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Acoustic Positioning

Transducer Alignment and LBL Calibration

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1 ABSTRACT

Acoustic positions are used as reference for DP systems. This note describes alignment and calibration that must be done for the acoustic systems.

Acoustic Super Short BaseLine (SSBL) systems measure the position of a transponder on the seabed relative to the transducer. It is done in the transducer’s co-ordinate system. The position must be transformed to a position relative to the vessel reference point in the vessel’s co-ordinate system before it can be used as a DP reference. In order to do so, the acoustic system must know the alignment of the transducer relative to the vessel, and the position of the transducer relative to the vessel reference point. The process to decide these values is often referred to as transducer calibration. The name “calibration” is misleading, because no parameters within the transducer are calibrated. We therefore name the process transducer alignment, which describes the process better. Accurate transducer alignment has earlier required a survey computer and the assistance of a surveyor. Now this function is incorporated into the HiPAP system, and it can be done by the personel on the vessel. Chapter 2, and the first section in the presentation, describes how the function is implemented into the HiPAP systems.

Acoustic Long BaseLine (LBL) systems calculate the position of the vessel by measuring the ranges, and optionally the directions, towards transponders in the LBL array on the seabed. To do so, the acoustic system must know the positions of the transponders relative to each other in a north east co-ordinate system. The process to decide these positions is LBL calibration. Accurate LBL calibration has earlier required the baselines between the transponders to be measured. It has also required box-in of either one or more of the transponders or of the whole LBL array to decide the orientation of the LBL array relative to geographical north. The measurements of the baselines between transponders require free line of sight between them, which in some cases is difficult to obtain. The LBL calibration could therefore be time-consuming. Now a new function, LBL run time calibration, is implemented into the HiPAP systems. It utilizes the accurate range and angle measurements to calibrate the LBL array. The baseline measurements between the transponders are no longer needed. The new function was introduced one year ago, and has been used to a great extend since. It is described in chapter 3 and in the last section of the presentation.

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2 TRANSDUCER ALIGNMENT

2.1 What to calculate

After a HiPAP installation it is necessary to determine a number of offsets between various sensor reference points and axes. These are:

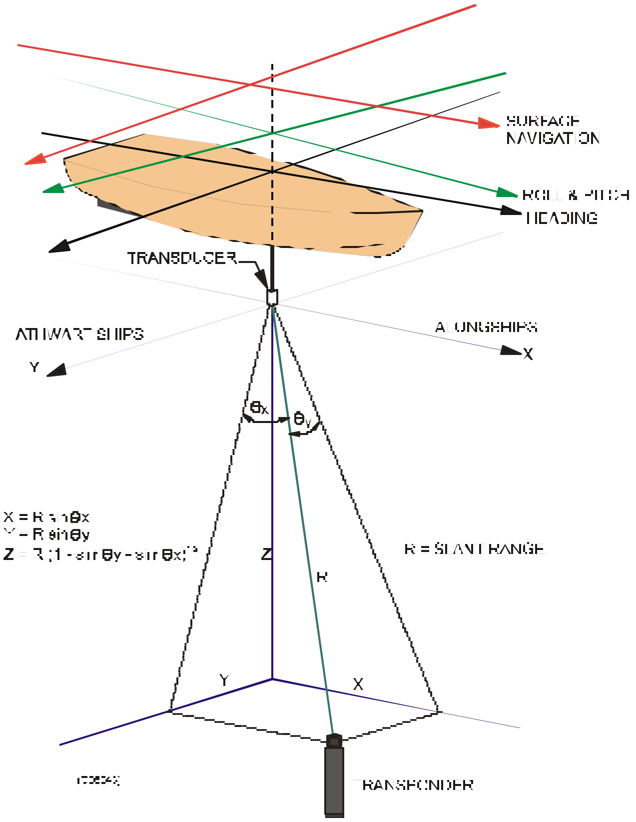
· Vertical angular offset between transducer axis and roll / pitch sensor axis.

· Horizontal angular offset between motion sensor and heading reference line.

· Horizontal angular offset between transducer axis and heading reference line.

· Horizontal distance offset between transducer location and reference point.

The principles for these alignment adjustments are based on the position of a fixed seabed transponder relative to the vessel and the geographical position of the vessel.



2.2 The implementation in APOS

In order to simplify and improve the quality of the alignment scenario, the alignment function in APOS can be used. By logging the vessel position from DGPS along with the measured HiPAP position of a seabed transponder, the program computes the alignment parameters. The normal procedure is to locate the vessel at four cardinal points and on top of the transponder with four headings. However, the alignment function does not require a specific scenario, and can be used very flexible. Various scenarios are analysed in the appendix.

This function is available for all HiPAP and HPR systems using the Windows NT operator station “APOS”. The APOS needs to be interfaced to a dGPS prior to the actual logging.

Immediately after the logging sequence, the alignment parameters can be computed and automatically transferred to the APOS alignment parameters. No manual transfer is needed. The results from the alignment are shown both numerical and graphically on the APOS. An example is shown in the two next figures.

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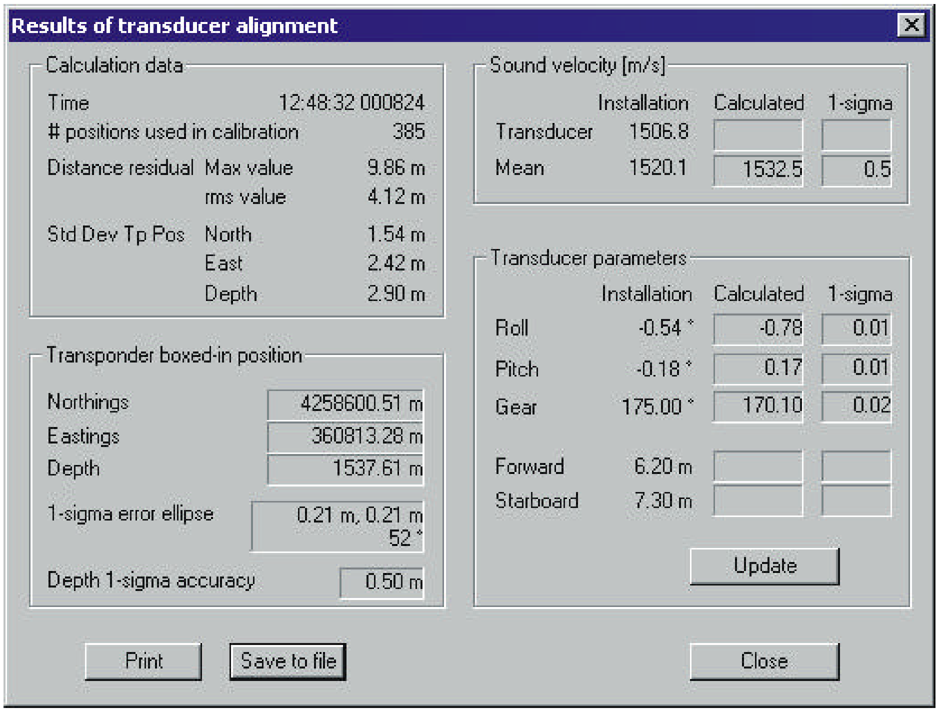

Results of transducer alignment

Calculation data

Time		12:48:32 000824
# positions used in calibration		385
Distance residual	Max value	9.86 m
	rms value	4.12 m
Std Dev Tp Pos	North	1.54 m
	East	2.42 m
	Depth	2.90 m

Sound velocity [m/s]

	Installation	Calculated	1-sigma
Transducer	1506.8		
Mean	1520.1	1532.5	0.5

Transponder boxed-in position

Northings	4258600.51 m
Eastings	360813.28 m
Depth	1537.61 m
1-sigma error ellipse	0.21 m, 0.21 m 52 °
Depth 1-sigma accuracy	0.50 m

Transducer parameters

	Installation	Calculated	1-sigma
Roll	-0.54 °	-0.78	0.01
Pitch	-0.18 °	0.17	0.01
Gear	175.00 °	170.10	0.02
Forward	6.20 m		
Starboard	7.30 m		

(Cl.5336)

Figure shows the result of transducer alignment – APOS presentation.

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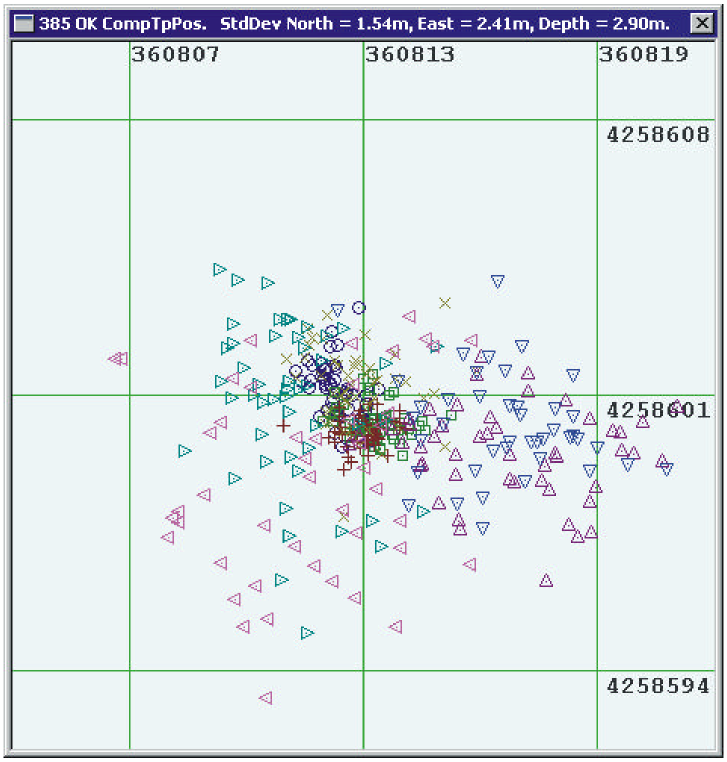

(Cd5386)

The figure shows the positions of the seabed transponder in UTM co-ordinates after the compensation values are determined and applied. The water depth is 1540m. The various symbols are used so measurements from different locations easy can be separated from each other.

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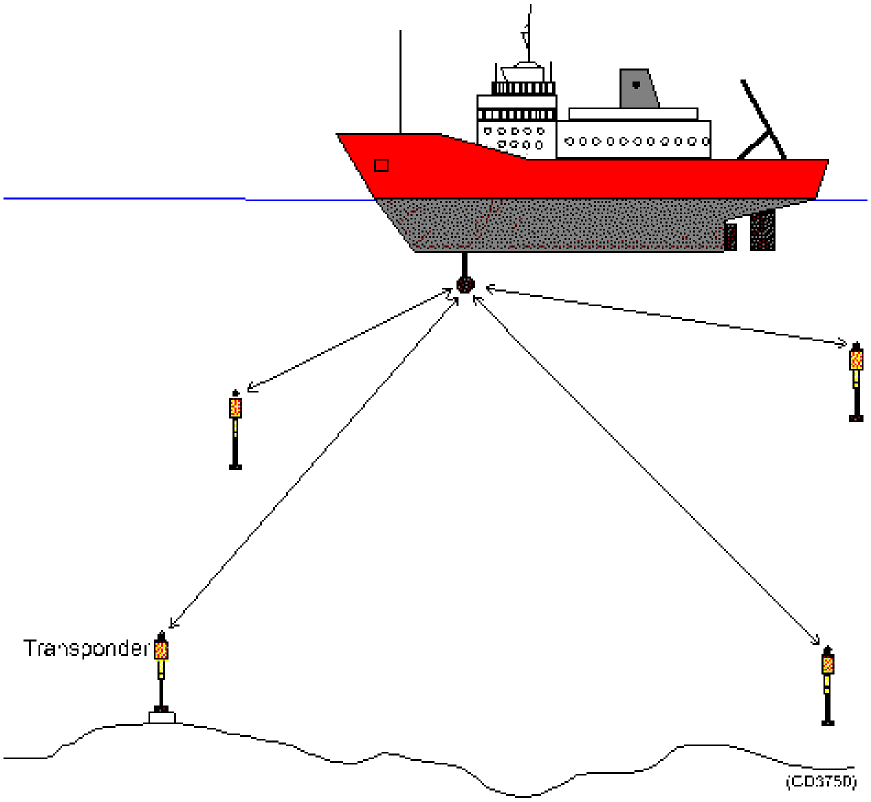
3 LBL ARRAY CALIBRATION

The principle of LBL positioning is shown in the figure below.



The acoustic system onboard the vessel measures the ranges and the directions to the transponders on the seabed. The system must know the positions of these transponders in order to calculate the position of the vessel. LBL calibration is the process to decide the transponder positions.

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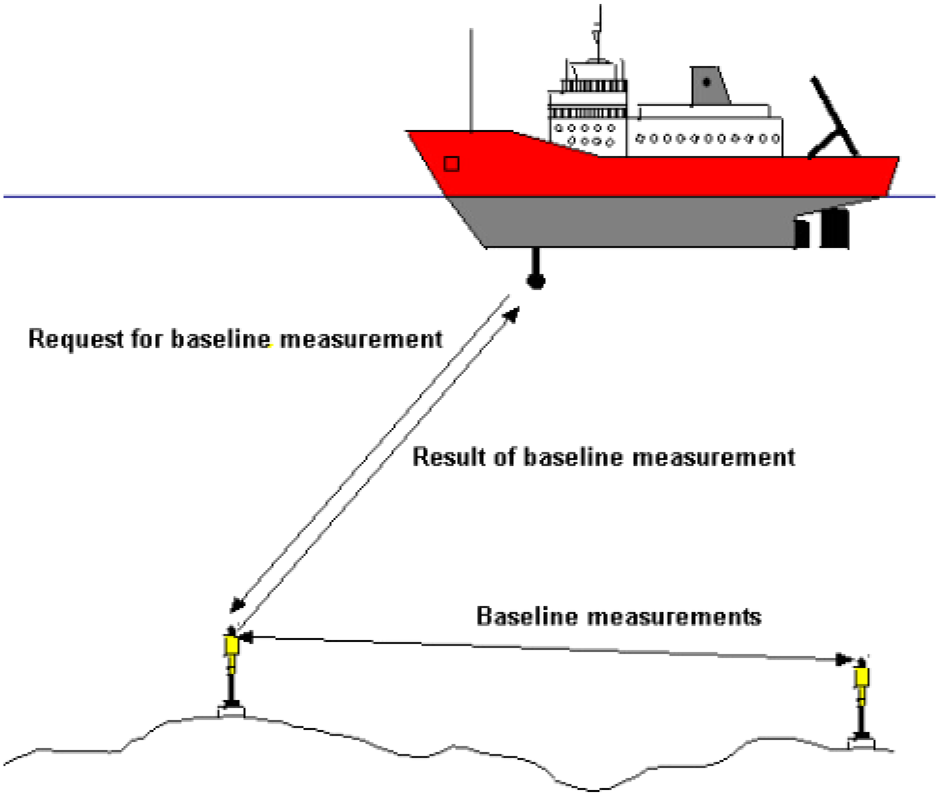
3.1 Baseline measurements

Accurate LBL calibration has earlier required the baselines between the transponders to be measured.



The baselines measurements are very accurate when the sound velocity at the seabed is known. When the baselines are measured, the relative positions of the transponders in a local co-ordinate system can be calculated very accurately. The baseline measurements have, however, no information about the depths of the transponders. The depths must be measured either by a depth sensor or by range measurements from the surface. The baseline measurements have no information of the orientation of the LBL array relative to geographical north. The orientation must be calculated based on box-in of either one or more of the transponders or of the whole LBL array.

The baseline measurements require free line of sight between the transponders. Sometims transponders must be moved to other locations to get free line of sight, and the process may therefore be time-consuming and difficult to predict.

Some applications, like ROV positioning, survey operations and Multiuser LBL, still requires the baseline measurements. As we will see in the next chapter, the new LBL Run Time calibration function eliminates the need for baseline measurements for DP LBL positioning.

3.2 LBL Run time calibration

The following steps are required for LBL run time calibration.

1. The transponders must be deployed on the seabed. It is not necessary with free line of sight between them, and it is not necessary to know the sound velocity at the seabed.
2. Position the transponders in SSBL with the vessel steady within the array.
3. The Kalman filter in the system will after some minutes establish good SSBL positions of the transponders. Then you command the system to use the transponder positions in the Kalman filter as positions for the LBL array. The Kalman filter uses its predictor to calculate the transponder positions valid at the same timestamp. These positions are accurate enough to start LBL positioning.
4. Set the transponders in LBL positioning mode. The system calculates the turn around delays to be used for the transponders, and sends the necessary information on telemetry to the transponders.
5. Start to position the vessel in LBL.
6. Log the LBL measurements for 10 to 15 minutes. The log file will typically contain 250 sets of LBL measurements. Each set contains the range and direction to each transponder in the LBL array. These measureemnts contain information about the relative positions of the transponders, the depth of the transponders and the orientation of the LBL array relative to geographical north.
7. Command the system to use the measurements that are logged, to calculate accurate positions for the transponders. The system uses a weigthed least square error algorithm in the calculations, which provides both the positions and quality data.

The next chapter describes how point 6 and 7 are implemented.

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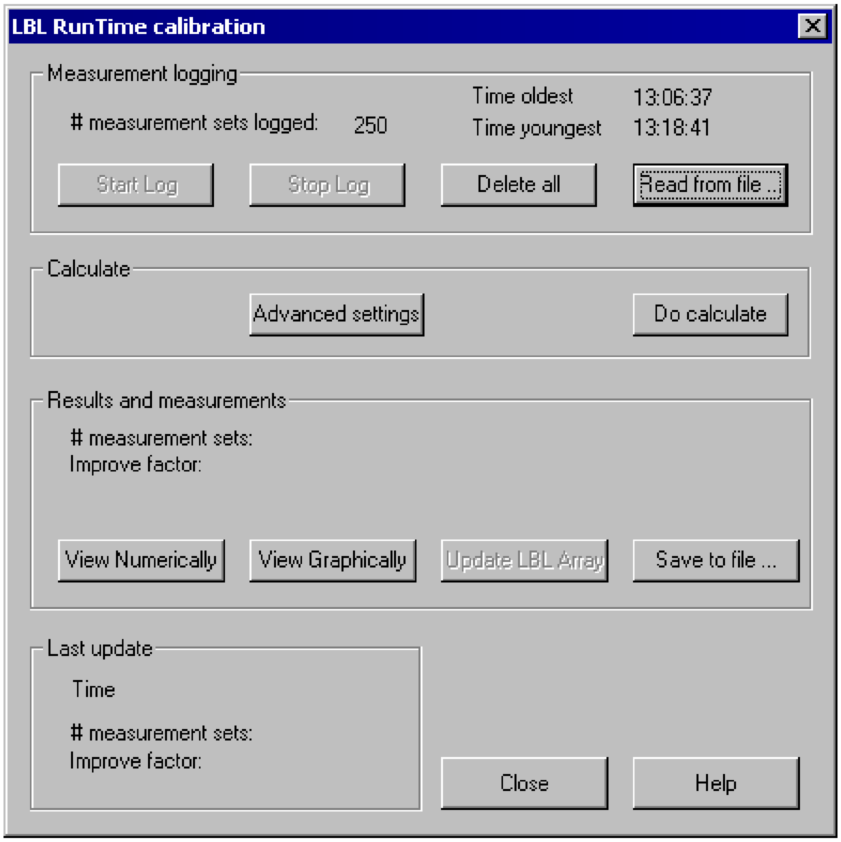
3.3 The implementation of LBL run time calibration

When finished with points 1 to 5 in the list in the previous chapter, the vessel positions in LBL. This chapter explains the implementation of point 6 and 7 in the same list.

You select the **”LBL run time calibration”** command from the main menu, and the dialog below is displayed. Tick the **”Start log”** button to start to log the measurements for the calibration. When 250 measurement sets are logged, you stop the logging by ticking the **”Stop log”** button.

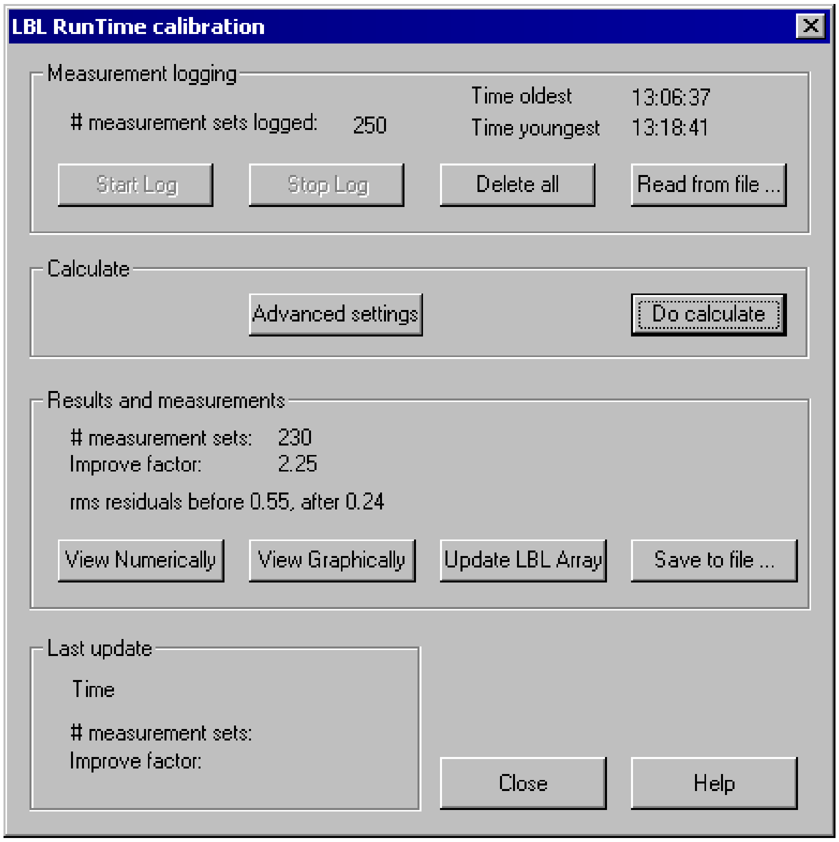


measurement sets logged: 250
Time oldest 13:06:37
Time youngest 13:18:41

Calculate the new positions for the transponder array by ticking the **”Do calculate”** button. The calculation lasts for typically 10 seconds, depending on the number of transponders and on the power of the computer in the system. With 5 transponders in the LBL array, the number of unknown North, East and Depth co-ordinates is 15, and the number of range and direction measurements is 3750.

The system automatically identifies outliers in the measurements, and excludes them from the calculation. It is done automatically by the system without operator intervention.

When the calculation is finished, a summary of the results is displayed in the dialog shown below.


LBL RunTime calibration

Measurement logging

measurement sets logged: 250

Time oldest 13:06:37

Time youngest 13:18:41

Calculate

Results and measurements

measurement sets: 230

Improve factor: 2.25

rms residuals before 0.55, after 0.24

Last update

Time

measurement sets:

Improve factor:

When the **"Improve factor"** is significantly greater than 1, we recommend to use the result. That is done by simply ticking the **"Update LBL array"** button.

The Improve factor and the presentation of the results are explained in the next subchapters.

3.3.1 Improve factor

For each LBL calculation, the system calculates the residuals of each measurement. The system divides each residual with the expected accuracy of the measurement, and calculates the rms (root mean square) of these quotients. This number is presented on the screen for the calculation of each vessel LBL position. A number less than 1 indicates that the measurements are more accurate than expected.

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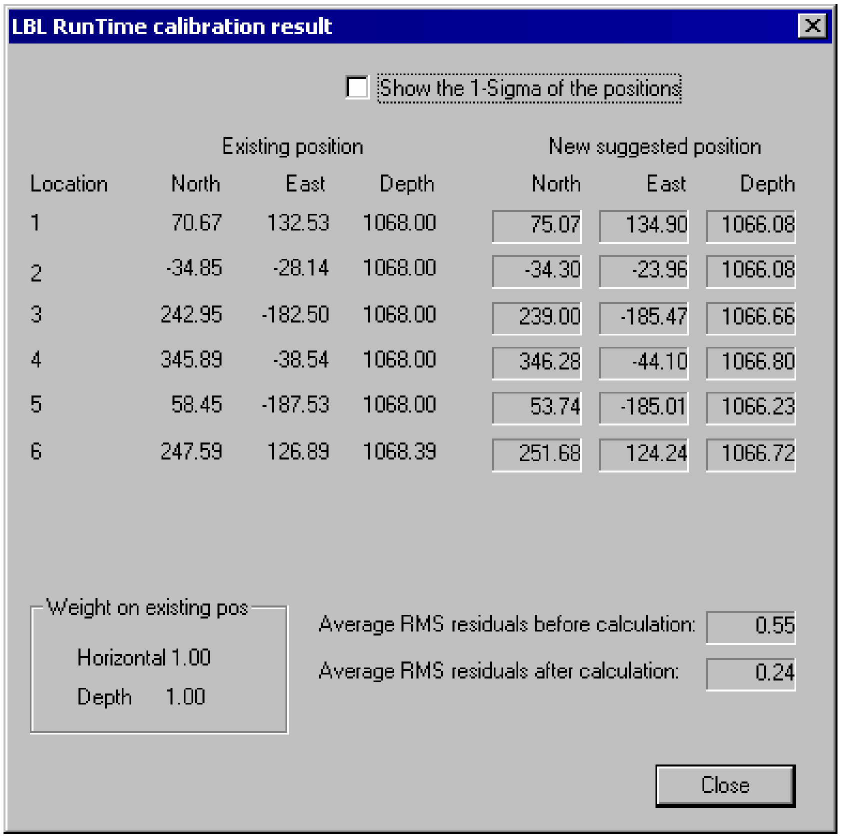
APOS calculates the average of these rms values as they were calculated with the existing transponder positions in the LBL array. It is named **”Average of rms residuals before”**.

When the run time calibration is done, new positions for the transponders are calculated. They match the measurement sets better than the existing transponder positions. For each measurement set, the system calculates the vessel position based on the new positions, and it calculates the rms value of the residuals. The average of the new rms values is named **”Average of rms residuals after”**. When this number is much less than the “before” value, the new positions match the measurements significantly better than the existing positions do. In the example shown above, the average is reduced from 0.55 to 0.24. The qutioent between these numbers is called the **”Improve factor”**.

3.3.2 Presentation of the results

The figure below shows the numerical values of the transponder positions. It is displayed when you tick the **”View Numerically”** button.



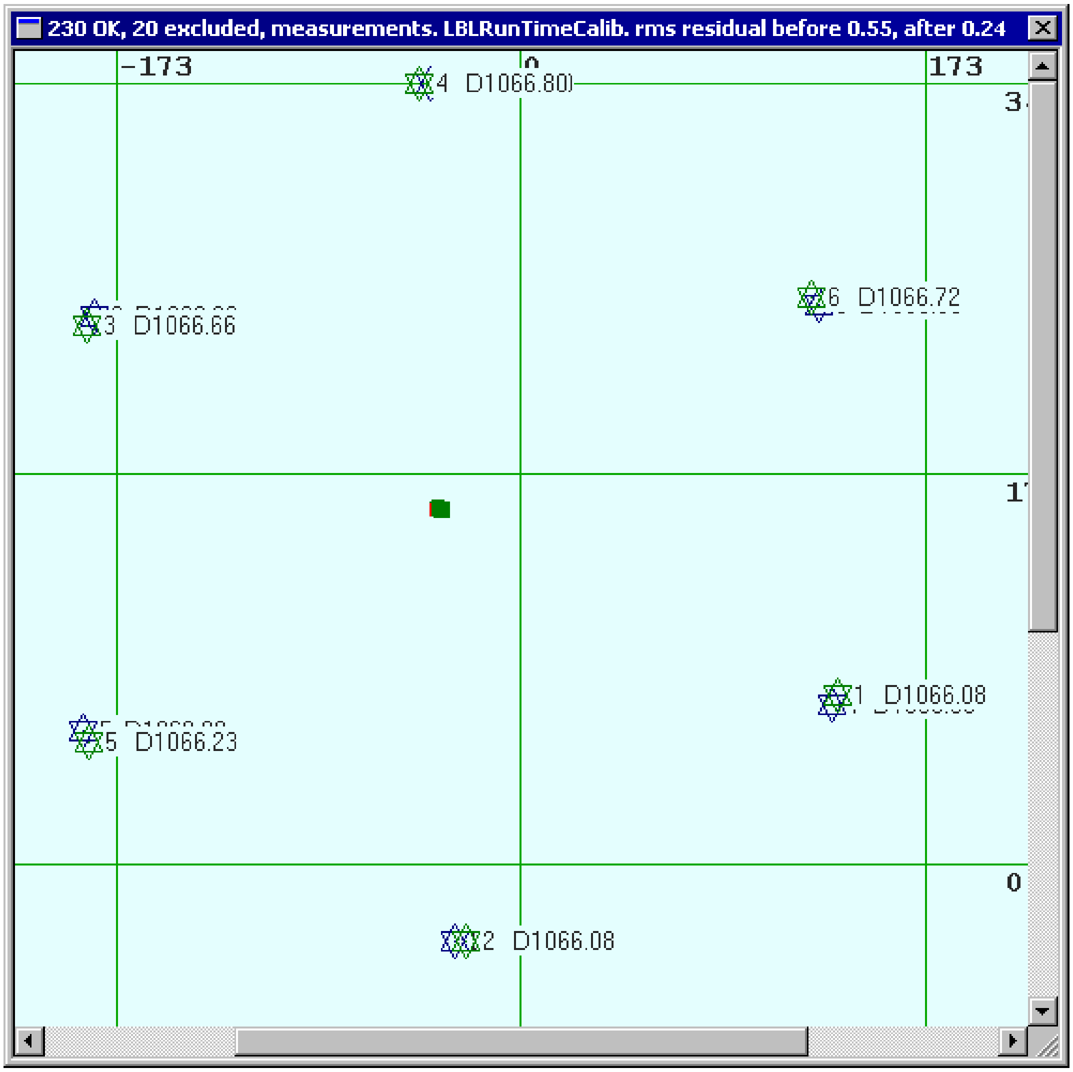
☐ Show the 1-Sigma of the positions

	Existing position			New suggested position		
Location	North	East	Depth	North	East	Depth
1	70.67	132.53	1068.00	75.07	134.90	1066.08
2	-34.85	-28.14	1068.00	-34.30	-23.96	1066.08
3	242.95	-182.50	1068.00	239.00	-185.47	1066.66
4	345.89	-38.54	1068.00	346.28	-44.10	1066.80
5	58.45	-187.53	1068.00	53.74	-185.01	1066.23
6	247.59	126.89	1068.39	251.68	124.24	1066.72

Weight on existing pos
Horizontal 1.00
Depth 1.00

Average RMS residuals before calculation: 0.55
Average RMS residuals after calculation: 0.24

The figure below shows the transponder positions graphically. It is displayed when you tick the **"View Graphically"** button.



230 OK, 20 excluded, measurements. LBLRunTimeCalib. rms residual before 0.55, after 0.24

The blue stars are the existing transponder positions. The green stars are the new positions. The numbers to the right for the transponder symbols are the depths of the transponders. The square symbols in the centre are the vessel positions when doing the measurements.

In the figure above, the depth numbers of the existing and the new positions are displayed on top of each other.

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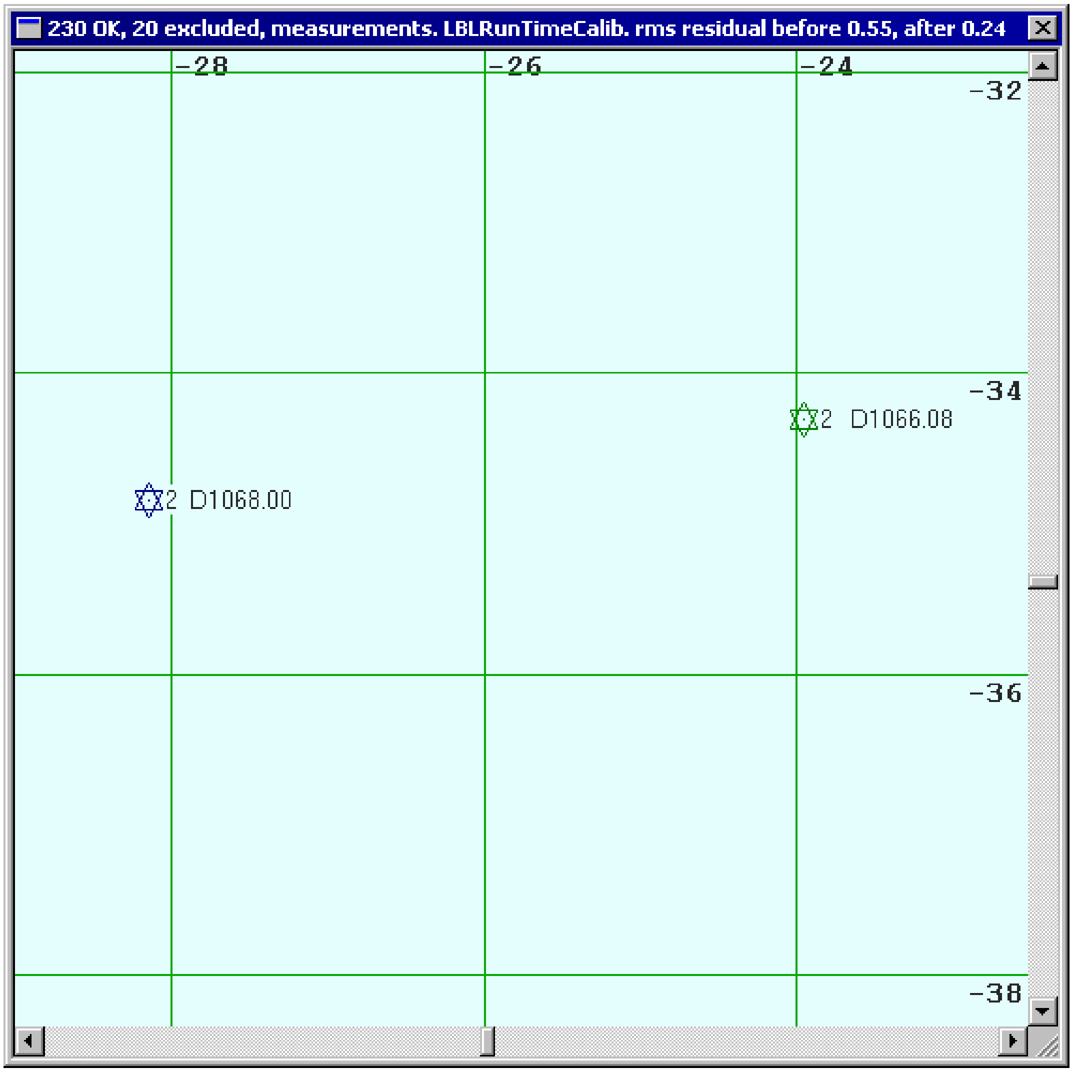
You can zoom in, as shown in the figure below.



230 OK, 20 excluded, measurements. LBLRunTimeCalib. rms residual before 0.55, after 0.24

Here we have zoomed in around transponder 2, which is south in the array. Now we can distinguish the two depth values from each other. The movement from the existing to the new position in the horizontal plane indicates a rotation of the LBL array.

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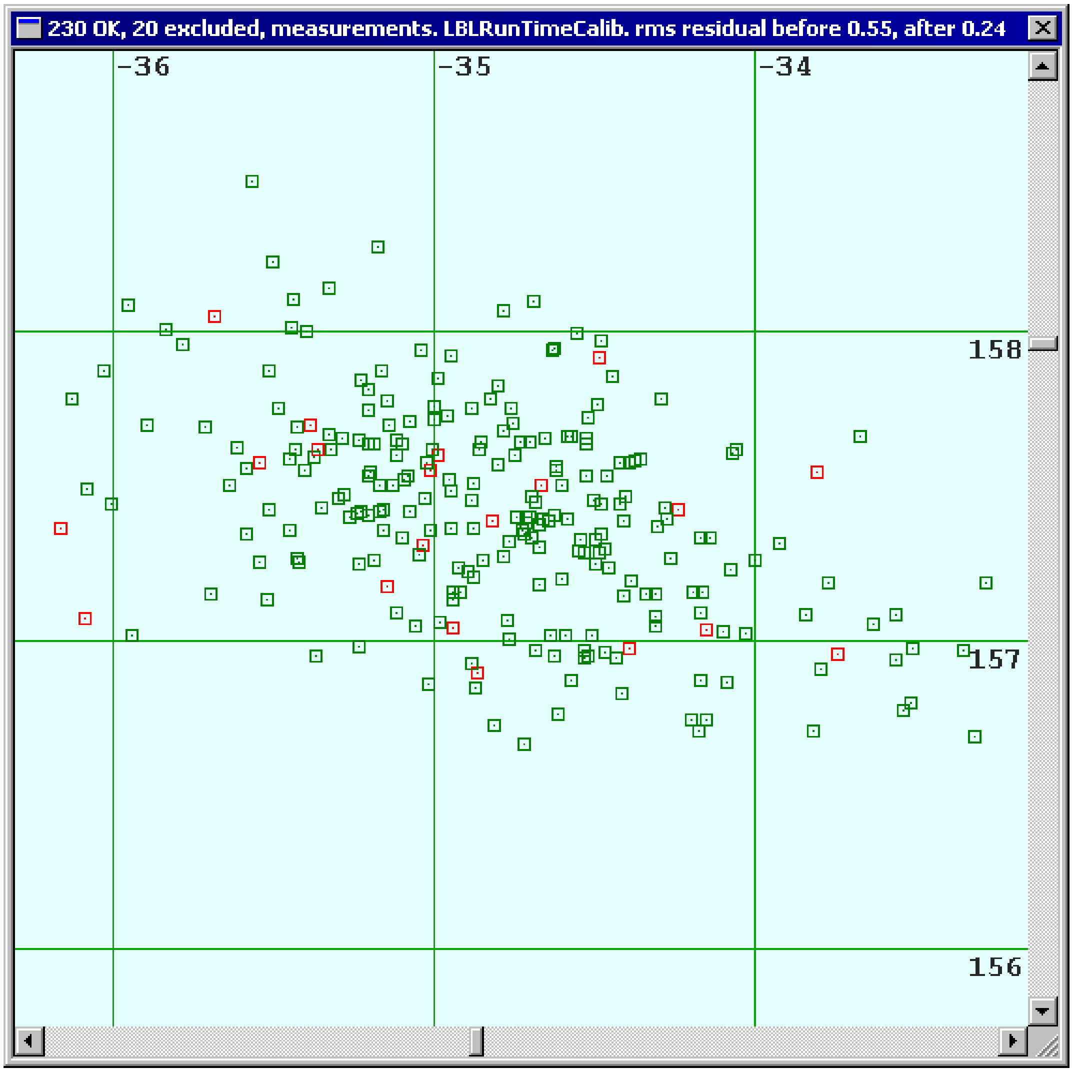
In the figure below, we have zoomed in at the squares showing the vessel positions when doing the measurements.



230 OK, 20 excluded, measurements. LBLRunTimeCalib. rms residual before 0.55, after 0.24

The red squares are the positions in the measurement sets that the system has excluded automatically.

3.4 Conclusion LBL run time calibration

The LBL run time calibration was introduced a year ago. Before introduction we tested it in the North Sea at 330 m waterdepth, in the Norwegian sea at 1060 m waterdepth and in the Gulf of mexico at 2000m waterdepth. In the last year it has been used with good results by the vessels with the HiPAP LBL systems. It is normally done without the need for assistance from kongsberg Simrad.

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4 APPENDIX. SCENARIOS FOR TRANSDUCER ALIGNMENT

The calculation of the alignment parameters are based on simultaneous measurements of the position of a transponder on the seabed relative to the vessel, and the geographical position of the vessel as measured by a dGPS system. The transponder position and the dGPS position are valid at the same time. They are named a position pair. The alignment function calculates the parameters of the transducer on which the acoustic measurements are done.

This analysis discusses different approaches for positioning of the vessel relative to the seabed transponder when logging measurements.

The approaches below are analysed:

1. Four cardinal points plus four headings on top of the transponder. The approach is explained in more detail in the APOS on-line help, with animation showing the vessel position and heading.
2. A circle around the transponder.
3. A triangle around the transponder.
4. Figure eight made of two circles.
5. Hourglass made of two triangles.

The report is based on simulated measurements. 64 dGPS / SSBL positions are used in each calculation. Gaussian noise can be added to the correct positions. The standard deviation of the SSBL noise is 0.3 degrees in the direction measurements and 0.20 m in the range measurements. The standard deviation of the dGPS noise is 1 m in both the north and the east direction.

APOS assumes that the measurements are done with approximately the same gaussian noise as described above. It is the basis for the covariance matrixes for the measurements. These covariance matrixes, together with the number of measurements and the geometry between the vessel and the transponder, decide the covariance matrix of the results. The covariance matrix of the result is used to calculate the 1-sigma uncertainty of the results. The report uses these uncertainties as basis when comparing the approach in the logging.

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We have checked several times that the accuracy of the result matches well with the calculated 1-sigma uncertainties. This check is not the scope of this report. Therefore, we did not put any gaussian noise on the measurements that is the basis for this report. The gaussian could have disturbed the comparison between the approaches.

All simulated positions are based on an error in the transducer roll, pitch and gear inclination, as shown below.

	Transducer roll	**Pitch**	**Gear**
Installed values	2.00 ?	-1.10 ?	2.3 ?
Correct values	2.80 ?	-1.80 ?	3.2 ?

There is no error in the transducer offset or in the GPS antenna offset. The transducer offsets below are used, except in the last chapter.

	Transducer Forward	**Starboard**	**Down**
Installed and correct values	- 2.10 m	1.20 m	9.80 m

The roll and pitch of the vessel is zero.

In some of the approaches, the vessel has a circular movement when logging the measurements. Kongsberg Simrad has often experienced that change of heading causes the attitude values to be wrong. In some cases, we have seen that the values read from the attitude sensors needs a constant heading for 15 minutes before the values stabilise. The effect of unstable attitude sensors is not taken into account in the numerical values presented in the note.

In most of the approaches the vessel is moving, either on a straight line or in a circle, when logging the measurements. This requires APOS to be accurately synchronised with the clock in the GPS receiver. Otherwise it is not possible to timetag the HiPAP/SSBL position to the same clock as the GPS position, and it introduces an error. The effect of this deskew error is not taken into account in the numerical values presented in the note.

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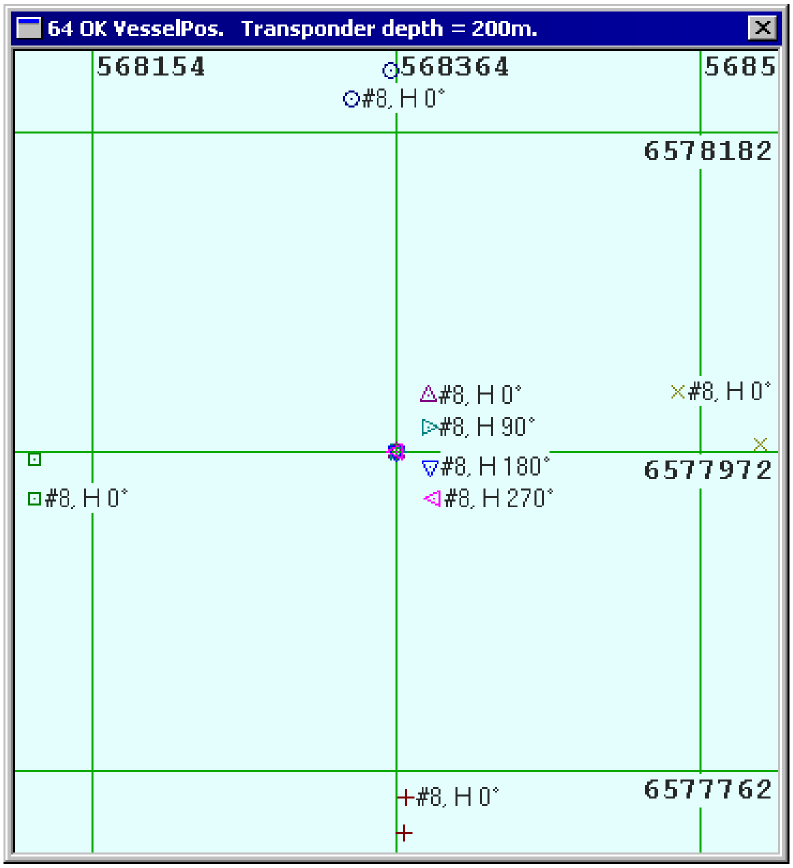
4.1 Four cardinal points plus four headings

The figure below shows the position of the vessel. The heading is 0 when being in the four cardinal points. The heading is 0, 90, 180 and 270 degrees when being on top of the transponder. The transponder is in the centre of the figure.



The same type of figure is shown for each of the approaches analysed in this report.

The vessel position is shown with different symbol and colour combination for each log series. For each log series, a legend is displayed with the symbol in front. The legend also includes the number of measurements (#) and the average heading (Hxxx?). In the figure above, the 8 symbols in each log sequence are in exactly the same position, and it looks as one symbol. That is the position of the vessel. The legend is displayed adjacent to the position.

The boxed -in position of the seabed transponder is in the centre of the figure.

In APOS, the same symbols are used when displaying the positions of the transponder. It allows us to see the connection between the vessel position and the transponder position

4.1.1 Shallow water

The waterdepth is 200m. The four cardinal points are 250 m away from the transponder in the horizontal direction, i.e. approximately 1 times the water depth.

8 SSBL / dGPS position pairs are logged in each of the 8 positions.

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			**Transducer offsets**	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.06 ?	0.06 ?	0.08 ?		
0.08 ?	0.08 ?	0.08 ?	0.28 m	0.28 m

4.1.2 Deep water

The waterdepth is 2000m.

The four cardinal points are 500 m away from the transponder in the horizontal direction, i.e. the vessel is close to the +- 15 degree beam limit of a narrow beam transponder.

8 SSBL / dGPS position pairs are logged in each of the 8 positions.

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			**Transducer offsets**	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.04 ?	0.04 ?	0.19 ?		
0.04 ?	0.04 ?	0.21 ?	0.92 m	0.77 m

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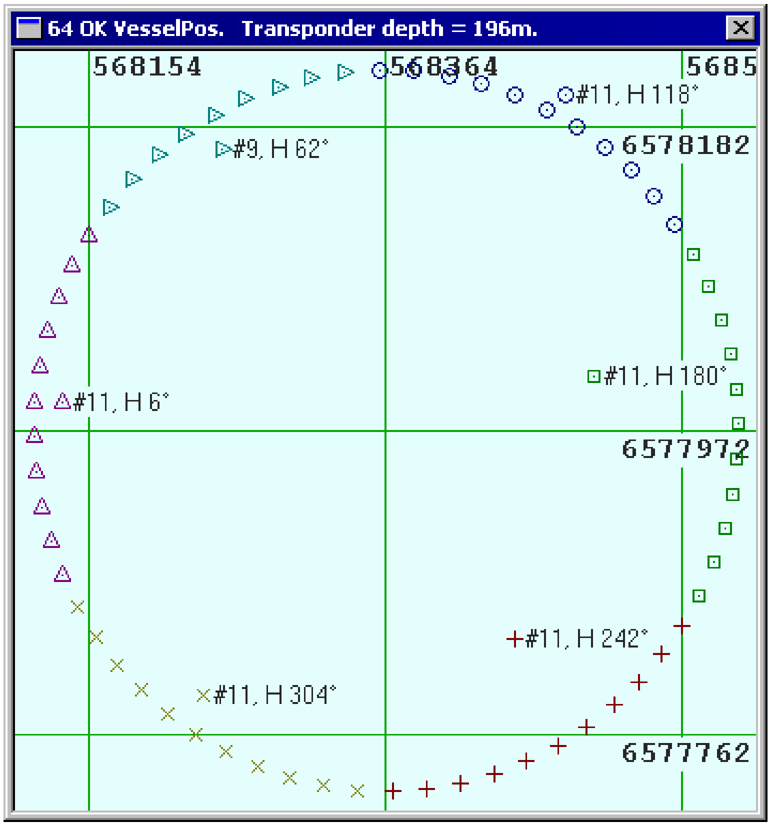
4.2 Circle around the transponder



The vessel moves clockwise around the transponder.

4.2.1 Shallow water one way

The waterdepth is 200m. The radius of the circle is 250 m, i.e. approximately 1 times the water depth.

64 SSBL / dGPS position pairs are logged when going clockwise around the circle.

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			Transducer offsets	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.77 ? 1.18 ?	11.84 ? 11.85 ?	9.05 ? 9.06 ?	3.00 m	2.96 m

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There is almost no information in the measurements to separate the pitch and the gear inclinations.

We have done simulations with an error in both the transducer offset and in the transducer inclinations. Then the calibration function calculates wrong values, but the transponder positions converge nicely close to the boxed-in position. Going in a perfect circle with the vessel around the transponder can tell if there is something wrong with the parameters. However, it can not tell that the parameters are correct!

When we simulate with vessel roll and pitch, the 1-sigma uncertainty is reduced because the transducer no longer has the transponder in the same position in its own co-ordinate system. However, we do not consider the circle one way pattern as good as the alternatives, and it is not covered any more in the note.

4.2.2 Shallow water two ways

The waterdepth is 200m. The radius of the circle is 250 m, i.e. approximately 1 times the water depth.

32 SSBL / dGPS position pairs are logged when going clockwise around the transponder, and 32 positions are logged when going counterclockwise.

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			Transducer offsets	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.06 ?	0.07 ?	0.06 ?		
0.08 ?	0.90 ?	0.06 ?	2.99 m	0.13 m

When not calculating the transducer offsets, the calculated values are OK. However, there is almost no information in the measurements to distinguish a pitch error from an offset error in the forward direction.

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4.2.3 Deep water two ways

The waterdepth is 2000m. The radius of the circle is 500 m, i.e. the vessel is close to the +- 15 degree beam limit of a narrow beam transponder.

32 SSBL / dGPS position pairs are logged when going clockwise around the transponder, and 32 positions are logged when going counterclockwise.

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			**Transducer offsets**	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.04 ?	0.04 ?	0.12 ?		
0.04 ?	0.09 ?	0.15 ?	3.00 m	0.25 m

When not calculating the transducer offsets, the calculated values are OK. However, there is little information in the measurements to distinguish a pitch error from an offset error in the forward direction.

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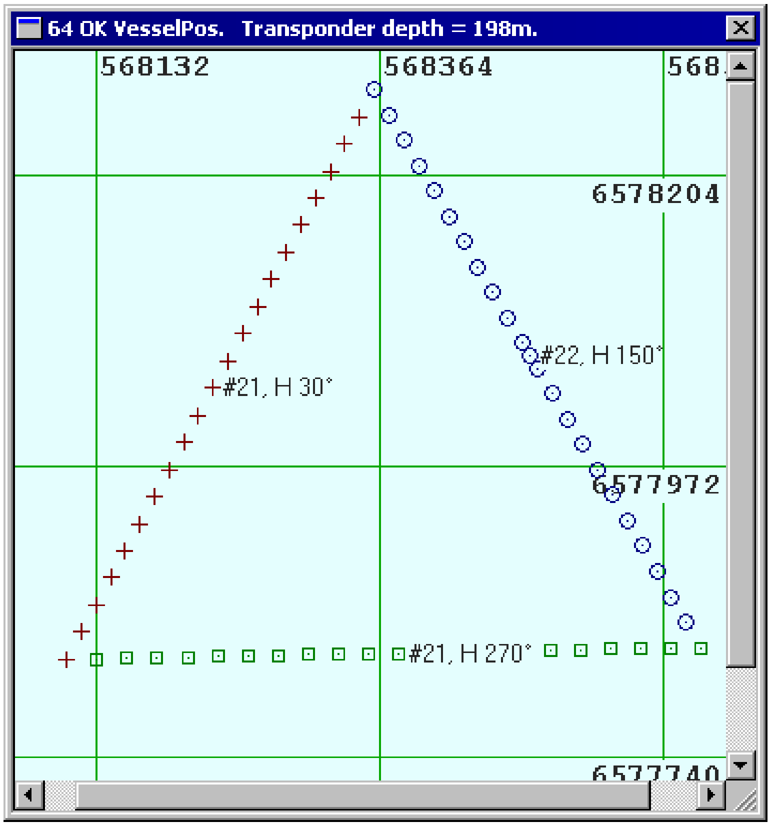
4.3 Triangle around the transponder



The vessel moves clockwise around the transponder.

4.3.1 Shallow water one way

The waterdepth is 200m. The horizontal distance from the transponder to the corners of the triangle is 300m, i.e. approximately 1 times the water depth.

64 SSBL / dGPS position pairs are logged around the triangle.

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			Transducer offsets	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.07 ?	0.09 ?	0.09 ?		
0.90 ?	0.10 ?	0.09 ?	0.20 m	2.98 m

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When not calculating the transducer offsets, the calculated values are OK. However, there is little information in the measurements to distinguish a roll error from an offset error in the stb / port direction

4.3.2 Deep waters one way

The waterdepth is 2000m. The horizontal distance from the transponder to the corners of the triangle is 600m, i.e. the vessel is close to the +- 15 degree beam limit of a narrow beam transponder.

64 SSBL / dGPS position pairs are logged when going clockwise around the triangle.

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			**Transducer offsets**	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.04 ?	0.05 ?	0.15 ?		
0.10 ?	0.07 ?	0.27 ?	0.54 m	3.00 m

The uncertainty of the calculated roll angle is strongly reduced compared to shallow waters.

4.3.3 Shallow water two ways

The waterdepth is 200m. The horizontal distance from the transponder to the corners of the triangle is 300m, i.e. approximately 1 times the water depth.

32 SSBL / dGPS position pairs are logged when going clockwise around the triangle, and 32 when going counterclockwise.

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			**Transducer offsets**	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.06 ?	0.06 ?	0.06 ?		
0.06 ?	0.07 ?	0.06 ?	0.19 m	0.16 m

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4.3.4 Deep waters two ways

The waterdepth is 2000m. The horizontal distance from the transponder to the corners of the triangle is 600m, i.e. the vessel is close to the +- 15 degree beam limit of a narrow beam transponder.

32 SSBL / dGPS position pairs are logged when going clockwise around the triangle, and 32 when going counterclockwise.

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			**Transducer offsets**	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.04 ?	0.04 ?	0.11 ?		
0.04 ?	0.04 ?	0.18 ?	0.42 m	0.33 m

4.3.5 Shallow water, constant heading, one way

The waterdepth is 200m. The horizontal distance from the transponder to the corners of the triangle is 300m, i.e. approximately 1 times the water depth.

64 SSBL / dGPS position pairs are logged around the triangle. The heading is constant at 12 degrees.

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			**Transducer offsets**	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.07 ?	0.07 ?	0.06 ?		
0.07 ?	0.07 ?	0.06 ?	2.96 m	2.96 m

When not calculating the transducer offsets, the calculated values are OK. However, there is little information in the measurements to detect an offset error.

We do not consider the triangle with constant heading as good as the alternatives, and it is not covered any more in the note.

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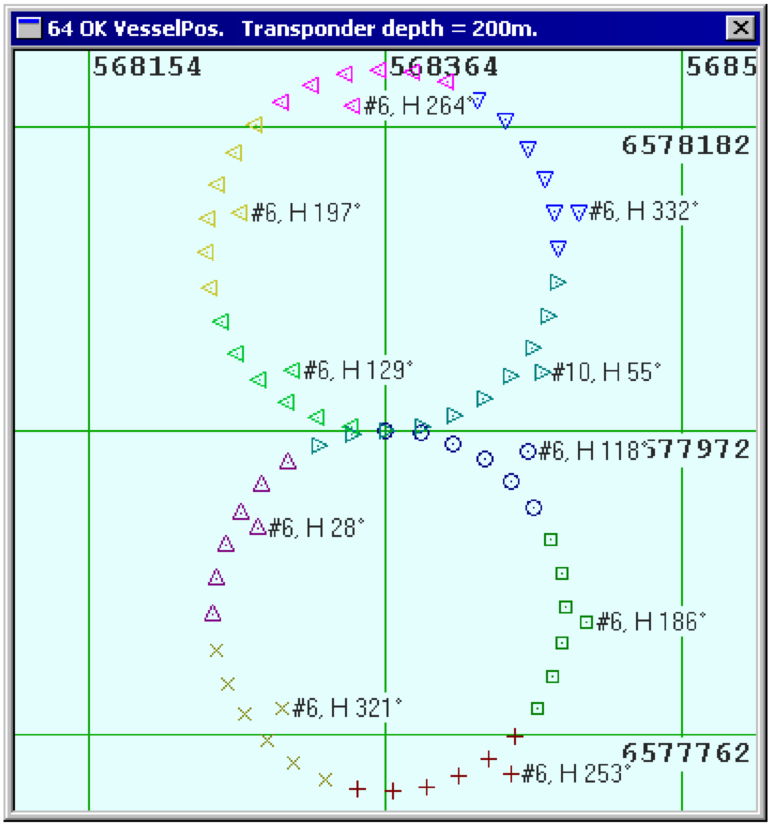
4.4 Figure eight above the transponder



The figure eight consists of two circles. The transponder is in the crossing between the two circles, i.e. in the centre of the figure. The vessel moves clockwise in the lower circle, and counterclockwise in the upper one. The logging can be done in one operation without stopping the vessel.

(We have also analysed figure eight based on two triangles and on two squares instead of based on the two circles . Figure eight based on two triangles is covered in the next chapter. Figure eight based on two squares does not give quite as good results as when it is based on two triangles, and it is more complicated for the steersman. Therefore, the figure eight based on two squares is not covered in this note.)

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4.4.1 Shallow water

The waterdepth is 200m. The horizontal distance from the transponder to the outer part of the figure eight is 250 m, i.e. approximately 1 times the water depth.

64 SSBL / dGPS position pairs are logged around the figure eight.

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			**Transducer offsets**	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.06 ?	0.06 ?	0.07 ?		
0.08 ?	0.08 ?	0.07 ?	0.24 m	0.21 m

4.4.2 Deep waters

The waterdepth is 2000m. The horizontal distance from the transponder to the outer part of the figure eight is 500m, i.e. the vessel is close to and within the +- 15 degree beam limit of a narrow beam transponder.

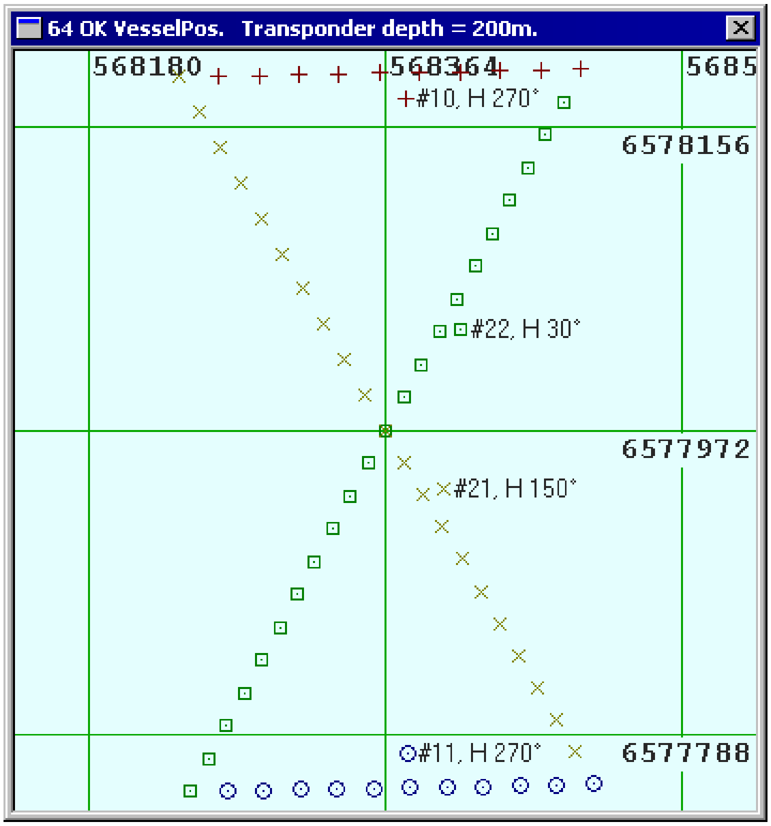
64 SSBL / dGPS position pairs are logged around the figure eight.

The 1-sigma uncertainties of the calculation are:

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			**Transducer offsets**	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.04 ?	0.04 ?	0.20 ?		
0.05 ?	0.05 ?	0.21 ?	0.82 m	0.73 m

4.5 Hourglass above the transponder



The hourglass consists of two triangles. The transponder is in the crossing between them, i.e. in the centre of the figure. The vessel moves clockwise in the lower triangle, and counterclockwise in the upper one.

The logging is done when moving the vessel in four straight lines, so the pattern is simple for the steersman.

4.5.1 Shallow water

The waterdepth is 200m. The horizontal distance from the transponder to the outer part of the hourglass is 250 m, i.e. approximately 1 times the water depth.

64 SSBL / dGPS position pairs are logged around the hourglass.

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The 1-sigma uncertainties of the calculation are:

Transducer inclinations			Transducer offsets	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.06 ?	0.06 ?	0.07 ?		
0.08 ?	0.06 ?	0.07 ?	0.17 m	0.24 m

4.5.2 Deep waters

The waterdepth is 2000m. The horizontal distance from the transponder to the outer part of the hourglass is 500m, i.e. the vessel is close to and within the +- 15 degree beam limit of a narrow beam transponder..

64 SSBL / dGPS position pairs are logged around the hourglass.

The 1-sigma uncertainties of the calculation are:

The 1-sigma uncertainties of the calculation are:

Transducer inclinations			Transducer offsets	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.04 ?	0.04 ?	0.14 ?		
0.04 ?	0.04 ?	0.21 ?	0.49 m	0.50 m

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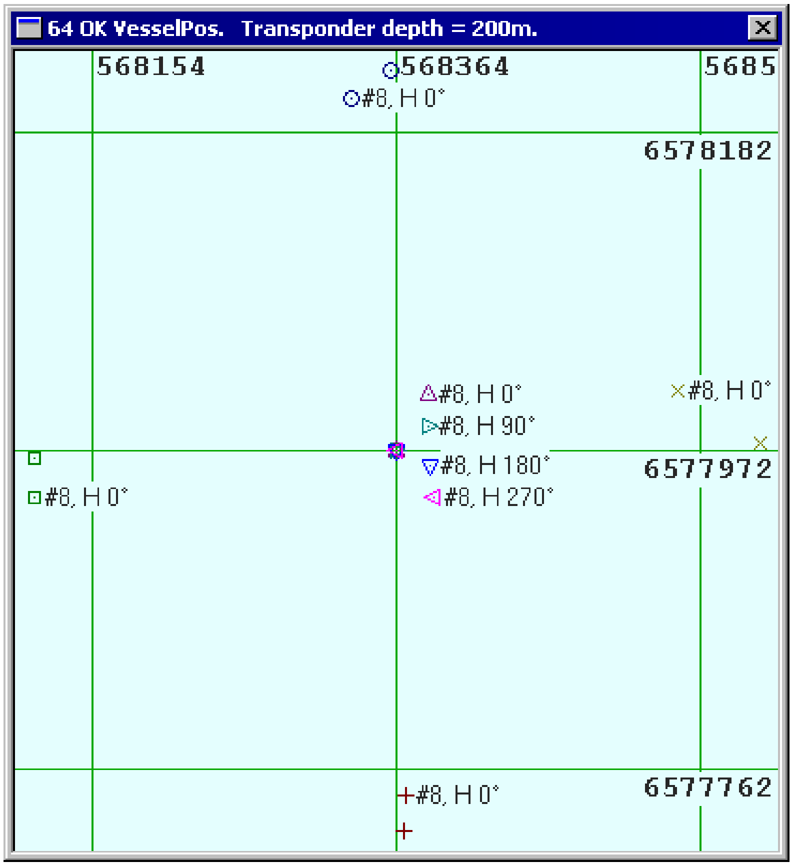
4.6 Asymetry due to big transducer offsets in shallow water

In chapter 2.1, we examined the expected accuracy with four cardinal points plus four headings on top of transponder. The transducer offset was small. Drilling vessels and rigs usually have big transducer offsets. When the vessel centre is on top of the transponder, the transducer is not. We therefore repeat the simulations in chapter 2.1 with big transducer offsets. Forward is – 125 m, Starboard is 100 m and Down is 30 m. The vessel centre is in the four cardinal points and on top of the transponder.

The waterdepth is 200m. The four cardinal points are 250 m away from the transponder in the horizontal direction.

8 SSBL / dGPS position pairs are logged in each of the 8 positions.



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The 1-sigma uncertainties of the calculation are:

Transducer inclinations			Transducer offsets	
Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
0.08 ?	0.07 ?	0.07 ?		
0.10 ?	0.08 ?	0.08 ?	0.23 m	0.28 m

The results are approximately the same as when the transducer was close to the reference point. It shows that it is not mandatory for the transducer to be exactly in the expected positions. The APOS knows where the transducer is based on the offsets and the measurements, and takes it fully into account when doing the calculation.

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4.7 conclusion

The table below is a summary of the shallow water results. It is the 1-sigma uncertainties of the alignment values when the three inclinations and the horizontal offset are calculated. It is based on 64 measurements in 200 m waterdepth. The vessel is mostly less than 1 times the waterdepth away from the transponder.

Shallow waters	**Transducer inclinations**			**Transducer offsets**	
	Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
Cardinal points	0.08 ?	0.08 ?	0.08 ?	0.28 m	0.28 m
Circle two ways	0.08 ?	0.90 ?	0.06 ?	2.99 m	0.13 m
Triangle	0.90 ?	0.10 ?	0.09 ?	0.20 m	2.98 m
Triangle two ways	0.06 ?	0.07 ?	0.06 ?	0.19 m	0.16 m
Figure eight	0.08 ?	0.08 ?	0.07 ?	0.24 m	0.21 m
Hourglass	0.08 ?	0.06 ?	0.07 ?	0.17 m	0.24 m

The table below shows the same results in 2000 m deep waters. The vessel is within the +- 15? narrow beam of the transponder

Deep waters	**Transducer inclinations**			**Transducer offsets**	
	Roll	**Pitch**	**Gear**	**Fwd**	**Stb**
Cardinal points	0.04 ?	0.04 ?	0.21 ?	0.92 m	0.77 m
Circle two ways	0.04 ?	0.09 ?	0.15 ?	3.00 m	0.25 m
Triangle	0.10 ?	0.07 ?	0.27 ?	0.54 m	3.00 m
Triangle two ways	0.04 ?	0.04 ?	0.18 ?	0.42 m	0.33 m
Figure eight	0.05 ?	0.05 ?	0.21 ?	0.82 m	0.73 m

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Hourglass	0.04 ?	0.04 ?	0.21 ?	0.49 m	0.50 m

The approach with four cardinal points plus four headings on top of the transponder is the only one without change of heading and/or movement when doing the measurements. It also gives good results. These considerations are the main reasons for Kongsberg Simrad to recommend this approach. It is not mandatory for the transducer to be exactly in the cardinal points and just above the transponder, as shown in the previous chapter. When the vessel does not have DP, it may be drifting when doing the measurements. It is often better than using the thrusters heavily.

Hourglass (two triangles) is the best alternative to the four cardinal points. It gives better accuracy of the horizontal offset, and the same accuracy of the inclinations. It consists of four straight lines, i.e. it is simple with respect to vessel manoeuvring. It does require an accurate time synchronisation of the APOS, meaning that the APOS must be interfaced to the 1 PPS from the GPS receiver.

When you have a narrow beam transponder on the seabed, the transducer must be in the transponder beam to achieve the best measurements. As a rule of thumb, it is far more important to have good signals than to have a good geometry between the transponder and the transducer.