DEVELOPMENT OF A NEW RESPIRATION RATE MONITOR FOR CATTLE

R. A. Eigenberg, G. L. Hahn, J. A. Nienaber, T. M. Brown-Brandl, D. E. Spiers

ABSTRACT. *Studies were conducted investigating bioenergetic responses of growing cattle to heat challenges using respiration rate as one of the primary measures. Respiration rate (RR) was measured using monitors designed from commercially available thin-film pressure sensors and a small battery powered micro-computer. The monitors were designed, fabricated, and tested to provide continuous records as a basis for evaluating stress responses associated with environmental conditions. This article provides details about the monitors and the suitability of obtained records as an indicator of stress, based on measures obtained in environmental chambers during constant and simulated heat wave conditions as well as a field study. Representative data from two laboratory studies indicated an association of RR and ambient temperature ($P < 0.01$) with diurnal changes being evident in the cyclic test and step changes being evident in the constant ambient temperature tests. A two to three breaths per minute (BPM) rate of change of RR with respect to ambient temperature (°C) was observed for steers in the laboratory studies. The field study revealed a striking response of RR to the ambient temperature (6.6 BPM/°C rate of change) for a steer that had direct solar load (no-shade) compared to a 1.6 BPM/°C rate of change in the shade.*

Keywords. *Bioenergetics, Respiration rate monitor, Transducer, Microcomputer, Environmental stress.*

Respiratory heat transfer is a significant pathway of heat loss for most mammals (homeotherms) under a wide range of environmental conditions (Ingram and Mount, 1975). Respiration rate (RR) provides an easily observed measure of an animal's thermal state and can be a valuable physiological parameter in conjunction with additional information, such as ambient temperature (T_a), humidity, radiation heat loads (Garrett et al., 1967; Hahn, 1976), and air velocity (Monteith, 1973). Physiological responses of cattle have been studied intensively and RR has been shown to behave predictably, increasing with rising ambient temperature (Hahn et al., 1997; Morrison and Lofgreen, 1979; Webster, 1973; Kibler and Brody, 1949). However, RR response is non-linear. As T_a increases beyond a threshold, RR increases more rapidly; this threshold occurs near heat stress conditions for cattle (Hahn et al., 1997). An understanding of the RR response for cattle should allow producers to better recognize animal distress and to initiate planned intervention to minimize performance losses and reduce death losses under stressing conditions (Hahn et al., 1997).

While RR is easily observable by traditional means (e.g., using a stopwatch while counting flank movement), long term studies that require frequent measures become tedious and labor intensive. There is also a possibility of observer influence on the animal. Automated RR monitoring is desirable to increase the frequency of measures as an evaluation of response dynamics and to provide a more robust application of time-series techniques; to provide consistent data; and to reduce the labor requirements for data collection. Existing automated RR equipment is quite limited, and unsuitable for large animal applications. A respiratory effort transducer for humans (BIOPAC Systems Inc., 1997) incorporates a thin-film transducer into a silicone rubber strain assembly that changes resistance with changing thoracic or abdominal circumference. Most human applications involve subjects that are cooperative and conscious of the limitations of such monitoring devices. Few devices for free-ranging animals are described in the literature. Data Sciences Intl. (Data Science Int., 1996) has developed a method that provides accurate determination of respiratory rate for free moving rats monitored via implanted telemetry sensors. The technique is patent-pending and is based on changes in cardiovascular data resulting from respiratory effort. The application to larger animals is still not fully developed. Monitoring of cattle respiration has been accomplished using temperature sensors positioned near the nostrils of the animals (Hahn, 1998) but this method has not come into widespread use. Rugged sensors and data logging equipment are needed to provide this response variable.

The purpose of this work was to develop respiration monitors suitable for use on cattle. These units are to measure and store respiration data under various laboratory and field conditions. Testing of these units was done in

Article was submitted for publication in November 1999; reviewed and approved for publication by the Structures & Environment Division of ASAE in February 2000. Presented as ASAE Paper No. 99-4211.

Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

The authors are **Roger A. Eigenberg**, Agricultural Engineer, **G. Leroy Hahn**, ***ASAE Fellow***, Collaborator, **John A. Nienaber**, ***ASAE Member***, Agricultural Engineer, **Tami M. Brown-Brandl**, ***ASAE Member***, Agricultural Engineer, Biological Engineering Research Unit, USDA/ARS U.S. Meat Animal Research Center, Clay Center, Nebraska; **Donald E. Spiers**, ***ASAE Member***, Associate Professor, University of Missouri, Columbia, Missouri. **Corresponding author:** Dr. Roger Eigenberg, USDA/ARS U.S. Meat Animal Research Center, PO Box 166, Clay Center, NE 68933, phone: 402.762.4272, fax: 402.762.4273, e-mail <eigenberg@email.marc.usda.gov>.

laboratory conditions to determine functionality and reliability.

MATERIALS AND METHODS

A respiration monitoring system was designed with three major components: (1) respiration rate sensor and the respiration belt that maintains tension and holds the transducer in place; (2) a data logging device capable of recording the respiration data and transferring it as data files for analysis; and (3) the analysis program that allows the data to be interpreted. Each of the components are described in the sections that follow.

RESPIRATION RATE SENSOR ASSEMBLY

A critical component of a RR monitor is the force transducer. Ruggedness and reliability are key requirements of any transducer used in this application while linearity and low hysteresis are less critical. A UniForce™ surface mount transducer (Force Imaging Technologies, Chicago, Ill.) (fig. 1) was chosen to provide an electrical signal in response to pulmonary effort (rib cage expansion/ contraction). The thin film transducer was constructed with a bottom layer of conducting substrate (typically silver) under a layer of a special pressure sensitive material applied in the sensing area. The transducer acts as a variable resistive element requiring a conditioning circuit (this can be a simple voltage divider) to provide meaningful input to a data logger. Attachment to the sensor assembly is made using the adhesive backing of the transducer. Electrical connection was made via the adhesive electrical contact material of the force transducer which was bonded to two small brass pins providing solder points for wires (fig. 1).

Respiration sensor requirements for cattle include rugged construction, reliable operation and ability to withstand environmental extremes. The RR sensor used in this application was constructed with the force transducer mounted to one of two small acrylic cylinders housed in a pull/pull dual cylinder arrangement (fig. 2). The two plastic cylinders were machined to fit into an outer aluminum tube which provided protection and housing for the mechanical sliding action. The two inner cylinders were free to move within the aluminum tube (fig. 3); any pull on either of the attach points resulted in compression against the transducer element.

The belt held the sensor in place and provided a constant low force tension (approximately one-third of full scale sensor output). The belt must conform to the shape of the animal and be unaffected by precipitation, manure and urine. After several material considerations, a lightweight shock-cord (bungee cord) was chosen for availability, structural integrity, elasticity, durability, ease of use, low cost, and low resistive drag on the animal hide. The mounting method involved using two cords to span the abdominal circumference (fig. 4), with each end of the cord attached to a ring on either side of the sensor.

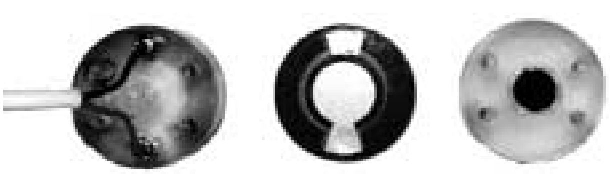

Figure 1–A force transducer (center) (8.9 newton) is attached to an acrylic cylinder (left). A second cylinder (right) acts as a pressure point. Electrical contact is made to brass contacts with conductive adhesive provided on the transducer.

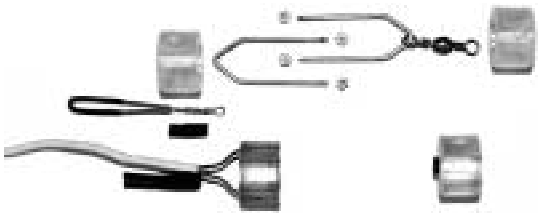

Figure 2–Detail of the two acrylic cylinders with assembly hardware.

Figure 3–The cylinders are free to move in the aluminum tube; any pull of either of the attach points results in compression against the transducer element.

The RR sensor provides relative changes and does not give sufficient signal repeatability to provide total volume measures or amplitude of breath. An altered force transducer and attachment method would be required to accurately assess these measures.

DATA LOGGER

A micro-power small board computer (TFX-11, Onset Computer, 1997) was used as the data collection device (fig. 5). The TFX-11 specifications included a small size (8.1 cm × 5.33 cm × 1.27 cm), 12-bit A/D converter, built in real-time clock, 512 k of EEPROM and an ultra low power mode. These specifications met the requirements for the RR monitor data capture device. The TFX-11 was equipped with 0.1 in. headers for electrical connection to an interface board. The user was responsible for development of the interface board for their application. An interface board was designed based on the prototype unit using a CAD (SuperPCB for Windows™, Mental Automation Inc.) circuit board design program. All communication and analog signals connected to the TFX-11 through the interface board with all signal conditioning and logger power switching handled on the interface board. The complete RR data logging system is shown in figure 6.

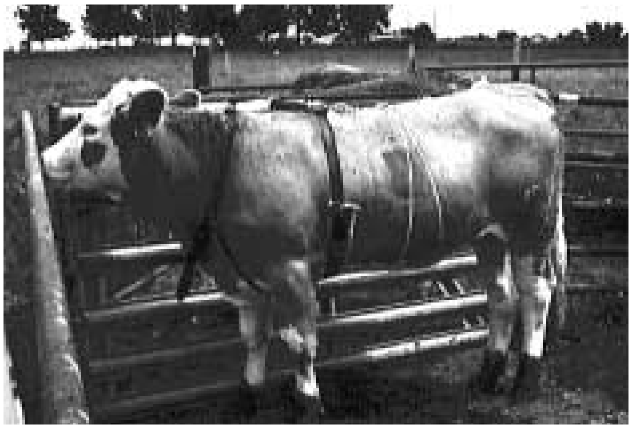

Figure 4–The sensor is held in place on the animal by using two lightweight bungee cords to span the abdominal circumference.

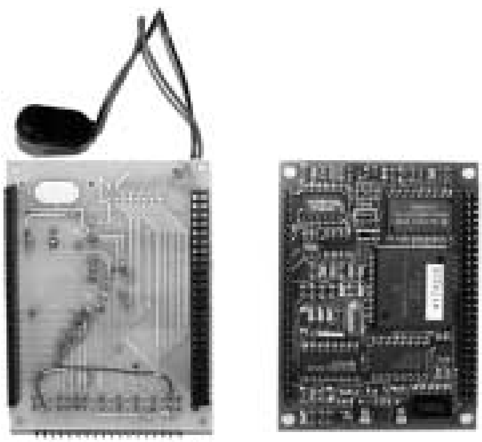

Figure 5–A micro-power small-board computer (right) is used as the data collection device. The interface board (left) provides signal conditioning and power control for the data logging application.

Figure 6–Complete data logging system as used in the studies described in this report.

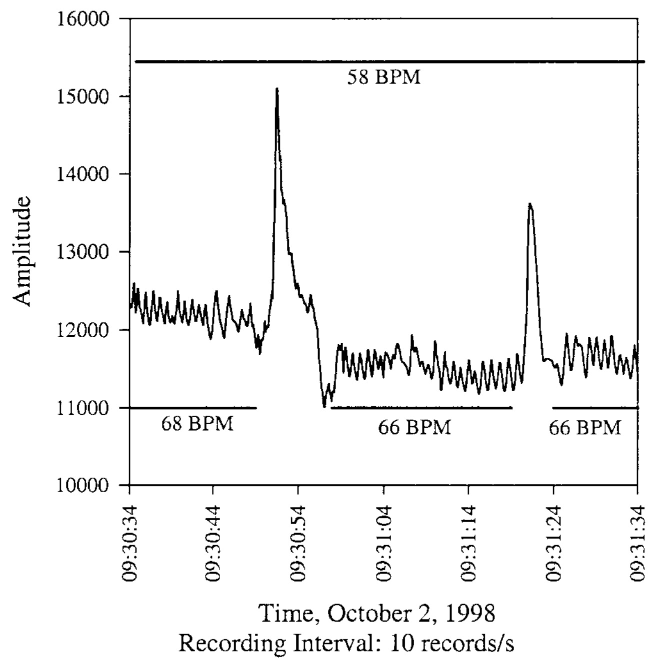

Figure 7–Sample of respiration data collected from a steer during a 1 min burst. Sample frequency was 10 records/s.

Respiration Monitor Support Software

Programming the TFX-11 using a modified BASIC programming language was accomplished via a development program (Onset Computer Corp., Pocasset, Mass.). Onset Computer provided specialized commands that performed routine tasks such as data acquisition and time functions. The data logger program was written to support RR signal logging bursts at user defined intervals. The logging bursts logged respiration sensor outputs every 0.1 s. Figure 7 shows a sample RR data output for a one minute burst. The data were stored in binary format in the on-board EEPROM and offloaded as binary data. The TFX-11 EEPROM memory was sufficient for collection of RR data over a four-day collection span with 1 min bursts acquired every 15 min.

A second program converted the data from binary to text format. The data was processed by a Visual Basic™ program that transformed the text RR data into graphical format for analysis. The program calculated the RR based on the entire record for each 1 min interval by counting reversals of direction of the transducer signal. The operator had the option of either accepting the 1 min record, without change, or selecting a more representative portion of the data-set. Figure 7 illustrates the importance of operator access to the full records. The RR sensor responded not only to motion due to breathing but also to any flank movement such as from stretching, swatting flies, etc. The computer generated RR count for the full record in figure 7 resulted in a value of 58 breaths per minute (BPM); when subsections were examined the values ranged from 66 to 68 BPM. The process of manually interpreting the data required about 4-5 min per 24-h period per animal. A program was written to automate the data reduction process. Human interpretation and the automated system were compared for 363 RR records from the USMARC chamber study. Overall the automated system yielded RR values that were on average within ±3.7 BPM of the human system. Of the 363 RR records examined about 10% (35) had RR that deviated by more than 10 BPM. The deviation was thought to be due to animal movement, loose belts or noisy sensors. The value of having full RR files reviewed by a human operator rather than on-board data reduction was apparent in these cases.

ENVIRONMENTAL CHAMBER AND FIELD STUDIES

The RR monitors were tested during two laboratory studies and one field study. The first study was conducted at the UMC Brody Environmental Laboratory using eight crossbred *Bos taurus* heifers as part of an evaluation of energy budgets during heat challenges. Physiological measures included rectal temperature and RR. The heifers began the experiment (day 1) in an environment of 18°C at approximately 50% relative humidity (RH). The temperature was increased for each successive day (28 ± 1°C on day 2, 30 ± 1°C on day 3, and 32 ± 1°C on day 4) with RH remaining at approximately 50%. Two heifers from each chamber were equipped with USMARC RR monitors for the duration of the study, with RR measures four times each hour for a duration of 1 min (samples taken every 0.1 s).

A second study, conducted in the USMARC Environmental Laboratory, focused on the impact of heat waves on dynamics of feeder cattle thermoregulatory response. The protocol imposed simulated heat waves on the eight steers in the study with physiological measures of RR, feed intake, and body temperature being recorded during the 79-day experimental period. The simulated heat waves were based on actual dry bulb and dewpoint conditions that occurred in Rockport, Missouri, during July 1995, and Central City, Nebraska, during July-August 1997. This study also used USMARC RR monitors on each of the eight steers assigned to this study. Respiration rates were measured four times per hour for a duration of 1 min with samples taken every 0.1 s.

A third study was conducted at the UMC Beef Research and Teaching Center using 10 crossbred *Bos taurus* steers. This was an outdoor study to assess thermoregulatory responses (RR and implanted body temperature telemetry devices) in shade and no-shade conditions. The late July study included the installation of USMARC RR monitors on four steers that were placed in shaded or unshaded pens (individually penned). The short-term (four-day) study called for the steers to rotate from shaded pens to unshaded pens on alternate days. The remaining steers were group penned in other shaded and unshaded pens. Again, RR was measured four times per hour for a duration of 1 min with samples taken every 0.1 s.

RESULTS AND DISCUSSION

The following results and discussion for the studies are presented to demonstrate the efficacy of the RR monitors to measure this important physiological parameter. This section is not intended to be a summary of all of the experimental results nor does this section explore all of the ramifications of the physiology involved.

Prior to experimental studies the RR monitors were evaluated on test animals with respiration rate determined both by the RR monitor and manual counting of flank movement; the initial tests resulted in RR that agreed within 2-3 BPM.

ENVIRONMENTAL CHAMBER STUDIES

Representative data from the first study that was conducted at the UMC Brody Environmental Laboratory are shown for one of the experimental animals in figure 8. The impact of environmental temperature is evident in figure 8. The RR for the 18°C temperature had a mean value of 39 ± 8 BPM. Following the imposition of heat stress the RR increased to a mean value of 71 ± 14, 79 ± 17, and 81 ± 14 BPM, respectively, for the environments of 28, 30, and 32°C. Using RR data for all chamber temperatures for this heifer, a straight line fit was found with a change of approximately 3.0 ± 0.14 BPM for each °C change (BPM/C_{T_a}) in the range of ambient temperatures represented (fig. 9). The correlation (Pearson correlation coefficient, SAS, 1985) of RR to temperature change was 0.73 ($P < 0.01$). The RR monitors performed well in this experiment with only two minor problems, maintaining tension on the belt, and transducer attachment wire breakage, requiring attention. The attachment wires were strengthened as a result of this experiment and a belt tension protocol was established.

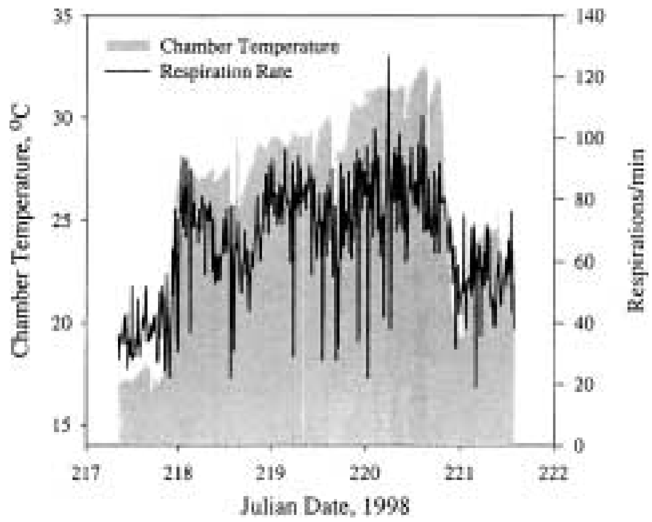

Figure 8–Respiration rate responses of a *Bos taurus* heifer to chamber temperature (Missouri study).

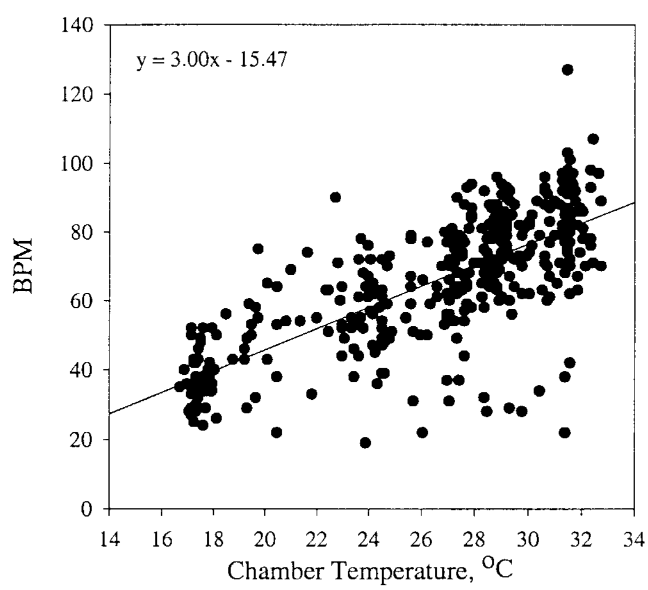

Figure 9–Respiration rate versus chamber temperature for a *Bos taurus* heifer (Missouri study). Straight line fit to data shows approximately 3.0 respiration per minute change for a 1.0°C temperature change in this range of temperatures.

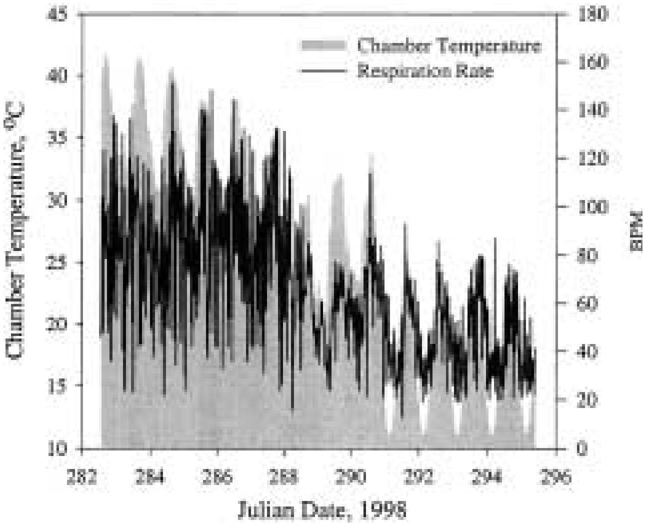

Figure 10–Respiration rate responses of a *Bos taurus* steer to chamber temperature (USMARC study).

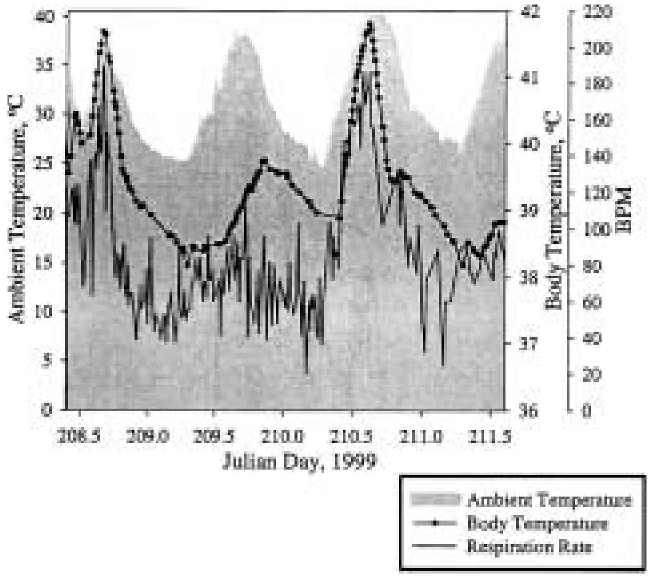

Figure 12–Respiration rate, body temperature, and ambient temperature for the period of the UMC field study for a representative steer (sun, days 208 and 210; shade, days 209 and 211).

The second study, conducted in the USMARC Environmental Laboratory, focused on the impact of heat waves on dynamics of feeder cattle thermoregulatory response. Figure 10 shows RR responses to environmental conditions during a 14-day portion of the data-set for a representative animal. The heat wave cycles are clearly evident as the RR tracks the chamber temperature closely. The average value of RR and the variability of RR was greater (78 ± 26 BPM/heat stress compared with 45 ± 16 BPM/thermoneutral) during the imposition of the simulated heat wave as compared with the cyclic thermoneutral temperature (18 ± 7°C) following the heat wave. A straight line fit (fig. 11) to the ambient temperature versus RR data showed a change of approximately 2.2 ± 0.1 BPM/C_{T_a} for this animal under the imposed conditions. The correlation of RR to temperature change was 0.64 (P < 0.01). Tests of the RR monitors resulted in minor software and hardware changes. A signal conditioner for the force transducer was implemented in the new design to provide more sensitivity over a wider range of respiration conditions. Also, additional checks were written in the software startup program to ensure erasure of the computer EEPROM; the data was overwritten on one occasion when the previous data had not been fully erased.

FIELD STUDY

The field study conducted at the UMC Beef Research and Teaching Center assessed thermoregulatory responses (RR and implanted body temperature telemetry devices) to shade and no-shade conditions during a hot summer

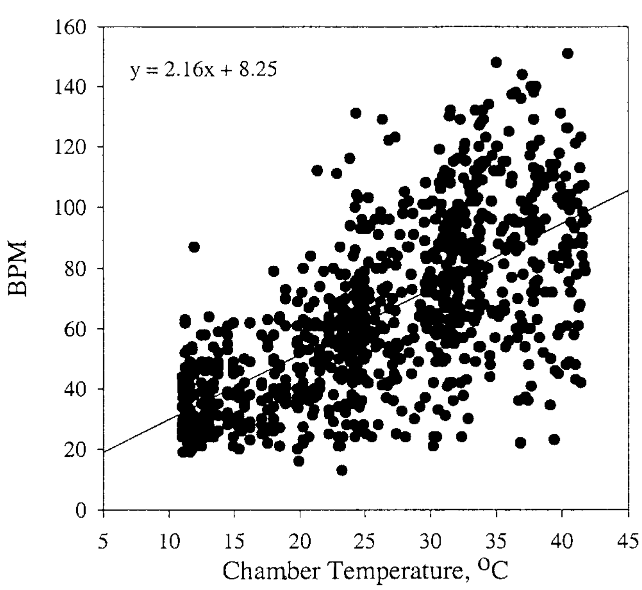

Figure 11–Respiration rate versus chamber temperature for a *Bos taurus* steer (USMARC study). Straight line fit to data shows approximately 2.2 respiration per minute change for a 1.0°C temperature change in this range of temperatures.

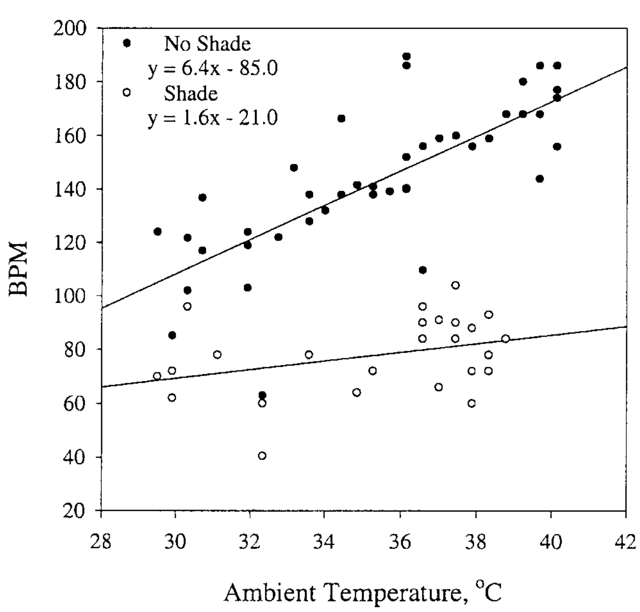

Figure 13–Respiration rate as a function of ambient temperature during shade and no-shade exposures (data taken from 10:00 A.M. through 3:00 P.M. each day) for the same steer.

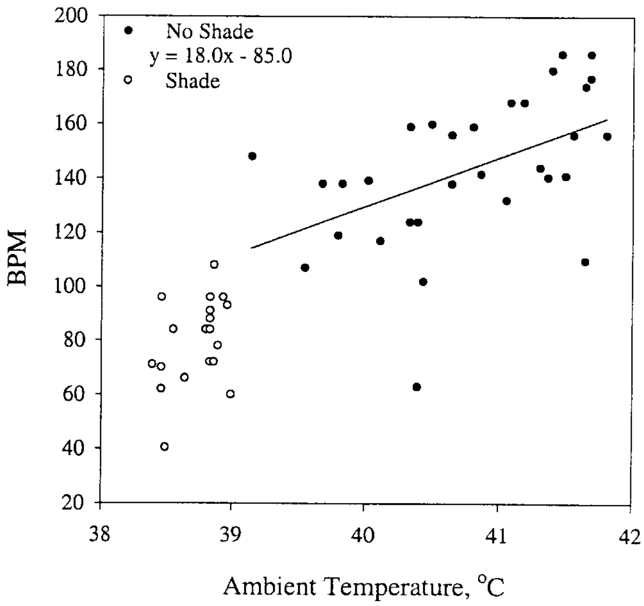

Figure 14–Respiration rate as a function of body temperature for the shade and no-shade conditions (data taken from 10:00 A.M. through 3:00 P.M. each day) for the same steer.

environment. Respiration rate, body temperature, and ambient temperature are shown in figure 12 for the period of the study for one representative steer. Figure 13 shows RR as a function of ambient temperature for both shade and no-shade conditions (data taken from 10:00 A.M. through 3:00 P.M. each day) for the same steer. The correlation of the no-shade ambient temperature and RR was significant ($P < 0.01$, $R = 0.77$) with a linear rate of change of 6.4 ± 0.8 BPM/C_{T_a}. By comparison, RR was weakly correlated with ambient temperature in the shaded period ($P = 0.06$, $R = 0.37$) and showed a linear rate of change of 1.6B ± 0.8 BPM/C_{T_a} for this animal. Respiration rate as a function of body temperature is shown in figure 14 for this steer in shade and no-shade conditions (data taken from 10:00 A.M. through 3:00 P.M. each day). Respiration rate was significantly ($P < 0.01$, $R = 0.49$) correlated to body temperature changes with an approximate 18 ± 6 BPM change for each 1°C change of body temperature for this animal in the sun. The body temperature did not correlate with RR in the shade ($P > 0.09$) for this animal.

SUMMARY

Rugged respiration monitors for cattle were designed and tested. Three separate studies demonstrated the value of the automated measurement in evaluating the physiological condition of the animals in both laboratory and field conditions. The respiration monitoring system performed well and with the experience gained from initial tests an improved version should prove very useful in future experiments and production settings.

ACKNOWLEDGMENTS. The authors would like to acknowledge the dedicated effort that was provided by John Holman on the mechanical aspects of this project as well as Diane Purcell's contribution to software applications related to this work. Additionally, animal management assistance was provided by John Holman, Bruce Larsen, and Michael Leonard.

REFERENCES

BIOPAC Systems Inc. 1997. MP100 Catalog. Santa Barbara, Calif.

Data Science International. 1996. *Telemetry Times* 10(3): 1.

Garrett, W. N., T. E. Bond, and N. Pereira. 1967. Influence of shade height on physiological responses of cattle during hot weather. *Transactions of the ASAE* 10(4): 433-434, 438.

Hahn, G. L. 1976. Shelter engineering for cattle and other domestic animals. In *Progress in Animal Biometeorology*, ed. H. D. Johnson. Vol. 1: 496-503. Amsterdam, The Netherlands: Swets & Zeitlinger, B.V.

Hahn, G. L., A. M. Parkhurst, and J. B. Gaughan. 1997. Cattle respiration rate as a function of ambient temperature. ASAE Paper No. MC97-121. St. Joseph, Mich.: ASAE.

Hahn, G. L. 1998. Personal communication. USMARC.

Webster, A. J. F. 1973. In *Heat Loss from Animals and Man*, eds. J. L. Monteith, and L. E. Mount, Ch. 10: 205-231. London, England: Butterworth.

Ingram, D. L., and L. E. Mount. 1975. In *Man and Animals in Hot Environments*, ed. K. E. Schaefer, Ch. 2: 19-31. New York, N.Y.: Springer-Verlag.

Kibler, H. H., and S. Brody. 1949. Influence of temperature, 50 to 5F and 50 to 95F, on heat production and cardiorespiratory activities in Brahman, Jersey and Holstein cows. Res Bul 450 (Envron. Physio. and Shelter Eng. Series VII). Columbia, Mo.: Missouri Agric. Exp. Sta., Univ. of Missouri.

Morrison, S., and G. Lofgreen. 1979. Beef cattle response to air temperature. *Transactions of the ASAE* 22(4): 861-862, 872.

Monteith, J. L. 1973. In *Heat Loss from Animals and Man*, eds. J. L. Monteith, and L. E. Mount, Ch. 1: 1-17. London, England: Butterworth.

Onset Computer Corp. 1997. *TFX-11 Remote Datalogger/ Controller Engine Users's Guide.* Pocasset, Mass.

Uniforce Technical Notes and Sensor Design Guide. 1995. Chicago, Ill.: Force Imaging Technologies.

SAS Institute. 1985. *SAS User's Guide*. Cary, N.C.: SAS Institute.

Webster, A. J. F. 1973. Heat loss from cattle with particular emphasis on the effects of cold. In *Heat Loss from Animals and Man*, eds. J. L. Monteith, and L. E. Mount, 205-231. Proc., 20th Easter School in Agric. Sci. London, England: Butterworths.

ABBREVIATIONS

USMARC = U.S. Meat Animal Research Center
RR = respiration rate
T_a = ambient temperature
RH = relative humidity
UMC = University of Missouri at Columbia
BPM = breaths per minute