SHORT COMMUNICATION

SARSIA

A TEMPERATURE-SENSITIVE ACOUSTIC TRANSMITTER FOR REMOTE MONITORING OF STOMACH TEMPERATURE IN AQUATIC ENDOTHERMS

TRINE BEKKBY & BÅRD HOLAND

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A temperature-sensitive acoustic transmitter was developed to record and store stomach temperature. The equipment was used to quantify meal sizes in captive animals and to monitor stomach temperature changes in captive animals as a result of intake of food, snow, ice and seawater. The equipment has also been used to time food ingestion in free-ranging animals. The transmitter consists of the electronic circuit, a thermal sensor, an electro-acoustic transducer, a battery and the encapsulation. The time between the transmitter pulses is a function of the surrounding temperature of the transmitter.

Trine Bekkby, Norwegian Institute for Nature Research. P.O. Box 736, N-0105 Oslo, Norway. E-mail: trbekkby@bio.uio.no – Bård Holand, SINTEF, UNIMED, Olav Kyrresgt. 3, N-7034 Trondheim, Norway. E-mail: bard.holand@unimed.sintef.no

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INTRODUCTION

Different technologies have frequently been used to examine movement (e.g. JOUVENTIN & WEIMERSKIRCH 1990; WILSON & al. 1991), activity (e.g. PONGANIS & al. 1991; THOMPSON & al. 1991) and prey consumption (e.g. WILSON 1984) in aquatic endotherms. To gain further information on foraging activity, WILSON and co-workers (WILSON & al. 1992) developed a unit to record and store stomach temperature using temperature-sensitive acoustic transmitters. The equipment was built and tested in the laboratory simulating endotherm stomachs, then tested on captive African penguins (*Spheniscus demersus* L.) and free-living wandering albatrosses (*Diomedea exulans* L.). Acoustic transmitters have been used on captive harp seals (*Phoca groenlandica)* by GALES & RENOUF (1993) to obtain information on stomach temperature changes as a result of intake of food, snow, ice and seawater. They have also provided information on timing of food ingestion in free-ranging harbour seals (*Phoca vitulina*) along the Norwegian coast (BJØRGE & al. 1995) and in Steller sea lions (*Eumetopias jubatus*) in Alaska (ANDREWS & CALKINS 1995). HEDD & al. (1996) used stomach temperature to differentiate between prey and water (free and frozen) consumption. Stomach temperature has also been used to quantify meal size in captive harbour seals (BEKKBY & BJØRGE in prep.). WILSON & al. (1995) describes the reliability of the stomach temperature changes in determining feeding activity.

This note describes the technology of the temperature-sensitive acoustic transmitters used in free-ranging (BJØRGE & al. 1995) and captive (BEKKBY & BJØRGE in prep.) harbour seals.

THE TRANSMITTER

The transmitter consists of 5 main parts: electronic circuit, thermal sensor, electro-acoustic transducer, battery, encapsulation.

The electronic circuit

The electronic circuit consists of a carrier frequency oscillator, a pulse generator, where the pulse rate is a function of the surrounding temperature, and an amplifier that provides the output signals to the electro-acoustic transducer (Fig. 1, see ‘Functional description’).

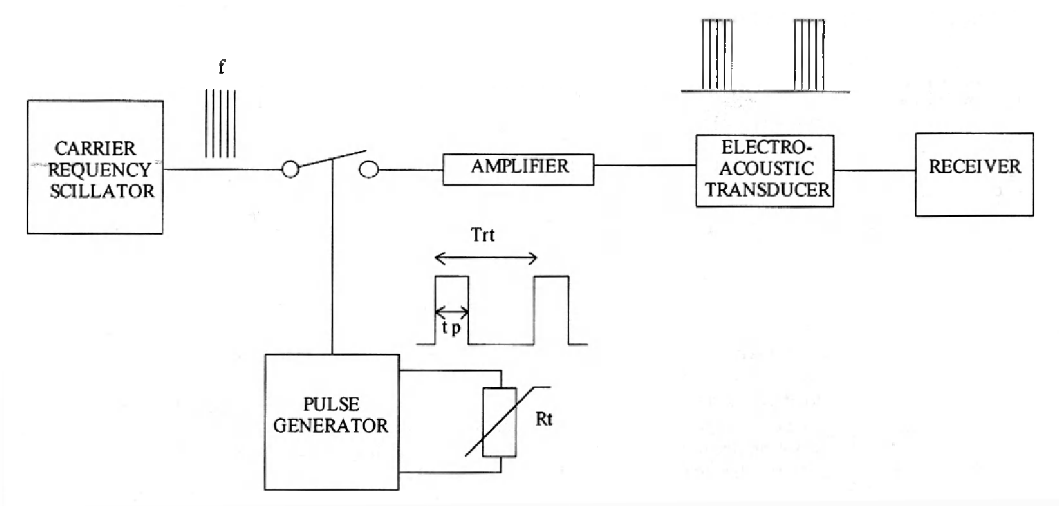

Fig. 1. A functional outline of the temperature-sensitive transmitter. The acoustic pulses leaving the transducer have a pulse width (tp) determined by the pulse generator. The frequency (f) is fixed by the carrier frequency oscillator and the temperature relative pulse period (Trt) controlled by the thermistor (Rt). The amplifier provides the output signals to the electro-acoustic transducer.

The thermal sensor

The thermal sensor is a thermistor type (Fenwal Electronics GA72J2). This is a small 'bead thermistor' (diameter < 1 mm), the size not limiting the time used to respond to a surrounding temperature change. The thermistor is positioned close to the end surface (< 0.5 mm below it) of the transmitter in order to reduce the time taken to respond to a temperature change due to the encapsulation. The thermistor may also be positioned just outside the transmitter.

The electro-acoustic transducer

The transducer is a piezoceramic cylinder (Pz 27) made by Ferroperm, Denmark. The dimensions are: 12.7 mm (outer diameter), 11.1 mm (inner diameter) and 10 mm (length). Resonance frequency (hoop mode) is approximately 80 kHz.

The battery

The electronic circuit requires a supply voltage of approximately 5 V. The battery used by Bekkby & Bjørge (in prep.) and Bjørge and co-workers (Bjørge & al. 1995) was a 5.4 V mercury battery (VARTA, 4MR9, Capacity: 450 mAh).

The encapsulation

The transmitter casting material is produced by CIBA-GEIGY, and consists of Araldite D resin and HY 2967 Hardener (10 : 3.5). The transmitter may be totally cast in Araldite, or, if the transmitter is recovered after use (e.g. under laboratory conditions), there may be a separate watertight compartment for the battery.

FUNCTIONAL DESCRIPTION

The components and function of the transmitter are outlined in Fig. 1. The carrier oscillator has a fixed frequency (f), normally between 80 and 100 kHz. The carrier oscillator is modulated by the pulse generator. The 'on' pulse from the generator is normally fixed to a width (tp) of 10-20 ms, and the time between pulses (Pulse period, Trt) is controlled by the thermistor (Rt). The pulse period is a function of the electrical resistance of the thermal sensor, and thus a function of the surrounding temperature of the transmitter. Carrier pulses are amplified and then transmitted 0.5-2 times per sec into the water via an electro-acoustic transducer. These pulses are detected with a VEMCO VR60 Ultrasonic receiver and hydrophone. The transmitter range is 200-300 m.

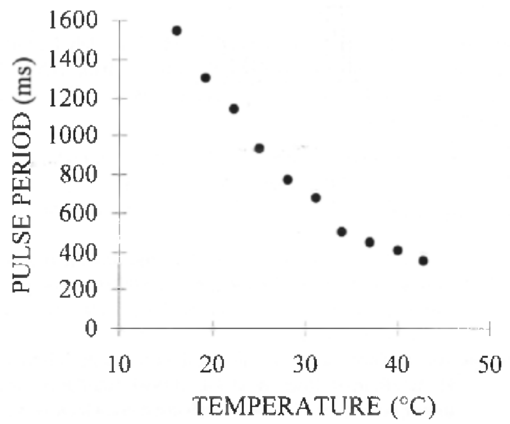

Fig. 2. The relationship between pulse period (time between pulses) and the surrounding temperature, for a calibration carried out in a waterbath in the laboratory.

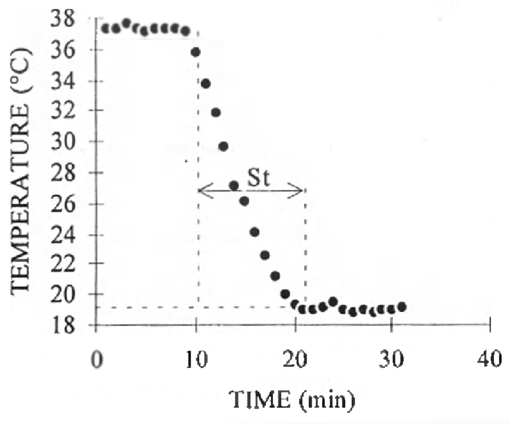

Fig. 3. The temperature response of a transmitter exposed to cold water (approximately 19° C) from a stable warm situation (approximately 37° C) in a waterbath. St is the time from the first response to the temperature change until the pulse period (time between pulses) is again stable.

Each transmitter has to be calibrated prior to use, providing a relationship between pulse period and surrounding temperature as shown in Fig 2. The receiver transforms the pulse period into temperatures and stores them together with date and time. The calibration lines for pulse periods against temperature are curved, and transformation in necessary to edit the equations into the receiver. Back calculations are therefore necessary to obtain true temperature values after collecting data.

Test transmitters (n = 7) responded immediately (< 1 sec) to a temperature change in a waterbath. All temperature measurements and transmitter calibrations were carried out in a Meto AT 110 laboratory waterbath using a mercury thermometer (produced by Corning ltd, UK) with an accuracy of 0.1° C. Fig. 3 shows an example of the recorded time response of a transmitter being exposed to 19° C water after being stabilised at 37° C. The average temperature prior to the temperature change was calculated in each calibration series. St (the stabilising time) is the time taken from the temperature change until the pulse period again stabilised at the new temperature. The temperature was considered stable when the temperature value differed less than 3 ‰ from the previous temperature value. The temperature drop was defined as the difference between the average temperature prior to the temperature change and the first stabilised temperature value.

A difference in temperature change responses for transmitters with externally and internally placed thermistors was tested. The difference in stabilising time between the two types of transmitters was significant ($p = 0.016$). In the transmitters with an internal thermistor (n = 3, Bekkby & Bjørge in prep.; Bjørge & al. 1995), the stabilising time (± SD) was 9.94 (± 1.79) min. The transmitters with externally placed thermistors (n = 4) had a stabilising time of 5.92 (± 1.25) min. All analyses was carried out in StatView, Version 4.5, and accepted a 5 % error due to chance. A further reduction in stabilising time might be possible if the resin surrounding the thermistor is further reduced.

The use of the transmitters to measure stomach temperature changes is affected by the transmitter response time as well as the position of the thermal sensor. In a stomach temperature change due to food/water ingestion, the measured temperature drop, the time used to reach minimum stomach temperature, and all operation values including these values will be strongly affected by the response time and the sensor position. The time used by the stomach to regain original temperature might be a better estimate of stomach temperature changes (Bekkby & Bjørge in prep).

There was no significant difference between the log transformed calibration lines based on one way temperature changes (n = 10). In all but one tag (n = 10) there was a significant difference ($p < 0.05$) between the calibration lines based on increasing temperature calibrations and the ones based on decreasing temperature calibrations. This implies that calibration both ways is necessary when calibrating the tags, and that the data recovered when using the equipment on animals is based on this common calibration line.

Both types of transmitters ($n_{intern} = 2$, $n_{extern} = 2$) provided stable temperature data when tested at a constant temperature. The standard error was ≤ 0.06 and there was no significant difference in variability between the two transmitter groups.

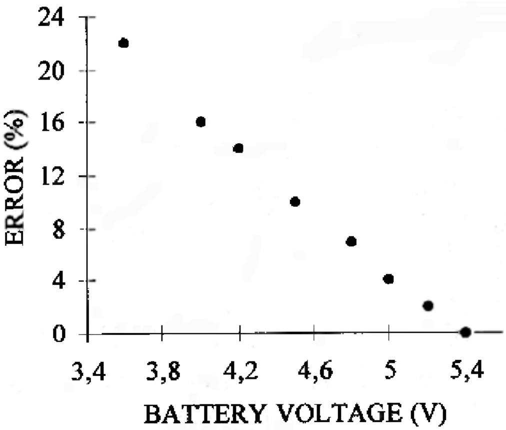

Fig. 4. The error (%) in the temperature measured as the battery voltage drops during discharge. These are laboratory measurements on one transmitter. 5.4 V is chosen as the reference voltage, meaning that the curve shows the error expected if the transmitter is calibrated at a battery voltage of 5.4 V.

Normally, the transmitter battery voltage is 5.4 V. An error may occur as an effect of battery voltage drops on the pulse generator. Fig. 4 shows the error (%) in the temperature measured as the battery voltage drops during discharge. These are laboratory measurements on one of the transmitters. 5.4 V is chosen as the reference voltage, i.e. the figure shows the error one may expect if the transmitter is initially calibrated at a battery voltage of 5.4 V. As a mercury battery generally has a very stable voltage during normal discharge, the expected error due to voltage variations is probably less than 2 % during approximately 80 % of the battery life time.

TECHNICAL SPECIFICATIONS OF THE TRANSMITTER

Size: Length: 76 mm. Outer diameter: 22 mm.
Weight: Including battery (VARTA, 4MR9): 51 g (in air).
Battery life: VARTA, 4MR9: Temperature dependent. At 37° C: typical 20 days.
Source level: 145-150 dB re 1 µPa.
Carrier frequency: Higher than 75 kHz (typical 80-100 kHz).

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