DETERMINATION OF WAVE ELEMENTS BY USING LASER-BASED DISTANCE MEASUREMENTS

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Abstract **–The paper proposes a method for measuring the wave elements (wave length, period, height, amplitude, direction) directly by an underway ship, by means of a laser-based measurement device fastened to the ship's bow, which is used as a sensor.**

Keywords: *wave, laser, gyrocompass, navigation, ship, pitching, rolling*

1. INTRODUCTION

The elements of marine waves are usually determined by using fixed platforms above the World Ocean, placed in certain locations. All these observations are completed with visual observations made by the underway ships. The wave characteristics are introduced in a database and are then processed by the hydro- meteorological centers. At pre-established hours, information about wave elements is sent to the ship, by means of different hydro-meteorological information systems.

Mariners need information referring to waves, in order to determine the DRUM DE CAPA in hard hydro-meteorological conditions. If the wave elements are not well determined, especially during night time, there may occur difficulties in the ship's safe steering. These are the reasons why, we propose an equipment for the exact measurement of the wave elements directly by the underway ship.

At the moment, American specialists are doing research for determining the wave elements; all these are being made from mobile platforms (ships). The above mentioned specialists have at their disposal databasis containing wave spectra for the entire Globe, where the determination of the wave elements is made using four laser sensors placed on an outside platform and not on the ship, which continuously measures the distance to the water. These distances are then introduced in a calculus pattern that uses stabilized platforms. The GPS technique, and the ship's course direction established by the Gyrocompass determines the wave elements in the area where the ship steers.

The solution proposed by the authors is more simple, and it doesn't require databasis. However, it has the disadvantage of being applicable only to the waves having a regular form (sinusoidal wave). Therefore, for a complete determination of wave elements it is necessary to stop the ship's course for a short period of time.

2. COMPOSITION OF THE EQUIPMENT FOR WAVE ELEMENTS MEASUREMENT OF AN UNDERWAY SHIP

Such equipment should contain a laser-based measuring device (figure 1), fastened horizontally,to a mast, in a diametric plan, in the bow of the ship, in order to determine the distance to the water, which is marked here with *hi*

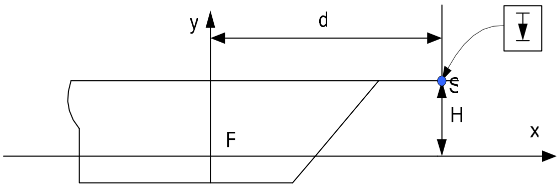

Figure 1: Display of the sensor with the ship on calm water

These measurements should be done with a frequency of 10 Hz and should be sent to a computer

(the calculus and display block), which, upon receiving information from :

-a stabilized base (this should transmit the longitudinal inclination of the ship – the pitching and the angle of the transversal inclination of the ship – the rolling);

- a GPS (this should measure the height to which the ship rises or goes down, related to a horizontal reference surface)

- gyrocompass (sends the direction to which the ship is steering, related to the true north)
- log (measures the ship's way speed)

will correct these measurements and then, by having an engine stoppage, the wave elements: period (T) , wave length (λ), wave direction (Dv) and wave propagation speed (c), will be determined, as shown in figure 2

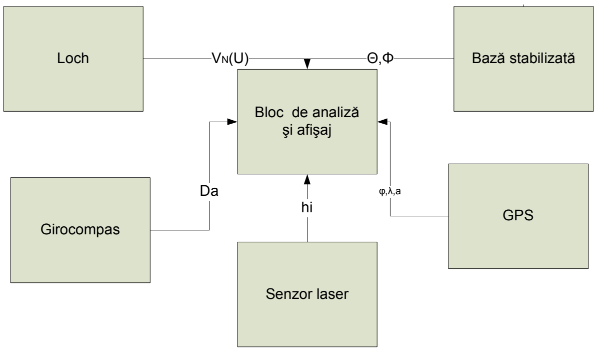

Figure 2: The block diagram of the equipment for wave elements determination

3. NOTIONS ABOUT WAVE THEORY

Figure 3 shows a ship steering at constant speed U in uniform sinusoidal wave, having the profile given by the equation:

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$$\varsigma = \varsigma_0 \cdot \sin(\omega t - KX_0)$$

The ship's making way direction forms an angle μ, (also called „angle of incidence") with the ship's making-way direction, also called incidence angle.?

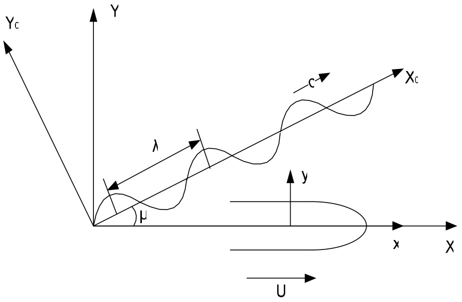

Figure 3:the ship's hull together with the solidary system of coordinates moves along the axis X of the OXYZ system under the angle μ related to the wave's propagation direction.

.The connection between the system of coordinates is given by the relation: $X_0 = X \cdot \cos\mu + Y \cdot \sin\mu = (Ut + x)\cos\mu + y \cdot \sin\mu$

The expression of the wave profile looks as follows:

$$\varsigma = \varsigma_0 \cdot \sin\{(\omega t - K[(Ut + x)\cos\mu + y \cdot \sin\mu)]\}$$

(3.1.),

which is the equation of the wave profile in the system of coordinates Oxyz, which is in solidarity with the ship.

The component that appears in equation (3.1) is marked with ωi and is called the frequency of the ship's contact with the wave. Therefore , we will have:

$$\omega i = \omega - KU\cos\mu = \omega - \frac{\omega^2 U}{g}\cos\mu \quad (3.2.)$$

We draw out the angle of incidence μ from this formula and the following expression will result:

$$\mu = \arccos\frac{g(\omega - \omega i)}{\omega^2 U} \quad (3.3)$$

In order to determine the wave direction as related to the geographical North we have to add the angle of incidence to the ship's true course.

$$Dv = Da + \mu \quad (3.4)$$

In which , μ will have the sign + , if the wave hits from the starboard, and the sign − , if the wave hits from the port.

4. CORRECTION OF THE DISTANCES, MEASURED IN RELATION TO THE PITCHING ANGLE, THE ALTITUDE DIFFERENCE , AND THE ROLLING ANGLE

2.1.Correction of the distances measured for the vertical movement and the pitching movement.

Due to the waves , ships may have an oscillatory vertical movement; the ship's mass centre moves downwardsor upwards in relation with the calm surface of the water.

Due to the waves, too, the ship can have an oscillatory longitudinal movement around,which causes the ship to rise above and lower below a reference surface, parallel with the calm water surface. This movement is called pitching. .

In order to determine the distance to the water surface correctly, in case the ship doesn't have these movements, it is necessary to determine the mathematical formulas which can lead to the correction of the distances, starting from an instantaneous altitude **a** , and an instantaneous pitching angle, Θ. Aboard ships, all these components can be determined very precisely, by using the modern effective technique.

If we take into account **a** as being the altitude at which the ship rises or goes down, related the reference plan of the calm water, then the height at which the sensor is placed, becomes:

$$Ha = H + a$$

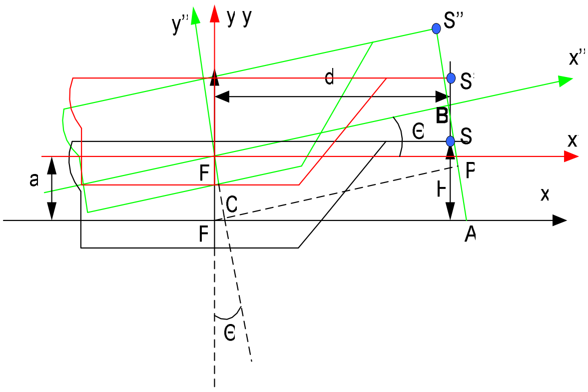

Figure 1: The determination of distance from the inclined distance

If we also introduce the pitching movement then the distance, measured from the horizontal reference plan to the sensor, is;:

$$H_{a\Theta} = S''A = PA + PB + BS'' \qquad (4.1).$$

From the FPA right triangle results that:

$$PA = PF \cdot tg\Theta = d \cdot tg\Theta$$

From the F'FC right triangle results that:

$$F`C = FF`\cdot \cos\Theta = BP = a \cdot \cos\Theta$$

But:

$$BS = H$$

So, the relation (4.1) becomes:

$$H_{a\Theta} = d \cdot tg\Theta + a \cdot \cos\,\Theta + H \quad (4.2)$$

So, again if we take into consideration all the ship's oscillations (rolling, pitching, vertical oscillations), then the distance up to the water level, becomes:

$$H = -d \cdot tg\Theta - a \cdot \cos\Theta + H_{a\Theta}$$

We have to take into account the fact that, the altitude *a* may have positive values, when the ship rises above the horizontal reference level, and may also have negative values when the ship goes down, below this level; the tangent tgΘ is positive when the ship is trimmed by the stern, and negative when the ship is trimmed by the head.

2.2. Correction of the distances measured for the rolling movement.

Rolling is the ship's movement on a vertical plan around the centre of gravity; this oscillatory movement is created by the external forces.

If we take into consideration the rolling movement of the ship in figure 5, there appears:
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$$H_{a\Theta\Phi} = H_{a\Theta} \cdot \cos\Phi \quad (4.3)$$

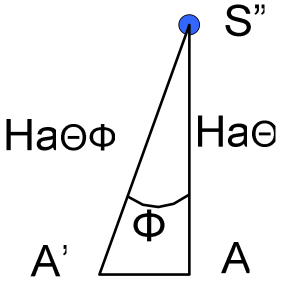

Figure 5: Correction of the rolling movement.

From the expressions (4.2.) and (4.3) appears that:

$$H_{a\Theta\Phi} = (d \cdot tg\Theta + a \cdot \cos\Theta + H) \cdot \cos\Phi \quad (4.4.)$$

In conclusion, if we take into consideration all the ship's oscillatory movements (rolling, pitching, vertical oscillatory movements). The distance up to the water level becomes:

$$H = -d \cdot tg\Theta - a \cdot \cos\Theta + H_{a\Theta\Phi} \cdot \sec\Phi \quad (4.5)$$

4. ALGORITHM FOR THE PRACTICAL DETERMINATION OF THE WAVE CHARACTERISTICS USING THE LASER-BASED TECHNIQUE.

When the ship is not underway, distance measurements are made at a frequency of 10Hz. The pieces of information given by these measurements are sent to the calculus and display block, where, by applying the formula (4.5) the values of distances from the sensor to the water are determined, as if in the case when the ship wouldn't have had any of the following:vertical oscillatory movements, rolling or pitching. With all these new values a diagram can be drawn H(t) , which will have, for the sinusoidal wave, a number of maximums and minimums. The length of the wave λ, is found to be the distance between the two successive maximums of the diagram.
The period of the wave *T* is the time span between two successive maximums, while the wave pulsation

is determined by the help of the relation: $\omega = 2\pi/T$

Then, the ship is set to constant course at constant speed, and thus, the encounter pulsation of the ship with the wave is determined,according to the formula where*Ti* is the period of encounter of the ship with the wave, calculated in the same conditions as *T*.

Using the formulas (3.3) and (3.4) the wave direction (Wd) is determined in relation to the geographical North.

6. CONCLUSIONS

Such type of equipment would be extremely useful for the ships' safe steering, especially at night time, or in reduced visibility conditions, or even in the case of crewless ships. Using the modern communication technique, each ship can become a small meteorological point, which may contribute to the elaboration of data basis for meteorological forecasts.

There are a few disadvantages of this method. One is that when the ship has to be stopped, in order to determine the wave characteristics; but this doesn't have to last more than a few minutes, when you have to determine the wave characteristics on a wave shape.

Another disadvantage is that the ship should have an efficient GPS which able to send the size of the ship's vertical movement, with a frequency of 10 Hz, to the ship's calculus and display block. There should also exist a stabilized base able to determine the rolling and pitching movements angles. These disadvantages can become insignificant in time, due to the expected small errors given by the GPS, and also due to the new, simple inclinometres, on a longitudinal and transversal plan, with electronic display.

A side utility of this equipment can be the recording of the wave elements in the naval black boxes, which would be of real help, for the investigating committees in case of accidents or naval sinisters.

The wave elements determination technique may be improved, if two such sensors would be used aboard ships, on the masts, and displayed horizontally and perpendicular to the longitudinal axis of the ship.

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