UNDERWATER ACOUSTICS, AN OIL INDUSTRY PERSPECTIVE

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1 INTRODUCTION

Large quantities of oil and gas have been discovered under the sea surrounding the world's continental shelves. Before this resource can be exploited, a method of accurately positioning oil field equipment on the seabed and controlling it must be developed. In very shallow water and, for simple structures, this can be achieved by simply lowering the equipment from a surface platform and communicating via an umbilical cable. However, as the water gets deeper and the structures more complicated it becomes more difficult and expensive to position from the surface and some method of measuring on the seabed has to be devised.

Early positioning methods consisted of divers with tape measures and protractors. These methods are still used today for high accuracy measurements over short ranges (0 to 10m). Diver intensive methods of underwater surveying are obviously slow and expensive, so a faster and more flexible method is required. Transmission of sound is one of the few viable underwater media. It is far from perfect, but as yet, no practical alternative has been found.

Normally oil field equipment is positioned with reference to some datum, generally an arbitrary position chosen by the oil company. Underwater acoustics is physically limited to relatively short ranges, so to provide the overall positioning required, it must be linked to a surface navigation system. Further, the two navigation systems must have complementary accuracies. Two basic forms of surface navigation are used; navigation relative to some known local datum (for example an oil production platform) and global navigation relative to some internationally recognised datum. A complete underwater positioning system must be capable of linking to either or both of these datums.

The accuracy required to position equipment underwater is very difficult to define. In practice it depends on a combination of the accuracy which can be achieved and practical engineering solutions. For example, when a pipeline is laid to an offshore installation, the final accuracy required is approximately 1mm. This is the accuracy required either for two flanges to meet and be bolted together or two pipelines to butt together before welding. Current positioning systems achieve this accuracy by using more than one technique in an iterative approach. The lay barge uses surface navigation to place the end of the pipeline in a target area which may be several tens of metres square. The pipe is then manoeuvred into position using pipe handling frames and acoustic systems until it is within a metre or so. Divers then take over and prepare the pipe ends to an accuracy of a few millimetres. Final alignment, often using powerful hydraulic rams, positions the pipe ends to 1mm or better.

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From an oil industry point of view, more accurate and reliable positioning systems will allow simpler engineering solutions with fewer iterations and most importantly a reduction in overall cost. In a similar way, faster and more reliable control and feedback from underwater equipment will allow safer and more effective control of subsea installations. These are also important factors in reducing construction and operating costs.

In summary, underwater acoustics is perceived by the offshore oil and gas industry as one of several tools which can be used to position and control oil field equipment. The more accurate and reliable the tool is, the less engineering is required, which helps minimise costs. However, because underwater acoustics is the only viable method of transmitting information over the required distances, it has and will take an increasingly important role in the development and operation of offshore oil and gas reserves.

2 CURRENT TASKS AND OPERATIONAL PRACTICES

Underwater acoustics is an essential part of a large number of offshore operations, for example:

- Jacket installations.
- Template and manifold installations.
- Laying pipelines, cables and umbilicals.
- Tracking underwater vehicles, eg: ROVs, trenchers, dredgers.
- Tracking divers.
- Metrology, eg: measuring the length of spool pieces
- Telemetry, eg: transmitting data from sensors and transmitting commands to valves and actuators.
- Tracking seismic streamers.
- Through water communications, eg: diver communications and emergency diving bell communications.

Underwater acoustics performs two essential roles. Firstly, it provides information on position by measuring the time taken for an acoustic pulse to travel from one point to another. Secondly, it transmits data as a stream of analog signals or digital pulses. The transmission of data is often used as an integral part of a positioning system. Current practice for both positioning and data transmission is outlined below.

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Two acoustic positioning methods are used in the North Sea; long base line arrays (LBL) and ultra short base line systems (USBL). Both methods use a transponder, an acoustic device which is equipped with both a transmitter and a receiver. The transponder is normally in a quiescent mode, listening for a coded acoustic signal. When the appropriate code is received, the transponder replies with a coded reply after a known delay. The codes are used to trigger selected transponders and to identify which transponder has replied.

Long base line arrays rely on a pattern of transponders being positioned on the seabed. The pattern must encompass the area to be surveyed and the position of the transponders must be known relative to the datum in use. This implies that the transponders have to be "surveyed in" relative to the datum. This is achieved by one of two methods.

The first method involves positioning one or more of the transponders on the local datum, eg well heads, measuring the range between each transponder and using normal surveying techniques to calculate the position of each transponder in the array. If a local subsea datum is available this method of calibration is quick and effective. It is also independent of water depth.

The second method uses a grid-on-grid technique based on surface navigation and measurements of slant range as the surface vessel navigates through the transponder array. In general the method provides good calibration. However it is slow and therefore expensive and the accuracy decreases as water depth increases. Because grid-on-grid methods are slow, a simpler but less accurate method of calibration known as "boxing in" is often used. In this method at least two transponders are chosen, normally the transponders which provide the longest base line. The transponders are surveyed in by circling them at a radius of approximately twice the water depth and collecting slant ranges. The position of each transponder is calculated using surface navigation and the ranges as measured acoustically between the transponders are compared. This process is continued until the required accuracy is achieved. The position of the other transponders can then be measured and the array orientated with reference to grid north.

The position of the mobile transponders within the array is calculated from the two way transmission time from the mobiles to three or more fixed transponders. More than three transponders allow multiple estimates of position from which a least squares best fit can be calculated. If the mobile unit has access to a surface umbilical then a hydrophone can be used in place of the transponder. A hydrophone is triggered not by an acoustically transmitted code, but by a pulse sent down the umbilical. This allows the hydrophone to be closer to the transponder array, at the same depth and remote from noise generated by the ship.

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Ultra short base line systems use both range and bearing information from the directional transducer on the surface vessel to a transponder. The range and bearing are derived from a vessel mounted transducer. The system uses a combination of a phase measure and electromechanical movement to track the transponder. In general, short base line systems are less accurate than long base line arrays. However they are very quick to set up and provide an excellent method of tracking moving objects (ROVs, trenchers, divers). Two types of calibration are normally performed; static and dynamic.

- A static calibration simply compares the depth of the transponder as measured by the short base line system with the echo sounder reading. This also confirms any offsets in the vessel's reference point.

- A dynamic calibration is performed by sailing in a triangular path around the transponder whilst measuring range and bearing. This forces the acoustic system to track the transponder through a range of angles in order to obtain an angular error factor for the tracking head. If the mobile has access to a surface umbilical then a responder can be used to improve the signal to noise ratio.

Data transmission is currently used in three ways:

- To provide communication between divers and diving bells. These systems are often simple amplitude modulation devices and because of their poor signal to noise ratio are often used only as an emergency or backup system.

- To provide command signals and collect data from remote oil field equipment. These systems are used when an umbilical is either expensive or inconvenient.

- To provide a data channel between transponders and the surface vessel as part of a long base line array. This is the most common use of acoustic data channels in the oil industry.

In summary, the dominant use of underwater acoustics in the offshore oil industry is for positioning. There are two methods commonly used, these are long base line arrays and ultra short base line arrays. The transmission of data using acoustic channels is an important part of long base line technology, however it is not as yet used extensively in its own right to replace umbilicals.

3 PRACTICAL EXPERIENCE

The most important practical consideration is the accuracy of the overall system. This depends on a range of parameters.

Acoustic parameters include:

- Geometric spreading losses.
- Signal absorption.
- Ambient acoustic noise.
- Vessel or ROV generated acoustic noise (particularly propeller noise).
- Reverberation.
- Transducer directivity.
- Speed of sound in water.
- The thermocline (refraction and reflection of acoustic signals).

Other factors include:

- Surface navigation (absolute position).
- Vessel gyro accuracy.
- Measurement of transducer offset to vessel reference point.
- Accuracy of processing software.

Table 1 presents typical accuracies for surface navigation systems together with practical limitations. It is clear that most surface navigation systems are capable of providing positions to better than 10m, whilst differential global positioning systems (DGPS) can often provide position information to better than 3m.

Table 2 illustrates typical accuracies achieved by various acoustic systems. Long base line arrays provide transponder to transponder accuracies of 0.5m or better, whilst ultra short base line systems working at typical ranges of 500m provide accuracies of 2.5m.

The combination of surface navigation systems and acoustic systems is presented in Table 3. It is possible to position a structure with an absolute accuracy of between ±3 and ±10m depending on the combination used.

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The main problem is the speed and accuracy of updates in position. LBL systems can provide a fix every 10 to 15 seconds with high accuracy ($\pm$1m). This can be speeded up by using simultaneous transponders. With USBL systems a position can be obtained every 2 to 3 seconds, however the accuracy falls to a typical value of $\pm$5m, a value which is dependent on both water depth and the surface navigation system.

A second problem is caused by reflections and reverberation from subsea structures and the thermocline. If the indirect path is similar in length to the direct path, then the receiving system has difficulty is measuring the time delay. This manifests itself as a high standard deviation in the position.

Both problems arise from the basic physics of the techniques. Although both LBL and USBL systems can undoubtedly be improved there are several fundamental problems. The speed of sound limits the speed at which a fix can be obtained, the effects of multipath are unlikely to be eliminated and the accuracy with which the speed of sound is known limits the system's accuracy.

Acoustic telemetry is used to communicate between transponder and the surface vessel. It has also been used to send information from measurement and control systems. Typical telemetry systems operate at around 300 bits per second using binary coded pulses to transmit data. These systems are, in general, reliable upto a range of several kilometres. However the data rates are low and it is not possible to transmit anything other than high level commands and simple feedback from the remote system.

In summary, current acoustic positioning systems are adequate for positioning large structures and measuring relatively long ranges. Acoustic telemetry systems are reliable up to a few kilometres with low data rates.

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Table 1 SURFACE NAVIGATION SYSTEMS

Type	Range	Typical 24hr Operational Accuracy	Comments
PULSE 8/III	Long (800km)	±10m	Affected by weather conditions ie. snow, hail, rain.
ARGO	Medium (500km)	±10m	
SYLEDIS	Medium (100km)	± 5m	Affected by derrick moves (if attached to same). Generally radio line of sight systems, ie, the higher the beacons, the greater the range.
MICROFIX	Medium (100km)	±2m	
D.G.P.S.	Long (1000m+)	Better than 5m	The system that most vessels will use in the future. The satellite system in use at present is the TRANSIT system which will be superseded by the NAVSTAR system. This is due to be commissioned by the end of 1993. G.P.S. accuracy ±50m (typical). Differential correction increases accuracy to better than ±5m (typical 3m).

Table 2 POSITIONING SYSTEMS RELATIVE ACCURACIES (TRANSPONDER - TRANSPONDER)

System Accuracy	Freq Band	Max Range	Accuracy Range
LBL Acoustics			
Low frequency	7.5kHz - 15kHz	15km	0.5m
Medium frequency	19kHz - 36kHz	3km	0.15m
High frequency	32kHz - 63kHz	1km	0.04m
Extra high frequency	55kHz - 110kHz	1km	0.02m
USBL Acoustics			
Medium frequency	21kHz - 40kHz	1km (Narrow) 500m (Medium) 300m (Wide)	0.5% of slant range

Table 3 POSITIONING SYSTEMS

ABSOLUTE ACCURACIES

Task	Acoustic System	Navigation System	Position Required	Specified Tolerance	Achievable Position	Comments
Jacket Installation	L.B.L.	DGPS SYLEDIS MICROFIX	Absolute and/or Relative	5 radius 5-10m radius 5m radius	±3m ±5m ±3m	Achievable position depends on navigation system used to calibrate acoustic array. Relative position to another structure is more accurate.
Template / Manifold Installation	L.B.L.	As Above	Absolute and/or Relative	As above	As above	Smaller structures take longer to position than larger structures therefore may cost more in vessel time to position.
Pipelay / Cable lay / Umbilical Lay	U.S.B.L.	DGPS SYLEDIS MICROFIX	Absolute	Dependent on navigation system, depth of water	± 7m (100m) ±10m (100m) ± 5m (100m)	One off fix normally not that accurate unless navigation system very stable and repeatable. Also HPR system needs to be stable ie. no water column noise. Average fix normally taken for more accurate position.
Diver Tracking	U.S.B.L.	D.G.P.S. SYLEDIS MICROFIX	Absolute	Dependent on navigation system, depth of water	± 7m (100m) ±10m (100m) ± 5m (100m)	One off fix normally not that accurate unless navigation system very stable and repeatable. Also HPR system needs to be stable ie. no water column noise. Average fix normally taken for more accurate position.
Spoolpiece Metrology	L.B.L.	N/A	Relative	Dependent on length of spool required	Better than 0.5m range	High accuracy, relative positioning required. Accurate depth measurements required also.
Seismic Streamer Tracking	L.B.L. + Hardwire	Various	Absolute	Dependant on navigation system	Dependant on navigation system	If combination of hardwire link and L.B.L. are used to position tailbuoy, streamers etc

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4 FUTURE TASKS

For the forseeable future final mechanical alignment will almost certainly be achieved by engineered alignment tools. It is difficult to envisage how acoustics could be used to measure to an accuracy of 1mm needed for final fit-up of a flange or weld. In a similar way the bandwidth of acoustic data transmission will always be limited by the trade off between frequency and attenuation.

It seems reasonable to split future tasks into two sections; short range measurement systems and long range high data rate telemetry systems.

Short range measurement systems are required to replace diver-intensive tape measure and protractor measurements of relatively complex structures. An ideal system would be capable of taking multiple measurements rapidly and without time consuming set-up procedures. Several systems have already been designed in an attempt to solve this problem, for example, stereo vision, acoustic holography, laser range finders, optical holography. None of these systems has been developed to a stage where they can successfully and routinely be used offshore in real time.

High speed data links will allow more detailed feedback to be sent from remote installations, including freeze frame pictures. An ideal telemetry system would be robust when faced with multipaths and have a very low data error rate.

5 WISH LIST OF ACCURACIES, SPEEDS AND RELIABILITY

It is clear from the tables presented above that acoustic position fixing as currently used offshore is adequate for positioning large structures. Further, relative measurements for spool piece metrology (and similar tasks) are adequate for large spools, say 30m or more, where the 0.5m error in the measurements can be accommodated by the elasticity designed into the pipework. Improvements in the accuracy of the systems would be of benefit, but more importantly improvements in the reliability, repeatability and time taken to set up acoustic systems would significantly reduce offshore costs by minimising the time taken to position systems.

All current systems rely on attaching a relatively large and unwieldy transponder to the object to be measured. Attaching a transponder has three associated problems; it is time consuming, it can introduce offset errors and it is limited to point-to-point measurements. Offset errors are not significant when measuring relatively large distances but they do become important when ranges of 5m or less are being measured. An accuracy of ±5mm would allow parts to be fabricated and fitted with the minimum of effort. Obviously 100% reliability of mechanical and electronic sub-systems is an ideal target. Similarly operators would like systems which have high repeatability.

If acoustic telemetry systems could reliably transmit data at 20k bits per second over ranges of 10km or more they would find extensive use in many subsea operations. High data rates will allow through water communications to replace umbilicals in many situations. This will make subsea oil installations cheaper to build and easier to maintain.

In summary, if a reliable survey tool can be produced which will quickly and accurately measure multiple short ranges without having to build jigs or fit transponders it would find many uses in the North Sea and form an important element of truly diverless intervention systems. The principle use of high speed acoustic telemetry will be in replacing copper signal cables.

6 CONCLUSION

The main use of underwater acoustics in the oil industry is in underwater surveying. An important secondary use is in telemetry. Existing systems are capable of absolute positioning with an error of ±3m, which is acceptable for positioning large structures. Relative positioning is better with a typical error of ±0.5m, which is inadequate for small spool pieces. The principle operational problems are associated with the time taken to set up high precision LBL arrays and the relatively slow update rates on position fixes.

Existing telemetry systems are too slow to be used for anything other than basic command and feedback.

There is a need for a short range, high accuracy (up to 10m, ±5mm) measurement system which can take multiple measurements with the minimum set-up time. These systems would be used for detailed surveys of critical sites.

An acoustic telemetry system with a data rate of 20kbits per second, a range of 10km or more and freedom from multipath interference would find may applications replacing convectional cables.