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DYNAMIC POSITIONING CONFERENCE

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SENSORS

Acoustic Positioning in Deep Waters

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Drilling in deep waters with dynamic positioning puts very high demands on the performance of acoustic positioning systems. The challenge is to design systems that can suppress environmental noise as well as to plan the installation so that an optimal location for the transducers can be found. On such vessels, the thrusters will normally be the dominating noise source.

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Document history

Rev.A	Initial version
Rev B	Changed figure 1 to correct scale, corrected description in 3.1
Rev C	Corrected equation for S/N

1 INTRODUCTION

Drilling in deep waters with dynamic positioning puts very high demands on the performance of acoustic positioning systems. The challenge is to design systems that can suppress environmental noise as well as to plan the installation so that an optimal location for the transducers can be found. On such vessels, the thrusters will normally be the dominating noise source.

By using estimated or measured noise data, the performance of the acoustic positioning systems on a given vessel can be estimated by calculations and simulations. The effect of various noise levels can be calculated. The position accuracy can be seen as a function of noise level and water depth. The effects of transducer directivity, receiver filters and powerful transponders are addressed.

Acoustic positioning systems used in deep waters also puts high demands to attitude sensors (roll, pitch, and heading) and also the timing of the data from them. How errors from attitude sensors affect the different types of acoustic positioning systems is being addressed in this paper.

1.1 Sonar equation

To be able to understand the behaviour of sound in water it is necessary to have a few basic facts in mind.

From the radiating source, the sound will spread in different directions. The wave front covers a larger and larger area and thus the intensity decreases. The transmission loss (TL) will increase by the square of the distance from the sound source

$$\mathbf{TL_1 = 20\log r}$$

where $\mathbf{TL_1}$ is the transmission loss.

In addition to this, part of the energy will be absorbed by the water and converted to heat. For each metre a fraction of the energy is lost

$$\mathbf{TL_2 = \alpha \cdot r}$$

where α is the absorption coefficient.

The total transmission loss that the sound will suffer during travel from the source to the target will thus be

$$\mathbf{TL = 20\log r + \alpha r}$$

where **r** is in meters α is in dB/m

We have now established a simple relation between the Range and the Transmission Loss that we have to overcome to achieve this range.

Figure 1 gives the absorption factor in dB/km as a function of frequency. As can be seen from the curve, it is about 5 – 7 dB/km around 30 kHz.

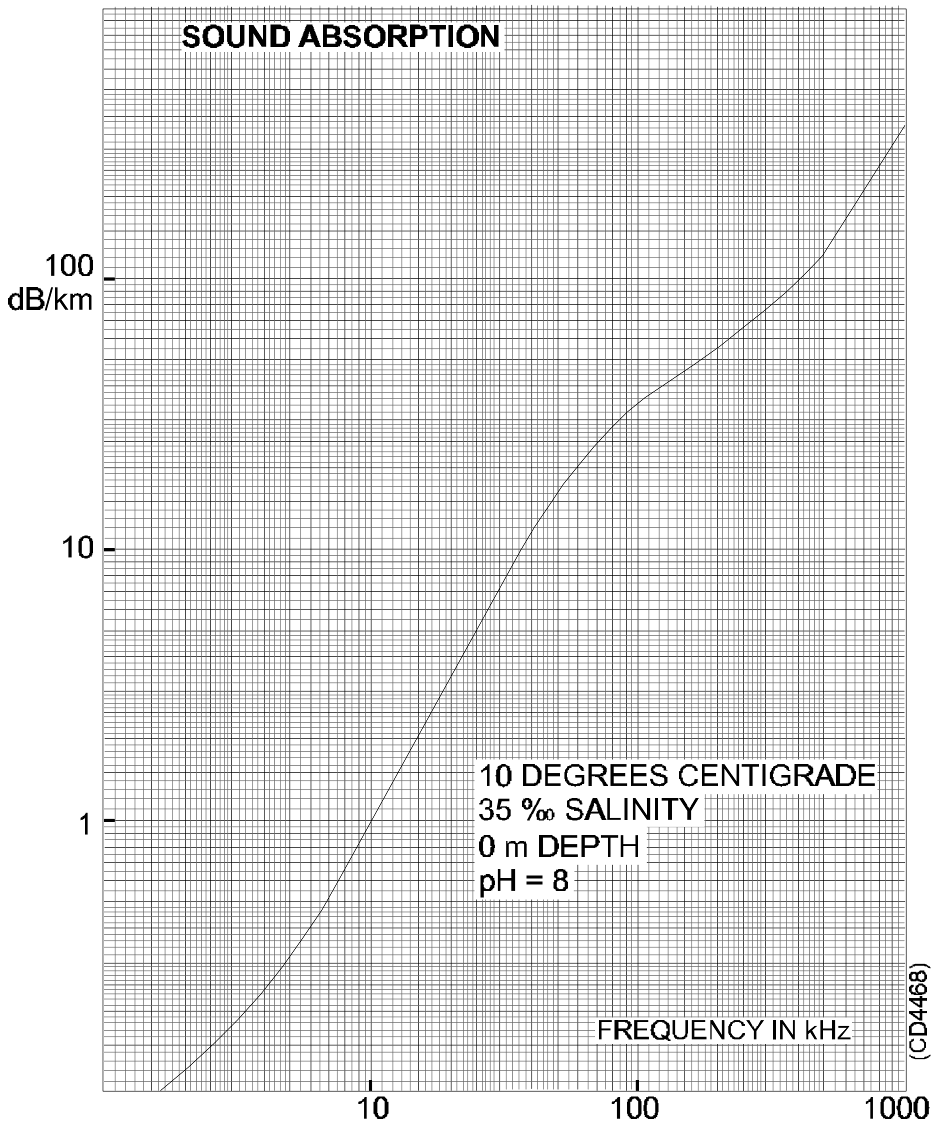

Figure 1: Absorption loss

2 ACOUSTIC NOISE

Being able to overcome spreading and absorption will not be the only factors to consider when it comes to using an acoustic positioning system as a reference in Dynamic Positioning (DP). Environmental noise will perhaps be the most critical factor especially in deep waters, i.e. for depths greater than 1000 m. Figure 2 shows the Noise Spectrum Level in dB rel.1µPa/√Hz for various types of noise. As can be seen, the thruster noise is the dominant factor and will be more than 40 dB above any other type of environmental noise. From Figure 2 it can also be detected that the noise will be reduced by approx. 10dB per octave above a certain frequency. This fact is an advantage to us and the effect might help us in the actual frequency range.

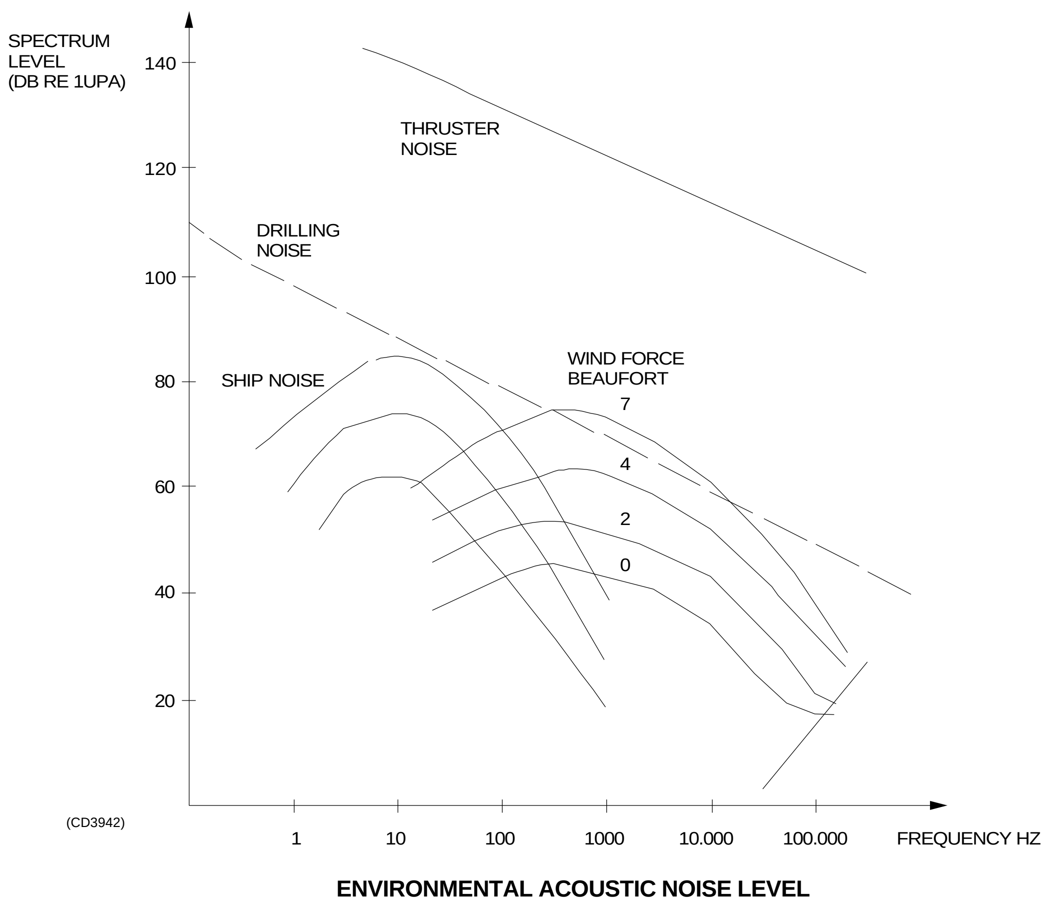

Figure 2. Noise spectrum level for various types of noise.

3 REDUCING THE IMPACT OF NOISE

3.1 Source Level

One very obvious way to reduce the impact of noise is to increase the level of sound transmitted from the sound source. In shallow waters, this solution has been an easy way out as the amount of power from the beacon/transponder in most practical cases would be within an achieving range. However, if you start to calculate the needed power level at 3000 meter depth you will realise that increasing the output power is not the only factor you have to influence to be able to achieve a long range or great depth.

The sonar equation gives the following relation:

$$\mathbf{SL = 171 + 10 \log P + E + DI}$$

Where:

SL = Source Level, (dB rel. 1µPa. ref. 1m)

P = Transmitter power output (w)

E = 10 log η

η = transducer efficiency

DI = Directivity index in dB

The new factor DI, describes the transducer ability to concentrate the emitted sound energy in a beam towards the target. It is obvious that a higher concentration will help to increase the Source Level.

3.2 Directivity (DI)

To start with we will just look at the transmitting directivity from the sound source on the bottom, a beacon or transponder. However, the same relationship will rule on the receiving end onboard the vessel:

- A high directivity will reduce the influence of noise from other directions than wanted.

To get a higher directivity, the opening angle of the transducer has to be reduced. To achieve this, the active area of the transducer has to increase if we assume that the frequency is the same. The following relation is valid for the transducer's opening angle:

$$b = \frac{l}{L} * \frac{180}{p}$$

Where:

β = opening angle in degrees. The angle where the SL or receiver sensitivity has decreased by 3 dB from the value for the centre beam.

λ = wave length = (c/f)

c = sound velocity

f = frequency

L = length of active transducer area in meters

In most cases, the transducers are circular or squared. This means that the opening angles in x and y directions are the same.

From the known opening angle the Directivity can be calculated as:

$$D \approx \frac{2.47}{\sin\left(\frac{b}{2}\right)^2}$$

and the Directivity Index

DI = 10 log D.

Figure 3 shows the relation between transducer diameter and directivity for two different frequencies.

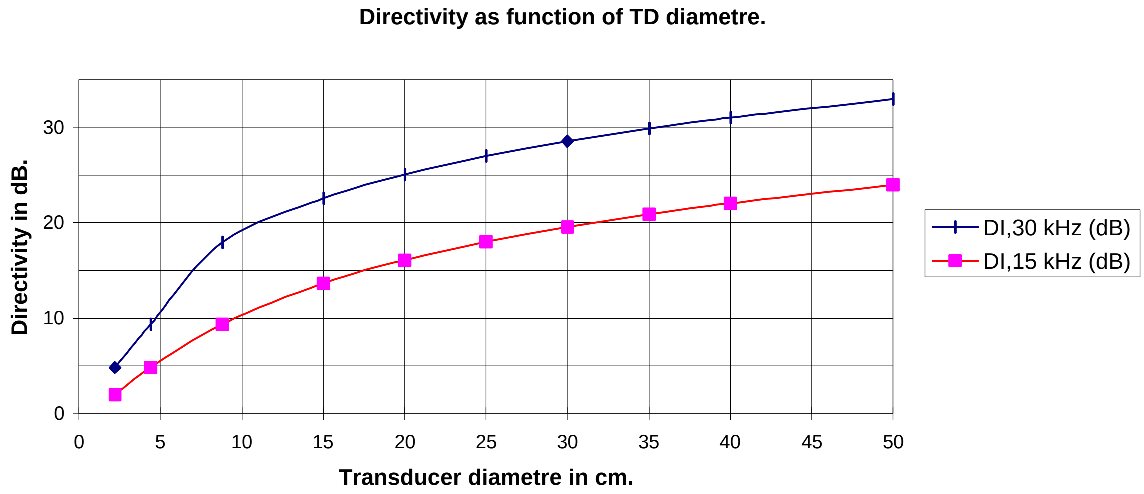

Figure 3. Directivity

Preliminary conclusion:

For good performance of the sub-sea equipment in deep waters, the main factor for the sound source is to give a high Source Level.

This is achieved in two ways:

- by a high power output from the beacon or transponder
- the transducer of the sound source should have a high Directivity Index.

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4 RECEIVED SIGNALS AT THE SURFACE

4.1 General

To be able to perform station keeping, the Dynamic Positioning System need reference data of a certain quality. In most cases other reference systems onboard will be compared with a DGPS surface navigation system. The DGPS will typically have Standard Deviations in the range of metres which will set the standard for other reference systems onboard, so also the Acoustic Positioning System.

4.2 Signal-to-noise ratio

The signal-to-noise ratio can be calculated by:

$$S = SL_{TP} – 20\log(R) -\alpha (R)$$

$$N = N_O – (20\log(R_T) + DI - 10\log(B))$$

Signal-to-noise ratio = S / N.

where:

S = signal at receiver

SL_{TP} = source level of transponder

R = range to transponder

α = absorption factor

N = noise level at receiver

N_O = noise level at thruster

DI = directivity index

B = receiver bandwidth

Note ! *If the signal-to-noise ratio is to be calculated for "in water" level, the DI must be set to 0.*

4.3 Super Short Base Line System

The position variance for an SSBL system can be calculated as follows:

$$\partial x = R\frac{\frac{l}{d}}{2p\sqrt{(S/N)}}$$

where:

∂x = position variance in X direction

R = distance between transponder and transducer

λ = wave length of transponder pulse carrier frequency

λ = C*T = Sound velocity times time period for transponder pulse frequency

d = base line length between transducer phase measurement groups

S / N = signal-to-noise power ratio,-in beams , not dB

Two new values show up as important factors to reduce the variance for the position measurement:

- It is important to have the longest possible distance (d) between the phase measuring groups at the surface transducer.
- The signal-to-noise (S / N) should be as high as possible.

The length of the base line (d) has to be a compromise between the wish for high accuracy and practical size of the transducer. Also a bigger transducer will give higher directivity and thus a smaller covered area (footprint) on the bottom. One way to overcome the small footprint is to introduce beam steering and this might be done both on the transmitting and the receiving sides.

The means for achieving a high S / N-ratio has been covered earlier for the transmitting side, but it is also important to have a high directivity for the receiving transducer.

Figure 4 shows the relationship between angular standard deviation (SD) and S/N-ratio for two types of transducers from Kongsberg Simrad.

The narrow beam (NB) transducer is a standard type of SSBL, phase measuring device.

The HiPAP transducer is a special multi-element device where a narrow beam is formed using digital beam forming. Figure 4 shows the angular accuracy of the HiPAP and Narrow Beam transducer. The signal-to-noise ratio in water is used in this figure. The bandwidth for the systems are identical. The standard deviation is:

$$\partial = \partial_x \sqrt{\frac{p}{2}}$$

where:

∂ = total variance

∂x = variance in X direction

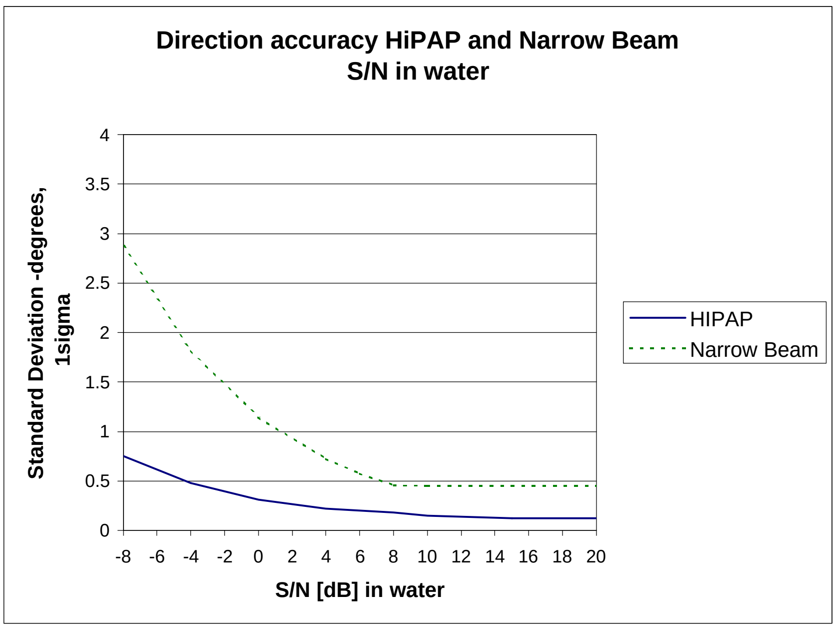


Figure 4: Angular variance as a function of S/N-ratio

4.4 Short and Long Base Line Systems

Both these systems are based upon detection of arrival time of signals at the transducer. The range variance can be calculated from the following formula:

$$S_R = \frac{C}{B\sqrt{2\frac{S}{N}}}$$

where:

S_R = range variance

C = speed of sound

B = bandwidth in Hz

As can be seen, it is still important to have a good S/N-ratio, but the speed of sound and the system bandwidth will have direct influence of the accuracy.

As the performance of these systems in deep waters will depend on good zero crossings for the received signals, it is obvious that this is not achievable for a short baseline (SBL) system where the base length athwartships on a drillship seldom can be more than 40 metres. As a rule, the base length for any LBL system used as DP reference should not be less than 20-25 percent of the water depth.

Figure 5 shows the error ellipse for an SBL system on board a drillship where the base length alongships is 50 metres and athwartships is 30 m. The total length of the ship is 150 m and the depth is 3000 m.

It is assumed that an S/N-ratio of better than 20 dB can be achieved.

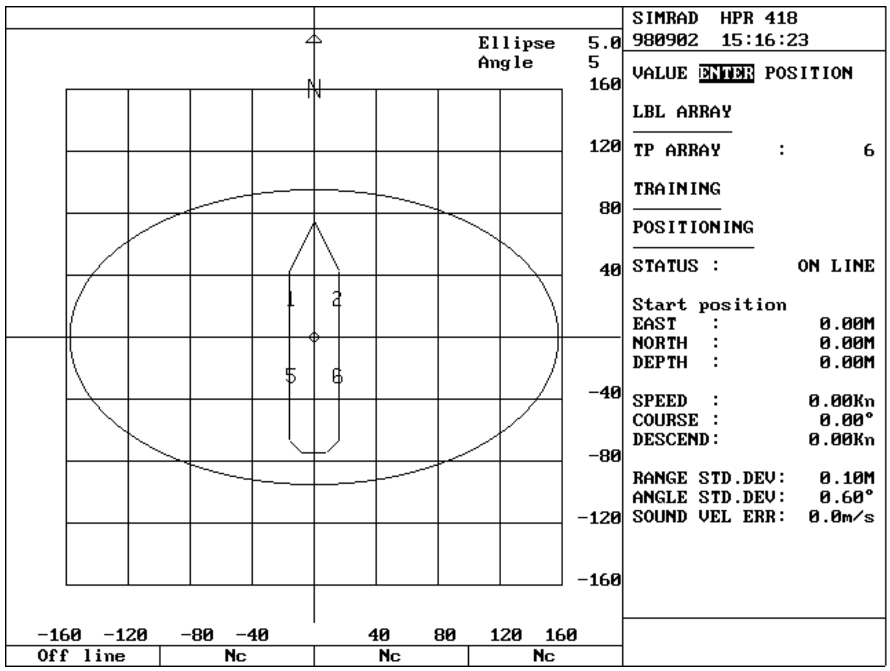


Fig. 5

As can be seen, it will not be possible to obtain Standard Deviations (SD) better than 23 metres, which will not be accepted by the DP-system.

The LBL-system will give the best variances of all types of acoustic positioning systems and as indicated in Figure 6. The SD-values are in the range of one meter and almost independent of water depth. Figure 6 is produced with Base Lines in the order of 1400 m, but considerably shorter Base Lines can be used for LBL-systems as reference for DP.

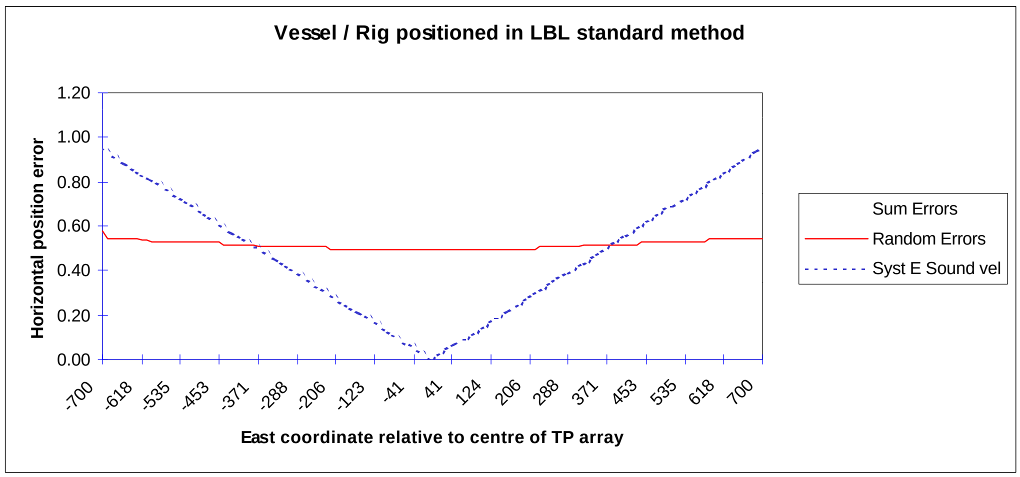


Figure 6

The main disadvantage of the LBL-system is the slow update rate in deep waters which can be solved or compensated for, but will not be covered here.

5 TRANSDUCER LOCATION

5.1 General

Now that we have done everything possible on the electronic side to get good signals, it is time to look at what can be done to outside and environmental factors that have impact on the positioning system's performance.

5.2 Thruster noise

Figure 7 shows the noise level from a Kamewa thruster with nozzle, propeller diameter of 3.5 m and a power of 4000 kW.

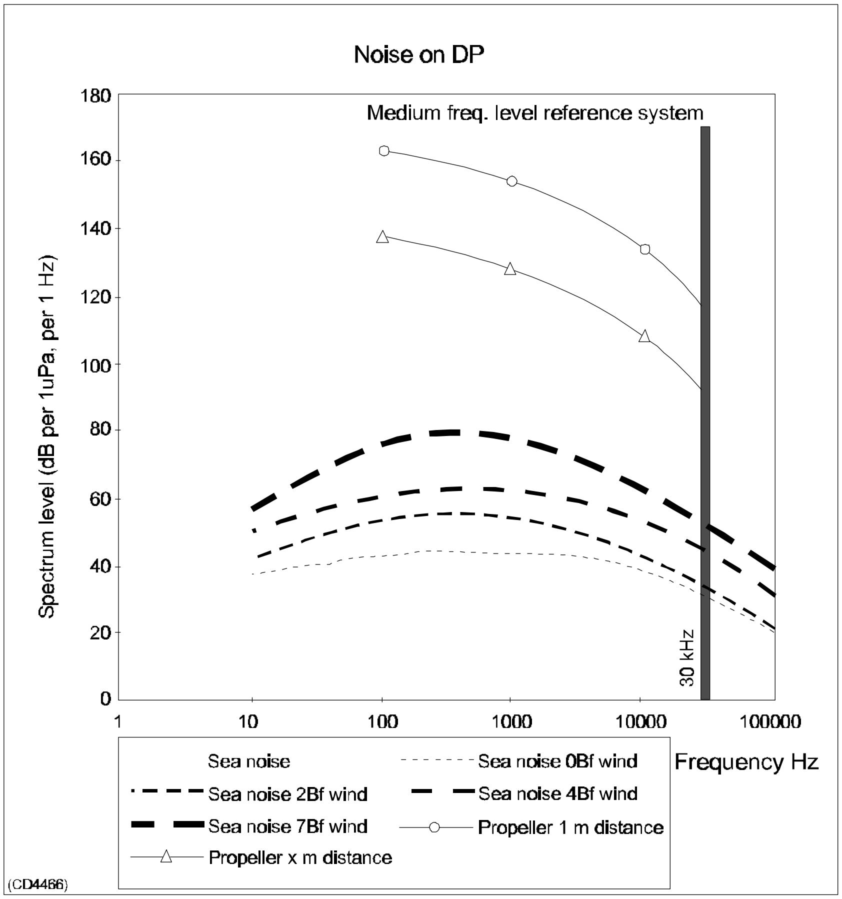


Figure 7. Kamewa

Figure 8 shows the noise level from an Ulstein thruster with constant RPM, variable pitch and approximately 1500 kW.

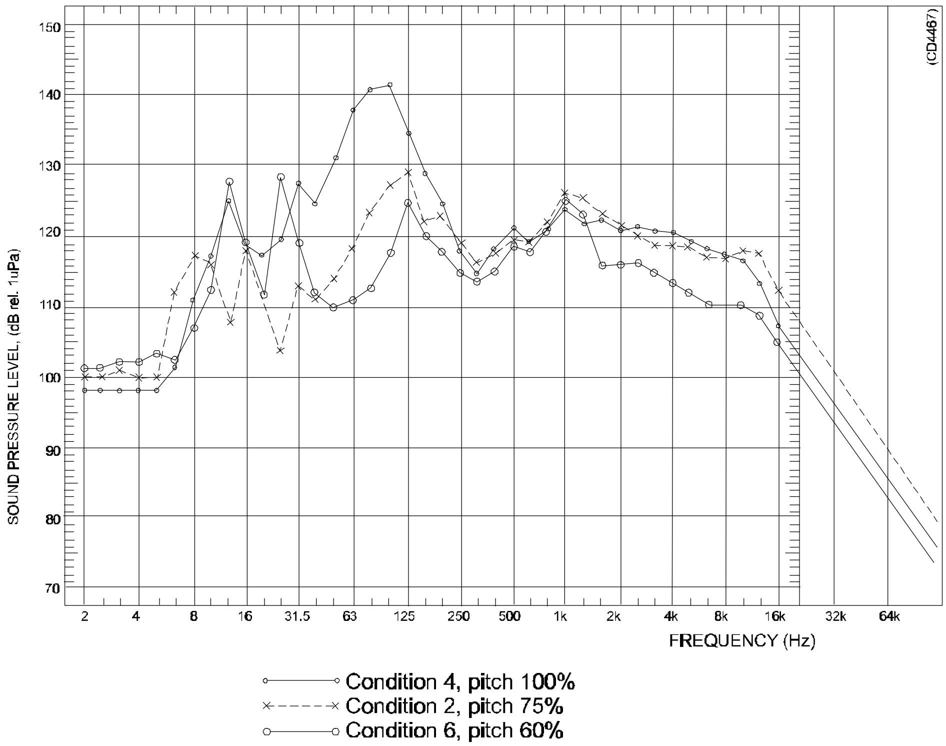


Figure 8. Ulstein

5.3 Transducer location

From all previous discussions, it is obvious that we want to get as far away as possible from the thrusters or main propellers with any transducer.

However, this has very often ended up in discussions between the acoustic supplier and the vessel owner or the yard. Even for new constructions, it is often seen that the acoustic system location is given low priority if any at all.

The result is often bad performance and costly reconstructions to get working systems.

It is our hope as acoustics supplier that we would be involved in the planning stage for any vessel with acoustics to achieve as good a solution as possible.

It should be noted that the optimal location is not always in the middle between the thrusters, but Figure 7 illustrate how quickly the noise is reduced when you get away from the thrusters.

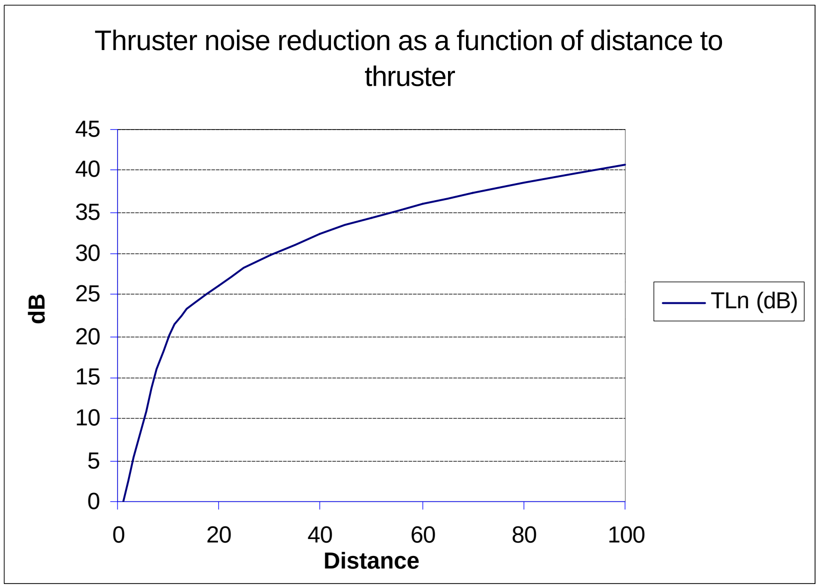


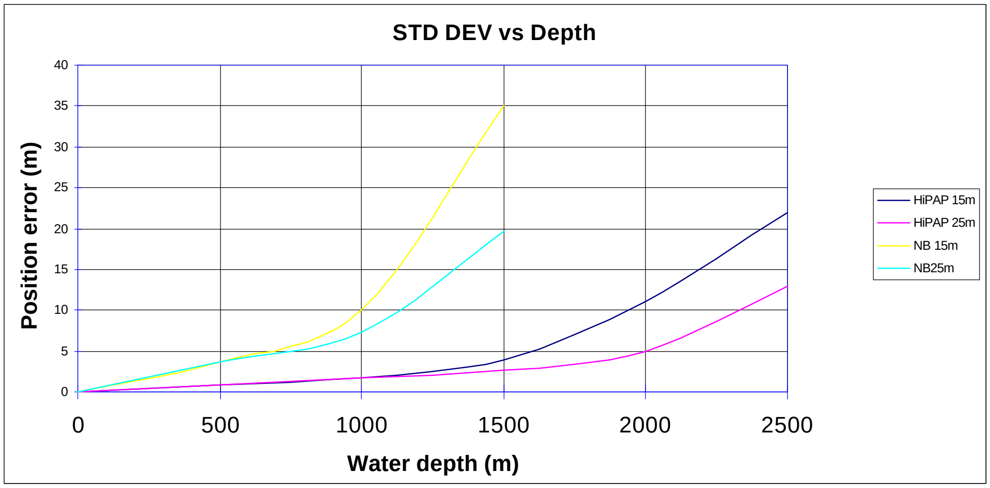
Figure 7.

5.3.1 SSBL accuracy vs. depth

Example:

Position error when distance from transducer to thruster is 15 m and 25 m.

System: HiPAP and HPR 410 Narrow beam



5.3.2 LBL accuracy vs. depth

Example:

Position error when distance from transducer to thruster is 15 m and 25 m.

System: HPR 418 Narrow beam

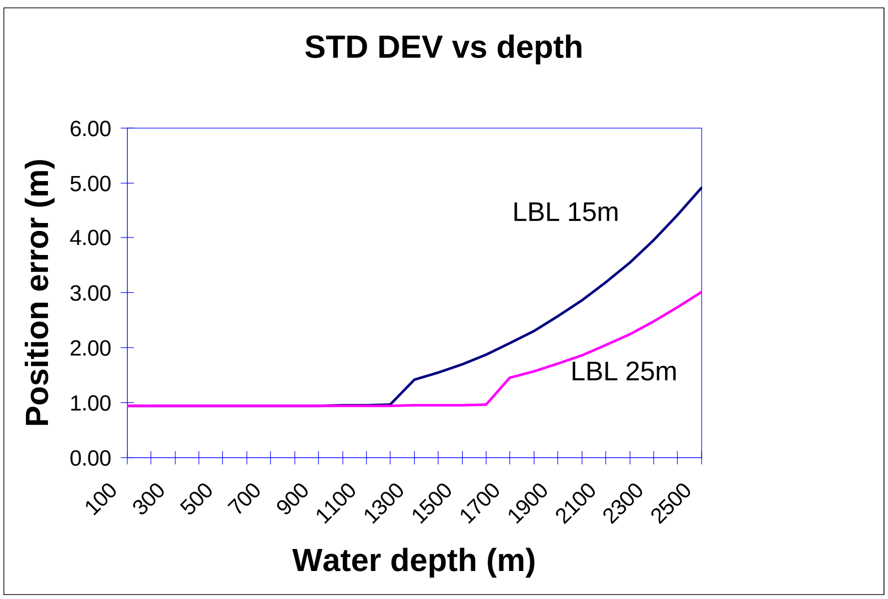
Transponder source level: 202dB rel 1μPa at 1 m

Thruster noise level: 125dB rel 1μPa / sqHz at 1 m

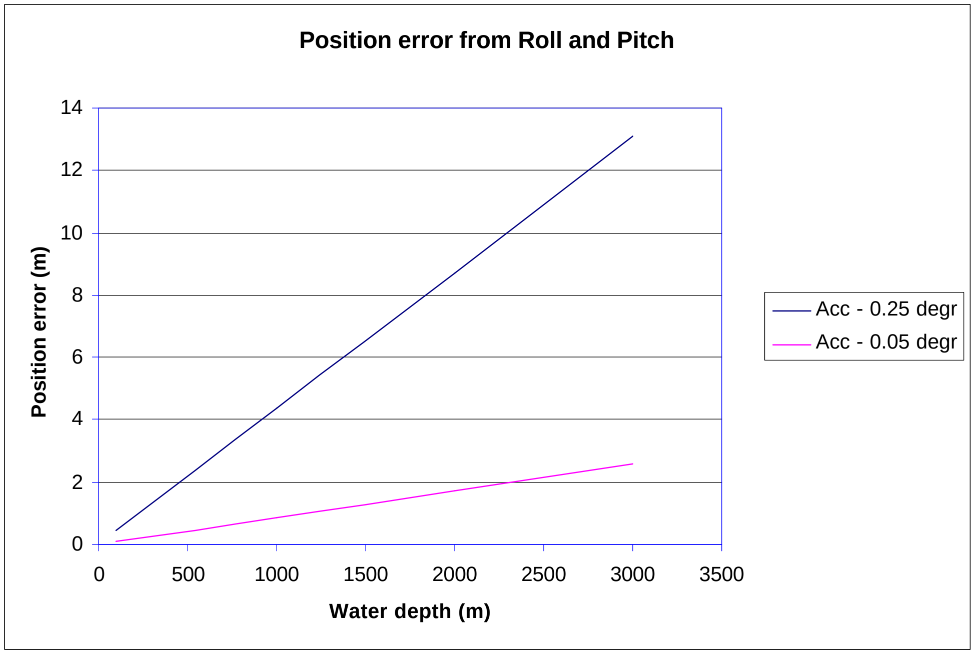
Array: 4 Tp's within 14 degrees from vertical

Note: The measurement errors are magnified by the bad geometry, 14 degrees from vertical.

This narrow array is only relevant for deep water application.



6 ERROR FROM ROLL AND PITCH SENSOR



Position error contribution from roll and pitch sensor with 0.25°

The total position error can be calculated by:

$$\partial = \sqrt{(\partial a^2 * \partial m^2)}$$

where:

∂ = total error

∂a = error from acoustic position systems

∂m = error from roll and pitch sensor