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Hydrography Committee

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A New 3 axis current speed sensor for measurements of microstructure velocities.

Summary:

The paper describes a general purpose 3 axis ultrasonic current velocity sensor which has so small dimensions that it can be used for microscale observations.
The sensor can measure velocities from 1 mm/s to several meters per second with a high degree of linearity.
The response time is appr. 10 ms.
The sensor can be used in modelling,microscale oceanography, limnography and in fish farming.

Introduction.

During the last 20 years the oceanic community has showed an increased eagerness to be able to understand microscale processes; i.e. processes that occur within water volumes of appr. 10x10x10 cm3 .Some important applications for observing water velocities on this scale can be mentioned:
In general oceanography there is a need to understand the microscale mixing processes that occur due to shear and waves in deep water, due to energy input across the sea surface and due to intrusive motions assosiated with horizontal variations of S and T.
In marine biology the living conditions for the planktonic communities are greatly dependent on turbulent mixing processes in the microscale level. These processes will to a large extent determine the distribution of food,oxygen, particles of prey etc. in the near vicinity of planktonic organismes .
Also the local conditions around underwater macroalgaes need a better understanding.
In fish farming, favourable living conditions for newly hatched fish severely depends on an even distribution of fresh,oxygenated water in the bassins used during their first year of breeding. To obtain this,a detailed knowledge of the distribution of properties in the bassin is neccesary.

In all kinds of work with scaled down physical models for oceanic systems, a detailed knowledge of the microscale conditions in the water volume under observation is neccesary.

Need for new instrumention.

Observations of microscale phenomena call for miniature,high sensitivity and fast response sensors.
During the last 10 years there has been made significant progress in design of miniature instruments for measuring conductivity,temperature,pressure and light intensity . Also for measurement of dissolved oxygen and other dissolved gases that can be measured by polarographic methods the situation has improved.
A good sensor for measuring microscale velocities however, has been missing.
This paper will describe a three axis ultrasonic current speed sensor which can be used to measure current speeds from 1 mm/second to several meters per second with the ability to describe the dynamic behaviour of the water up to appr. 30 Hz.

Physical sensor design.

To make an ultrasonic sensor which will combine high linearity with small dimensions,care must be made to avoid interaction between the acoustic signal paths and the unavoidable turbulent wakes which are locally generated around the sensor itself.
Fig.1 shows some design principles for ultrasonic sensors.
In general the best results will be obtained if the mechanical parts of the sensor are very thin, and if the acoustic signals are directed away from regions of local turbulence by using an acoustic mirror.
Fig. 2 shows the physical design of the three axis sensor which is described in this paper. Bursts of 4 Mhz acoustic signals are generated by three pairs of 3x5 mm piezoelectric elements which are mounted on tip of three 3 mm thick metal prong pairs. The signals are directed into two "V" shaped and one "I" shaped acoustic signal paths.
This mechanical sensor arrangement can be used to measure current speeds by the travel time difference method.(Fig.3)
At the time T= 0, a short burst of acoustic energy is emitted from elements 1 and 2. After a travel time of $t1 = L/c1$ and $t2 = L/c2$, where L is the total signal path length between 1 and 2, c1 is the mean acoustic propagation velocity from 1 to 2 and c2 is the mean sound velocity from 2 to 1 , the emitted signals are detected by the emitters which now act as acoustic receivers.
If there excists a velocity field v1 in the 1-2 direction,$c1 = c+v1$ and $c2=c-v1$
where c is the propagation speed for acoustic signals in still water.
It can be shown that mean water speed in the 1-2 direction equals
$v12 = c.c(t1-t2)/2l$ (1)
where l is the lenght of the straight distance between 1 and 2 .
Similary, by emitting acoustic signals between elements 3-4 and between 5-6 respectively, an expression for the velocity component in the 3-4 and 5-6 direction can also be obtained.
To convert this mathematical expression to an electric output signal which can later be processed in modern electronic circuits and computers,the mechanical sensor in fig.1 must be assisted by a high speed and high sensitivity electronic circuitry.

The purposes of the electronic circuits are:

1 Excitation of piezoelectric elements 1-2,3-4, and 5-6 in sequence to generate acoustic signal bursts in the three directions.

2 : Detection of travel times t1,t2,t3,t4,t5 and t6

3: Computation of the time differences t1-t2,t3-t4and t5-t6 (Point no 3 is the hard to realise part of the instrumentation system.The sensor uses a path length of 30 mm . A velocity of 1mm/s will only generate a travel time difference of appr 2.6x10-11 secods. Small changes in the component properties due to changes in temperature,aging,physical displacements etc. may easily induce larger variations in the circuit response time than what corresponds to 26 picoseconds.To compensate for such effects a special feedback compensation system is used.)

4: Computation of the sound speed c

5:Computation of analogue voltage signals proportional to the instantaneous water velocity in the 1-2,3-4 and 5-6 direction according to the equation(1)

Fig.4 shows a simple block diagram for the electronic circuit.

The three pairs of piezoelectric transducers are sequentially excited with high voltage impulses to generate acoustic signals . The received signals are sequentially put through a common processing stage and demultiplexed to 3 separate analogue voltage signals which represent the current speed components in X,Y and Z direction respectively.

Each channel is sampled 100 times per second,which means that each of the 3 output channels will be updated with new velocity information for every 10 ms.

To make possible a simple transfer of data to a computer, an analogue to RS 232 C converter has been added.

The complete electronic circuit has been designed to be housed in a pressure tube with diameter of 60 mm and length 340 mm.

Calibration results

Linear response.

The sensor has been towed at different velocities in a towing tank in the X,Y and Z direction. Fig. 5 shows the calibration for velocities in the mean velocity range . The diagrams show that a high degree of linearity in the main directions have been obtained.

Fig 6 shows the angular response in the horizontal plane.

The sensor has been towed at 20 cm/s and rotated 360 degrees in steps of 15 degrees during the towings.

Fig.6 shows that the sensor has a good cosine response except for a small angular region where turbulences from the mirror holder enter into the acoustic paths.

Zero stability

Long term tests in still water indicates that a long term stability of +/- 2mm/s can be expected.

Applications.

The sensors ability to combine high sensitivity with a high dynamic range makes it potentially useful for a large range of oceanographic and hydrodynamic applications both in the laboratory and in the open sea.

In the laboratory the sensor has been used in connection with a computing system which will procesess the different variables on line.

In order to use the sensor in the open sea it must be connected to an integrated power supply/data acquisition system.
Till now the main applications have been as a velocity sensor in modelling experiments and as a tool for designing optimal bassins for newly hatched fish in fish farming .

Fig. 7 shows an excample of the latter application.
During running times of 10 seconds the velocity in X,Y and Z direction was sampled 100 times by a personal computer(Olivetti M-10)
The computer then computed the mean current velocity and its standard deviation in each direction.The standard deviation is taken as a measure for the turbulence in each direction,which in turn describes the degree of local mixing in the water volume. By dividing the bassin into a number of cells and measuring for 10 seconds in each cell, a good measure for the bassin mixing properties was obtained

Fig 8 shows a plot of the variations in current speed around the mean in Y and Z direction(from which the table was made).

Future applications

The sensor with its electronic circuits is a general device which can be used in a variety of applications.The most immediate application will be to integrate the sensor into a self contained data acquisition system for use down to appr. 1000 meters dept
Another obvious application is to combine the velocity sensor with small scale CTD- systems to compute the vertical variations in the Richardson number during profilings.

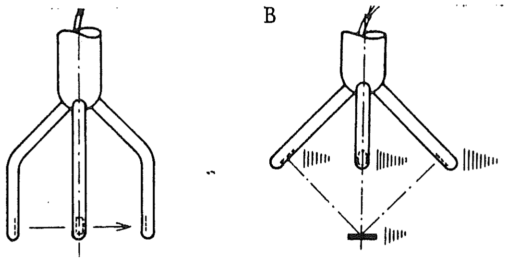


Fig.1 Mechanical design principles for ultrasonic current speed sensors.

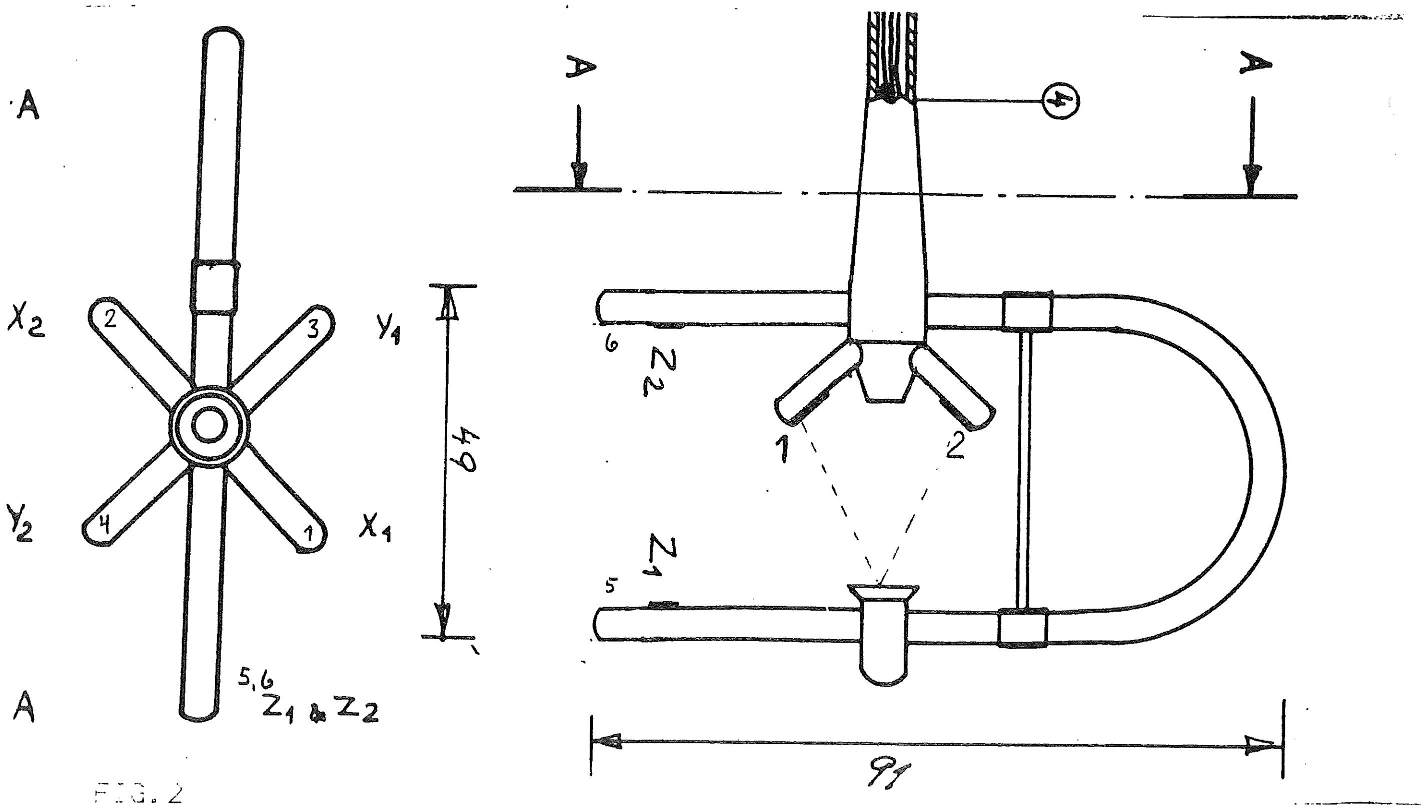
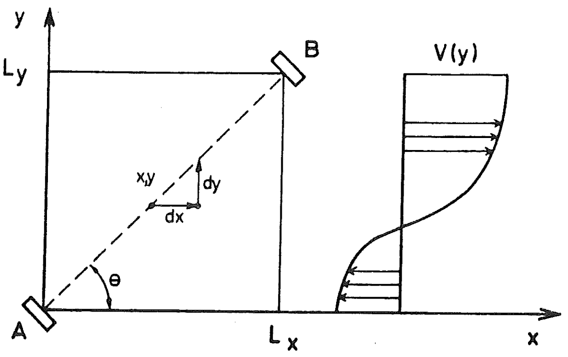


FIG. 2
FULL SIZE DRAWING OF THE NEW 3-AXIS ULTRASONIC CURRENT SPEED SENSOR



Principle of operation for acoustic current meters. Two transducers in a one-dimensional flow field V(y) emit acoustic signals to each other at an angle θ with the current direction.

FIG.3

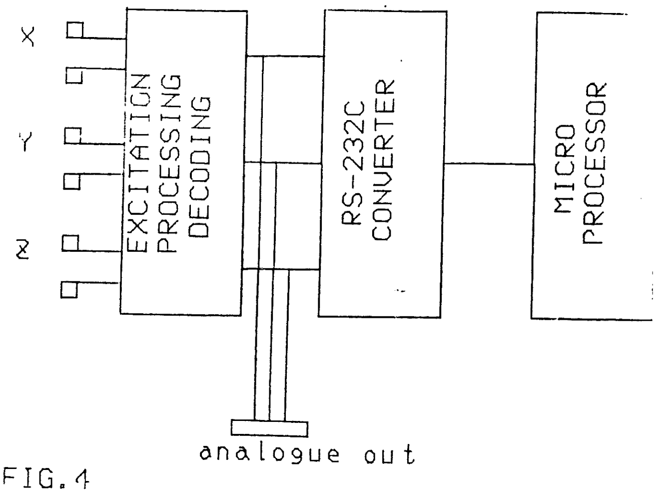
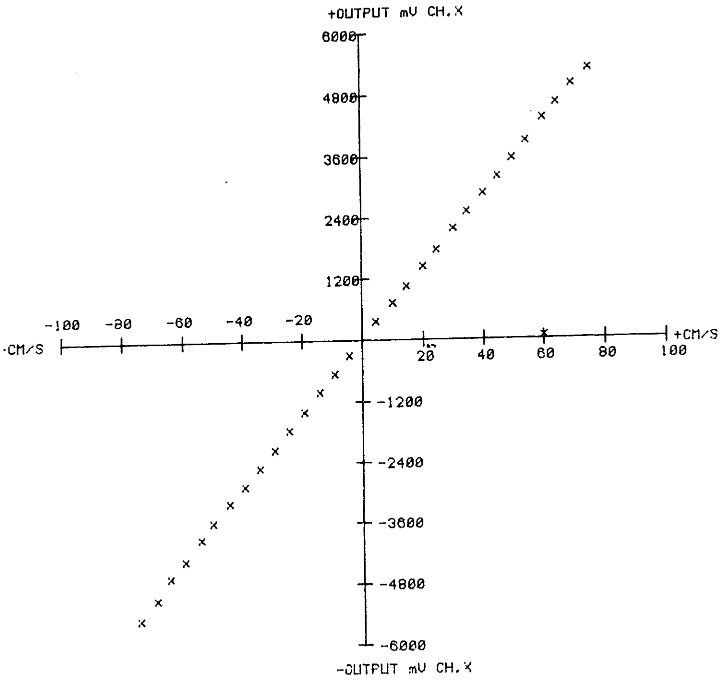
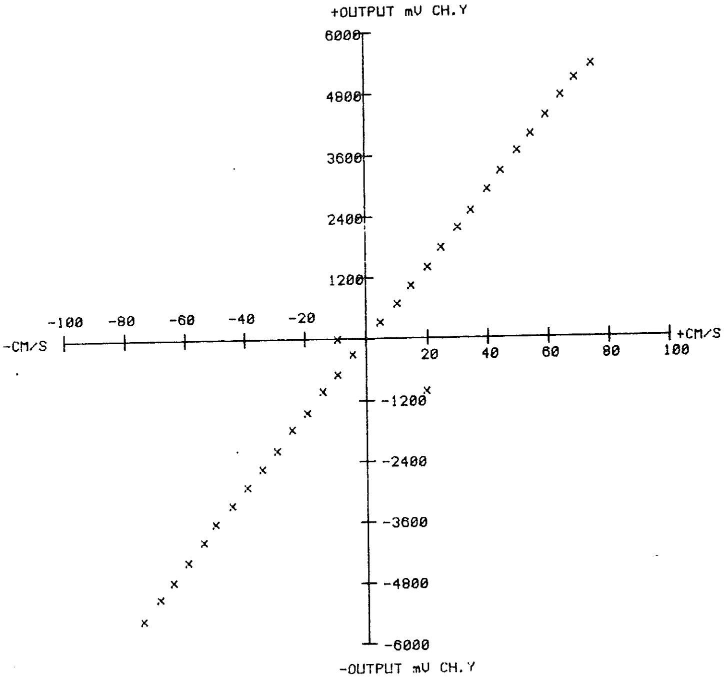


FIG.4

Block diagram for the electronic circuit





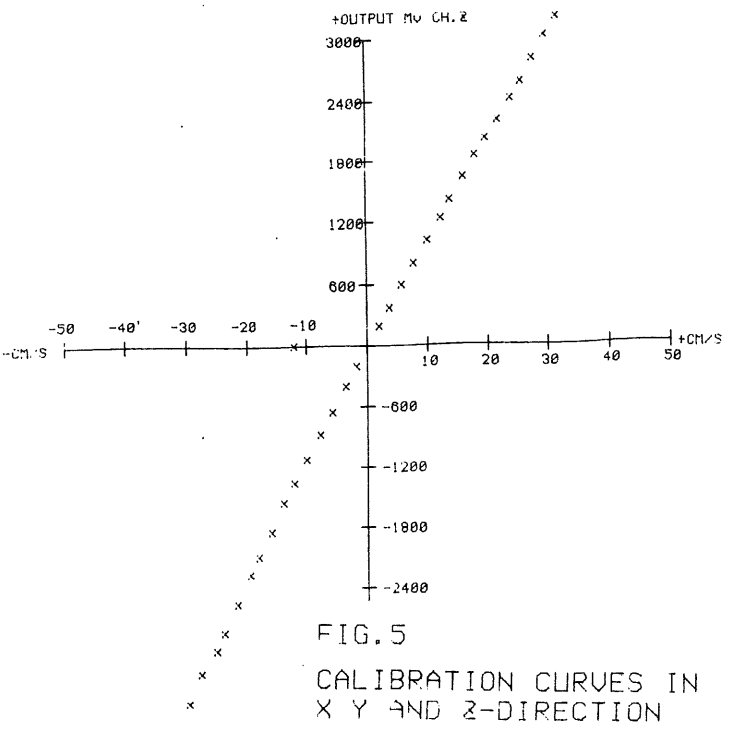


FIG.5

CALIBRATION CURVES IN X Y AND Z-DIRECTION

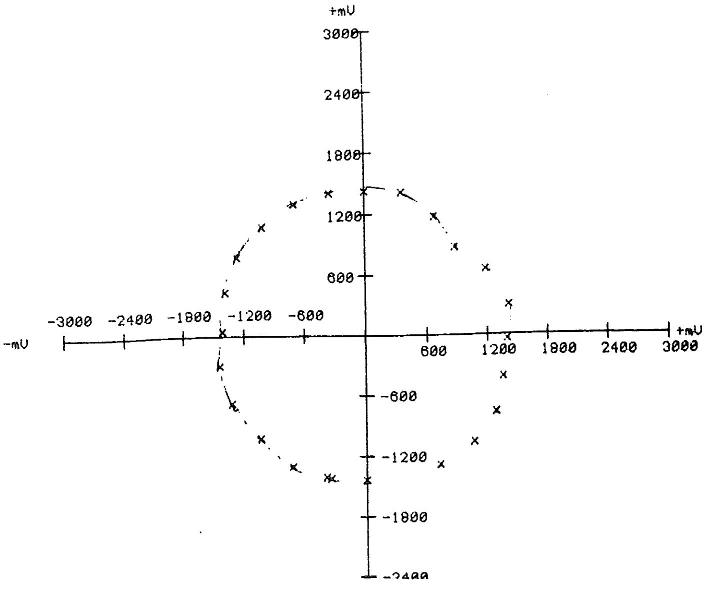


FIG.6

COSINE RESPONSE IN THE X-Y PLANE

Str|mhastighet og turbulens i celle 123

	x-retn.	y-retn.	z-retn.
V middel	-0.558m/s	-0.150m/s	-0.037m/s
Turbulens	+0.360m/s	+0.248m/s	+0.022m/s

FIG.7
COMPUTED VALUES FOR MEAN CURRENT SPEED AND TURBULENCE IN A SMALL BASSIN

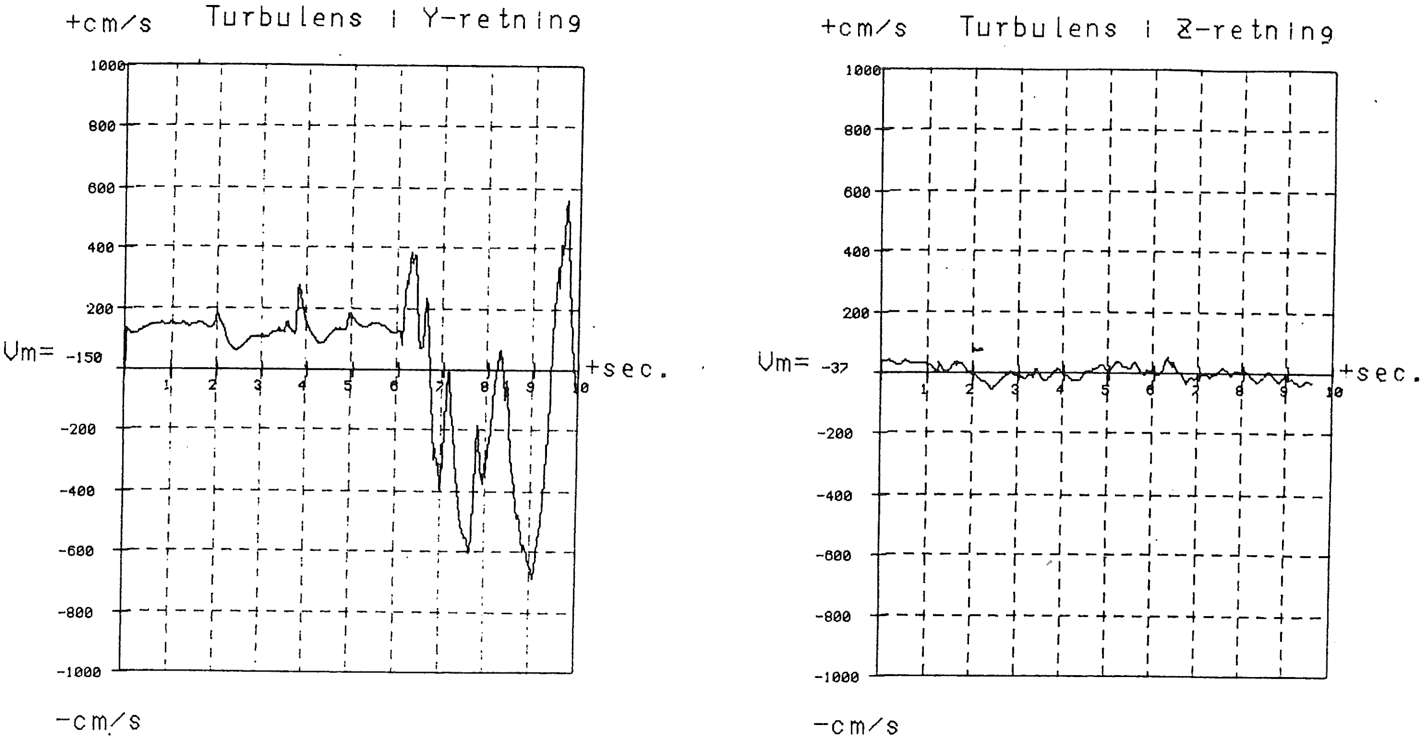


FIG. 8

VARIATIONS IN THE CURRENT SPEED AROUND THE MEAN IN Y AND Z - DIRECTION IN CELL NO 123