only the wing tanks are adjusted for trim optimisation as the double bottom tanks are usually either completely filled or completely emptied. For a vessel having a heavier fore portion, and as shown in **Figure 11**, two methods are used to optimise the trim. One method is to deballast the heavier fore end or the other is to ballast the lighter aft end to bring the vessel toward the optimum trim or to a predetermined range close to the optimum trim. For a vessel having a heavier aft portion, and as shown in **Figure 11**, two methods, one being to deballast the heavier aft end or the other is to ballast the lighter fore end to bring the vessel toward the optimum trim or a predetermined range close to the optimum trim. The process of trim optimisation preferably starts with the fore and aft peak tanks of the quadrant and work towards the center of the vessel as these tanks contribute the most to adjusting the trim of the vessel.

[092] The controller will send the ballasting or deballasting of the ballast tank pair data to the loading computer. The loading computer will compute the trim, providing the computed trim to the controller for comparison with the optimum trim. In the context of the present invention, the computed trim refers to the calculations performed by the loading computer based on the trim data post-ballasting or deballasting of the ballast tank pair. The computed trim will be assessed if it is equivalent to the optimum trim or within a predetermined range close to the optimum trim. If so, the trim optimisation process will end and the suggested criteria or recommendations will be shown to the user on a display terminal connected via the second main processor. Should the computed trim not be equivalent to the optimum trim or within a predetermined range close to the optimum trim, the process will be iterative and repeat the steps as above until the computed trim reaches the optimum trim or within a predetermined range close to the optimum trim. The amount of volume of liquid used to adjust the ballast tanks is termed a "step" and the size of this step is dependent on the difference between the computed trim and optimum trim. The larger the difference between these two values, the larger the size of the "step" or volume used to adjust the tanks.

[093] Preferably, for a difference in trim of about 5 degrees or more, the "step" or adjustment to the volume of the ballast tank is approximately 25% of the volume of the ballast tank. This is reduced to approximately 5% of the volume of the tank for a difference in trim of 2 degrees or more and finally approximately 1% of the volume of the tank for a difference in trim of 1 degree or more. Adjustments made in this manner will likely not reach the optimum trim, the difference in the trim is

checked based on the influence of the adjustment to see if the adjustment to the volume brings the trim closer to the optimum trim or adjusts the trim away from the optimum trim. If the adjustment to the volume of the tank brings the trim away from the optimum trim, a reverse step adjustment is made and the step size will be adjusted accordingly. If the adjustment is small or the difference to the trim is not significant or the reverse step adjustment is performed several times, trim optimisation process will end. The adjustment to the volume of the tanks occurs until the ballast tanks can no longer be adjusted. When this happens, the next available ballast tank is selected and the iterative adjustment continues. When there are no longer any available ballast tanks or the optimum trim is achieved, trim optimisation is complete. Once adjustment to trim is complete, a check will be initiated on the parameters to ensure they are within safety limits. The parameters for this check include the VCG and draft from the first draft optimisation process and the trim, heel and bending moment from the second trim optimisation process.

[094] The third and final operation will initiate the check on the heeling of the vessel. The check on the heeling of the vessel is for ensuring there is even heel of the vessel to ensure vessel stability (no excessive heeling of the vessel to port or starboard). Once adjustment to the heel is complete, a check will be initiated on the parameters to ensure they are within safety limits. The parameters for this check include the VCG and draft from the first draft optimisation process and the trim, heel and bending moment from the second trim optimisation process The check on heeling will not be described hereinafter as this is a standard routine

procedure conducted by mariners and a person skilled in the art would therefore be able to perform this routine check.

[095] Once the check on the heeling is completed, the estimated power saved is computed and presented to the user via a display interface of the main processor. The power savings achieved is computed by the main processor on the difference in displacement of water of the vessel from the initial loading condition before optimisation and the displacement of the vessel after optimisation. The displacement of water of the vessel is directly related to the draft of the vessel and the displacement of water may therefore be obtained by the draft of the initial loading condition and optimised draft. The percentage change of displacement of water of a specific hull form is related to the percentage change of the area of the specific hull form submerged in water. The power savings achieved is therefore an approximation and is presented as a percentage change from the initial loading condition displacement and the optimised displacement.

[096] In a preferred embodiment of the invention, a recommendation is made to the user via the display interface in terms of percentage of fuel saved. The recommendation also includes which of the available ballast tank pairs of the vessel to deballast to achieve the power savings and therefore fuel efficiency of the vessel. The user, based on the recommendation presented, may manually adjust the selected ballast tank levels via the existing ballasting control panel.

[097] The method is designed to recommend to the user the optimised loading condition based on the selected speeds of the vessel as defined by the user at the

beginning of optimisation. The draft optimisation of the vessel is largely based on the loading condition of the vessel and the available ballast tanks for adjustment. As these two parameters remain constant with the speed of the vessel, at any loading condition, only one draft optimisation may be performed, even though several speeds may be selected at the beginning of optimisation. The trim optimisation operation is performed from the same optimised draft with various different optimum trim curves at various speeds.

[098] The aforesaid methods may be implemented as a software algorithm which, in turn, may be provided as a machine monitoring and control system incorporating at least one of data acquisition means, data processing unit, software for implementing aforesaid methods, and command centre console comprising display unit and control actuating means.

[099] Although preferred embodiments have been depicted and described in detail therein, it will be apparent to those skilled in the art that various modifications, additions, substitutions and the like can be made without departing from the spirit of the invention and these are therefore considered to be within the scope of the invention.

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CLAIMS

1. A method for optimising fuel efficiency in a marine vessel, the method comprising the steps of:

(a) Retrieving first operational data of the vessel from a main processor;

(b) Comparing first operational data with first optimum data to obtain a first variance;

(c) Automatically adjusting one or more ballast tank pairs of the vessel based on the first variance to obtain a computed draft of the vessel;

(d) Proceeding with step (a) if the computed draft is not equivalent to optimum draft;

(e) Retrieving second operational data based on the computed draft obtained in step (c) from the main processor;

(f) Comparing second operational data with second optimum data to obtain a second variance;

(g) Automatically adjusting one or more ballast tank pairs of the vessel based on the second variance to obtain a computed trim of the vessel;

(h) Proceeding with step (e) if the computed trim is not equivalent to optimum trim;

(i) Outputting suggested criteria to the user for optimising the fuel efficiency of the vessel.

2. The method according to claim 1, further comprising the step of verifying the computed draft and the computed trim is within safety limits of vessel stability and stress.

3. The method according to claim 1, wherein the suggested criteria of step (i) includes a recommendation to adjust the volume of liquid of the one or more ballast tank pairs selected.

4. The method according to claim 3, wherein the recommendation to adjust the volume of liquid includes increasing or decreasing the volume of liquid to the one or more ballast tank pairs selected.

5. The method according to claim 3, wherein the suggested criteria of step (i) includes percentage in terms of power saved based on the recommendation to adjust the volume of liquid to the one or more ballast tank pairs selected.

6. The method according to claim 1 wherein the first operational data includes current vertical center of gravity of the vessel.

7. The method according to claim 6, wherein the first optimum data includes the allowable vertical center of gravity of the vessel.

8. The method according to claim 7, wherein the first optimum data includes a predetermined range of vertical center of gravity that is close to the allowable vertical center of gravity of the vessel.

9. The method according to claim 6, wherein the first optimum data includes the maximum vertical center of gravity of the vessel.

10. The method according to claim 9, wherein the first optimum data includes a predetermined range of vertical center of gravity that is close to the maximum vertical center of gravity of the vessel.

11. The method according to claim 1, wherein the first variance is the absolute difference between vertical center of gravity and allowable vertical center of gravity of the vessel.

12. The method according to any of the preceding claims, wherein step (b) further comprises:

(i) Sending an alert to user if the first variance is negative; or

(ii) Comparing the first variance with a first predetermined range if the first variance is positive.

13. The method according to claim 12, wherein optimum draft is achieved if the first variance is within the first predetermined range.

14. The method according to any of the preceding claims, wherein step (c) of claim 1 will initiate if the first variance is positive and falls outside of the first predetermined range.

15. The method according to the preceding claims, wherein the first predetermined range is within the range of 5% of the maximum allowable VCG curve.

16. The method according to claim 1, wherein step (c) comprises the following steps:

(a) retrieving second operational data of the vessel from the main processor;

(b) Comparing second operational data with a second optimum data to obtain a second variance;

(c) Identifying one or more ballast tank pairs for deballasting based on the second variance so that the computed draft is equivalent to the optimum draft.

17. The method according to claim 16, wherein the second operational data includes the current trim of the vessel.

18. The method according to claim 17, wherein the second optimum data includes the optimum trim data at a specific speed and displacement.

19. The method according to claim 18, wherein the second variance is the absolute difference between the current trim of the vessel and the optimum trim.

20. The method according to claim 19, wherein the step of identifying one or more ballast tank pairs for deballasting further comprises the following steps:

(a) Selecting the aft quadrant tank pairs when the second variance is positive; or

(b) Selecting the fore quadrant tank pairs when the second variance is negative.

21. The method according to claim 20, wherein selecting the aft quadrant tank pairs further comprise the following steps:

(i) Selecting available aft wing tank pairs; or

(ii) Selecting aft double bottom tank pairs; or

(iii) Selecting a combination of aft wing tank and aft double bottom tank pairs,

wherein the selection of any of the above (i) to (iii) depends on the contribution of each of the above (i) to (iii) to the first variance.

22. The method according to claim 20, wherein selecting the fore quadrant tank pairs further comprise the following steps:

(i) Selecting available fore wing ballast tank pairs; or

(ii) Selecting fore double bottom ballast tank pairs; or

(iii) Selecting a combination of fore wing ballast tank pairs and fore double bottom ballast tank pairs,

wherein the selection of any of the above (i) to (iii) depends on the contribution of each of the above (i) to (iii) to the first variance.

23. The method according to claims 21 and 22 wherein the selected ballast tank pairs are stored in a second main processor.

24. The method according to any of the above claims, wherein step (g) of claim 1 further comprises the following steps:

(a) Identifying one or more ballast tank pairs for deballasting based on the results of the second variance; and

(b) Selecting forward wing ballast tank pairs when the second variance is negative; or

(b) Selecting aft wing ballast tank pairs when the second variance is positive.

25. The method according to claim 24, wherein selecting forward wing ballast tank pairs includes deballasting the forward wing ballast tank pairs or ballasting the aft wing ballast tank pair.

26. The method according to claim 25, wherein selecting aft wing ballast tank pairs includes deballasting the aft wing ballast tank pairs or ballasting the aft wing ballast tank pairs.

27. The method according to claim 26, wherein the computed trim is computed by the main processor from the ballasting and deballasting of the wing ballast tank pairs of step (g).

28. The method according to claim 27, wherein the selected wing ballast tank pairs are stored in the second main processor.

29. The method according to claim 28, wherein a further step of comparing the computed trim with the optimum trim is made to determine if the computed trim value is close to or equal to the optimum trim.

30. The method according to claim 29, wherein if the computed trim is not close to equal to the optimum trim, step (e) of claim 1 will be initiated.

31. A system for optimising fuel efficiency of a marine vessel, the system comprising:

a controller configured to electronically retrieve operational data of a vessel from a main processor;

said controller configured to electronically compare the operational data with optimum data;

said controller configured to automatically adjust the ballast tank pairs of the vessel based on the comparing to optimise the fuel efficiency of the marine vessel.

32. A program storage device readable by a machine, embodying at least one program of instructions executable by the machine to perform a method of optimising fuel efficiency of a marine vessel according to claim 1.