CONTRIBUTION TO REAL TIME STABILITY MONITORING IN WAVES BASED IN FFT ALGORITHM

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Abstract:

This paper describes a methodology to implement and operate an automatic onboard device destined to compute ship stability in real time. The system comprises a software based set of instruments linked to a PC computer which measure roll motions in waves and process acquired data supplying a value related with ship stability by means of an algorithm based in the frequency domain analysis of ships motions related with sea state parameters

Introduction

The basic methodology for most of the methods to compute ship stability in any operating condition, is the designer's information supplied as "stability and model loading manual". The information serves to define the stability characteristics in typical and unspecified cases of ship loading based on the data of masses and static moments for the deadweight components with regard to the influence of liquid cargo free surfaces.

As is well know for practice, the actual weights of many categories of standard cargo units, like containers or trailers may differ significantly from those specified in the terminal documentation.

Also important is the error of the basic data on the cargo centre of gravity co-ordinates, that together with errors in the necessary amount of ballast contribute to show that the calculation method of stability does not satisfy with permissible parameters and therefore cannot always guarantee safety of navigation.

The problem for calculate the initial stability based on instrumentation data , i.e. true KG of the ship demands the realisation of two different tasks:

- ship stability calculation at the berth on the basis of an operational heeling experiment.
- real time ship stability computation and/or monitoring on sea keeping conditions.

In the actual state of marine technology, vessels like containerships and ro-ro, could easily implement onboard devices destined to measure roll motions in waves as well as data processing equipment to calculate real time initial ship stability values, by means of frequency domain analysis based algorithms applied on the information gathered from ships motions related with sea state parameters,[1].

The following illustration represents a flow chart showing how stability GM is being computed.

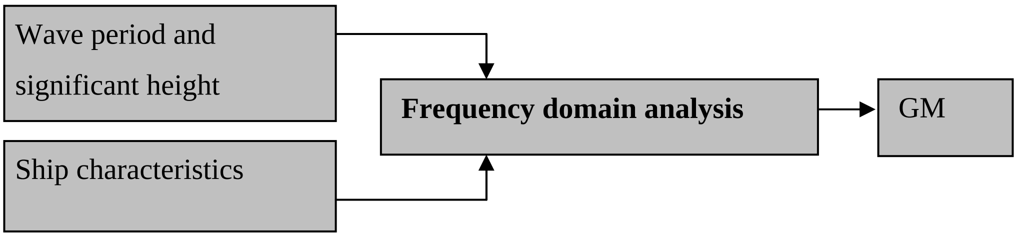

Fig. 1. Stability computation block diagram

From ship characteristics, basically from draft information, it is possible to obtain information about Metacentric height, KM, approximate roll radius of inertia, as fraction of ship beam, and the value obtained from ship cargo documents about the vertical position of the centre of gravity ,KG. We could then have an approximately idea of ship roll period value, based in the knowledge of ship mass displacement, but this single calculation could have accumulated a big quantity of error to be safe and useful.

The Basic Ship Motion Model

The motion of a ship in a seaway is extremely complex and the full solution to the problem has yet to be established,[2].The difficulties lie in the non-linear interaction between the rigid body structure of the ship and the surrounding random fluid field.This issue is further complicated if the structural deformation of the vessel is taken into account when considering its response, changing from a six degree of freedom model to an infinite modes of motion elastic body.

The motion considered in the ship is mainly due to the wave disturbance, which in effect, is the input to the system considered.

For a rigid ship travelling with constant speed v at a arbitrary angle to sea waves, the resultant motions in the six degrees of freedom are governed by a set of second order differential equation, that for all linear motions of the ship,has the following standard form,[2]

$$(m+a)\ddot{q}(t)+b\dot{q}(t)+cq(t)=Q(t) \qquad (1)$$

where in equation (1), $q(t)=[x(t),y(t),z(t),\phi(t),\theta(t),\psi(t)]^T$,$x(t)$, $y(t)$, $z(t)$, are the surge, sway and heave linear motions and $\phi(t)$, $\theta(t)$ *and* $\psi(t)$ *are the roll, pitch and yaw* angular motions, and $Q(t)=[X(t),Y(t),Z(t),K(t),M(t),N(t)]^T$, $X(t)$, $Y(t)$, $Z(t)$ are the amplitudes of surge, sway and heave forces and $K(t)$, $M(t)$, $N(t)$ are the amplitudes of roll, pitch and yaw moments; the components $q(t)$, are the corresponding responses. The matrix m includes as its elements , the mass of the ship and the principal moments of inertia. The elements of the 6x6 matrix a are a combination of hydrodynamics forces; *b* is a damping matrix and *c* is a matrix which account for hydrostatic contributions.

The systems of equation (1), has been written in the co-ordinate system associated with a ship. Of course we can simplifies system (1) if we consider only selected motions like symmetric or vertical motions, heave and pitch, or anti-symmetrical or horizontal motions like roll, yaw or sway that usually are decoupled in such equation.

It is clear that equation (1) is a system of differential equations with random excitation and can be analysed by the classical methods of random differential equations, with the possible difficulties of computed nature due the interactions of hydrodynamic forces.

Because of such factors as free surface conditions, viscous effects, geometric properties of the hull, etc., in spite of the non-linear description of ship motions is often necessary.To make the problem tractable only one degree of freedom is considered from the point of view of ship stability.For normal ships, rolling is probably the most obviously non-linear mode and it is also considered to be the motion which can be most realistic treated in isolation, related with the other modes of motion,[2].

To obtain de initial stability characteristics of the ship, like GM, or the KG, the height of the centre of gravity over the keel of the ship is to be estimated, firstly the normal or natural frequency or roll period of the ship, through a relation between roll motion, wave excitation, and other quantities like ship roll inertia and roll damping moment, all of them strongly dependent of the ship draft.

In the present paper a work model for the roll response is required in order to relate the transverse metacentric height with the wave exciting moment. One of such dynamic models is the single degree of freedom non-linear rolling equation given by,[3]

$$\ddot{\phi}(t)+2k_{\dot{\phi}}\omega_{\phi}\dot{\phi}(t)+\omega_{\phi}^{2}\sum_{n=1,2}d_{2n-1}\phi^{2n-1}(t)=K(t) \tag{2}$$

It is supposed that the effects of roll damping moment due to the frictional resistance of the wetted surface and the generation of eddies by the hull could be not considered in a first order approximation. It is supposed also also that the roll exciting moment and the roll angle are both stationary Gaussian processes with zero mean expectation.

The linear model of equation (2), is

$$\ddot{\phi}(t)+2k_{\dot{\phi}}\omega_{\phi}\dot{\phi}(t)+\omega_{\phi}^{2}\phi(t)=K(t) \tag{3}$$

The rolling motion would be then characterised in the frequency domain by the well know expression

$$S_{\phi\phi}(\omega) = \left|H(\omega)\right|^2 S_{kk}(\omega) \qquad (4)$$

where the transfer function is expressed by equation , (7).If we now suppose that roll equation,(2), have a deterministic roll excitation moment of the single harmonic form,e.g.

like $K(t) = K_0 e^{i\omega t}$

Then the linear rolling motion solution of linear equation (3), would be given by [4] as

$$\phi(t) = e^{-k\omega t}\left(\frac{\dot{\phi}(0) + k\omega\phi(0)}{\omega\sqrt{1-k^2}}\sin\sqrt{1-k^2}\,\omega t + \phi(0)\cos\sqrt{1-k^2}\,\omega t\right) + \int_0^t K_0(\tau)h(t-\tau)d\tau \qquad (5)$$

In a more realistic non-linear approach, the solution will be more complicated and many times without analytical solution.

The mean square spectral density function relation for the non-linear equation (2), between roll motion, and roll waves moment will be,[3]

$$S_{\phi\phi}(\omega) = \left\{1 - 2\omega_\phi^2 N_m H(\omega)\cos\omega\tau\right\}\left|H(\omega)\right|^2 S_{kk}(\omega) \qquad (6)$$

$$N_m = \sum_{n=2,3}\frac{2d_{2n-1}}{\sqrt{\pi}}\left(\sqrt{2}\sigma_\phi\right)^{2n-1}\Gamma\left(\frac{2n+1}{2}\right) \qquad (7)$$

$$H(\omega) = \left(\omega_\phi^2 - \omega^2 + 2ik\omega_\phi\omega\right)^{-1} \qquad (8)$$

If it is supposed a quadratic non linear roll damping moment, the solution will be,

$$S_{\phi\phi}(\omega) = \left\{1 - N_d\left|H(\omega)\right|^2 + N_d^2\left|H(\omega)\right|^4 + \ldots\right\}\left|H(\omega)\right|^2 S_{kk}(\omega) \qquad (9)$$

$$N_d = 4\beta\sqrt{\frac{2}{\pi}}\sigma_{\dot{\phi}}\left(2k\omega_\phi + \beta\sqrt{\frac{2}{\pi}}\sigma_{\dot{\phi}}\right)^2 \qquad (10)$$

The undamped natural roll period, T, is given by

$$T_{\phi} = \frac{2\pi}{\omega_{\phi}} \tag{11}$$

The values in the expression changes if we considered the results of a non-linear relation like in equation,(2), or a more simpler linear relation like in (3).The ship roll frequency is affected specially at low angles, initial static stability, by the type of damping moment selected in the ship behaviour model: linear potential damping or non-linear, like Froude´s moment type, relation (9) shown at [5].

Simulation Results

In figure 2 and 3 a layout of the graphical interface to monitoring the stability parameter value in waves is show for a specific ship, sailing in waves by on-line sea-state estimation. The ship natural frequency of roll is easily discriminated from the range of sea incidence wave frequencies,[4],[9].

In figure 2, and 3, a display screen to test the reliability of the system is presented, allowing the selection of a limited number of different ships by means of introduction of changes in their main relevant dimensions, like length, beam and draft, as well as select the mean encounter wave frequency, that as is well know, due Doppler effect,(12), it is a function of wave mean frequency, ship speed and course relative to mean wave direction.As the same time the characteristic wave height is selected in the static stability measure simulation, i.e. in the estimation of ship roll frequency,[6].

$$\varpi_{e} = \varpi - \frac{\varpi^{2} V}{g} \cos(\chi) \tag{12}$$

The display screen shows also, the computation time, the maximum roll angle reach during the FFT process, and the spectrum peak corresponding to ship roll frequency. In figure 4 a simplified version of the object oriented algorithm used to make the computation is shown like a flow diagram with the main sequence of operation achieve to obtain finally the computed GM.

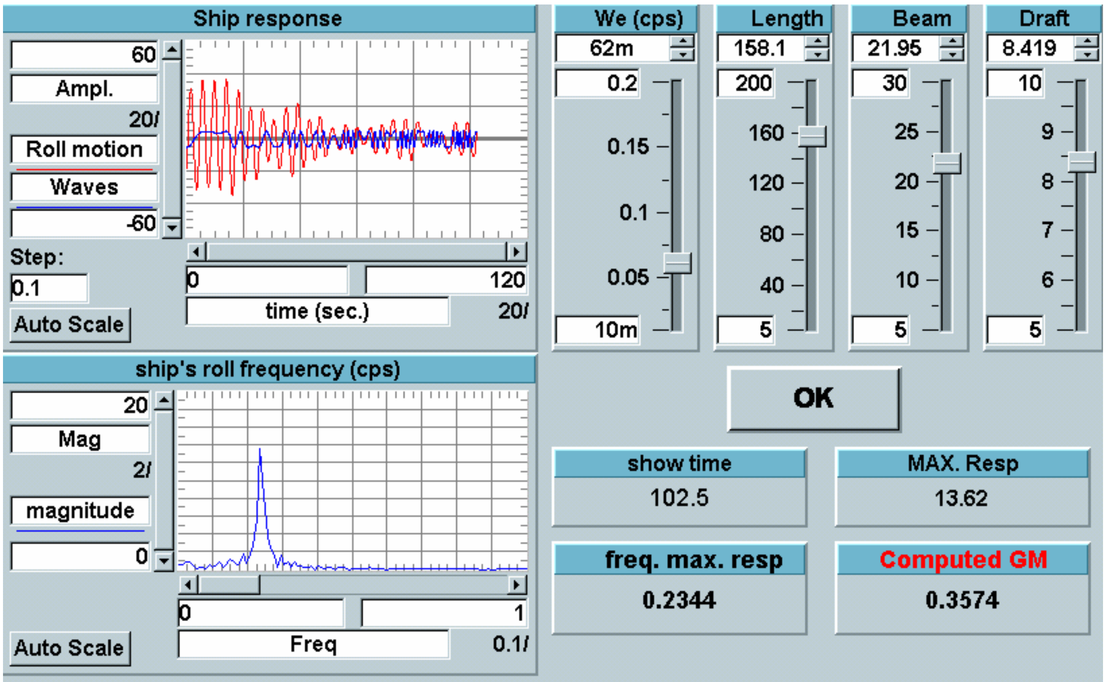

Fig. 2. A Session of Stability searching under a sea state scenario

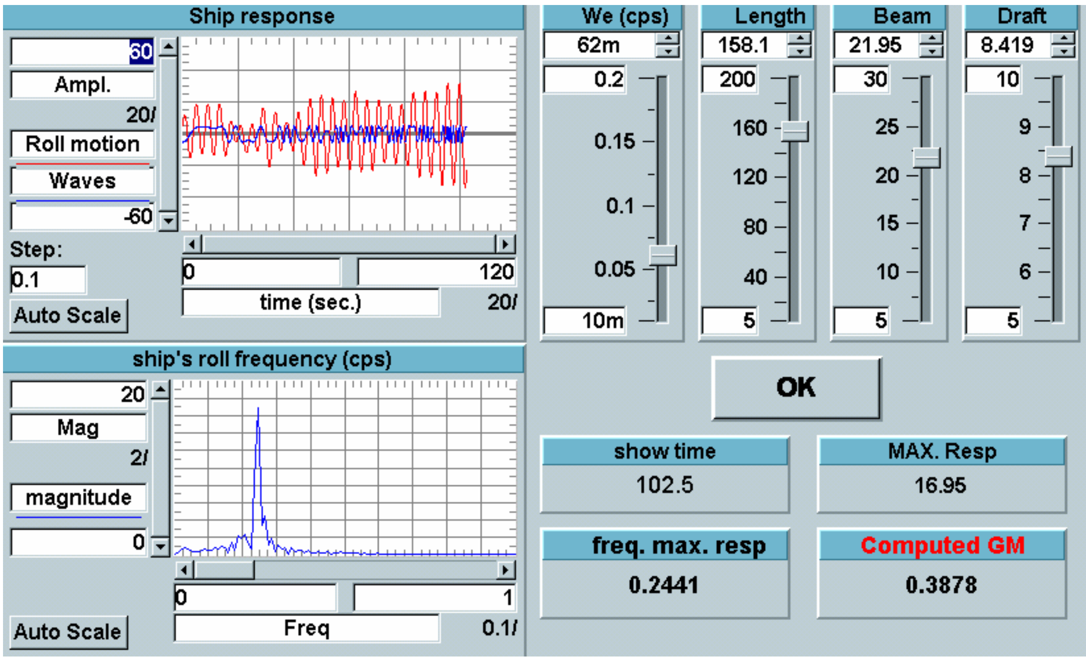

Fig. 3. A Session of Stability Searching under a different sea state scenario

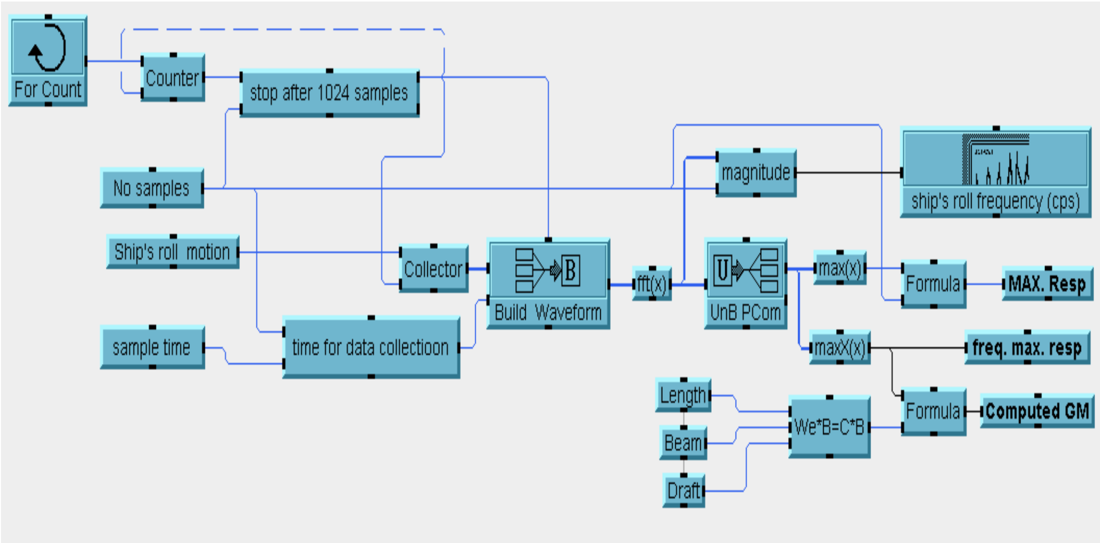

Fig 4. The Object oriented Algorithm

Conclusions

A method based on FFT processing [1], of random roll angles time series is presented, which allows the estimation of initial stability to be carried out using simultaneous measurements of wave excitation and the corresponding roll angle response for a floating vessel in a seaway.The method implemented in a stability monitoring and measurement device which consist in a PC based station together with measurement transducers of the seaway and a display screen, supply the value of the estimated static stability in a satisfactory way.This system is considerably more reliable,[3] than other based on response records only ,without wave excitation measured, e.g. assuming a deterministic excitation (7), like roll decrement method , the solution of the autocorrelation equation, the modulation function technique [7,8], or other using signal processing [10], like system identification , or even neural network models to extract roll natural frequencies for a statical stability assessment in waves [5].

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