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OPTIMAL ACOUSTIC BEAM PATTERN CORRECTIONS FOR SPLIT BEAM TRANSDUCERS

by

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ABSTRACT

Precise in situ target strength estimates of fish can only be made when the effect of the transducer directivity is totally removed from the recorded target amplitudes. By guiding a standard calibration target through the acoustic beam while simultaneously recording the amplitudes and angular positions of the target, a precise reconstruction of product of transducer transmit and receiving directivity can be made. From several thousand point measurements taken in a cross section through the acoustic beam, the recorded data have been fitted to a generalized three dimensional model by the use of non-linear estimation. The suggested model functions yield very low residual beam correction error with 95% of the data within ± 0.5 dB. Within the half power points of the beam, the residual beam correction error is close to the observed ping to ping system stability of ±0.1 dB. The precision and repeatability of the method is demonstrated through data from four split beam transducers mounted on four different research vessels. These are three ES-400 transducers and one EK-500 transducer, all working on 38 kHz.

INTRODUCTION

To obtain an unbiased target strength measurement of fish, a precise calibration of on-axis system sensitivity as well as beam directivity is needed. When the transducer beam directivity is known, and the target beam position is given, the recorded amplitude or energy can be corrected to on axis reference values. This is similar in both dual and split beam systems. (Ehrenberg 1983). When the dual beam only measure the off axis angle, θ , by a comparative measurement of the reflected intensity from the target in the narrow and wide beam, an estimate of the angular position (α,β) of the target is available in split beam systems. These are estimated through measurements of phase differences between paired transducer quadrants, and a calibration of the phase to angle conversion is necessary to obtain absolute angles. The deviations between estimated and actual angles have, however been proven to be small (Bodholt, 1989). For target strength work, where a calibrated, mapped beam is used to compensate the fish targets, the absolute angles is not required.
By guiding a calibration target through the beam while measuring energy and position, both the axis sensitivity and the beam directivity pattern can be mapped within the safe limits of the angle detectors, ± 5 degrees in the 38 kHz echo sounder.

Several mathematical functions have so far been used to fit the directivity surface, or to correct for non-ideal compensation of sampled target strength data (Brede et al., 1987; Reynisson, 1987; MacLennan & Svellingen 1986; Traynor & Ehrenberg, 1987; Degnbol & Lewy, 1987; Degnbohl 1988; Kieser & Ona, 1988) . These include everything from elaborate barge calibrations, to statistical procedures for post correction of target strength data from non-ideal real-time corrections. One of the most accurate methods involves a detailed mapping of the beam through 800 - 3000 data points, where the entire directivity surface is fitted to a bicubic spline (Degnbol, 1988). Later, Kieser & Ona, (1988), suggested that stabilizing the fitted surface to a modified Bessel function could reduce the residual variance, and also simplify the calibration.

In this paper I suggest a simple improvement of the Kieser & Ona method, where now a full three dimensional function is fitted by nonlinear estimation technique to the beam directivity surface. The function is parametrized to speed up real-time applications, and is a modified version of a function suggested by Nes, (1989).

MATERIAL & METHODS

The raw data for the analysis is respectively the parallel data from the Simrad ES-400, and the serial target strength data from

the Simrad EK-500 split beam echo sounders.
On each research vessel, except for R/V "PASQUALE" (Washington State, Dept. of Fisheries), the calibration sphere was lowered to a measurement depth around 20 m in a standard three winch rig, and moved across the acoustic beam in a systematic pattern by mechanically adjusting the winches. An example of a typical mapping of the beam is shown in Fig 1.
During the measurements on the Norwegian R/V " ELDJARN" and R/V "G.O.SARS" , no real time display of the sphere position was available, but later this feature have been incorporated in the logging software for the ES-400 parallel data. On EK-500 mounted on the R/V "MILLER FREEMAN" (Alaska Fisheries Science Center), a real time display of the target is part of the echo sounder software. On R/V "PASQUALE", the split beam transducer was side mounted on a 3.5 m log steel rod, extending well below the keel of the 35 feet vessel. The calibration was here achieved by centering the sphere in a two line rig, crossing the vessel, and then moving the rod back and forth, or in circles while monitoring the sphere position in the acoustic beam on the display of the recording computer, a portable PC-AT.

The raw 10 cm sample data from the ES-400 was reduced by depth, amplitude, angle jitter, and effective pulse length thresholding.

The available data for the statistical beam fitting algorithms are:
ping number, peak number, range, amplitude, alongship angle, athwartship angle, theta, phi, effective pulse length, half amplitude pulse length.

From the EK-500 the following data were available:
time, range, alongship angle, athwartship angle, internally beam compensated TS, uncorrected TS.

The amplitude and angle data was then used to fit the data to the function:

$$b(\alpha,\beta) = 2^{-\left[\left(\frac{\alpha-\Delta\alpha}{\Phi_A}\right)^2+\left(\frac{\beta-\Delta\beta}{\Phi_B}\right)^2\right]^E}$$

where :

α - athwartship angle
β - alongship angle
$\Delta\alpha$ - athwartship angular offset, estimated

$\Delta\beta$ - alongship angular offset, estimated

Φ_A - effective athwartship half power angle (half angle), estimated
Φ_B - effective alongship half power angle, half angle,estimated
E - shape parameter, estimated

The angular offsets is here estimated as the difference between actual angle measured by the split beam at maximum transducer gain, and the expected acoustic center at (0,0) angles. In all the measured systems, however, this offset is small, between 0.0 degrees to 0.25 degrees.
The shape parameter in the function is included for correcting for small deviations from a clean Bessel directivity, caused by the tapering of some of the outer elements in the transducer.(Bodholt, 1989). A value of E higher than 1.00 indicate a slight flatness of the main lobe.

The recorded data were fitted to the suggested model by a nonlinear iteration algorithm by the use of the statistical software in SYSTAT, (Wilkinson, 1988).

RESULTS

The basic results of the estimated parameters in six different beam calibrations on four different research vessels are shown in Table 1. The measurements were made on three ES-400 split beam systems, and one EK-500 system. The used calibration targets, and the temperature salinity during the calibrations are given in the table. Between the different ES-400 transducers, the variability in half power angles are within 0.4 degrees, with G.O. Sars as the one different. On this particular vessel, the transducer is mounted behind a polycarbonate window, while the others are free or flush mounted. Both the ES-400 and the EK-500 beam patterns are very close to circular, with a slightly wider athwartship half power angle. The difference between the estimates of alongship and athwartship opening angles are only 0.08 to 0.19 degrees, the EK-500 transducer being the most circular. The important phase offsets are estimated to be within 0.25 degrees on all the transducers measured, and the shape parameter from 1.00 to 1.16, larger for the ES-400 than for the EK-500.
On repeated measurements on the same transducer, the fit to the function is dependent of the degree of coverage of points measured in the beam cross section. If this is defined through a grid of one degree elements in each direction, a typical coverage in these measurements is 60 to 75 %, so that 25 to 40 of the 100 elements in the 10 by 10 degree grid do not contain measurements. If all elements within the 5 degree circular limit are covered, DC is 78.5%.

The degree of coverage in Fig. 1 is 61%.

The estimated beam pattern function for the ES-400 transducer mounted on R/V "ELDJARN" is shown in Fig.3, with the contour lines estimated by distance least square algorithm on the actual data shown in Fig. 4. Out to at least the half power points, the beam pattern is close to ideal, with small deviations further out, where the algorithm also is affected by a loser coverage. The residual target strength of the sphere after compensating with the function for R/V "ELDJARN" is shown in Fig. 5. Within the beam limits for what I recommended used for fish target strength measurements, -3 dB, all the measurements fall within ± 0.3 dB, with 80% of the data within ± 0.1 dB. This is close to the observed ES-400 ping to ping variance on a stationary, centered target.

DISCUSSION

Compared to earlier methods for removing the beam pattern effect, the suggested function does a better job than the modified Bessel function suggested by Kieser and Ona (1988), and is more stable at larger angles than a bicubic spline fit suggested by Degnbol (1988). The low residual target strength of the sphere is so close to the ping to ping variance both for the ES-400 and the EK-500, that higher order terms in the function only will fit eventual differences in this jitter along the beam cross section. For any practical target strength work on fish, other sources of errors, such as the single fish recognition criteria, angle, pulse and amplitude thresholding, will mask the bias of the beam correction.

On the other hand, the evaluation and mapping of the beam should always be made routinely to quantify this particular bias, and to check the overall performance of the transducer.
The indicated function does not necessarily need a detailed mapping input, as the basic shape of the beam is already determined. A very close to correct function can be estimated only from two cross sections through the beam, as was the case for the first calibration of R/V "PASQUALE". Fig. 6. show a contour plot of the difference between the respective functions estimated from a full mapping, degree of coverage 72%, and a simple calibration with only a longitudinal and a transversal section trough the beam. The largest difference is 0.2 dB at the borders of the beam and less towards the center.

CONCLUSIONS

New logging software for the Simrad ES-400 and internal software in the Simrad EK-500 split beam echo sounders, with real time displays of the sphere position significantly simplify the calibration and detailed mapping of the acoustic beam.

The suggested function describes the directivity function of the acoustic beam effectively, including the effects of phase offsets and array tapering, inside the limits of the angle detectors.

The suggested function is optimized for fast real time applications, and the parameters can be estimated using standard available PC software.

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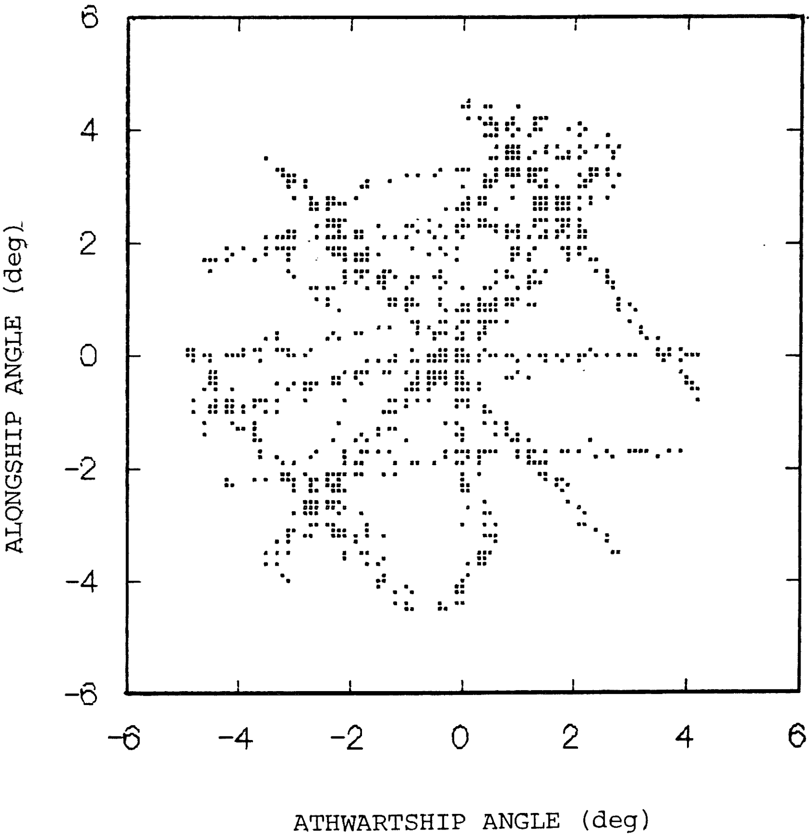

Fig.1. Example of the degree of coverage of measured points in a cross section through the acoustic beam of R/V "Miller Freeman", EK-500. A three line sphere suspension rig was used here.

TABLE 1. Calibration data for seven data sets of three ES-400 and one EK-500 transducer, mounted on four different research vessels. Estimates of the five parameters in the function, with corresponding 95% confidence intervals are given, together with sphere type, temperature / salinity during the calibration.

VESSEL	TDCER	SPHERE	t/S%	Φ_A	Φ_B	$\Delta\alpha$	$\Delta\beta$	E	N
ELDJARN	ES-400	CU60	8/34	3.57 3.55/3.58	3.70 3.68/3.72	0.11 .093/.120	0.06 .039/.075	1.09 1.07/1.10	899
G.O.SARS	ES-400	CU60	5/34	3.59 3.57/3.61	3.41 3.40/3.42	0.07 .061/.086	-0.12 -.127/-.109	1.03 1.03/1.04	1669
MILLER FREEMAN	EK-500	CU60	10/33	3.40 3.39/3.41	3.48 3.47/3.49	-0.25 -.26/-.25	-0.03 -.04/.02	1.00 .99/1.01	1396
PASQUALE	ES-400	TC38	10/0	3.67 3.65/3.69	3.80 3.79/3.81	-0.08 -.09/-.06	0.03 .02/.04	1.15 1.14/1.16	831
PASQUALE	ES-400	TC38	10/0	3.64 3.62/3.66	3.83 3.81/3.85	-0.06 -.08/-.05	0.08 .00/.02	1.16 1.15/1.18	824
PASQUALE	ES-400	TC38	10/0	3.61 3.60/3.62	3.75 3.75/3.77	-0.09 -.09/-.08	0.01 .00/.02	1.10 1.09/1.11	1386

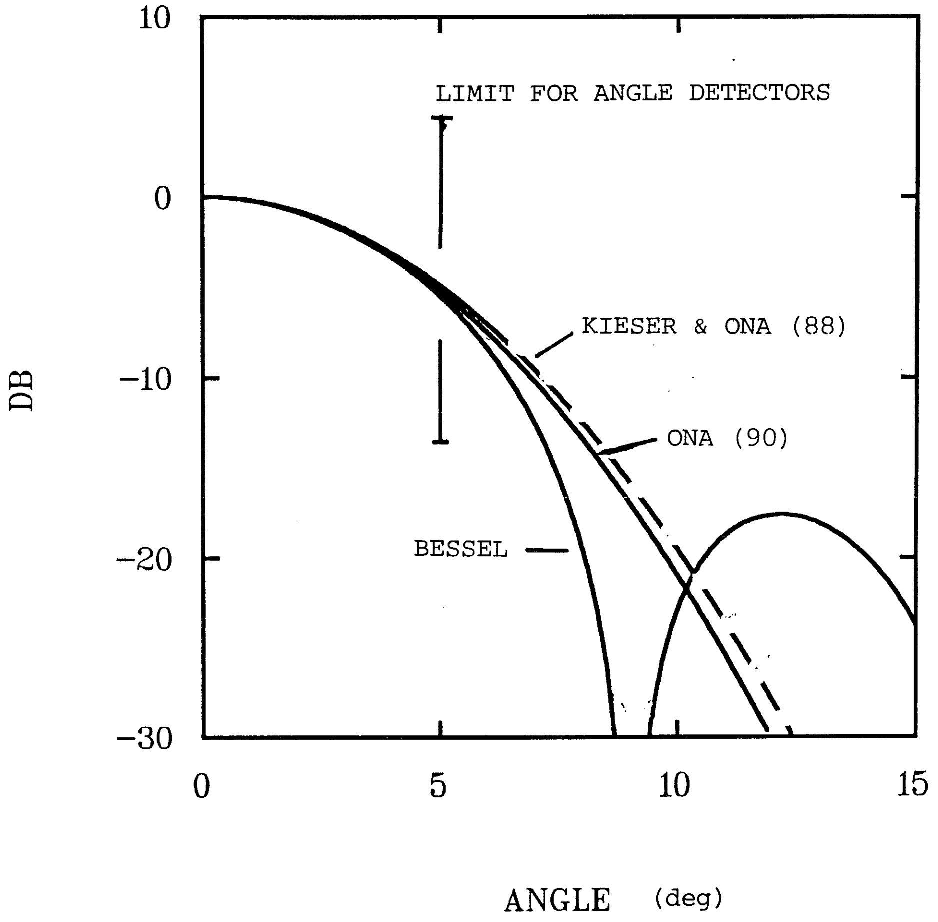

Fig.2. Comparison of the used function with the Kieser & Ona (1988) suggestion, and a standard Bessel directivity. Within the limits of the angle detectors, the three functions are close to identical.

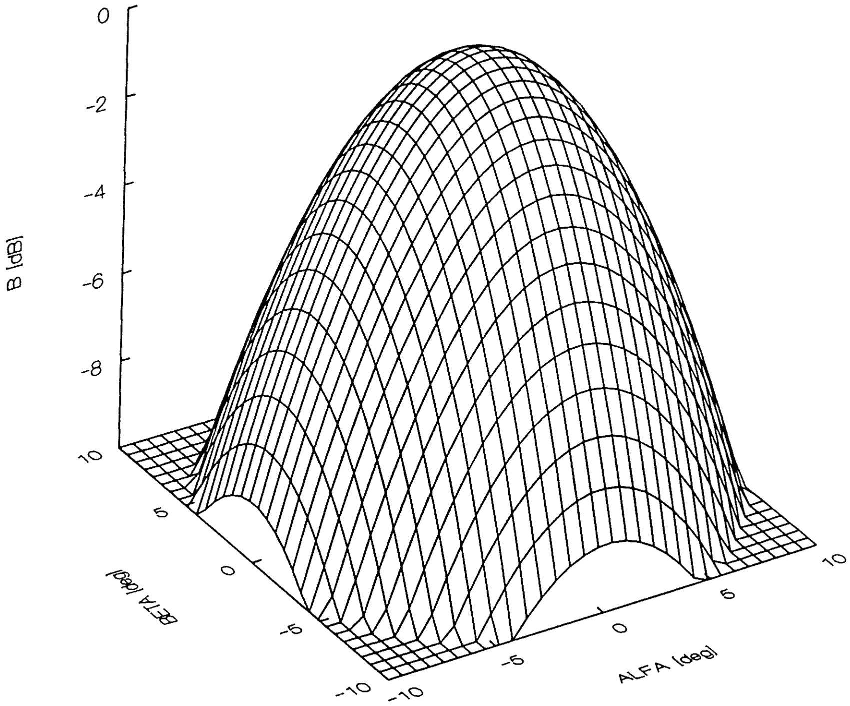

Fig.3. The estimated beam pattern on R/V "Eldjarn", ES-400 transducer.

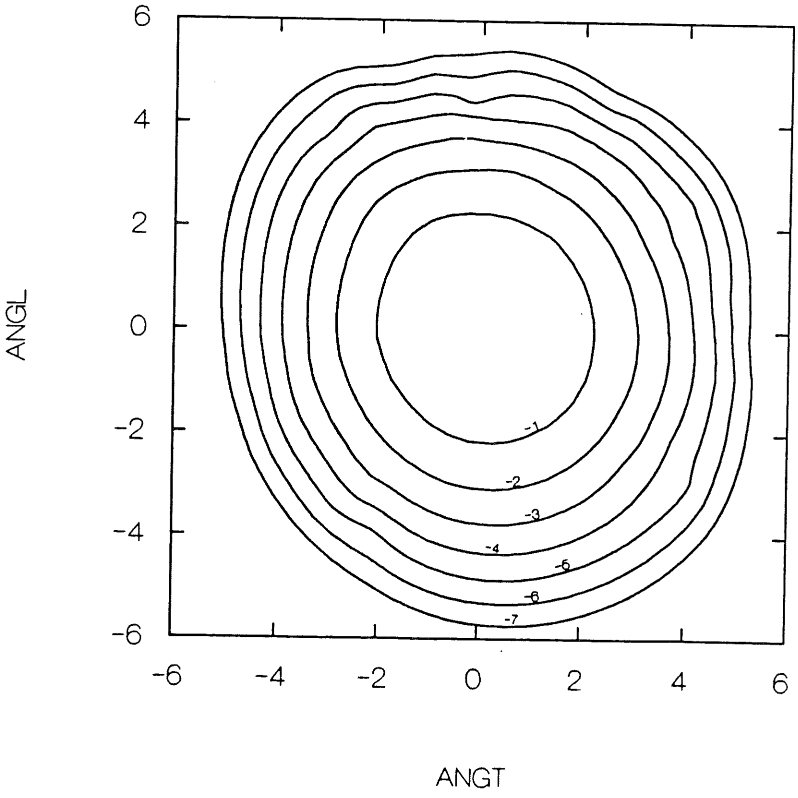

Fig.4. Estimated dB contour lines by the use of distance least square methods.
R/V "Eldjarn", ES-400.

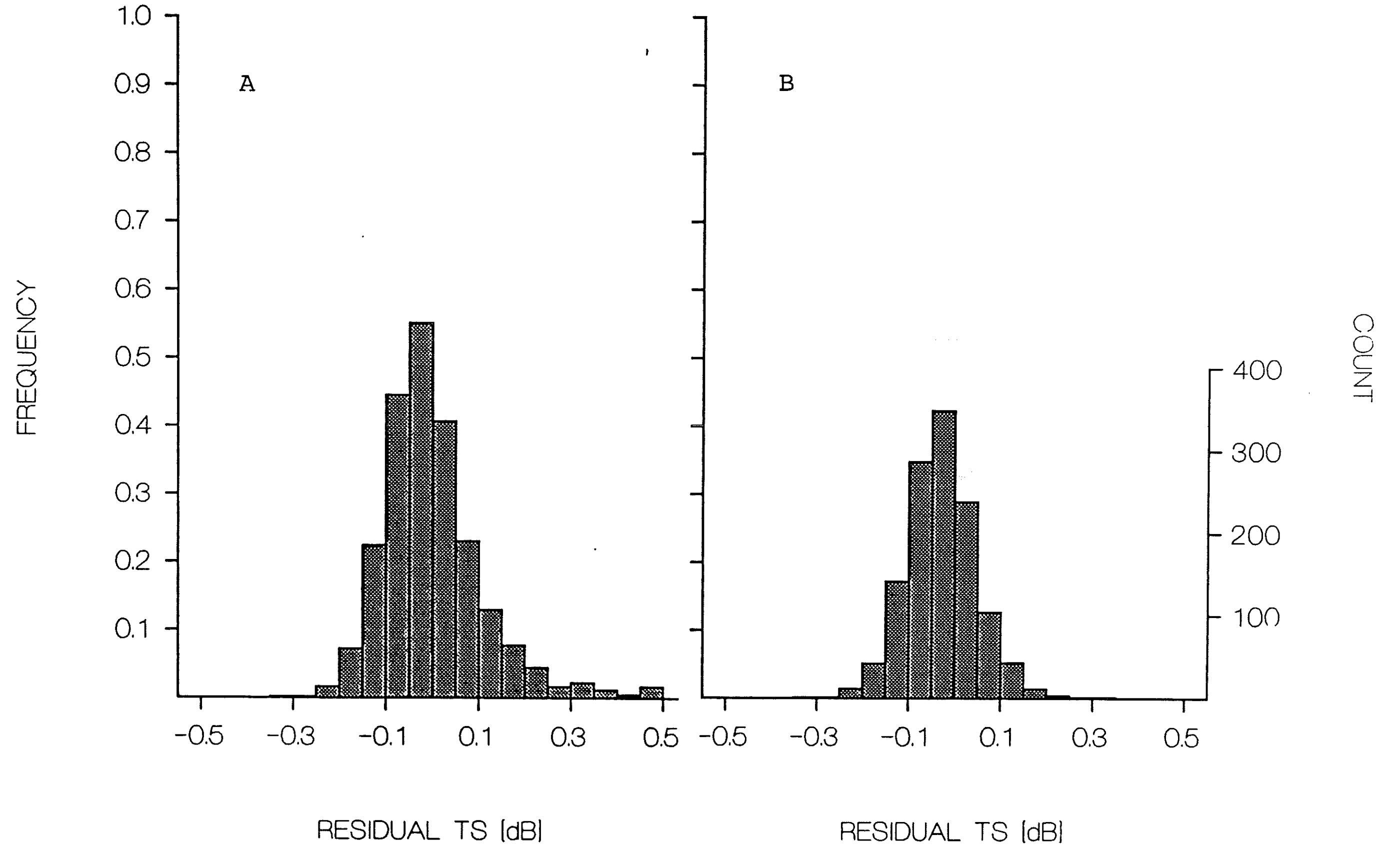

Fig.5. The residual target strength of the calibration sphere after correction. A - full beamwidth within the limits of the angle detectors, B-- Within the half power points of the beam.

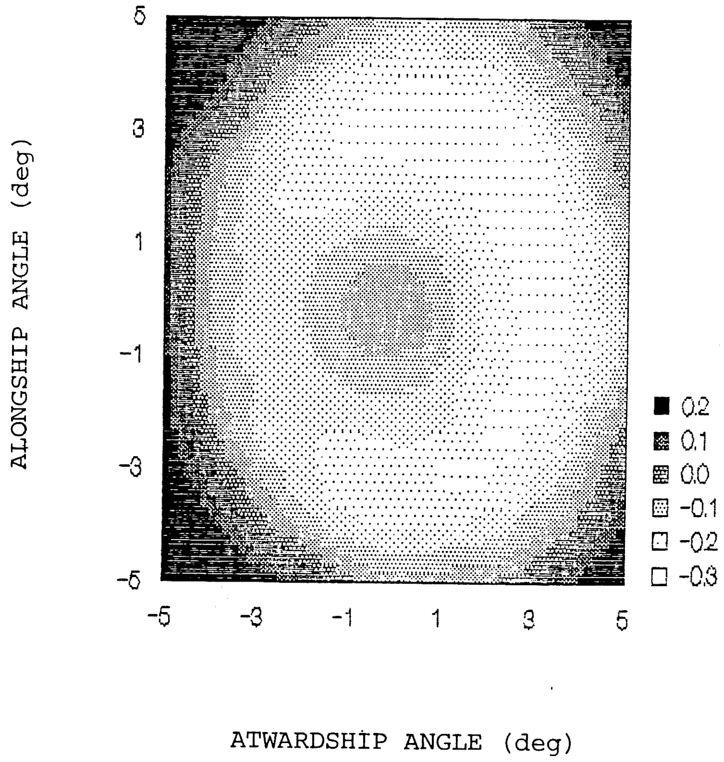

Fig.6. Contour plot of the difference between two calibrations on R/V "Pasquale", PASQALE 1 minus PASQUALE 3, table 1, expressing the diffe- between two simple cross sections and a full mapping.