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Datasheet for the decision of 13 March 2007

Case Number: T 0518/06 - 3.4.01

Application Number: 99968442.6

Publication Number: 1110101

IPC: G01S 15/58

Language of the proceedings: EN

Title of invention:
System and method for measuring wave directional spectrum and wave height

Applicant:
Teledyne RD Instruments, Inc.

Opponent:
-

Headword:
-

Relevant legal provisions:
EPC Art. 52(1), 56

Keyword:
"Inventive step (no)"

Decisions cited:
-

Catchword:
-

Case Number: T 0518/06 - 3.4.01

D E C I S I O N
of the Technical Board of Appeal 3.4.01
of 13 March 2007

Appellant: Teledyne RD Instruments, Inc.
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Decision under appeal: **Decision of the Examining Division of the European Patent Office posted 15 November 2005 refusing European application No. 99968442.6 pursuant to Article 97(1) EPC.**

Composition of the Board:

Chairman: B. Schachenmann
Members: R. Bekkering
G. Assi

Summary of Facts and Submissions

I. European patent application 99 968 442.6 (publication nos. WO-A-00 20893 and EP-A-1 110 101) was refused pursuant to Article 97(1) EPC by a decision of the examining division dispatched on 15 November 2005, on the ground of lack of inventive step, Articles 52(1) and 56 EPC.

II. The applicant (appellant) lodged an appeal against the decision on 20 January 2006 and paid the appeal fee on the same day. The statement setting out the grounds of appeal was received on 24 March 2006.

III. Reference is made to the following documents:

D1: E. Terray et al, "Measuring wave height and direction using upward-looking ADCPs", OCEANS '97, MTS/IEEE, Conference proceedings, Halifax, NS, Canada, 6-9 October 1997, vol. 1, 1997, New York, USA, pages 287 to 290

D2: E. A. Terray et al, "Measuring wave direction using upward-looking Doppler sonar" Proceedings of the Working Conference on Current Measurement, US, New York, IEEE, vol. conf. 4, 1990, pages 252 to 257

D5: JP-A-07 218 254
D5b: Computer generated English translation of D5
D5c: JP-B-2 948 472 (patent publication of D5)
D5d: English translation of D5c

D6: T. Takayama et al, "Development of a submerged Doppler-type directional wave meter", Proceedings of the 24th International Conference on Coastal Engineering, Part 1 (of 3), Kobe, Japan, 23-28 October 1994, ASCE 1995, New York, USA, pages 624 to 634

D7: J. Allender et al, "The WADIC project: A comprehensive field evaluation of directional wave instrumentation", Ocean Engineering, vol. 16, no. 5/6, 1989, pages 505 to 536

D8: H. E. Krogstad: "Maximum likelihood estimation of ocean wave spectra from general arrays of wave gauges", Modeling, Identification and Control, 1988, vol. 9, no. 2, pages 81 to 97

D9: O. Haug et al, "Estimation of directional spectra by ML/ME-methods", Ocean Wave Measurement and Analysis, Proceedings of the Second International Symposium, 25-28 July 1993, New Orleans, ASCE, New York, USA, pages 394 to 405

IV. Oral proceedings, requested as an auxiliary measure by the appellant, were held on 13 March 2007.

V. The appellant requested that the decision under appeal be set aside and a patent be granted on the basis of the following documents:

Main request:

Claims: nos. 1, 12, 14 and 16 filed on 13 February 2007;

nos. 2 to 11, 13, 15 and 17 to 25 of the main request of 24 March 2006;

Description: pages 1 to 25 as published;

Drawings: Sheets 1/20 to 20/20 as published.

First auxiliary request:

Claims: nos. 1, 12, 14 and 16 filed on 13 February 2007;
nos. 2 to 11, 13, 15, 17 to 25 of the second auxiliary request of 24 March 2006;

Description and drawings as for the main request.

Second auxiliary request:

Claims: nos. 1, 11, 13 and 14 filed on 13 February 2007;
nos. 2 to 10 and 15 to 23 of the third auxiliary request of 24 March 2006;

Description and drawings as for the main request.

Third auxiliary request:

Claims: nos. 1, 2, 13 and 14 filed on 13 February 2007;
nos. 3 to 12 and 15 to 27 corresponding to claims 2 to 11 and 13 to 25 of the main request;

Description and drawings as for the main request.

VI. Claim 1 according to the main request read as follows:

"*1. A system for measuring the directional spectrum of waves in a fluid medium (110) having a substantially planar surface, comprising:*

a sonar system having a plurality of transducers (103) for generating respective acoustic beams (104) and receiving echoes from range cells (107) located at successive positions along and substantially within the beams, the beams being inclined at a non-zero angle with respect to the surface of the fluid medium (110); and

a computer program executed by a processor for calculating the directional spectrum associated with the waves from the received echoes, wherein the computer program further utilizes a sensitivity vector (H) related to a geometry of an array formed by the range cells within the beams as part of the calculation of the directional spectrum,

characterised in that the sensitivity vector comprises elements, wherein each range cell from a particular beam (104) and depth corresponds to an element of the sensitivity vector (H)."

Claim 1 according to the first auxiliary request differs from that according to the main request in that it contains the following additional feature "*[...element of the sensitivity vector (H)] having the form*

$$\frac{2\pi f \exp\left[i\vec{k}\bullet\vec{x}_n(z)\right]}{\sinh(kh)}\left[\cosh[k(h+z)]\left(\frac{\vec{k}\bullet\vec{b}_n}{k}\right)-i\sinh[k(h+z)]\left(\vec{i}_z\bullet\vec{b}_n\right)\right]$$

where f is a wave frequency, k a wavenumber, h a water depth, z a vertical position of the range cell, $\vec{k}$ *a* *wavenumber vector,* $\vec{b}_n$ *a unit vector pointing outward in the direction of the* n^{th} *acoustic beam of the sonar system,* $\vec{x}_n(z)$*a horizontal displacement vector for the range cell and* $\vec{i}_z$ *a unit vector in the vertical direction.*"

Claim 1 according to the second auxiliary request differs from that according to the main request in that it contains the following additional features:

"*and the calculation includes:*
calculating a non-directional wave height spectrum;
calculating a cross-spectral matrix;
calculating the directional spectra at each observed frequency; and calculating the dimensional directional spectrum from the non-directional wave height spectrum, the cross-spectral matrix, the directional spectra, and the sensitivity vector."

Claim 1 according to the third auxiliary request differs from that according to the main request in that it contains the following additional feature:

"and the sensitivity vector includes elements corresponding to pressure within the fluid medium."

Furthermore, all requests contain a corresponding independent claim directed to a method of calculating the directional spectrum of a wave in a fluid medium.

Reasons for the Decision

1. The appeal complies with the requirements of Articles 106 to 108 and Rule 64 EPC and is, therefore, admissible.

2. Main request

2.1 Amendments

Independent claim 1 is based on claim 1 as originally filed, the additional feature relating to receiving echoes from range cells located at successive positions along and substantially within the beams being disclosed on page 3, lines 19 to 22 and page 9, lines 8 to 9 of the application as published and the additional feature relating to each range cell from a particular beam and depth corresponding to an element of the sensitivity vector being derivable from page 20, lines 24 to 26 of the application as published.

In this context it is, furthermore, noted that as can be seen from the above latter passage, in the particular case of N range cells along four beams, the sensitivity vector H, thus, includes 4N elements corresponding to a three dimensional arrangement of range cells. Accordingly, contrary to what is held in the decision under appeal (see Reasons II.3), the application discloses the calculation of a wave directional spectrum using a three dimensional data set.

In view of the above, the Board is satisfied that the amendments to claim 1 comply with the requirements of Article 123(2) EPC.

2.2 Novelty, inventive step

2.2.1 Document D2 discloses a system for measuring the frequency-direction spectrum of waves in water using an upward looking Doppler sonar (Acoustic Doppler Current Profiler (ADCP)) (see point 2 "Measurement principles"). The ADCP employs a Janus configuration consisting of four independent acoustic beams inclined at a fixed angle to the vertical. The sonar measures the instantaneous velocity component projected along the beam axis, averaged over a range cell whose length is roughly one-half that of the acoustic pulse.

Since successive positions along the beams correspond to different horizontal locations, the set of range cells (bins) constitutes a spatial array and useful information concerning the wave direction is contained in the velocity cross-spectra between the various cells (ie the array covariance matrix). The velocity measured by the sonar is a linear combination of horizontal and vertical wave velocities. Hence the feasibility of the approach rests on the availability of a known connection (ie transfer function) between wave velocity and surface wave height.

The transfer function is assumed to be correctly given by linear wave theory. With this assumption, the cross-spectrum $C(\omega|x,x')$ is given by equation (1)

$$C(\omega|x,x') = \int_{-\pi}^{+\pi} d\theta e^{ik\cdot(x-x')} \times H(\theta,\omega,z) D(\theta,\omega) H^{+}(\theta,\omega,z')$$

The Maximum Likelihood (ML) Method available in the literature is used to compute the results.

A principal qualitative factor affecting the resolution of the system is the cell (bin) spacing. The correlation scale of wind-waves is typically a few wavelengths, and therefore lags of less then a wavelength are necessary. For high frequency waves, these are typically provided by adjacent bins along a single beam, whereas for long waves nearby bins have essentially the same phase, and correlations from beam to beam become important. In a simulated example, a Janus configuration is used with a 30^o beam angle in 20m water depth on an input spectrum having a wavelength of 25m and a heading of 50^0. A first ML direction spectrum is calculated using only the four range cells (bins) at the surface, which are separated by 23m (or roughly one wavelength). A second ML direction spectrum is calculated using both the range cells (bins) at the surface and at 5m depth so that the minimum lag distance is now 3m (ie $5\tan30^o$), corresponding to a difference in wave phase of over 40^o. The second direction spectrum shows an improved resolution and less noise/artefacts (see page 253, right-hand column, second paragraph to page 254, left-hand column, first paragraph and figure 1).

The feasibility is demonstrated in the field with range cells (bins) located at 0.5, 1.5, 2.5 and 3.5 meters depth and with all range cells having a vertical extent of 1m (see page 255, point 4 "Field Observations", first paragraph). The obtained frequency-direction wave spectrum is shown in figure 4.

2.2.2 Accordingly, document D2 discloses in the terms of claim 1 a system for measuring the directional spectrum of waves in a fluid medium having a substantially planar surface, comprising:

a sonar system (ie a Doppler sonar) having a plurality of transducers for generating respective acoustic beams (ie four in a Janus configuration) and receiving echoes from range cells located at successive positions along and substantially within the beams (ie at different depths, eg at the surface and 5m depth, or eg at 0.5, 1.5, 2.5 and 3.5 meters depth) the beams being inclined at a non-zero angle with respect to the surface of the fluid medium (typically 20-30^{o} from the vertical); and

a computer program executed by a processor for calculating the directional spectrum associated with the waves from the received echoes (see page 257, left-hand column, first paragraph), wherein the computer program further utilizes a sensitivity vector (ie transfer function) related to a geometry of an array formed by the range cells within the beams as part of the calculation of the directional spectrum.

In view of the above, document D2 discloses a system having all the features provided in the preamble of claim 1.

2.2.3 As is apparent from the above, in document D2 the correlation between the measured wave velocities in range cells arranged in a three dimensional array is determined.

Accordingly, the calculation of the wave frequency-direction spectrum requires a transfer function between wave velocity and wave elevation wherein each of the range cells corresponds to an element of the transfer function.

2.2.4 The appellant acknowledged that the sensitivity vector in the application corresponded to what was commonly referred to as a transfer function in the technical field at issue. However, he argued that the transfer function $H(\theta,\omega,z)$ in document D2 was not dependent on x and, therefore, not identical to the sensitivity vector defined in claim 1, so that the subject-matter of claim 1 was novel with respect to document D2.

$H(\theta,\omega,z)$ in equation (1) of document D2 is defined as the transfer function between the velocity at depth z and the Fourier amplitude of the wave elevation (height). The variables z and x, defining the vertical and horizontal position of the range cell, respectively, are however dependent variables for range cells located at successive positions along a beam. Accordingly, a dependency on the depth z entails a dependency on the horizontal position x. Furthermore, the horizontal position x is accounted for in the exponential term in equation (1) providing, with H, the "transfer function" between wave velocity as measured and surface elevation in a broader sense.

The difference between the sensitivity vector defined in claim 1 and the transfer function disclosed in document D2, if at all relevant to novelty, would only reside in the mathematical form in which the transfer function is represented.

The objective problem to be solved having regard to document D2 may, thus, be seen as to provide a suitable mathematical form for the transfer function.
However, providing a suitable mathematical form, eg a vector (in the sense of a one-dimensional array of elements) as per claim 1, allowing to perform the calculations as disclosed in document D2 including range cells at different depths, is considered to be obvious to a person skilled in the art working in the technical field of wave spectra at issue.

2.2.5 The appellant, furthermore, submitted that document D2 did not disclose in a sufficiently clear manner how information from range cells at different depths was included. Moreover, it was argued that there was a general prejudice in the art against using information from depth range cells as this merely increased noise. If information from depth range cells was available, it was integrated along the beam axis or averaged, as was the case in documents D1 and D5. The inclusion of depth information according to the invention, on the other hand, resulted in better wave spectra with fewer artefacts, as could be seen from the wave spectra on explanatory sheet A filed at the oral proceedings.

In the Board's view, however, as discussed above, it is clear from document D2 (see figure 1 and equation (1) with corresponding description) that the correlation between range cells at different positions including different depths is determined, thereby reducing the lag between the cells. As disclosed in document D2, this improves the spectrum resolution and reduces artefacts (see figure 1), just like this was the case in the application according to the appellant.

The fact that the frequency-direction wave spectrum obtained by document D2 using range cells along four beams at 0.5, 1.5, 2.5 and 3.5 meters depth as shown in figure 4 is identical, also in terms of resolution and absence of artefacts, to the wave spectrum of figure 8 obtained with an embodiment of the invention, actually shows that the depth information in document D2 is included in the same manner as in the application.

Finally, it is noted that the alleged existence of a prejudice in the art against using information from depth range cells is not supported by document D2 which uses the correlation between range cells at different depths. The fact that other documents propose integrating or averaging over depth indicates that other solutions are available in the state of the art, rather than that any technical prejudice would exist.

Moreover, it is noted in this respect that in document D1, besides the reference to the average over the three depth levels (see page 289, right-hand column, first paragraph), reference is also made to use of the array covariance formed from 12 range cells (made up of the cells in each of 4 beams at 3 depth levels) and thus without any averaging (see page 289, left-hand column, penultimate paragraph). Furthermore, as far as document D5 is concerned, the integration referred to by the appellant is an integration over the width of the range cell (see document D5b, paragraph [0056] and D5d, page 18, lines 9 to 12) and not over more range cells in the depth direction. An averaging over a range cell is in fact standard in ADCP measurements and as such also provided for in the application (see page 1, lines 12 to 14 of the application as published).

2.2.6 In view of the above, the subject-matter of claim 1 according to the main request lacks an inventive step (Articles 52(1) and 56 EPC).

The main request is, therefore, not allowable.

3. First auxiliary request

Claim 1 according to the first auxiliary request differs from that according to the main request in that it contains the following additional feature "*[...element of the sensitivity vector (H)] having the form*

$$\frac{2\pi f \exp\left[i\vec{k}\bullet\vec{x}_n(z)\right]}{\sinh(kh)}\left[\cosh\left[k(h+z)\right]\left(\frac{\vec{k}\bullet\vec{b}_n}{k}\right)-i\sinh\left[k(h+z)\right]\left(\vec{i}_z\bullet\vec{b}_n\right)\right]$$

where f is a wave frequency, k a wavenumber, h a water depth, z a vertical position of the range cell, $\vec{k}$ *a wavenumber vector,* $\vec{b}_n$ *a unit vector pointing outward in the direction of the* n^{th} *acoustic beam of the sonar system,* $\vec{x}_n(z)$ *a horizontal displacement vector for the range cell and* $\vec{i}_z$ *a unit vector in the vertical direction.*"

As discussed above, document D2 rests on the availability of a known connection (ie transfer function) between wave velocity and surface wave height. The transfer function is assumed to be correctly given by linear wave theory.

The objective problem to be solved having regard to document D2 is, thus, the provision of such a transfer function.

Document D6 discloses a transfer function between the water particle velocity as measured along a tilted beam of an upward looking Janus ADCP and the water surface elevation for the purposes of calculating a directional wave spectrum. The transfer function H, using linear wave theory is expressed as follows (see equation (8))

$$H_0(\alpha, \beta, r, h, z_0; \omega, \theta) = \frac{\omega \exp(-i\omega\Delta t)}{\sinh kh} \times$$

$$\left[\cosh\{k(r\cos\alpha + z_0)\} \times \sin\alpha\cos(\theta - \beta) - i\sinh\{k(r\cos\alpha + z_0)\} \times \cos\alpha\right] \times$$

$$\exp\{ikr\sin\alpha\cos(\theta - \beta)\}$$

where h, k, ω, θ and z_0 respectively represent the water depth, wave number, angular frequency, wave propagation direction and height at which the meter is installed above the seabed and where Δt is the time lag between the measurement of each velocity component and that of surface elevation above the origin (0,0,0) η_0.

As can be seen by a straightforward conversion from polar coordinates as defined in figure 4 to vector products and by taking the time lag $\Delta t = 0$, this equation is identical to that provided in claim 1 of the first auxiliary request.

Accordingly, the subject-matter of claim 1 according to the first auxiliary request is obvious to the skilled person and, hence, lacks an inventive step (Articles 52(1) and 56 EPC).

4. Second auxiliary request

Claim 1 according to the second auxiliary request differs from that according to the main request in that it contains the following additional features:

"*and the calculation includes:*
calculating a non-directional wave height spectrum;
calculating a cross-spectral matrix;
calculating the directional spectra at each observed frequency; and calculating the dimensional directional spectrum from the non-directional wave height spectrum, the cross-spectral matrix, the directional spectra, and the sensitivity vector."

The objective problem to be solved having regard to document D2 is, thus, the provision of a suitable calculation for obtaining the frequency-direction wave spectrum.

As disclosed in document D2 the frequency-direction wave spectrum $D(\theta,\omega)$ is related to the cross-spectrum $C(\omega|x,x')$ by equation (1). The frequency-direction wave spectrum $D(\theta,\omega)$ is thus obtained by inversion of the equation. According to document D2 a number of methods are available in the literature for this purpose of which the "Maximum Likelihood (ML) Method" is used. As can be seen from any one of documents D5 (see D5b, page 9 and D5d, page 18), document D6 (see page 630), document D7 (see page 516), document D8 (see pages 86 to 88) and document D9 (see page 396) the wave spectrum is, thus, given by the following equation

$$D(\theta, \omega) = \frac{K}{H^{*}C^{-1}H}$$

where H is the matrix comprised of the transfer functions discussed above, H^{*} the complex conjugate transpose of H, C^{-1} the inverse matrix of the matrix consisting of the cross-spectrum and κ a normalisation factor. The calculation of the directional spectra at each observed frequency is part of the ML method. Furthermore, the calculation of the non-directional wave height spectrum is required for normalising at each frequency.

Accordingly, the calculation as defined in claim 1 is obvious to the skilled person from the state of the art. The subject-matter of claim 1 of the second auxiliary request, therefore, lacks an inventive step (Articles 52(1) and 56 EPC).

The second auxiliary request is, thus, not allowable either.

5. Third auxiliary request

Claim 1 according to the third auxiliary request differs from that according to the main request in that it contains the following additional feature:

"and the sensitivity vector includes elements corresponding to pressure within the fluid medium."

The use of pressure data is not disclosed in document D2. As argued by the appellant, the addition of pressure data correlated with water velocity data adds useful information and reduces noise in the spectrum.

The objective problem to be solved having regard to document D2 may, thus, be seen as reducing spectrum noise.

Document D5 discloses a system for measuring the wave spectrum of the sea surface. The water particle velocity is measured by means of an upward looking Janus ADCP and underwater pressure variations caused by waves are measured by a water pressure sensor, to thereby obtain a plurality of wave motion quantities for estimating the directional wave spectrum (see document D5b, paragraph [0055] and D5d, the paragraph bridging pages 17 and 18). In the calculation of the directional wave spectrum a matrix H is used composed of transfer functions for the respective wave motion quantities (see page 18, last paragraph and equations (5) and (6)).

Accordingly, in document D5 the cross-spectrum contains correlations between water velocity and pressure, which has the effect of increasing the wave spectrum resolution and reducing wave spectrum noise.

In view of the above, it would be obvious for the skilled person in order to solve the above problem, to include in the ADCP system provided in document D2 a pressure sensor as suggested by document D5 and to include elements corresponding to water pressure in the transfer function in order to take account of the correlations between water velocity and pressure as measured. The subject-matter of claim 1 according to the third auxiliary request, thus, lacks an inventive step (Articles 52(1) and 56 EPC).

Therefore, the third auxiliary request is not allowable either.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar: The Chairman:

R. Schumacher B. Schachenmann