Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE
01 SEP 2003

2. REPORT TYPE
N/A

3. DATES COVERED
-

4. TITLE AND SUBTITLE
Comparing two scientific echo sounders

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Northeast Fisheries Science Center (NOAA/NMFS), 166 Water St., Woods Hole, MA 02543

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002146. Oceans 2003 MTS/IEEE Conference, held in San Diego, California on September 22-26, 2003. U.S. Government or Federal Purpose Rights License

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**3**	

Comparing two scientific echo sounders

[1]J. Michael Jech, [2]Kenneth G. Foote, [1]Dezhang Chu, [1]Stephen P. Liberatore

[1]Northeast Fisheries Science Center (NOAA/NMFS), 166 Water St., Woods Hole, MA 02543
[2]Woods Hole Oceanographic Institution, Woods Hole, MA 20543

***Abstract*-** **The Simrad EK500 and EK60 scientific echo sounders have been operated with the same 38-kHz, 12-deg-beamwidth, split-beam transducer, with alternate pinging by means of an external triggering-and-switching system. The respective performances of the two systems are compared by means of standard-target calibrations conducted at the acoustic calibration facility on Iselin Dock at Woods Hole Oceanographic Institution with a 60-mm-diameter copper sphere. Principal comparisons include those of time series of echo strength and target strength, split-beam-determined angles, and derived measures of directivity.**

I INTRODUCTION

The Simrad** EK500 scientific echo sounder [1] is a standard echo sounder used for fisheries applications throughout the world and has been used to survey a number of fish populations for over a decade. The Simrad EK60 scientific echo sounder is the next-generation system. Maintaining a high-quality time series of density and abundance estimates of marine fisheries is a goal of fisheries managers. The introduction of a new echo sounder system requires that comparisons be made between the current and the new systems and potential differences quantified to evaluate population estimates derived from acoustical measurements.

Calibration of scientific echo sounders is a fundamental component for ensuring high-quality acoustical data [2], [3]. Standard target calibration methods are convenient for measuring system stability and calibrating the echo sounder system to an absolute standard [4], [5]. Because scientific echo sounders are calibrated to an absolute standard, comparisons among echo sounders are straightforward. Calibration parameters include on-axis sensitivity, beam patterns, and beamwidths.

In this paper, on-axis sensitivities and beam pattern measurements using the standard target calibration method are compared between EK500 and EK60 echo sounders operating at 38 kHz.

II METHODS

A companion paper [6] details the experimental design and methodology. We provide a brief description of the methods pertinent to the comparisons here. Acoustic backscatter data were collected with a Simrad EK500 scientific echo sounder [1] and a Simrad EK60 scientific echo sounder operating at 38 kHz during 6-7 January 2003 on the Iselin dock at the Woods Hole Oceanographic Institution. The echo sounders shared the same 38-kHz split-beam transducer, Simrad model number ES38-12, by means of a multiplexing junction box. The beamwidth was 12° (measured by the total angular distance between the half power points). The transducer was mounted looking sideways on a 6-m shaft suspended at a water depth of approximately 3 m. A personal computer (PC) controlled rotation of the transducer [7]. For each rotation increment, the EK500 and EK60 were alternately ‘triggered’ at a rate of 2 pings per second (one ping per second for each echo sounder). Alternate triggering allowed direct comparisons between echo sounders under the same environmental and experimental conditions. Operational parameters for both echo sounders are discussed in [6]

The transducer was mounted facing sideways with the ‘alongship’ axis oriented vertically (positive angles up) and the ‘athwartship’ angles oriented horizontally (positive angles to the right). A 60-mm-diameter copper sphere was used as the standard target [8] and was suspended with a monofilament line in the acoustic beam. The sphere was placed at a range of approximately 11.5 m from the transducer. At this range, 20-cm subtends a 1-degree arc. Transducer directivity was measured by rotating the transducer from –15° to +15° in 0.5° increments (a ‘sweep’) and raising and lowering the sphere in 1° increments between sweeps.

Calibration results in [6] suggested that the sphere was aligned with the alongship axis but that an angular offset was present in the athwartship direction. Because of this offset between the split-beam derived (observed) angles and the angles based on experimental geometry between the transducer and sphere (expected angles), the observed angles were adjusted by the offset amount. Slopes and intercepts from linear regressions between the alongship observed and expected angles and between the athwartship observed and expected angles were applied to the measured angles.

$$\begin{aligned} \alpha_{adj} &= M\alpha_{obs} + B \\ \beta_{adj} &= M\beta_{obs} + B \end{aligned} \tag{1}$$

where α is the alongship angle, β is the athwartship angle, and M and B are the slope and intercepts of the linear regressions. An empirically-derived transducer directivity was computed using these adjusted angles in the polynomial [6]

$$TS_{comp}(\alpha,\beta) = TS_{const} + c_0\alpha_{adj} + c_1\alpha_{adj}^2 + c_2\beta_{adj} + c_3\beta_{adj}^2 \tag{2}$$

where TS_{const} is the overall echo strength compensation value and c_0, c_1, c_2, and c_3 are the empirically derived coefficients. The empirical transducer beam pattern was then compared to the theoretical beam pattern (equation (1) in [6]).

An index of the inconsistency between the expected, observed, and adjusted transducer directivity responses was defined as the mean difference per each 1-degree off-axis interval. Mean beam pattern differences ($\overline{\Delta}(\gamma)$) within specified angular intervals were computed by

$$\gamma = \sqrt{\alpha^2 + \beta^2}\ , \tag{3}$$

** Any use of trade names does not imply endorsement by NOAA.

$$\overline{\Delta}(\gamma) = 10\log_{10}\left(\left\langle 10^{\left(|\Delta(\alpha,\beta)|/10\right)}\right\rangle\right), \qquad (4)$$

where γ is the angular distance between the axis and the target location, $\langle\ \rangle$ denotes an arithmetic mean, and $||$ denotes the absolute value. $\overline{\Delta}(\gamma)$ was calculated for 1-degree angle increments ($0^o \leq r < 1^o$, $1^o \leq r < 2^o$, $2^o \leq r < 3^o, \ldots, 5^o \leq r < 6^o$). The absolute value of the difference was computed to determine the magnitude of the discrepancies.

III RESULTS AND DISCUSSION

On-axis Comparisons

One thousand echo time series were collected for each echo sounder with the 60-mm copper sphere positioned on-axis of the EK500 and EK60. While mean target strengths were similar, target strength distributions differed between the EK500 and EK60 (right panels, Figure 1). Both split-beam target strength distributions were unimodal; however, the EK500 target strength distribution was narrower (~1.5 dB total range) with greater than 70% of the target strengths within ±0.2 dB of the mean, whereas the EK60 target strength distribution was skewed towards target strengths greater than the mean, had a wider range (~3 dB), and only 55% of the target strengths were within ±0.2 dB of the mean.

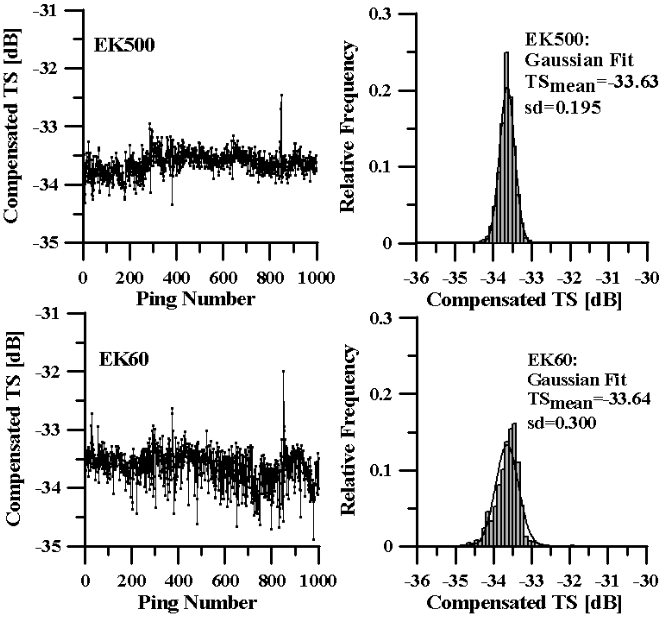

Figure 1. Time series (left panels) and split-beam target strength distributions (right panels) of on-axis echo amplitude measurements of a 60-mm-diameter copper sphere for the EK500 and EK60. Ping rate was 1 ping s^{-1} per echo sounder and 1000 pings represents approximately 17 minutes. Echo strength measurements were compensated for location in the acoustic beam to give split-beam target strengths. Mean split-beam target strength (TS) and standard deviation (sd) are derived from the Gaussian fit to the data [6].

A one-hundred-ping subset of the time series was arbitrarily chosen to investigate consistency in target strength measurements between the EK500 and EK60 (Fig. 2). A general pattern of coherence does not appear to exist in target strength measurements between the two echo sounders. For example, a slight increase is observed between pings 560 and 580 on the EK500 and EK60; however, the decrease observed in the EK60 target strengths between pings 580 and 600 is not observed in the EK500 measurements.

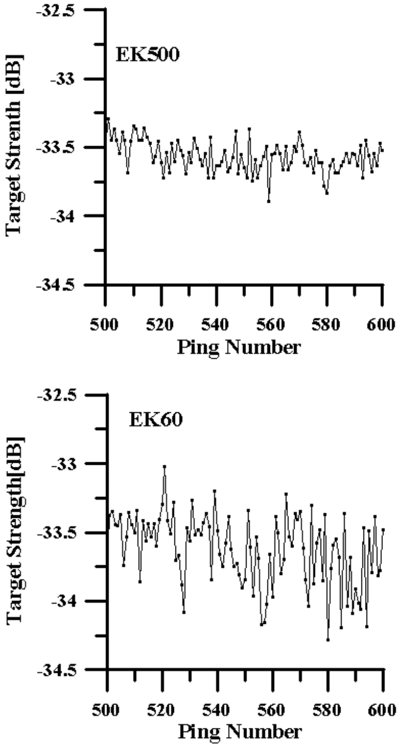

Figure 2. Pings 500-600 of the 60 mm copper sphere time series in Fig. 1. Echo strengths were compensated for location in the beam.

Beamwidth Comparisons

Beamwidths of the observed EK500 and EK60 beam patterns were compared to the manufacturers stated beamwidth of 12^o. The beamwidth was measured as the total angular distance between the 3 dB ‘down-points’ of the beam pattern. Although beamwidths were similar between the EK500 and EK60, the athwartship beamwidths for the EK60 and EK500 were closer to the specified 12^o than were alongship beamwidths (Table 1). Athwartship beamwidths were within 0.2^o whereas alongship beamwidths were off by 0.6^o.

Table 1. Beamwidths (degrees) of the EK500 and EK60 observed beam patterns. TS_{const} is derived from equation (2).

	EK500	EK60
Alongship beamwidth	11.4	11.4
Athwartship beamwidth	12.0	12.2
TS_{const}	-33.6	-33.5

The polynomial constant in equation 2 (TS_{const}) is the on-axis echo strength compensation (0^o alongship and 0^o athwartship) value. TS_{const} sets the overall compensation level for echo strength measurements. Differences between TS_{const} and the calibrated on-axis sensitivity may affect the accuracy of split-beam-compensated target strengths. The TS_{const} value for the EK500 was within 0.05 dB of the theoretical target strength of the 60-mm copper calibration sphere (-33.6 dB). However, the TS_{const} for the EK60 was 0.1 dB greater than the theoretical value.

Beam pattern Comparisons

The observed split-beam angles were adjusted using equation (2) with the slope and intercepts derived from the linear regressions of the expected and observed alongship and athwartship angles (Table 2). The mean of the absolute differences between the expected, observed, and adjusted beam patterns were computed using equation (4). Figure 3 displays the mean of the magnitudes of the differences between the expected and observed beam patterns and between the expected and adjusted beam patterns for the EK500 and EK60, respectively. The mean difference was computed for each 1-degree interval.

Table 2. Slopes and intercepts of the linear regressions between the expected and observed alongship and athwartship angles for the EK500 and EK60.

	EK500	EK60
Alongship		
Slope	1.061	1.080
Intercept	0.114	0.060
Athwartship		
Slope	1.017	1.018
Intercept	-0.860	-0.868

The mean of the absolute differences between expected and observed or adjusted beam patterns increased with angular distance off-axis (Fig. 3). Mean absolute differences were greater for the expected versus observed beam patterns than for the expected versus adjusted beam patterns. The intercept of the expected versus observed beam patterns is a result of the athwartship angular offset. The difference between the expected and the observed beam patterns ranged from 0.3 to 1.6 dB for both the EK60 and EK500. Adjusting the beam pattern for the athwartship and alongship offsets decreased the mean differences, as the differences between the expected and the adjusted beam patterns ranged from near 0 to 0.3 dB.

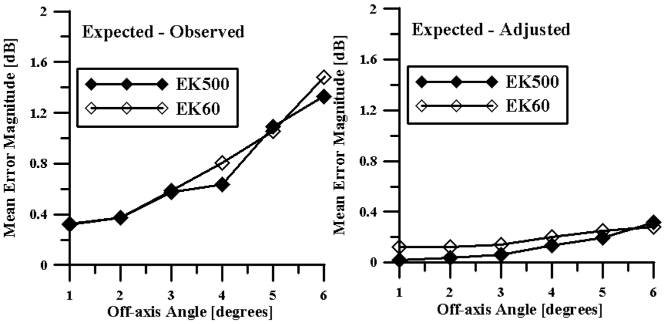

Figure 3. Mean of the absolute error [dB] between the expected and observed compensated target strengths (left panel) and the expected and the compensated target strengths using adjusted angles (right panel) for the EK500 (solid diamonds) and the EK60 (open diamonds). The mean error was computed at 1-degree off-axis angle increments (i.e., ‘1’ is the mean error between 0 and 1-degree off-axis).

An interesting result is that adjusting the EK60 beam pattern did not completely remove the error between 0- and 1-degrees, as the adjustments did for the EK500. This may be due to the error in the TS_{const} value for the EK60 (Table 1), and potentially due to the skewed target strength distribution (Fig. 1). The TS distribution for the EK500 is unimodal and has a Gaussian shape, whereas the TS distribution for the EK60, which is also unimodal, is skewed towards higher TS values. This skewed distribution may affect calculations of the empirical beam pattern and ultimately degrade the ability to compensate single-target echo strength measurements for location in the beam.

ACKNOWLEDGEMENTS

The work supported by National Science Foundation, Grant No. OCE-0002664. This is Woods Hole Oceanographic Institution contribution number 10985.

REFERENCES

[1] Bodholt, H., N. Nes, and H. Solli. 1989. A new echo sounder system. Proc. Inst. of Acoustics. 11(3): 123-130.

[2] Foote, K.G., H.P. Knudsen, G. Vestnes, D.N. MacLennan, and E.J. Simmonds. 1987. Calibration of acoustic instruments for fish density estimation: A practical guide. ICES Coop. Res. Rep. 44.

[3] MacLennan, D. N. 1990. Acoustical measurement of fish abundance. J. Acoust. Soc. Am. 87(1): 1-15.

[4] Foote, K.G. 1983. Maintaining precision calibrations with optimal spheres. J. Acoust. Soc. Am. 73: 1054-1063.

[5] Foote, K.G. 2001. Calibrating a narrowband 18 kHz sonar. *Oceans 2001 MTS/IEEE Conference Proceedings*, vol. 4, pp. 2503-2505.

[6] Jech, J.M., D. Chu, K.G. Foote, T.R. Hammar, and L.C. Hufnagle, Jr. Calibrating two scientific echo sounders. *Oceans 2003 MTS/IEEE Conference Proceedings*. (these proceedings).

[7] Doherty, K.W., T.R. Hammar, and K.G. Foote. 2002. Transducer mounting and rotating system for calibrating sonars in a sea well. *Oceans 2002 MTS/IEEE Conference Proceedings*, pp. 1407-1410.

[8] Foote, K.G. 1982. Optimizing copper spheres for precision calibration of hydroacoustic equipment. J. Acoust. Soc. Am. 71(3): 742-747.