Proceedings of the Ninth (1999) International Offshore and Polar Engineering Conference
Brest, France, May 30-June 4, 1999

ISBN 1-880653-39-7 (Set); ISBN 1-880653-42-7 (Vol. III); ISSN 1098-6189 (Set)

Time Domain Model Representations of Standard Wind Gust Spectra

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ABSTRACT

Time domain models are developed for representation of standard wind gust spectra, like those of Davenport and Harris, and the new NPD spectrum. The models are obtained by iterative least squares fitting of rational spectrum functions to the given spectra and deriving transfer functions and hence state space models from these. Good agreement between the original spectra and those of the fitted models were obtained with model orders as low as 2 or 3. The resulting models are recursive and well suited for simulation in cases when the wind is not stationary. This is in contrast to the conventional method by which long time series must be precomputed by FFT techniques.

INTRODUCTION

For comparatively short durations of time (minutes up to an hour) the speed of wind can be regarded as a stationary random process composed of a constant mean speed and a fluctuating component (gust), modelled by a power spectral density function. Assuming the gust to be gaussian, the model is complete.

Several mathematical definitions have been proposed for the gust spectrum, some of the best known being the Davenport spectrum and the Harris spectrum (Davenport, 1977):

$$S_{DAV}(f) = \frac{4\kappa L U \chi}{(1+\chi^2)^{4/3}}$$
$$S_{HAR}(f) = \frac{4\kappa L U}{(2+\chi^2)^{5/6}} \qquad (1)$$
$$\chi = \frac{fL}{U}$$

where f is the frequency (Hz), U the mean speed, L a scale length and κ the surface drag coefficient. For the Davenport spectrum the value of L is usually chosen as 1200 m, whereas L=1800 m is recommended for the Harris spectrum. For wind over rough sea 0.0025 is an appropriate value for κ

In recent years a new spectrum type has been developed, based on extensive wind measurements off the coast of mid-Norway. This spectrum is found in a publication by the Norwegian Petroleum Directorate (NPD) (1992) and is henceforth referred to as the "NPD spectrum". The spectrum is formulated as:

$$S_{NPD}(f) = \frac{320\cdot(\frac{U}{10})^2}{(1+\bar{f}^n)^{5/3n}}$$
$$\bar{f} = 172 f\cdot(\frac{U}{10})^{-3/4} \qquad (2)$$
$$n = 0.468$$

The NPD spectrum is intended for describing gust at mean wind speeds above 10 m/s.

The Davenport, Harris and NPD spectra are shown in Figure 1. The NPD spectrum deviates significantly from the other two in that it contains considerably more power at low frequencies. The reason for this is that the Davenport and Harris spectra are based on observations of wind over land while the NPD spectrum model is fitted to measurements of wind over sea, where the thermal structure is different. Put differently, the generally accepted spectral 'gap' in the range 1 – 5 cycles /hr was found not to exist, cf. T. Heggem et al., (1992).

For increasing frequency, however, the three spectra agree in that they all approach infinity as $const\cdot f^{-5/3}$, a result which is based on accepted turbulence theory.

Structures moored at sea will have low frequency resonant periods of motion in the range 1-5 minutes. It is therefore of great concern to model the power density of the wind spectrum in this range realistically.

To calculate wind loads in the time domain it is necessary to create a time function of wind gusts that correspond to the chosen spectral density function. The most common method is to derive a complex discrete amplitude spectrum from the continous spectral density