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WAVE GAGE ARRAYS FOR OBTAINING OCEAN-WAVE SPECTRA

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The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The present invention is directed to equipment for telemetering ocean-wave information and more particularly to apparatus and a method of determining the spectra of ocean waves.

Those who are responsible for operation on the oceans desire information on wave height, wave period and the general state of the ocean waters as well as the weather. Heretofore devices have been made available which can be stationed in the oceans by use of buoys to periodically transmit weather conditions such as wind speed, wind direction, barometric pressure, air temperature and water temperature at timed intervals or by remote control. Such information is useful for many purposes; however, additional information on the sea-state is useful to a ship's captain and others.

The present invention is directed to a sensor to obtain some measure of the sea condition. One description of the sea surface is that of an energy spectrum which gives estimates of wave energy as a function of frequency. Energy spectra are usually obtained by digital computer processing of a time series of data of the surface elevations taken over a time interval of the order of 20 minutes. The area under such a spectrum is a measure of the total energy of all the waves. Since the weather buoy cannot be equipped with a complex computer, nor is it practical to supply the power required to transmit 20 minutes of wave-height data to a shore station for analysis, apparatus for obtaining the integrated value of the mean square of the surface deviation over a 20-minute period using a pressure transducer suspended below the buoy and working into an integrating device has been developed. This integrated value is a measure of the total energy of the measured waves.

Trochoidal wave theory depicts ocean waves as circular motions of water particles which decrease exponentially with the depth expressed in wavelength. If one prefers to consider the ocean surface as an infinitely broad distribution of sinusoidal waves, the variations in pressure due to the waves decrease with depth, the rate of decrease being a function of the wavelength. For water depths of the order of a few wavelengths, either concept results in virtually the same rate of decay of wave effects with depth. Because the wave effects diminish with depth as a function of wavelength and because wavelength is directly related to the square of the wave period, the sensor of the present invention is directed to a means for sensing and telemetering the energy spectrum of the ocean waves.

It is therefore an object of the present invention to telemeter ocean-wave information from remotely positioned buoys.

Another object is to provide a method for determining sea condition by use of a remotely positioned buoy.

Still another object is to use simple relatively inexpensive equipment for transmitting sea-state conditions of ocean waters.

Yet another object is to provide a wave height measuring system which is independent of water depth and of bottom pressure.

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Other and more specific objects of this invention will become apparent upon a careful consideration of the following description taken together with the accompanying drawings, in which:

FIG. 1 illustrates a pair of separate spaced buoys each with five wave pressure sensors secured thereto and schematically displayed relative to constant pressure contours for a wave period of 9.34 seconds;

FIG. 2 illustrates an illustrative wave sensor-pressure transducer, and

FIG. 3 illustrates a pressure sensor secured to a system for telemetering wave information.

The present invention makes use of an electrical calorimeter, such as disclosed in patent application Serial No. 300,948 filed August 8, 1963, to integrate the output of a wave sensor over a period of time, for example, about twenty minutes. One type of weather buoy instrument package presently used has five spare channels for telemetering outputs. These spare channels can be used for telemetering the outputs of wave sensors used in carrying out the teaching of the present invention. Wave sensors are suspended vertically at various depths below a buoy at various depths and evenly spaced along an effectively rigid cable such that the array remains substantially vertical while ascending and decending as the buoy follows the rise and fall of the waves. Less expensive equipped buoys can be used where instrumentation for telemetering only wave information is desired. It is contemplated that the receiving equipment may be ashore, aboard a sea-going vessel, or on an airplane.

Now, referring to FIG. 1, there is illustrated a buoy **10** having five pressure transducers **11** secured onto vertical cable **12** which is attached to the buoy. The buoy is illustrated in two positions with respect to the wave, that is, as the wave propagates the buoy is first in position A in the trough of the wave, then in position B on the crest of the wave. The somewhat horizontally directed lines **13** illustrates equally-spaced constant-pressure contours that represent corresponding pressure areas for a wave crest and trough. It can be seen that as the buoy goes from position A to position B, the transducer at the top will cross fewer contour lines than does the transducer at the bottom thus the lower transducer will show a greater response because it is encountering a greater pressure change. The pressure change to which each transducer in the array is exposed is proportional to the difference in amplitude between the constant-pressure surface at the water surface and the constant pressure surface at the depth of the transducer. Therefore, the response of each transducer is proportional to 1–K, where K is the factor by which the amplitude of the constant-pressure surface at depth Z is reduced compared to the constant pressure surface at the water surface. K is determined by the formula:

$$K=e^{-2\pi Z/L}$$

$$K=\text{Cos}\ h[2\pi d/L(1-Z/d)]$$

where d is the water depth, Z is the mean depth of the pressure surface and L is the wavelength. One can compute (1–K) for each of the five transducers as illustrated in FIG. 1, for each of the five different wave periods. Each transducer will respond to the five waves but with different sensitivities due to the different depths of the transducers below the buoy. The squared and integrated output over an interval of time of each transducer in the array is a linear combination of such response to the five waves having different periods. Thus one can form a set of linear equations describing the outputs of the five transducers as follows:

$$R_i=(1-K_{ij})^2E_j \quad (3)$$

where R_i is the output energy over a given interval from the i^{th} sensor, K_{ij} is the depth attenuation for the i^{th}