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(54) METHOD OF MAINTAINING A FLOATING VESSEL IN A DESIRED POSITION OR ON A DESIRED COURSE

(71) We, SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ N.V., a company organised under the laws of the Netherlands, of 30, Carel van Bylandtlaan, The Hague, the Netherlands, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a method of maintaining a floating vessel in a desired position or on a desired course so as to keep the deviation between the actual position or course of such vessel and the desired position or course small without the use of anchors. To this end, use is made of the propulsion unit(s) and/or the rudder(s) of the vessel, which means are controlled by signals representative of the deviation between the actual position of the vessel and the desired position thereof.

The desired position or course of a vessel may be indicated by at least one co-ordinate of a Cartesian co-ordinate system, a polar co-ordinate system or any other co-ordinate system in the horizontal plane suitable for the purpose and/or by the heading of the vessel which is indicated by the angle between an axis of the vessel and a pre-determined compass-direction. For the sake of convenience, the heading of the vessel is considered hereinafter to be one of the co-ordinates suitable for indicating the position of a floating vessel.

The present invention provides a method for dynamically maintaining a floating vessel in a desired position or on a desired course, which vessel is provided with means for measuring along at least one co-ordinate the deviation of the vessel from the desired position or course, said method including the steps of:

- 1) generating in the time domain a deviation signal representative of the measured deviation a component of

which deviation signal results from wave action on the vessel;

- 2) filtering the deviation signal to remove a selected part of the wave component of the deviation signal;
- 3) deriving a control signal from the deviation signal having the selected part of the wave component removed therefrom; and
- 4) supplying the control signal to means capable of reducing the deviation measured along the co-ordinate,

wherein the auto-correlation function of the signal that is representative of that part of the deviation signal which is in a frequency band comprising the selected part of the wave component is periodically determined and the impulse response of a minimum delay filter adapted for filtering the deviation signal in step 2 is periodically synthesized from this auto-correlation function.

The present invention further provides means for dynamically maintaining a floating vessel in a desired position or on a desired course comprising (1) a system for measuring along at least one co-ordinate the deviation of the vessel from the desired position or course and for generating, in the time domain, a deviation signal that is representative of the measured deviation which deviation signal incorporates a component resulting from wave action on the vessel, (2) a controller, (3) signal communicating means suitable to be connected to means adapted to reduce the deviation of a vessel as measured along the co-ordinate, and (4) a filter for attenuating a selected part of the wave component present in the deviation signal, the controller and the filter being operatively connected between the measuring system and the signal communication means, wherein the filter includes a system for periodically determining the auto-correlation function of the signal that is representative of that part of the deviation signal which is in a frequency band comprising the selected part of the wave component,

and a system for periodically synthesizing a minimum delay filter impulse response from this auto-correlation function.

5 The means employed for reducing the deviation of the vessel from a desired position may include one or more propulsion units and/or one or more rudders. The propulsion unit or units may be of various types, and may, inter alia, be formed by vertical
10 axis propellers of the Voith-Schneider type, or by bow and/or stern thrusters which can create forces acting athwartships. They may further include propellers as applied for normal displacement of the vessel and suitable for
15 applying forces acting fore and aft.

Dynamic stationing is of particular interest for vessels, barges or other floating units which are used for drilling wells into the sea or ocean bottom. However, dynamic stationing
20 is further of interest for all other types of vessels which should be maintained close over a fixed location or close over a continuously or discontinuously changing location. As
25 examples of vessels which should be kept over a fixed location during operation, oceanographic, weather, salvage and radar vessels may be mentioned. Fire boats, tugs, cranes, dredgers, and cable or pipe-laying barges
30 should be able to be manoeuvred between fixed locations, often along a pre-determined route. Further, the method according to the invention may be applied for maintaining a vessel on a pre-determined course. Then,
35 the deviation from a desired course along which the vessel should be sailing is measured, and signals representative of the measured deviation are used to control the propulsion unit(s) and/or the rudder(s) of the vessel.

The invention relates in particular to the problem of dynamically stationing vessels which are susceptible to wave action. Any displacement of a vessel resulting from wave action exerted thereon will be followed by a displacement in the opposite direction, which
45 latter displacement is a result of the elliptical movements of the water particles constituting the waves. The time interval between each displacement and the subsequent return displacement depends on the periods of the waves
50 in which the vessel is operating, and it will be appreciated that for relatively short period lengths, the dynamic positioning system of the vessel is better switched off as being superfluous or even unwanted since it may for
55 certain wave periods even be responsible for starting oscillations.

However, since waves will occur simultaneously with water flow and/or wind, the dynamic stationing system cannot simply be
60 switched off because no correction would then take place for those deviations from the desired position which result from wind and/or water flow acting on the vessel.

One object of the invention is to provide
65 a method for dynamically positioning a vessel

in such a manner that in composing the control signal the wave action exerted on the vessel is partly neglected, resulting in a control which shows no tendency to oscillate.

Another object of the invention is to provide a means for dynamically stationing a vessel, which means permit a relatively cheap operation of such vessel as it does not respond to those deviations which are automatically compensated by their very source. This minimizes unrequired action of the propulsion unit(s) and/or the rudder(s) of the vessel, and consequently reduces energy costs as well as maintenance costs of the propulsion unit(s) and/or the rudder(s).

Still another object of the invention is to optimize the operation of dynamic stationing means to increase the efficiency thereof.

The filtering step may include the steps of synthesizing a filter impulse response capable of generating from the deviation signal a signal representative of a selected portion of the wave component present in the deviation signal and subtracting this second signal from the first signal to form the filtered signal.

Where in this specification and claims the expression "phase spectrum" is used, such spectrum indicates the relationship between the frequencies of the sinusoidal components of a signal and the phase difference between the input and output of each component when passing through a filter or other member of a control scheme. The expression "amplitude spectrum" indicates the relationship between the frequencies of the sinusoidal components of a signal and the amplitude of each of the components. The expression "amplitude spectrum of a filter" indicates the relationship between the frequencies of the sinusoidal components of the unit impulse response of the filter, and the amplitude of each of the components. The expression "phase spectrum of a filter" indicates the relationship between the frequencies of the sinusoidal components of the unit impulse response of the filter and the phase lag of each component with respect to the unit impulse. The expression "filter length" refers to an arbitrarily chosen time period of the unit impulse response of a filter. Further, the expression "power spectrum" indicates the energy distribution of a signal over the frequencies of the sinusoidal components thereof.

The invention will now be described with reference to the drawings which show by way of example some embodiments of the invention.

Figure 1 shows schematically a side view of a vessel carrying a derrick and provided with dynamic stationing means;

Figure 2 shows in plan view the deviation from the desired position of the vessel according to Figure 1;

Figure 3 shows a view similar to Figure 2, but now indicating the position of the

vessel as if no wave action was being exerted on the vessel;

Figure 4 indicates a vector diagram applied for calculating the action to be carried out by one of the propulsion units of the vessel according to Figure 1, in order to move the vessel to the desired position;

Figure 5 shows another vector diagram, this diagram indicating the action to be carried out by the other propulsion unit of the vessel according to Figure 1, in order to move the vessel to the desired position;

Figure 6 shows schematically the flow of signals from a measuring system to the propulsion units of the vessel;

Figure 7 shows the deviation signal and a selected portion of the wave component thereof in the time domain;

Figure 8 shows the amplitude spectrum $|X(f)|$ of the deviation signal according to Figure 7;

Figure 9 shows schematically the steps to be carried out in the method according to the invention; and the calculating units in which these steps are carried out; and

Figure 10 shows the spectrum $|G(f)|$ of the amplitude of the transfer function $G(f)$ of a zero-phase shift filter having an impulse response $g(\tau)$, as shown in Figure 9.

The floating vessel 1 shown in Figure 1 is suitable for carrying out drilling operations in a submerged well 2 having the wellhead 3 thereof located above the sea bottom 4. A tubing string 5 is suspended in the well 2 in a suitable manner (not shown since known per se) from the derrick 5A mounted on the vessel 1. For the sake of simplicity all other equipment required for carrying out drilling operations is omitted in the drawing.

The vessel 1 is provided with two propulsion units 6 and 7, which are rotatably arranged around axes 8 and 9, respectively, to vary the directions of the thrusts exerted thereby. Further, the magnitude of the thrusts delivered by the units 6 and 7 is variable, so that by a suitable choice of the direction and magnitude of each thrust exerted by the propulsion units 6 and 7, the vessel 1 may be displaced from the actual position thereof to a desired position.

The manner in which the dynamic stationing means operates to reduce the deviation of the vessel 1 from the desired position, will now be explained with reference to Figures 2—6 of the drawing.

As shown in Figure 2, the position of the vessel 1 is indicated with reference to the X-axis and the Y-axis. These axes are the axes of a measuring system as applied for measuring the deviation of the actual position 1 of the vessel from the desired position 1' thereof. The desired heading is in the direction of the negative part of the X-axis. The angle deviation of the actual position with respect to the desired position is indicated by

ϕ . To reach the desired position 1', the vessel 1 should be rotated over the angle ϕ , and displaced over the distance x and y in the directions of the X-axis and Y-axis respectively.

The deviation of the vessel 1 from the desired position 1' results from a combined action of waves, wind and water flow. The wave action exerted on the vessel 1 differs from the wind action and water flow in that any deviation resulting from the high frequency part of the waves acting on the vessel 1 is compensated within a relatively short period, since the oscillatory movement of the water particles forming the waves causes any object which is subjected to wave action to be oscillated to and fro around a mid position. Since any deviation of the vessel 1 from the desired position is automatically compensated within a short period for that part thereof which is due to the high frequency part of the wave action exerted on the vessel, the influence of this portion of the wave component of the deviation is neglected in the method according to the invention when composing the control signal for dynamically positioning the vessel 1.

By attenuating the high frequency portions of the wave components present in the components x , y and ϕ (as indicated in Figure 2) of the deviation signal in a manner as described in more detail hereinafter, signals S_x , S_y and S_ϕ remain, and these signals are representative of the deviation of the vessel 1 along the X-co-ordinate, the Y-co-ordinate and in a rotational sense, respectively. Thus, if the influence of the high frequency portion of the wave action would be neglected, the position of the vessel 1 could be indicated by the deviation signal components S_x , S_y and S_ϕ (Figure 3). As shown in Figures 4 and 5, the thrust to be exerted by the propulsion units 6 and 7, respectively, to return the vessel to its desired location, can, in the case wherein only the deviation resulting from wind, water flow and the low-frequency wave components are to be counteracted, be found by vectorially adding the signals S_x and S_y and vectorially adding the signal S_ϕ for the propulsion unit 6 and vectorially subtracting S_ϕ for the propulsion unit 7.

The thrust vectors V_A and V_B resulting from the vector diagrams as shown in Figure 4 and 5, respectively, are representative of the magnitude and direction of thrust to be applied by the propulsion units 6 and 7, respectively.

As schematically indicated in Figure 6, the dynamic stationing means according to the invention comprises measuring units 10, 11 and 12 for measuring and generating signals corresponding to the deviation of the vessel from the desired position the X-axis, the Y-axis and in a rotational sense with respect to the X-axis, respectively. The deviation

signals x , y and ϕ generated by the units 10, 11 and 12, respectively, are the components of the displacement of the vessel in relation to the desired position as a result of wave action, wind action and water flow action exerted on the vessel. According to the invention, these signals are passed through filters 13, 14 and 15, respectively, whereby the wave components present in the deviation signals x , y and ϕ are selectively attenuated, thus leaving the signals S_x , S_y and S_ϕ (compare Figure 3), which are representative of the components of the deviation of the vessel from the desired position, under the influence of the action of the wind and water flow and the low frequency part of the water waves. Since the low frequency part of the wave components present in the deviation signal should be taken into account in the dynamic stationing action, it is not removed from the signals x , y and ϕ by the filters 13, 14 and 15, respectively, and thus is included in the signals S_x , S_y and S_ϕ . The vectors S_x , S_y and S_ϕ are subsequently vectorially combined in the unit 16 as indicated in Figure 4 and 5, and the resultant vectors V_A and V_B describing the direction and magnitude of the correction signals to be supplied to the propulsion units 6 and 7, respectively, are passed thereto through controllers 17 and 18, respectively, which have proportional, and optionally derivative and/or integrating actions.

The time domain function $x(t)$ of the deviation signal along the X-axis is indicated in Figure 7 over a certain period. The high frequency part $W_x(t)$ of the wave component present in this deviation signal $x(t)$ is indicated by the dashed curve. For each time t the signal $S_x(t)$ can be found by subtracting the high frequency part $W_x(t)$ of the wave component at time t from the deviation signal $x(t)$ at the same time t . By way of example this subtraction is indicated at the time t_0 .

As shown in Figure 8, the amplitude spectrum $|X(f)|$ of the signal $x(t)$ taken over a certain period of time (time window T_x as indicated in Figure 7) shows two sharply distinguished frequency bands. Frequency band Δf_1 , in which relatively low frequencies occur, comprises that part of the deviation signal $x(t)$ which has to be compensated for in the dynamic stationing procedure. The amplitude spectrum within the band Δf_1 consists substantially of the deviation component resulting from wind action and water flow, whereas the amplitude spectrum of the frequency band Δf_2 consists substantially, if not solely, of the deviation component resulting from the high frequency part of the wave action. Thus, it can be said that the component of the deviation signal within the frequency band Δf_2 is formed by the signal $W_x(t)$, and that the component of the deviation signal within

the frequency band Δf_1 is formed by the signal $S_x(t)$.

The high frequency portion of the wave component present in the frequency band Δf_2 of the deviation signal $x(t)$, which portion need not be compensated, can now be removed by selectively attenuating this wave component by passing the deviation signal $x(t)$ through a low pass filter of which the amplitude spectrum is indicated in Figure 8 by the dashed curve 20. Since such filters are known per se they are not described here in detail. The filter cut-off frequency f_c is chosen such that it is about equal to the upper limit of the frequency band Δf_1 . As the width of the band Δf_1 should be varied with changing water depth and/or weather conditions, the filter should be equipped with a selectively variable cut-off frequency f_c . Such a filter, which is applied as filter 13 in the dynamic stationing means according to Figure 6, may be formed by an electrical network, to which electrical signal $x(t)$ is supplied to the input thereof and a signal $S_x(t)$ is derived from the output thereof. The signal $S_x(t)$ is, however, due to an inevitable phase lag of the electrical filter, not available at time t_0 , but at some time ΔT_x after time t_0 .

If the signal $x(t)$ is passed in digital form through the dynamic stationing means as schematically indicated in Fig. 6, the electrical network mentioned above may be simulated by a digital calculating unit, which convolves the impulse response of a filter with amplitude spectrum 20 (vide Figure 8), with the signal $x(t)$ over the time window T_x preceding the time t_0 (as indicated in Figure 7). The result of this convolution is then signal S_x which, however, due to an inevitable phase lag of such a filter, is not available at time t_0 , but at some time ΔT_x after time t_0 .

It will be understood that the same operations as described with reference to Figure 8 are carried out for determining the signals S_y and S_ϕ .

For a given shape of the amplitude spectrum of the filter, the time lag ΔT_x is minimal if the filter is a minimum delay filter. However, if this minimum time lag ΔT_x is considered still too large for a particular dynamic stationing operation, a higher speed system will have to be used, which system will now be described with reference to Figure 9.

Figure 9 shows in schematic form the calculating units to be applied and the steps which are to be carried out when it is desired to remove almost instantaneously by filter action the selected high frequency part of the wave component present in the x -component of the deviation signal. In the various blocks as shown in Figure 9, these steps are indicated by reference letters a, b, c, d, e, f and g.

The deviation signal component $x(t)$, shown

as a function of time by curve 21, is sampled every second and stored in a memory section 22. The successive values are sampled within a time window T_x . The time window T_x ranges from $t_0 - T_x$ to t_0 (t_0 being the time at which the latest sample has been measured).

If the time window T_x extends over a period of 500 seconds, then 500 samples of $x(t)$ will be stored in the memory unit 22. Each new second, one more sample will be added to this memory unit 22 and one other, namely the oldest sample, will be discarded therefrom (step a).

Once every T_p seconds (T_p having, e.g., a value of 500 seconds), the auto-correlation function of the signal $x(t)$ thus stored is calculated in calculating unit 24 (step b). This auto-correlation function $R_{xx}(\tau, t_0)$ having a length of T_R seconds (vide reference numeral 25) is stored for T_p seconds and is applied in calculating unit 26 (step c) for obtaining the auto-correlation function of the signal that is representative of a selected part of the wave component present in the deviation signal component $x(t)$. This latter auto-correlation function $R_{ww}(\tau, t_0)$ is obtained by

convolving the auto-correlation function $R_{xx}(\tau, t_0)$ with the impulse response $g(\tau)$ of a filter, of which the transfer function $G(f)$ has an amplitude spectrum (as indicated by curve 27 in Figure 10), with relatively high values for a frequency band Δf_2 corresponding to the frequency band of the selected portion of the wave component present in the deviation signal, and relatively low values for a frequency band Δf_1 , and having a phase spectrum that is zero for all frequencies. The cut-off frequency f_c corresponds to the lowest frequency of the selected portion of the wave component which is to be removed from the signal $x(t)$. It will be appreciated that the parameters of the filter with the impulse response $g(\tau)$ may be varied from time to time. Thus, parameter f_c may be varied with varying weather conditions and/or water depths.

The convolution operation in step c, as carried out in calculating unit 26 is a well-known manner of calculation (see e.g. Design Electronics, January 1964, "The minimum delay concept in system design", by E. A. Robinson). The convolution of two signals:

$$p = (p_0, p_1, p_2, \dots)$$

and

$$q = (q_0, q_1, q_2, \dots)$$

is defined to be

$$r = p * q = (r_0, r_1, r_2, \dots)$$

where the coefficients of c are given by the formula:

$$r_t = \sum_{s=0}^t p_s q_{t-s} \quad 60$$

The asterisk * used in this way, that is, as a binary operation between two time functions, denotes convolution.

The auto-correlation function $R_{ww}(\tau, t_0)$ resulting from the convolution carried out by the calculating unit 26 is represented by the curve 31. The length of the function is indicated by T_w .

Subsequently, the filter impulse response function $f(\tau, t_0)$ with length T_f is determined by calculating unit 32 (step d) by deconvolving the auto-correlation function $R_{ww}(\tau, t_0)$

with respect to the auto-correlation function $R_{xx}(\tau, t_0)$. In other words, a function $f(\tau, t_0)$ (vide diagram 33) is determined, which when convolved with the auto-correlation function 25 of the deviation signal $x(t)$ will result for the time window $0 - T_f$ in the auto-correlation function 31 of the signal which is representative of the selected part of the wave action component present in the deviation signal.

Since the power spectrum of the wave action component present in the deviation signal component $x(t)$ can be considered constant for a certain period of time T_p (say, 500 seconds), the filter $f(\tau, t_0)$ need only be computed every T_p seconds.

The impulse response of the filter $f(\tau, t_0)$ is convolved with the stored deviation signal component $x(t)$ in calculating unit 34 (step e) to calculate $W_x(t_0)$, being the selected high frequency part of the wave component present in the deviation signal $x(t_0)$. The value $W_x(t_0)$ is subsequently subtracted from the value $x(t_0)$ (step f). This is carried out by subtracting unit 35 and gives the value of the signal $S_x(t_0)$ in the direction of the X-axis and resulting from the wind, water flow and wave components in the deviation signal $x(t_0)$ in so far as the frequency thereof is below the frequency f_c . Each time a new sample of $x(t)$ has been stored, the step e is repeated, while taking into account the newly stored value of $x(t)$ to obtain the component W_x of this new value of $x(t)$. This value W_x is then subtracted from the newly stored value of $x(t)$ (step f) to obtain a new value of the signal S_x . The same impulse response of the filter $f(\tau, t_0)$ is used for all these operations, until after T_p seconds a new auto-correlation function $R_{xx}(\tau, t_0)$ and a new impulse response $f(\tau, t_0)$ has been calculated.

In a similar manner as described above, the values of S_y and S_ϕ are calculated at time t_0 , which values are vectorially added (step g), as shown in Figures 4 and 5, by the vector adding unit 36 to yield the vectors $V_A(t_0)$ and $V_B(t_0)$. Each time a new sample of $y(t)$ and

$\phi(t)$ has been stored, new values of S_y and S_z are calculated and vectorially combined with S_x to generate the signals V_A and V_B .

The dynamic stationing means further includes controllers 37 and 38 to process the signals V_A and V_B , respectively. These controllers have proportional and, optionally, derivative and/or integrating action. After being processed, the signals are sent to the propulsion units 6 and 7 for controlling the magnitudes of the thrusts thereof as well as the directions of these thrusts. Equipment for such control is known per se and hence not described here in detail.

An analysis of the calculations as performed by the units according to Figure 9 will now be given.

The time domain function $x(t)$ is representative of the deviation of the vessel in the direction of the X-axis. This function consists of two components $W_x(t)$ and $S_x(t)$. $W_x(t)$ represents the high frequency part of the signal $x(t)$, and consists of that part of the wave component having frequencies above frequency f_c . $W_x(t)$ further includes wind and water flow components having frequencies higher than f_c , should such components be present.

Removal of the high frequency part $W_x(t)$ of the deviation signal $x(t)$ at time t_0 would be possible if a minimum phase, low pass filter would be available, having an impulse response $F(\tau, t_0)$ such as would give the quantity:

$$E = \int [F(\tau, t_0) * x(t) - S_x(t)]^2 dt \quad (1)$$

a minimum value. This would be the case if:

$$F(\tau, t_0) * R_{xx}(\tau, t_0) = R_{ss}(\tau, t_0) \quad (2)$$

for $0 \leq \tau \leq T_F$, wherein T_F represents the length of the filter $F(\tau, t_0)$. However, since $R_{ss}(\tau, t_0)$ is unknown, $F(\tau, t_0)$ cannot be

determined in this way.

This problem is solved by calculating the impulse response $f(\tau, t_0)$ of a high pass filter, the relationship of which to $F(\tau, t_0)$ is indicated by:

$$F(\tau, t_0) = \delta(\tau) - f(\tau, t_0) \quad (3)$$

wherein $\delta(t)$ is the unit pulse (Dirac-pulse).

Since

$$W_x(t) = x(t) - S_x(t) \quad (4)$$

equation (1) can be replaced by

$$E = \int [f(\tau, t_0) * x(t) - W_x(t)]^2 dt \quad (5)$$

From equation (5) it is seen that the problem of minimizing E can also be stated as finding a high pass filter with impulse response $f(\tau, t_0)$ such that the difference between the response of this filter to $x(t)$ and the signal $W_x(t)$ is minimal in a least square sense.

E will be minimal, if

$$f(\tau, t_0) * R_{xx}(\tau, t_0) = R_{ww}(\tau, t_0) \quad (6)$$

for $0 \leq \tau \leq T_t$, wherein T_t represents the length of the filter $f(\tau, t_0)$.

Since the power spectrum of the wave component $W_x(t)$ in the deviation signal does not change over rather long periods (this is not the case with the signal $S_x(t)$ (which signal would be required in the calculation of the filter $F(\tau, t_0)$ as referred to above) the auto-correlation function $R_{ww}(\tau)$ as required

in equation (6) can be determined at a time prior to time t_0 , by passing the function $R_{xx}(\tau)$ through a high pass filter $g(\tau)$ with zero-phase shift spectrum for all frequencies. As

$$R_{xx}(\tau) = R_{ss}(\tau) + R_{sw}(\tau) + R_{ws}(\tau) + R_{ww}(\tau) \quad (7)$$

and $R_{sw}(\tau)$ as well as $R_{ws}(\tau)$ are equal to

zero since $S_x(t)$ and $W_x(t)$ are within different frequency bands, being separated by the cut-off frequency f_c of the filter having the impulse response $g(\tau)$, and the cut-off frequency of the high pass filter $g(\tau)$ is chosen between the frequency band of $R_{ss}(\tau)$ and

the frequency band of $R_{ww}(\tau)$, convolving of

$R_{xx}(\tau)$ with $g(\tau)$ results in the auto-correlation function $R_{ww}(\tau)$.

As a result of the stationary property of $R_{ww}(\tau, t_0)$, this function is available at time $t = t_0$ and can be applied for computing $f(\tau, t_0)$.

The function $R_{ww}(\tau, t_0)$ is kept constant

over the period T_p and is applied to determine the filter function $f(\tau, t_0)$ by deconvolving this function $R_{ww}(\tau, t_0)$ with respect

to the function $R_{xx}(\tau, t_0)$ (cf. equation 6). For stability purposes, it is advisable to add in the deconvolution process some positive value to $R_{xx}(0, t_0)$, say 1%.

In conclusion, it can be said that it follows from equation (6) that the computed high pass

filter $f(\tau, t_0)$ will determine from the deviation signal $x(t) = S_x(t) + W_x(t)$ a signal $\wedge$
 $W_x(t) = f(t, t_0) * x(t)$, which is close to the high frequency part $W_x(t)$ of the wave component present in the deviation signal $x(t)$.

This computation can be carried out, since

- 1) the least square criterium needs only correlation functions,
- 2) $S_x(t)$ and $W_x(t)$ are in different frequency bands, and
- 3) the power spectrum of $W_x(t)$ does not change over the period T_p , which allows computing of $R_{W_x W_x}(\tau, t_0)$ prior to time

t_0 .

The quantities T_x , Δt , T_p , T_R , T_W , T_g and T_f as described above, may for practical purposes have the following values. It is to be understood that these values are preferred values, to which the application of the invention is not limited.

T_x = time window over which samples are taken of the deviation signal $x(t) = 200$ to 2000 seconds.

Δt = sample time for the deviation signal $x(t) = 0.1$ —1 second.

Step b for calculating the auto-correlation function $R_{xx}(\tau, t_0)$ is carried out once in every period $T_p = 1$ to 1000 seconds. The same period applies for steps c and d.

Steps e and f for calculating the value of the control signal $S_x(t_0)$ are carried out every $\Delta t = 0.1$ to 1 second.

The length T_R of the auto-correlation function $R_{xx}(\tau, t_0)$ is between 200 and 1000 seconds.

The length T_W of the auto-correlation function $R_{W_x W_x}(\tau, t_0)$ is between 100 and 500 seconds.

The length T_g of the impulse response $g(\tau)$ is between 50 and 250 seconds.

The length $T_R = T_W + 2 T_g$.

The length T_f of the high pass filter $f(\tau, t_0)$ is between 50 and 250 seconds.

It will be understood that the calculations which have to be carried out to determine the values of the signals S_y and S_ϕ are similar to the calculations described with reference to the signal S_x and that the values of the periods in which these calculations take place, as well as the lengths of the auto-correlation functions, the time window and the filters are preferably equal to the values discussed with reference to signal S_x .

It will further be understood that although the calculations required for determining the values S_x , S_y and S_ϕ , as well as the vectorial additions thereof may take place in separate units, it is attractive to apply a single com-

puter for all these calculations. Multiplexing equipment may then be applied for feeding the information on the measured deviation signals $x(t)$, $y(t)$ and $\phi(t)$ to the computer. The high speed at which the various calculations may be carried out allows the deviation signals to be processed within extremely small time periods, thus making the filtered signals S_x , S_y and S_ϕ as well as the vector signals V_A and V_B available almost instantaneously, once the information on the deviation of the vessel from the desired location has been measured by the measuring equipment.

For measuring the deviations along two co-ordinates (perpendicularly or non-perpendicularly arranged with respect to each other), a taut wire may be applied, which wire extends between a fixed point on the sea bottom and the vessel, and is provided with means for measuring the angles between the wire and two planes. Further, there are numerous other types of position measuring equipment, such as those based on acoustic or electrical waves which are transmitted from fixed points and which, when detected by receivers mounted on the vessel, can give an indication of the position of the vessel relative to these points. All these types of position measuring equipment, as well as other types suitable for the purpose, are known per se, and hence not described here in detail.

The angular deviation with respect to an axis may be measured by means of any equipment suitable for the purpose, such as a compass mounted on the vessel. It will be understood that control of this co-ordinate is not always required, and that the dynamic stationing method according to the invention may also be restricted to a control of the deviations along two co-ordinates only.

The separate vector adding unit applied for calculating the vectors V_A and V_B , which are to be supplied to the propulsion units 6 and 7, may be omitted if the propulsion units are of the Voith-Schneider type, since the signals S_x , S_y and S_ϕ can then directly be supplied to the steering means of these propulsion units.

The means for reducing the deviation of the vessel shown in Fig. 1 from a desired position comprises two propulsion units. However, the invention may also be applied for dynamically stationing vessels equipped with any other type of means for reducing the deviation. These means may include one, three or more propulsion units of any suitable design, and/or one or more rudders, all these means, or at least some of them, being controlled by control signals derived from the deviation signals.

Alternatively, the controllers provided with proportional and, optionally, derivative and/or integral action may be applied for processing the signals x , y and ϕ or the signals S_x ,

S_x and S_y instead of the vectors V_A and V_B . When applying a single computer instead of the calculating units shown in Figure 9, these controllers may, just like the vector adding unit, be incorporated in the computer.

Alternatively, the processing steps described with reference to Figure 9 in relation to the deviation signals $x(t)$, $y(t)$ and $\phi(t)$ may be applied for processing the vectors $V_A(t)$ and $V_B(t)$ which are obtained from a vector adding unit to which the signals $x(t)$, $y(t)$ and $\phi(t)$ are fed.

The selective wave attenuation method need not be applied to all the components of the signal indicating the deviation of a vessel from a desired position. If desired, the method according to the invention may be applied to control the deviation components x and y only.

The method may further be applied for controlling the deviation along a single co-ordinate only, such as for controlling the deviation in a rotational sense. This will be of interest when steering a ship in a fixed direction. The ship is then kept on a pre-selected heading and the high frequency portion of the wave component in the signal indicating the deviation from the pre-selected heading is removed therefrom by the filtering technique according to the invention. The filtered signal is then supplied to the actuating means of at least one of the rudders of the vessel and/or to the actuating means of propulsion means suitable to apply forces acting athwartships.

WHAT WE CLAIM IS:—

1. Method for dynamically maintaining a floating vessel in a desired position or on a desired course, which vessel is provided with means for measuring along at least one co-ordinate the deviation of the vessel from the desired position or course said method including the steps of:

- 1) generating in the time domain a deviation signal representative of the measured deviation a component of which deviation signal results from wave action on the vessel;
- 2) filtering the deviation signal to remove a selected part of the wave component of the deviation signal;
- 3) deriving a control signal from the deviation signal having the selected part of the wave component removed therefrom; and
- 4) supplying the control signal to means capable of reducing the deviation measured along the co-ordinate,

wherein the auto-correlation function of the signal that is representative of that part of the deviation signal which is in a frequency band comprising the selected part of the wave

component is periodically determined and the impulse response of a minimum delay filter adapted for filtering the deviation signal in step 2 is periodically synthesized from this auto-correlation function.

2. Method according to claim 1, wherein the auto-correlation function of the signal that is representative of that part of the deviation signal which is in the frequency band comprising the selected part of the wave component of the deviation signal is determined by convolution of the auto-correlation function of the deviation signal with the impulse response of a filter having an amplitude spectrum with relatively high values for the frequency band comprising the selected part of the wave component present in the deviation signal, and relatively low values for frequencies outside this band, and further having a phase spectrum that is zero for all frequencies.

3. Method according to claim 1 or 2, wherein the filter impulse response is synthesized by deconvolving the auto-correlation function of the deviation signal with the auto-correlation function of the signal that is representative of that part of the deviation signal which is in the frequency band comprising the selected part of the wave component of the deviation signal.

4. Method according to claim 2, wherein the length of the auto-correlation function of the deviation signal is between 200 and 1000 seconds.

5. Method according to claim 4, wherein the time gate over which the deviation signal is auto-correlated has a length between 200 and 2000 seconds.

6. Method according to claim 2, wherein the length of the zero-phase shift filter is between 50 and 250 seconds.

7. Method according to any one of the claims 1—6, wherein the auto-correlation of the signal that is representative of that part of the deviation signal which is in the frequency band comprising the selected part of the wave component of the deviation signal, is determined once in every period selected from a range of 1 to 1000 seconds.

8. Method according to any one of the claims 1—7, wherein the length of the minimum delay filter impulse response is between 50 and 250 seconds.

9. Method according to any one of the claims 1—8, wherein the filter impulse response is synthesized once in every period selected from a range of 1 to 1000 seconds.

10. Method according to any one of the claims 1—9, wherein the deviation signal is sampled once in every period selected from a range of 0.1 to 1 second.

11. Method for dynamically maintaining a floating vessel in a desired position or on a desired course, substantially as described with

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5 S_x and S_y instead of the vectors V_A and V_B . When applying a single computer instead of the calculating units shown in Figure 9, these controllers may, just like the vector adding unit, be incorporated in the computer.

10 Alternatively, the processing steps described with reference to Figure 9 in relation to the deviation signals $x(t)$, $y(t)$ and $\phi(t)$ may be applied for processing the vectors $V_A(t)$ and $V_B(t)$ which are obtained from a vector adding unit to which the signals $x(t)$, $y(t)$ and $\phi(t)$ are fed.

15 The selective wave attenuation method need not be applied to all the components of the signal indicating the deviation of a vessel from a desired position. If desired, the method according to the invention may be applied to control the deviation components x and y only.

20 The method may further be applied for controlling the deviation along a single co-ordinate only, such as for controlling the deviation in a rotational sense. This will be of interest when steering a ship in a fixed direction. The ship is then kept on a pre-selected heading and the high frequency portion of the wave component in the signal indicating the deviation from the pre-selected heading is removed therefrom by the filtering technique according to the invention. The filtered signal is then supplied to the actuating means of at least one of the rudders of the vessel and/or to the actuating means of propulsion means suitable to apply forces acting athwartships.

WHAT WE CLAIM IS:—

40 1. Method for dynamically maintaining a floating vessel in a desired position or on a desired course, which vessel is provided with means for measuring along at least one co-ordinate the deviation of the vessel from the desired position or course said method including the steps of:

- 45 1) generating in the time domain a deviation signal representative of the measured deviation a component of which deviation signal results from wave action on the vessel;
- 50 2) filtering the deviation signal to remove a selected part of the wave component of the deviation signal;
- 55 3) deriving a control signal from the deviation signal having the selected part of the wave component removed therefrom; and
- 4) supplying the control signal to means capable of reducing the deviation measured along the co-ordinate,

60 wherein the auto-correlation function of the signal that is representative of that part of the deviation signal which is in a frequency band comprising the selected part of the wave

component is periodically determined and the impulse response of a minimum delay filter adapted for filtering the deviation signal in step 2 is periodically synthesized from this auto-correlation function. 65

2. Method according to claim 1, wherein the auto-correlation function of the signal that is representative of that part of the deviation signal which is in the frequency band comprising the selected part of the wave component of the deviation signal is determined by convolution of the auto-correlation function of the deviation signal with the impulse response of a filter having an amplitude spectrum with relatively high values for the frequency band comprising the selected part of the wave component present in the deviation signal, and relatively low values for frequencies outside this band, and further having a phase spectrum that is zero for all frequencies. 70 75 80

3. Method according to claim 1 or 2, wherein the filter impulse response is synthesized by deconvolving the auto-correlation function of the deviation signal with the auto-correlation function of the signal that is representative of that part of the deviation signal which is in the frequency band comprising the selected part of the wave component of the deviation signal. 85 90

4. Method according to claim 2, wherein the length of the auto-correlation function of the deviation signal is between 200 and 1000 seconds. 95

5. Method according to claim 4, wherein the time gate over which the deviation signal is auto-correlated has a length between 200 and 2000 seconds. 100

6. Method according to claim 2, wherein the length of the zero-phase shift filter is between 50 and 250 seconds.

7. Method according to any one of the claims 1—6, wherein the auto-correlation of the signal that is representative of that part of the deviation signal which is in the frequency band comprising the selected part of the wave component of the deviation signal, is determined once in every period selected from a range of 1 to 1000 seconds. 105 110

8. Method according to any one of the claims 1—7, wherein the length of the minimum delay filter impulse response is between 50 and 250 seconds. 115

9. Method according to any one of the claims 1—8, wherein the filter impulse response is synthesized once in every period selected from a range of 1 to 1000 seconds.

10. Method according to any one of the claims 1—9, wherein the deviation signal is sampled once in every period selected from a range of 0.1 to 1 second. 120

11. Method for dynamically maintaining a floating vessel in a desired position or on a desired course, substantially as described with 125



reference to Figures 7—9 of the accompanying drawings.

12. Means for dynamically maintaining a floating vessel in a desired position or on a desired course, comprising (1) a system for measuring along at least one co-ordinate the deviation of the vessel from the desired position or course and for generating, in the time domain, a deviation signal that is representative of the measured deviation which deviation signal incorporates a component resulting from wave action on the vessel, (2) a controller, (3) signal communicating means suitable to be connected to means adapted to reduce the deviation of a vessel as measured along the co-ordinate, and (4) a filter for attenuating a selected part of the wave component present in the deviation signal, the controller and the filter being operatively connected between the measuring system and the signal communication means, wherein the filter includes a system for periodically determining the auto-correlation function of the signal that is representative of that part of the deviation signal which is in a frequency band comprising the selected part of the wave component, and a system for periodically synthesizing a minimum delay filter impulse response from this auto-correlation function.
13. Means according to claim 12, wherein the system for calculating the auto-correlation function of the signal that is representative of that part of the deviation signal which is in the frequency band comprising the selected part of the wave component of the deviation signal is capable of convolving the auto-correlation function of the deviation signal with the impulse response of a filter having an amplitude spectrum with relatively high values for the frequency band comprising the selected part of the wave component

present in the deviation signal and relatively low values for frequencies outside this band, and further having a phase spectrum that is zero for all frequencies.

14. Means according to claim 12 or 13, comprising a system for sampling the deviation signal and storing a limited number of samples with relation to the sampling time by discarding the oldest sample each time a new sample is added.

15. Means according to any one of claims 12, 13 and 14, wherein the system for synthesizing the minimum delay filter impulse response is capable of deconvolving the auto-correlation function of the deviation signal by the auto-correlation function of the signal that is representative of that part of the deviation signal which is in the frequency band comprising the selected part of the wave component of the deviation signal, the means further comprising a system for convolving this filter impulse response with the deviation signal, and a subtractor for subtracting the result of this latter convolution from the deviation signal.

16. Means for dynamically maintaining a floating vessel in a desired position or on a desired course, substantially as described hereinbefore with reference to Figures 7—9 of the accompanying drawings.

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