(54) **Control system for positioning of marine seismic streamers**

Steuerungssystem zur Positionierung mariner seismischer Streamer

Système de contrôle de la position des flûtes sismiques marines

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Description

BACKGROUND OF THE INVENTION

[0001] This invention relates generally to systems for controlling seismic data acquisition equipment and particularly to a system for controlling a marine seismic streamer positioning device.

[0002] A marine seismic streamer is an elongate cable-like structure, typically up to several thousand meters long, which contains arrays of seismic sensors, known as hydrophones, and associated electronic equipment along its length, and which is used in marine seismic surveying. In order to perform a 3D marine seismic survey, a plurality of such streamers are towed at about 5 knots behind a seismic survey vessel, which also tows one or more seismic sources, typically air guns. Acoustic signals produced by the seismic sources are directed down through the water into the earth beneath, where they are reflected from the various strata. The reflected signals are received by the hydrophones, and then digitized and processed to build up a representation of the subsurface geology.

[0003] The horizontal positions of the streamers are typically controlled by a deflector, located at the front end or "head" of the streamer, and a tail buoy, located at the back end or "tail" of the streamer. These devices create tension forces on the streamer which constrain the movement of the streamer and cause it to assume a roughly linear shape. Cross currents and transient forces cause the streamer to bow and undulate, thereby introducing deviations into this desired linear shape.

[0004] The streamers are typically towed at a constant depth of approximately ten meters, in order to facilitate the removal of undesired "ghost" reflections from the surface of the water. To keep the streamers at this constant depth. control devices known as "birds", are typically attached at various points along each streamer between the deflector and the tail buoy, with the spacing between the birds generally varying between 200 and 400 meters. The birds have hydro-dynamic deflecting surfaces, referred to as wings, that allow the position of the streamer to be controlled as it is towed through the water. When a bird is used for depth control purposes only, it is possible for the bird to regularly sense its depth using an integrated pressure sensor and for a local controller within the bird to adjust the wing angles to maintain the streamer near the desired depth using only a desired depth value received from a central control system.

[0005] While the majority of birds used thus far have only controlled the depth of the streamers, additional benefits can be obtained by using properly controlled horizontally steerable birds, particularly by using the types of horizontally and vertically steerable birds disclosed in our published PCT International Application No. WO 98/28636. The benefits that can be obtained by using properly controlled horizontally steerable birds can include reducing horizontal out-of-position conditions that necessitate reacquiring seismic data in a particular area (i.e. in-fill shooting), reducing the chance of tangling adjacent streamers, and reducing the time required to turn the seismic acquisition vessel when ending one pass and beginning another pass during a 3D seismic survey.

[0006] It is estimated that horizontal out-of-position conditions reduce the efficiency of current 3D seismic survey operations by between 5 and 10%, depending on weather and current conditions. While incidents of tangling adjacent streamers are relatively rare, when they do occur they invariably result in prolonged vessel downtime. The loss of efficiency associated with turning the seismic survey vessel will depend in large part on the seismic survey layout, but typical estimates range from 5 to 10%. Simulations have concluded that properly controlled horizontally steerable birds can be expected to reduce these types of costs by approximately 30%.

[0007] One system for controlling a horizontally steerable bird, as disclosed in UK Patent GB 2093610 B, is to utilize a manually-operated central control system to transmit the magnitudes and directions of any required wing angle changes to the birds. While this method greatly simplifies the circuitry needed within the bird itself, it is virtually impossible for this type of system to closely regulate the horizontal positions of the birds because it requires manual input and supervision. This becomes a particularly significant issue when a substantial number of streamers are deployed simultaneously and the number of birds that must be controlled goes up accordingly.

[0008] Another system for controlling a horizontally steerable bird is disclosed in our published PCT International Application No. WO 98/28636. Using this type of control system, the desired horizontal positions and the actual horizontal positions are received from a remote control system and are then used by a local control system within the birds to adjust the wing angles. The actual horizontal positions of the birds may be determined every 5 to 10 seconds and there may be a 5 second delay between the taking of measurements and the determination of actual streamer positions. While this type of system allows for more automatic adjustment of the bird wing angles, the delay period and the relatively long cycle time between position measurements prevents this type of control system from rapidly and efficiently controlling the horizontal position of the bird. A more deterministic system for controlling this type of streamer positioning device is therefore desired.

[0009] It is therefore an object of the present invention to provide for an improved method and apparatus for controlling a streamer positioning device.

[0010] An advantage of the present invention is that the position of the streamer may be better controlled, thereby reducing the need for in-fill shooting, reducing the chance of streamer tangling, and reducing the time needed to turn

the seismic survey vessel.

[0011] Another advantage of the present invention is that noise in marine seismic data associated with streamer position over-correction and streamer positioning errors can be significantly reduced.

SUMMARY OF THE INVENTION

[0012] The present invention involves a method of controlling a streamer positioning device configured to be attached to a marine seismic streamer and towed by a seismic survey vessel and having a wing and a wing motor for changing the orientation of the wing. The method includes the steps of: obtaining an estimated velocity of the streamer positioning device, calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and actuating the wing motor to produce the desired change in the orientation of the wing. The present invention also involves an apparatus for controlling a streamer positioning device. The apparatus includes means for obtaining an estimated velocity of the streamer positioning device, means for calculating a desired change in the orientation of the wing using the estimated velocity of the streamer positioning device, and means for actuating the wing motor to effectuate the desired change in the orientation of the wing. The invention and its benefits will be better understood with reference to the detailed description below and the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

Figure 1 is a schematic diagram of a seismic survey vessel and associated seismic data acquisition equipment;

Figure 2 is a schematic horizontal cross-sectional view through a marine seismic streamer and an attached streamer positioning device;

Figure 3 is a schematic vertical cross-sectional view through the streamer positioning device from Figure 2; and

Figure 4 is a schematic diagram of the local control system architecture of the streamer positioning device from Figure 2.

DETAILED DESCRIPTION OF THE INVENTION

[0014] In Figure 1, a seismic survey vessel 10 is shown towing eight marine seismic streamers 12 that may, for instance, each be 3000 meters in length. The outermost streamers 12 in the array could be 700 meters apart, resulting in a horizontal separation between the streamers of 100 meters in the regular horizontal spacing configuration shown. A seismic source 14, typically an airgun or an array of airguns, is also shown being towed by the seismic survey vessel 10. At the front of each streamer 12 is shown a deflector 16 and at the rear of every streamer is shown a tail buoy 20. The deflector 16 is used to horizontally position the end of the streamer nearest the seismic survey vessel 10 and the tail buoy 20 creates drag at the end of the streamer farthest from the seismic survey vessel 10. The tension created on the seismic streamer by the deflector 16 and the tail buoy 20 results in the roughly linear shape of the seismic streamer 12 shown in Figure 1.

[0015] Located between the deflector 16 and the tail buoy 20 are a plurality of streamer positioning devices known as birds 18. Preferably the birds 18 are both vertically and horizontally steerable. These birds 18 may, for instance, be located at regular intervals along the streamer, such as every 200 to 400 meters. The vertically and horizontally steerable birds 18 can be used to constrain the shape of the seismic streamer 12 between the deflector 16 and the tail buoy 20 in both the vertical (depth) and horizontal directions.

[0016] In the preferred embodiment of the present invention, the control system for the birds 18 is distributed between a global control system 22 located on or near the seismic survey vessel 10 and a local control system located within or near the birds 18. The global control system 22 is typically connected to the seismic survey vessel's navigation system and obtains estimates of system wide parameters, such as the vessel's towing direction and velocity and current direction and velocity, from the vessel's navigation system.

[0017] The most important requirement for the control system is to prevent the streamers 12 from tangling. This requirement becomes more and more important as the complexity and the total value of the towed equipment increases. The trend in the industry is to put more streamers 12 on each seismic survey vessel 10 and to decrease the horizontal separation between them. To get better control of the streamers 12, horizontal steering becomes necessary. If the birds 18 are not properly controlled, horizontal steering can increase, rather than decrease, the likelihood of tangling adjacent streamers. Localized current fluctuations can dramatically influence the magnitude of the side control required to properly

position the streamers. To compensate for these localized current fluctuations, the inventive control system utilizes a distributed processing control architecture and behavior-predictive model-based control logic to properly control the streamer positioning devices.

[0018] In the preferred embodiment of the present invention, the global control system 22 monitors the actual positions of each of the birds 18 and is programmed with the desired positions of or the desired minimum separations between the seismic streamers 12. The horizontal positions of the birds 18 can be derived, for instance, using the types of acoustic positioning systems described in our U.S. Patent No. 4,992,990 or in our PCT International Patent Application No. WO 98/21163. Alternatively, or additionally, satellite-based global positioning system equipment can be used to determine the positions of the equipment. The vertical positions of the birds 18 are typically monitored using pressure sensors attached to the birds, as discussed below.

[0019] The global control system 22 preferably maintains a dynamic model of each of the seismic streamers 12 and utilizes the desired and actual positions of the birds 18 to regularly calculate updated desired vertical and horizontal forces the birds should impart on the seismic streamers 12 to move them from their actual positions to their desired positions. Because the movement of the seismic streamer 12 causes acoustic noise (both from seawater flow past the bird wing structures as well as cross current flow across the streamer skin itself), it is important that the streamer movements be restrained and kept to the minimum correction required to properly position the streamers. Any streamer positioning device control system that consistently overestimates the type of correction required and causes the bird to overshoot its intended position introduces undesirable noise into the seismic data being acquired by the streamer. In current systems, this type of over-correction noise is often balanced against the "noise" or "smearing" caused when the seismic sensors in the streamers 12 are displaced from their desired positions.

[0020] The global control system 22 preferably calculates the desired vertical and horizontal forces based on the behavior of each streamer and also takes into account the behavior of the complete streamer array. Due to the relatively low sample rate and time delay associated with the horizontal position determination system, the global control system 22 runs position predictor software to estimate the actual locations of each of the birds 18. The global control system 22 also checks the data received from the vessel's navigation system and the data will be filled in if it is missing. The interface between the global control system 22 and the local control system will typically operate with a sampling frequency of at least 0.1 Hz. The global control system 22 will typically acquire the following parameters from the vessel's navigation system: vessel speed (m/s), vessel heading (degrees), current speed (m/s), current heading (degrees), and the location of each of the birds in the horizontal plane in a vessel fixed coordinate system. Current speed and heading can also be estimated based on the average forces acting on the streamers 12 by the birds 18. The global control system 22 will preferably send the following values to the local bird controller: demanded vertical force, demanded horizontal force, towing velocity, and crosscurrent velocity.

[0021] The towing velocity and crosscurrent velocity are preferably "water-referenced" values that are calculated from the vessel speed and heading values and the current speed and heading values, as well as any relative movement between the seismic survey vessel 10 and the bird 18 (such as while the vessel is turning), to produce relative velocities of the bird 18 with respect to the water in both the "in-line" and the "cross-line" directions. Alternatively, the global control system 22 could provide the local control system with the horizontal velocity and water in-flow angle. The force and velocity values are delivered by the global control system 22 as separate values for each bird 18 on each streamer 12 continuously during operation of the control system.

[0022] The "water-referenced" towing velocity and crosscurrent velocity could alternatively be determined using flow-meters or other types of water velocity sensors attached directly to the birds 18. Although these types of sensors are typically quite expensive, one advantage of this type of velocity determination system is that the sensed in-line and cross-line velocities will be inherently compensated for the speed and heading of marine currents acting on said streamer positioning device and for relative movements between the vessel 10 and the bird 18.

[0023] Figure 2 shows a type of bird 18 that is capable of controlling the position of seismic streamers 12 in both the vertical and horizontal directions. A bird 18 of this type is also disclosed in our PCT International Application No. WO 98/28636. While a number of alternative designs for the vertically and horizontally steerable birds 18 are possible, including those utilizing one full-moving wing with ailerons, three full-moving wings, and four full-moving wings, the independent two-wing principal is, conceptually, the simplest and most robust design.

[0024] In Figure 2, a portion of the seismic streamer 12 is shown with an attached bird 18. A communication line 24, which may consist of a bundle of fiber optic data transmission cables and power transmission wires, passes along the length of the seismic streamer 12 and is connected to the seismic sensors, hydrophones 26, that are distributed along the length of the streamer, and to the bird 18. The bird 18 preferably has a pair of independently moveable wings 28 that are connected to rotatable shafts 32 that are rotated by wing motors 34 and that allow the orientation of the wings 28 with respect to the bird body 30 to be changed. When the shafts 32 of the bird 18 are not horizontal, this rotation causes the horizontal orientation of the wings 28 to change and thereby changes the horizontal forces that are applied to the streamer 12 by the bird.

[0025] The motors 34 can consist of any type of device that is capable of changing the orientation of the wings 28,

and they are preferably either electric motors or hydraulic actuators. The local control system 36 controls the movement of the wings 28 by calculating a desired change in the angle of the wings and then selectively driving the motors 34 to effectuate this change. While the preferred embodiment depicted utilizes a separate motor 34 for each wing 28, it would be also be possible to independently move the wings 28 using a single motor 34 and a selectively actuatable transmission mechanism.

[0026]   When the bird 18 uses two wings 28 to produce the horizontal and vertical forces on the streamer 12, the required outputs of the local control system 36 are relatively simple, the directions and magnitudes of the wing movements required for each of the wings 28, or equivalently the magnitude and direction the motors 34 need to be driven to produce this wing movement. While the required outputs of the local control system 36 for such a two full moving wing design is quite simple, the structure and operation of the overall system required to coordinate control of the device is relatively complicated.

[0027]   Figure 3 shows a schematic vertical cross-sectional view through the streamer positioning device shown in Figure 2 that will allow the operation of the inventive control system to be described in more detail. The components of the bird 18 shown in Figure 3 include the wings 28 and the body 30. Also shown in Figure 3 are a horizontal coordinate axis 38 and a vertical coordinate axis 40. During operation of the streamer positioning control system, the global control system 22 preferably transmits, at regular intervals (such as every five seconds) a desired horizontal force 42 and a desired vertical force 44 to the local control system 36.

[0028]   The desired horizontal force 42 and the desired vertical force 44 are combined within the local control system 36 to calculate the magnitude and direction of the desired total force 46 that the global control system 22 has instructed the local control system to apply to the streamer 12. The global control system 22 could alternatively provide the magnitude and direction of the desired total force 46 to the local control system 36 instead of the desired horizontal force 42 and the desired vertical force 44.

[0029]   While the desired horizontal force 42 and the desired vertical force 44 are preferably calculated by the global control system 22, it is also possible for the local control system 36 in the inventive control system to calculate one or both of these forces using a localized displacement/force conversion program. This type of localized conversion program may, for instance, use a look-up table or conversion routine that associates certain magnitudes and directions of vertical or horizontal displacements with certain magnitudes and directions of changes in the vertical or horizontal forces required. Using this type of embodiment, the global control system 22 can transmit location information to the local control system 36 instead of force information. Instead of the desired vertical force 44, the global control system 22 can transmit a desired vertical depth and the local control system 36 can calculate the magnitude and direction of the deviation between the desired depth and the actual depth. Similarly, instead of transmitting a desired horizontal force 42, the global control system 22 can transmit the magnitude and direction of the displacement between the actual horizontal position and the desired horizontal position of the bird 18. One advantage to this alternative type of system is that the required vertical force can be rapidly updated as the local control system receives updated depth information from the integrated pressure sensor. Other advantages of this type of alternative system include reducing communication traffic on the communication line 24 and simplifying the programming needed to convert the measured vertical and/or horizontal displacements into corresponding forces to be applied by the birds 18.

[0030]   When the local control system 36 has a new desired horizontal force 42 and desired vertical force 44 to be applied, the wings 28 will typically not be in the proper orientation to provide the direction of the desired total force 46 required. As can be seen in Figure 3, the wings 28 introduce a force into the streamer 12 along an axis perpendicular to the rotational axis of the wings 28 and perpendicular to the streamer. This force axis 48 is typically not properly aligned with the desired total force 46 when new desired horizontal and vertical force values are received from the global control system 22 or determined by the local control system 36 and some rotation of the bird 18 is required before the bird can produce this desired total force 46. As can be seen, the force axis 48 is directly related to the bird roll angle, designated in Figure 3 as φ.

[0031]   The local control system 36 optimizes the control process by projecting the desired total force 46 onto the force axis 48 (i.e. multiplying the magnitude of the desired total force by the cosine of the deviation angle 50) to produce an intermediate desired force 52 and then adjusting the wing common angle α (the angle of the wings with respect to the bird body 30, or the average angle if there is a non-zero splay angle) to produce this magnitude of force along the force axis. The calculated desired common wing angle is compared to the current common wing angle to calculate a desired change in the common wing angle and the wing motors 34 are actuated to produce this desired change in the orientation of the wings.

[0032]   A splay angle is then introduced into the wings 28 to produce a rotational movement in the bird body 30 (i.e. to rotate the force axis 48 to be aligned with the desired total force 46). The splay angle is the difference between the angles of the wings 28 with respect to the bird body 30. As the bird body 30 rotates and the force axis 48 becomes more closely aligned with the desired total force 46, the bird roll angle and the bird roll angular velocity are monitored, the splay angle is incrementally reduced, and the common angle is incrementally increased until the intermediate desired force 52 is in the same direction and of the same magnitude as the desired total force. The local control system 36

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