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TIME SERIES PROGRAMME

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This programme has been written to allow another method of assessment of the seagoing performance of surface ships to be quantified. This assessment method is different from other methods in that this requires that a time history is formed which is in contradistinction to spectral techniques that are frequency based. The use of such an assessment method will be many fold, one in particular may be the quantification of the likelihood of the landing ability of helicopters on moving ships; another may be the assessment of the emergence of the ships propeller whilst the ship is under way in a random seaway.

The theory behind the program is not novel and is used extensively elsewhere in engineering applications and is well documented in many sources, in particular in the field of signal processing. The basic need of the programme is a frequency response for the motion that is under scrutiny.

In this particular case the frequency response is provided from the Total motions at a point module of the Seakeeping suite of programmes. These are documented elsewhere in Ship Science reports. The Total motion at a point programme allows the coupling of all the rigid body modes of oscillation of the ship.

In particular if the rigid body motion of the centre of gravity of the ship is defined, in vector form, to be (Su,Sw,He) and the rotational motion to be (Ro,Pi,Ya) where

Su	–	Surge, along the x-axis
Sw	–	Sway, along the y-axis
He	–	Heave, along the z-axis
Ro	–	Roll, about the x-axis
Pi	–	Pitch, about the y-axis
Ya	–	Yaw, about the z-axis

The motion at some general point P with co-ordinates (x,y,z) relative to the centre of gravity is given by the vector sum.

$$(Su,Sw,He) + (x,y,z) \times (Ro,Pi,Ya)$$

or in component form

$$(Su + y.Ya - z.Pi,\ Sw + z.Ro - x.Ya,\ He + x.Pi - y.Ro)$$

It is usually the case that the motion in the x direction is insignificant and then the total rigid motion at P can be written as

Displacement at P(x,y,z) is (0, La, Ve)

This displacement of the ship at P is an absolute value, relative to a fixed observer at the mean free surface of the sea. The absolute velocity and absolute acceleration can be found by differentiation taking into account the fact that the ship is moving in space and time.

If the sea surface is defined to be Wa(x,y) at P (x,y,z) then it is easy to see that the relative motion of the ship to the sea surface can be found by differencing the vertical components, i.e. Ve − Wa.

The relative velocity and acceleration can be found as indicated above by a simple differentiation. The usual method is now to use some spectral formulation of the sea surface e.g. a Bretschneider spectrum $S(\omega)$ where ω is the radian wave frequency, to produce a statistic that aims to measure the performance of the ship, usually on probablistic grounds on the assumption of a Rayleighian probability function.

The zeroth moment of the spectrum is given by

$$Mo = \int Ve^2\ S(\omega)\ d\omega$$

The equivalent amplitude of the spectrum is given by

$$a(\omega) = p\ \ 2\ S(\omega)\ Ve^2\ d\omega$$

This then allows the time series of the vertical motion at P to b calculated from the following Fourier integral

$$D(t) = \int a(\omega)\ \cos(\ \omega t + \epsilon(\omega))\ d\omega$$

where $\epsilon(\omega)$ is the phase of the wave of frequency ω .

This phase angle has to be found from a uniform random distribution of angles in the range $[0, 2\pi]$. The reason for the randomness of this phase angle is that all information has been lost in the forming of the spectrum $S(\omega)$, and there will be an infinity of time simulations that correspond to any particular spectral formulation.

The computer simulation of D(t) is found most easily from the use of the ubiquotous Fast Fourier Transform (FFT) method. The speed and use of this method are legend and can be found in many references. As is usual the method is most efficient when the number of spectral components is a power of 2.

The responses at P(x,y,z) for a given set of frequencies, ship speeds and wave headings will have been calculated in the Total motions module. These responses have been calculated at a finite and usually small set of regularly spaced wave frequencies, commonly about 40 in number. Since the response function for the vertical motions is well behaved, the range and number of frequencies can be expanded without too many problems. The reason for the need to perform such an operation is detailed in the following paragraph.

If the maximum wave frequency is denoted by ωmax radians per second and the minimum as ωmin radians per second, then the FFT algorithm will produce a time series at intrvals of time of dt and for a length of time T, where

$$T = 2 \pi / \omega min$$

$$dT = 2\pi / \omega max$$

If, for example, for the seakeeping calculation $\omega min = 0.05$ rads/sec and $\omega max = 2.0$ rads/sec then

$$T = 2 \pi / 0.05 = 3 \text{ mins . (approx)}$$
$$dt = 2 \pi / 2.0 = 3 \text{ secs . (approx)}$$

Thus the simulation is for only a relatively short time period. The way to increase the time scale is to decrease wmin, and equally the way to increase the resolution of the time series is to increase ωmax.

To increase ωmax would allow a finer definition of the time series but the actual shape of the response function is a little uncertain in this region especially when considering the acceleration spectrum because of the inclusion of the $\omega 2$ multiplier to the spectral ordinate. To increase the total time of the simulation is relatively easy since the vertical motion tends to unity and the spectral content tends to zero in a well defined and regular manner, as ω tends to zero.

The programme reduces the minimum wave frequency from ωmin to ωmax/(nfft−1), where nfft is the number of spectral ordinates that are to be used by the simulation. Typically nfft is 256 or greater, the larger choice of nfft, the longer the run time of the simulation. The programme interpolates the responses from the input set of the regularly spaced wave frequencies (ωmin to ωmax) to the wave frequencies

$$j\Delta\omega \quad \text{for } j = 0, 1, 2, \ldots. \text{ nfft}-1$$

where $\Delta\omega$ = ωmax/(nfft−1) and $\Delta\omega$, is also the minimum wave frequency. This means that the time simulation can cover a time scale of 2π nfft/ωmax seconds. Which using the previous value of ωmax equalling 2 rads/sec is for a total time of 2π*256/2 seconds i.e. about 12 minutes.

The programme produces the time history using the FFT method that is detailed in the NAG library together with the random number generator for uniform distributions from the same computer library.

The motion at any point P(x,y,z) within the ship can be calculated as a time series . The programme also contains an algorithm that interrogates up to three time series ,with the task of determining when specified limits , input by the programme user , are exceeded . The time between the limit values is often termed the QUIESCENT PERIOD .

There are 15 different possible motions that can be used to determine the quiescent periods . These are detailed as the displacements , velocities (rates) and the accelerations of the rotational and linear motion of the ship i.e.

that of the total Sway , Heave at the point P(x,y,z) and of the rotational motions Roll Yaw and Pitch

The fifteen explicit choices are

heave displacement , heave velocity , heave acceleration
pitch displacement , pitch velocity , pitch acceleration
sway displacement , sway velocity , sway acceleration
roll displacement , roll velocity , roll acceleration
yaw displacement , yaw velocity , yaw acceleration

The programme allows the user to choose which of these fifteen motions are to be included in the determination of the quiescent period .

For example

1) the ship designer may only be interested in heave velocity as the 'window' parameter thus for this case only one time series needs to be calculated and then interrogated for exceedence of the limit values .

2) the ship designer may be interested in helicopter landing on a moving ship and it is considered that the heave acceleration heave velocity and pitch angle are the pertient parameters . Thus in this case three time series are generated and interrogated for mutally occuring quiescent periods .

The output from the programme is given in two forms,
he first a histogram of groupings of quiescent periods, the second a list of actual quiescent periods.

The programme allows a maximum of five conditions of sets of limit(s) to be processed at any one time.

In a future release of this software the programme will incorporate the effect of spectral spreading.

In the Appendix is an example of the input and output that can be expected to be found in this programme

```
          TIMES SERIES PROGRAM
Input generic file name SHIPC


Source drive letter N
Target drive letter N
For assessment purposes there is a choice of variables
How many variables do you wish to use (max is 3) 3
For variable number  1
 Which variable ?
Heave  1
Sway   2
Pitch  3
Roll   4
Yaw    5   1
For variable number  1 Which motion type ?
Displacement  1
Velocity      2
Acceleration  3      2
For variable number  2
 Which variable ?
Heave  1
Sway   2
Pitch  3
Roll   4
Yaw    5   1
For variable number  2 Which motion type ?
Displacement  1
Velocity      2
Acceleration  3      3
For variable number  3
 Which variable ?
Heave  1
Sway   2
Pitch  3
Roll   4
Yaw    5   3
For variable number  3 Which motion type ?
Displacement  1
Velocity      2
Acceleration  3      1
Do you want output to the printer (1) or not (0) 0
          Positions
  xpos      ypos      zpos
    3.00      5.00      6.00


How many threshold limits (max 5 ) 1

Condition number.   1 HEAVE   velocity       .5

Condition number.   1 HEAVE  acceleration    .5

Condition number.   1 PITCH  displacement    1.

Speed number  1 Speed = 10.00 knots
```

Condition number. Pitch displacement 1.

Speed number 1 Speed = 10.00 knots

Heading number 1 spectra number 1 position no. 1

Simulation time was 784.6 seconds

Each range is 36.78 seconds
Condition number 1
For range number 1 Number in range 2 % of total 50.00
For range number 2 Number in range 0 % of total .00
For range number 3 Number in range 0 % of total .00
For range number 4 Number in range 0 % of total .00
For range number 5 Number in range 1 % of total 25.00
For range number 6 Number in range 0 % of total .00
For range number 7 Number in range 0 % of total .00
For range number 8 Number in range 0 % of total .00
For range number 9 Number in range 0 % of total .00
For range number 10 Number in range 0 % of total .00
For range number 11 Number in range 0 % of total .00
For range number 12 Number in range 0 % of total .00
For range number 13 Number in range 0 % of total .00
For range number 14 Number in range 0 % of total .00
For range number 15 Number in range 1 % of total 25.00
For range number 16 Number in range 0 % of total .00
For range number 17 Number in range 0 % of total .00
For range number 18 Number in range 0 % of total .00
For range number 19 Number in range 0 % of total .00
For range number 20 Number in range 0 % of total .00

For condition no. 1 Max quiescent period is 533.2 seconds
Quiescent period number 1 is 6.13 seconds
Quiescent period number 2 is 183.89 seconds
Quiescent period number 3 is 24.43 seconds
Quiescent period number 4 is 533.19 seconds
Total quiescent time is 747.6 seconds

Heading number 1 spectra number 2 position no. 1

Simulation time was 784.6 seconds

Each range is 36.78 seconds
Condition number 1
For range number 1 Number in range 26 % of total 100.00
For range number 2 Number in range 0 % of total .00
For range number 3 Number in range 0 % of total .00
For range number 4 Number in range 0 % of total .00
For range number 5 Number in range 0 % of total .00
For range number 6 Number in range 0 % of total .00
For range number 7 Number in range 0 % of total .00
For range number 8 Number in range 0 % of total .00
For range number 9 Number in range 0 % of total .00
For range number 10 Number in range 0 % of total .00
For range number 11 Number in range 0 % of total .00
For range number 12 Number in range 0 % of total .00
For range number 13 Number in range 0 % of total .00
For range number 14 Number in range 0 % of total .00
For range number 15 Number in range 0 % of total .00
For range number 16 Number in range 0 % of total .00
For range number 17 Number in range 0 % of total .00
For range number 18 Number in range 0 % of total .00
For range number 19 Number in range 0 % of total .00
For range number 20 Number in range 0 % of total .00

For condition no. 1 Max quiescent period is 9.3 seconds
Quiescent period number 1 is 3.06 seconds
Quiescent period number 2 is 3.22 seconds
Quiescent period number 3 is 3.30 seconds
Quiescent period number 4 is 3.63 seconds
Quiescent period number 5 is 4.79 seconds
Quiescent period number 6 is 3.79 seconds
Quiescent period number 7 is 3.57 seconds
Quiescent period number 8 is 4.91 seconds
Quiescent period number 9 is 3.19 seconds
Quiescent period number 10 is 7.25 seconds
Quiescent period number 11 is 3.45 seconds
Quiescent period number 12 is 3.25 seconds
Quiescent period number 13 is 6.35 seconds
Quiescent period number 14 is 3.18 seconds
Quiescent period number 15 is 3.36 seconds
Quiescent period number 16 is 3.09 seconds
Quiescent period number 17 is 5.44 seconds
Quiescent period number 18 is 3.25 seconds
Quiescent period number 19 is 5.36 seconds
Quiescent period number 20 is 3.95 seconds
Quiescent period number 21 is 3.80 seconds
Quiescent period number 22 is 7.36 seconds
Quiescent period number 23 is 9.30 seconds
Quiescent period number 24 is 3.66 seconds
Quiescent period number 25 is 3.08 seconds
Quiescent period number 26 is .00 seconds
Total quiescent time is 108.6 seconds