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ACOUSTIC SYSTEMS FOR SURVEYING FISH STOCKS

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1. INTRODUCTION

There is a need for accurate estimation of fish stocks throughout the world. Sampling by means of trawl survey backed up by statistics of fish landed in the commercial markets provides the main information on stocks at present.

A rapid acoustic survey method is needed which will give the extent and density of shoals in addition to the size and numbers of fish. To do this with minimum effort, equipment is required which will discriminate and count individual fish of different size groups at varying depths and give estimates of shoal density. Data must be readily available in a simple form but also recorded for further processing. It is therefore necessary to work with short pulse lengths to give good range resolution for the best vertical discrimination of fish targets, and also to use a transducer of known beam pattern, sensitivity and source level to make volumetric analyses of surveys. To give a good signal-to-noise ratio and to overcome range attenuation, high-powered transmitters are used. The received signals are standardized by time-varied gain amplifiers.

2. METHODS

To achieve all functions we use two systems:

(a) a 30 kHz (λ = 5 cm, pulse length 500 μs) equipment giving a range capability for single fish echoes of up to 600 m;

(b) two 100 kHz (λ = 1.5 cm, pulse length 100 μs) equipments, to obtain greater range resolution, as follows:

  (i) a short range system with hull-mounted transducers,

  (ii) a high-powered equipment with a narrow beam transducer mounted in a towed body.

Time-varied gain receivers are used to compensate for the spreading and absorption loss in acoustic signal amounting to $(40 \lg R + 2\alpha R)$ dB or $(20 \lg R + \alpha R)$ dB, where R is the range in metres and α is the frequency-dependent coefficient of absorption (Figure 1). The $(40 \lg R + 2\alpha R)$ mode is required when dealing with single fish echoes, whereas the $(20 \lg R + \alpha R)$ mode is used for multiple echoes or scattering layers. The dynamic range of received signals (from about 1 volt to 0.1 μ volts RMS at noise limitation) is compressed to 40 dB, which is the anticipated range of variation of target strength of fish (from -20 dB to -60 dB with reference to a 2 m radius sphere). Processing equipment is thus fed from these receivers with range-corrected fish echo signals.

Four parallel signal processing functions are carried out:

(a) discrimination of single fish from shoals by counting the cycles of signal frequency is based on a set number of cycles occurring in the echo; the total cycle counts for single fish and shoals are separately displayed;

(b) integrating separately single and shoal echoes over each nautical mile;

(c) a Simrad Echo Integrator recording of signals per time interval between transmission pulses or the integral of signals after voltage amplitude squaring per nautical mile of ship's track, within independently adjustable range gates, so giving an indication of fish target strengths and density;

(d) pulse height analysis of the maximum amplitude of single fish echo signals received from echo discriminator (a) in adjustable range gates, to give a measure of fish size distribution.

3. TRANSMITTER AND TRANSDUCER SYSTEMS

(a) The 30 kHz transmitter is a standard part of the Kelvin Hughes Humber fish detection system, having an electrical output of 8 kW pulse power with a pulse length of 500 μs. The 6 λ by 4 λ magnetostrictive transducer with a beam angle of $12^{o} \times 8^{o}$ between the 3 dB points is either hull-mounted or carried in a towed body and capable of being towed at survey speeds. The transducer is common to transmission and reception; the source level has been calibrated at 126 dB/μbar/m and the reception sensitivity at -81 dB/V/μbar.

(b) There are two 100 kHz transmitter systems, both designed and built at the Fisheries Laboratory, Lowestoft:

(i) the low-power system consists of a valve transmitter giving an electrical output of 1 kW pulse power with a pulse length of 100 μs. The separate hull-mounted transducers for transmission and reception are identical 75 mm diameter electrostrictive discs, epoxy resin-encapsulated, in phosphor bronze housings. The beam angle is 12^{o} between the 3 dB points and the source level is nominally 115 dB/μbar/m;

(ii) the 100 kHz high-power transmitter consists of untuned valve output and driver stages with an EHT of 6 kV producing 18 kW pulse power and a source level of 133 dB/μbar/m at the transducer. A transistorized oscillator and a tuned power amplifier form the earlier stages. The output and driver stages are gated to give an output pulse of 100 μs duration. The equipment has thermal delay and overload protection circuits incorporated into the power supplies.

The transmitting transducer is an array 60 x 35 cm curved over the longer axis to give a beam angle of $5^{o} \times 3^{o}$; its elements are of an aluminium/ceramic sandwich construction mounted on 11 strips of aluminium which in turn are mounted on an angular stepped bridge, giving a total curvature of 5^{o}. This assembly is housed in a castor oil-filled chamber, which has an epoxy rubber diaphragm, the whole being integral with a towed body which is a bronze casting with fibreglass fairings. The lower fairing has a thin section to improve acoustic transmission. Including the stabilizing tail, the body is 2.5 m long and is about 400 kg in weight. Reception is made on a separate 12^{o} beam angle transducer mounted aft of the transmitting transducer. A preamplifier is mounted in a separate chamber in the towed body, and transmission and reception are on separate cores of a multicore armoured and faired towing cable. The preamplifier consists of a transformer coupled cascode FET tuned amplifier stage with a gain of 12 dB and a dynamic range of 100 dB. It connects via the cable to the receiver.

4. TIME-VARIED GAIN (TVG) RECEIVERS

(a) 30 kHz (Figure 2) The principle of operation of the 30 kHz TVG receiver is that the 800 ms time delay corresponding to 600 m range is divided into 8 approximate binary steps, commencing at 3 m (Figure 2); each of these requires a fixed gain correction of 13 dB for the $(40 \lg R + 2\alpha R)$ dB mode and 7.25 dB for the $(20 \lg R + 2\alpha R)$ dB mode.

The receiver signal path (Figure 3) consists of a low noise cascode FET preamplifier (with overall 20 dB gain) followed by a double tuned filter of 3 kHz bandwidth feeding a high gain wide-band hybrid operational amplifier. The feedback ratio of this amplifier is changed at each TVG step. Next comes an operational transconductance amplifier with gain swept by a linear sawtooth current waveform reset at each step. A further 3 kHz bandpass filter precedes a fixed gain operational amplifier to bring the fish echo signals to a level suitable for driving the processing equipment, i.e. 50 mV to 5 V RMS for single fish at all ranges from 3 to 600 metres.

A Transistor-Transistor-Logic (TTL) circuit generates control voltages necessary for selecting resistors in the feedback loop of the stepped gain amplifier via chopper FET's, and selecting timing resistors via transistor switches in a linear sawtooth generator controlling the swept gain amplifier for each of the 8 steps. The logic circuit is driven by a multivibrator clock, the whole divider system being reset/triggered at transmission pulse time.

(b) 100 kHz A receiver with an approximate ramp gain correction has been used for short ranges. A long-range system with accurate TVG correction is at present under development. Figure 1 shows that an extra 30 dB correction is required at 600 m for the 100 kHz system, which renders the present design unsuitable owing to dynamic range limitation.

5. SIGNAL PROCESSING (Figure 4)

The signal processing equipment analyses within one range gate, sorting signals into single and shoal echoes and counting and integrating them separately. A pulse height analyser records the peak amplitude of single echoes. Data are recorded by a 16 channel logger every nautical mile.

Standardized signals from the receiver are passed through a linear gate having an on/off ratio of 50 dB. The gate opens at the end of the start timer period and remains open for the duration of the width timer. Both timers have ranges up to 100 m with a resolution of 0.1 m.

A comparator squares and limits signals above the threshold setting, which is chosen by monitoring the input and output of the comparator. The threshold is adjusted until noise signals are rejected.

The single fish shoal discriminator analyses each echo and, on the basis of pulse length, i.e. the number of cycles within the echo, sorts the echoes into singles and shoals. The number of cycles, N, that makes up a shoal is adjustable from 8 to 28, so that the equipment may be used with either 30 kHz or 100 kHz signals. Bandwidth limitations in the present transducers and receivers limit N to around twice the number of cycles transmitted, i.e. to 20 for 100 kHz operation and to 28 for 30 kHz use.

Two 7-digit counters, with 7-segment displays, count the cycles of single and shoal echoes, the 5 most significant digits of each being available for data-logging. The shoal cycle counter may be switched to count the number of single echoes, and thus the average number of cycles per single echo can be calculated.

An echo integrator receives gated signals from a rectifier of wide dynamic range, which is clamped between echoes to avoid errors due to noise. This echo integrator has a time constant such that normally it will not saturate, but signal overload is indicated. The echo integral is gated into either the single or the shoal mile integrator, both of which sum the integrals for a period of one nautical mile, 6 minutes at normal survey speed.

A pulse height analyser is used to record the peak amplitude of single echoes for the measurement of fish target strengths and their distributions. To achieve this the gated rectified signals are fed to a peak detector circuit and then to the signal input of the analyser. This is commanded by the single fish/shoal discriminator to sample only the single targets.

A 16-channel, 5 digits per channel, data logger records the information on both punched tape and a strip printer. All integrators and counters are reset at the end of each print-out. A digital voltmeter in the logger can be used to monitor threshold and integral voltages.

6. CALIBRATION OF EQUIPMENT

Towed transducers can be readily calibrated at anchor in calm conditions by mounting them in a specially designed frame and using standard hydrophones to measure source level and receiver sensitivity. The source level of the 30 kHz towed body can be readily measured using a hydrophone at the end of the frame on the transducer axis, but the 100 kHz narrow beam towed body with its extended near field requires slightly greater separation. Calibration using a standard target is also made and used as a check whilst on survey.

7. SURVEY RESULTS FROM RV CIROLANA, CRUISE 1a/73

Two surveys were carried out in Lyme Bay on 5 and 6 January respectively to test standard 100 kHz equipment and signal processing gear.

Survey 1

A grid with 8 x 2 mile legs was followed with the gate set to start at a depth of 2.5 metres. The gate width was changed at each leg to compensate for the bottom depth changes.

Volts per 10^6 m^3 swept volume were calculated for each mile and plotted at the mean point of each mile. No correction was made for actual ground covered and thus there are errors in the volumes sampled per mile.

Figure 5 shows the voltage contour plots obtained, which are a measure of the relative density of the fish in the area covered. (At the completion of the cruise it was learned that commercial operators had been working in the area prior to the survey and had made large catches of sprat within the contour of highest voltages.)

Survey 2

A grid with 4 x 1 mile legs was followed covering the denser areas of Survey 1. The volts per 10^6 m^3 for each mile are plotted in Figure 6.

Pulse height analyses

The pulse height analyser was used to display the signal voltage distribution obtained from single echoes.

To obtain samples of fish being analysed, a Granton trawl and an Engels midwater trawl were shot on separate occasions. The gate depth and width were set to approximate to the depth and width of the respective net gapes, and the PHA was used to analyse the single echoes.

Figures 7 and 8 show the fish length distributions of the Granton and Engels trawl hauls respectively. The insets on each figure are copies of the PHA display. The signal voltage distributions are similar to the fish length distributions.

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