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Automatic Health and Oestrus Control in Dairy Husbandry through Computer Aided Systems

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Disturbances in health and reproduction are leading to immense economic losses in dairy husbandry. Improvements are possible by using computer and sensor technology in animal monitoring and herd management. The development and usefulness of sensors for automatic health and oestrus monitoring, integrated into a "computer aided management system", are presented in this paper.

1. Introduction

Health and failure to detect oestrus are the reasons for considerable losses of income in dairy farming. It has been estimated that the Federal Republic of Germany thereby faces losses in receipts of about two thousand million marks every year as a result. These disorders are moreover leading to a reduction of the production periods of the cows which at the moment last on average 3·1 lactations over the life of each cow. Causes of early losses of the animals are especially oestrus disorders with about 30%, udder diseases with about 12%, claw and limb diseases with approximately 5%, and metabolic disorders with about 2% (*Fig. 1*).

An improvement of this situation is possible by better husbandry and feeding but above all by better management. At present, computer-based systems are being developed[1] for dairy-farming management (*Fig. 2*). The main developments are computer-based herd management, computer-based individual feed rationing, and computer-based animal monitoring.

In this paper, investigations on computer-aided animal monitoring are summarized which have been carried out to develop a comprehensive herd management system. In the case of computer-based animal monitoring, production and animal data are collected by means of sensors, processed by the computer and deviations from the production target or from standard values are indicated in time. This monitoring includes both health and reproduction.

2. Development and choice of sensors

Besides a suitable computer capacity for a computer-aided management system, it is necessary for animal monitoring to develop and use sensors which enable an automatic and continuous gathering of animal physiological data.

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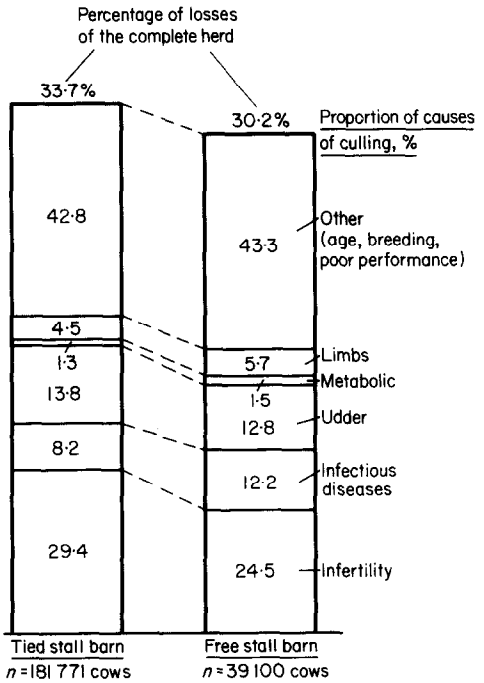

Fig. 1. Causes and percentage of the losses in the tied stall barn and free stall barn

2.1. *Physiological associated reactions*

For selecting and developing the sensors the physiological associated reactions of the animal are taken as a starting point, as they are suitable for continuous data recording without disrupting production (Table 1).

Suitable sensors are those:

(a) that are used for process-controlled feeding such as automatic feeders, milk yield recording systems and automated weighing stations,

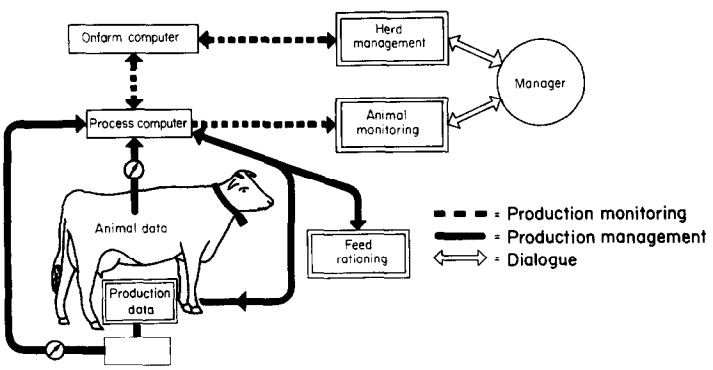

Fig. 2. Computer-based system for dairy-farming production management and monitoring

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Table 1

Possibilities for measured input of reactions associated with different diseases and reproduction stages

Symptoms	*Associated reactions*	*Measured input*
Diseases		
Udder	Change in feed and water intake	Feed and water intake
Metabolism	Change in milk production	Quantity of milk
Infection	Change in milk constituents	Concentration of fat, protein and lactose, cell content, pH, electrical conductivity (milk)
Claws and limbs	Change in weight	Live weight
	Increase in body temperature	Temperature (Vaginal, rectal, milk)
Reproduction		
Oestrus	Change in feed and water intake	Feed and water intake
Conception and pregnancy	Change in milk production	Quantity of milk
Birth	Change in milk constituents	Concentration of fat, protein and lactose, cell content, pH, electrical conductivity (milk)
	Increase in body temperature	Vagina pH
		Temperature
		Locomotion
		Pulse rate
		Ultrasound test

(b) special sensors which continuously and automatically register and indicate the animals' physiological data.

Fig. 3 shows the sensors we have used up to now.

2.2. *Sensors for collecting physiological data*

2.2.1. *Temperature sensors*

The body temperature is most important for animal monitoring. Direct temperature measurements by means of a contact thermometer require a lot of time and thus they are only taken in certain cases. Direct measuring of the body temperature through an ear mounted sensor seems to be possible following the first experiments.[2]

Automatic measuring of the body temperature can be achieved by indirect measurement of the milk temperature for which Paul and Speckmann[3] have developed a method which consists of four thermal sensors that are integrated in the claw pieces.

In a measuring series carried out before the actual experiment, the milk temperature of three cows was compared with the vaginally measured body temperature over three days. A reliable correlation (correlation coefficient 0·9) between milk temperature and body temperature was demonstrated with the milk temperatures lying about 0·14 K on average below the vaginal temperatures (*Fig. 4*).

These values correspond approximately to the differences noted by Maatje and Rossing[4] when studying a larger number of cows. This result proved the objective to be right that changes in the cows' body temperature can be noticed within certain limits by continuous measurement of the milk temperature.

Furthermore, the experiments have shown that the measured values of the udder quarters, showing normal milk temperatures, do not differ significantly from one another (mean 0·07 K, standard deviation 0·097). Therefore, for further monitoring of the normal temperature development *one* combined temperature sensor in the claw piece would be sufficient.

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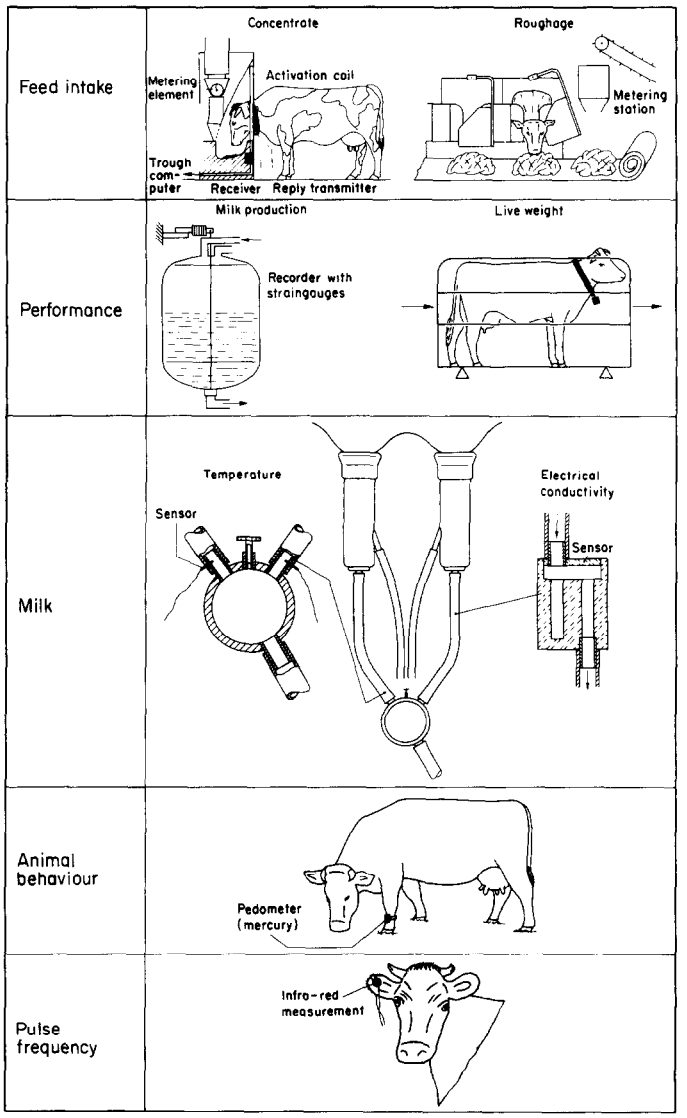

Fig. 3. Selected sensors for production and feeding monitoring

2.2.2. *Sensors for the electrical conductivity of the milk*

Disorders of the animal are usually the reason for a change in the content of milk constituents, above all in the content of protein and lactose as well as of progesterone and in the cell content. Furthermore, these constituents can only be measured by time-consuming laboratory methods. Within the bounds of an improved early detection of diseases their recording has to be ruled out for the time being.

Diseases and changes in reproduction also lead to an impedance variation that is caused mainly by a change in concentration of K, Na and Cl ions. These ion concentrations can be measured using electrical conductivity and for this purpose, special transducers have been developed that are integrated in the short milk tubes of the milking cluster. This method

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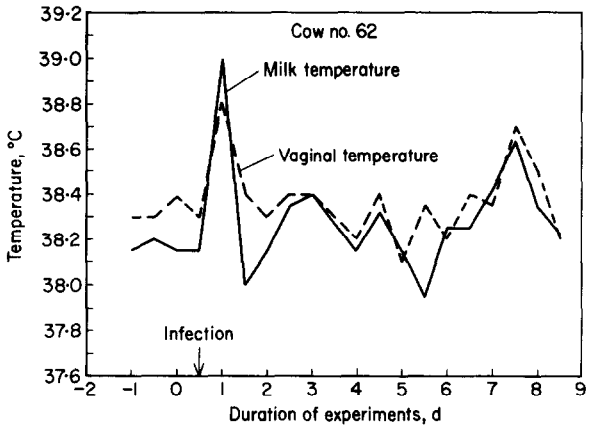

Fig. 4. Mean course of the milk and vaginal temperature

enables an automatic and continuous measurement of the electrical conductivity of the milk during milking.[5] The highest value shown in the initial flow of the milk yield is used for analysis. Observing the measured values of the bacterial cell count and the electrical conductivity, agreement between the two can be demonstrated (*Fig. 5*).

2.2.3. *Physiological sensors on the milking cluster*

Sensors for the measurements of the milk temperature and electrical conductivity can easily be integrated in conventional milking clusters (*Fig. 6*). Temperature measurements are not difficult technically but due to the slight differences in physiological alterations they require extensive analysis programmes for each animal. Conductivity measurements, however, provide clear signals that are easy to analyse, but the development of sensors usable in practice still presents a challenge. Constantly, the measuring cells have to be filled with milk, otherwise false results are obtained. In the case of using carbon electrodes, an ageing process is detectable and a change of the measured values is produced.

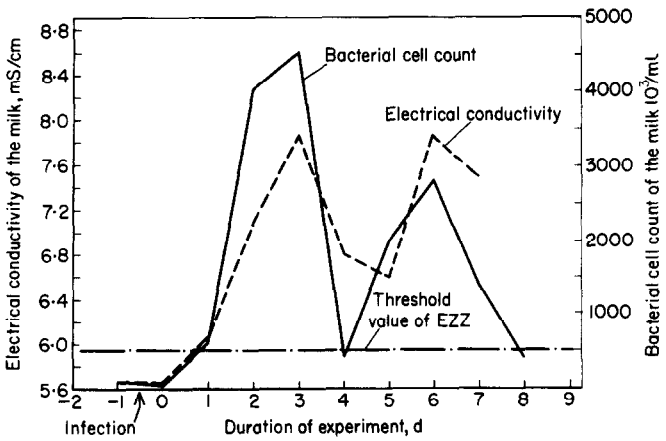

Fig. 5. Graph of averaged electrical conductivity and cell content of the milk in infected udder quarters

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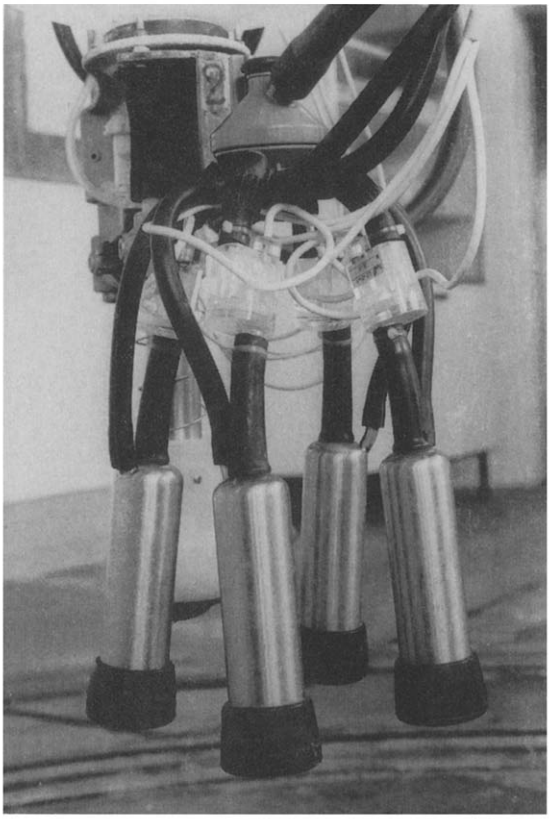

Fig. 6. Milking cluster with integrated temperature sensors and electrical conductivity transducers

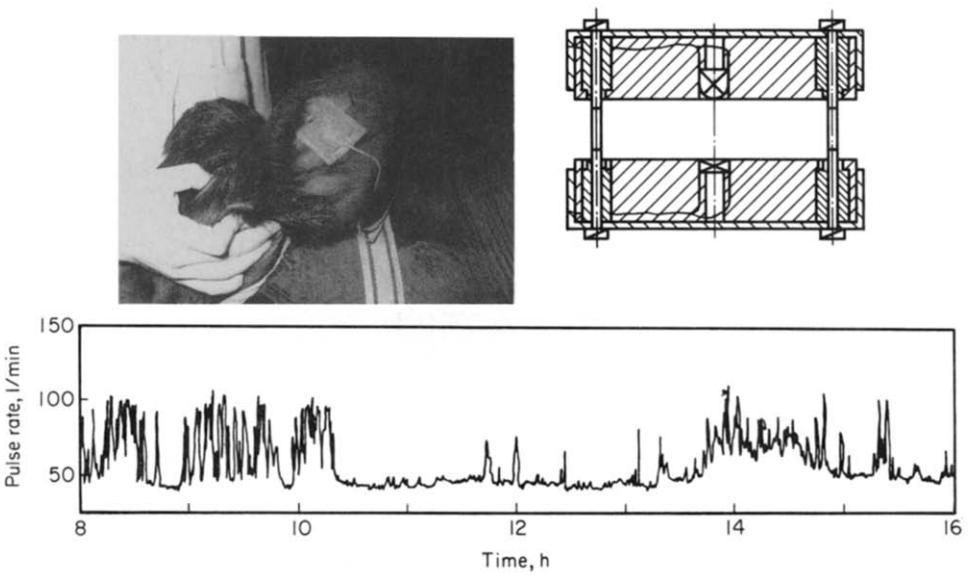

Fig. 7. Pulse rate sensor and example for the pulse rate during the day of a healthy cow

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2.2.4. *Pulse rate sensors*

Further sensors for collecting physiological data can be mounted at the animals ear if necessary. Our own experiments have been carried out by means of a pulse rate sensor which was developed by Paul *et al.*[6] (*Fig. 7*). The core of the sensor is an infrared transducer that consists of a light-emitting diode functioning as the transmitter and a diode sensitive to light working as the receiver. By means of a filter function the time history of the pulse rate can be described. It is shown for a day of a healthy cow in *Fig. 7*.

3. Early diagnosis of diseases by indirect recording of the body temperature by milk temperature measurements

The increase in the body temperature is a typical associated reaction in the case of diseases. The temperature responds immediately to pathological variations of the organism, in many cases already in the preclinical stage. By means of a measuring instrument for the milk temperature developed by Paul and Speckmann[3] a herd of sixty Holstein-Friesian cows has been monitored over a period of 6 years under practical conditions. During the lactation the animals are accommodated in a stable with mobile boxes for the cows which is equivalent to the husbandry conditions of a tied stall barn.

3.1. *Normal reactions*

The normal milk temperatures are subject to small variations between morning and evening milking. Over the complete herd a definite difference between the milk temperature of the morning milking and that of the evening milking was shown which, on average,[7] amounted to a mean of 0·05 K, and standard deviation 0·195. Occasionally temperature variations in different animals have been determined during the measurements without the animals showing pathological variations or being in oestrus. In some cows no variations were noticed during the day (*Fig. 8*).

An influence of the stage of lactation and the surrounding temperature in the temperature controlled barn on the milk temperature could not be proved. In all cases, the accuracy of the measurement was $\pm 0{\cdot}2$ K. When a herd of dairy cows is monitored the temperature of each animal has to be investigated. It is intended therefore, to develop learning microcomputer programs which will derive from the measured temperatures the typical standard history of temperature for the individual cow.

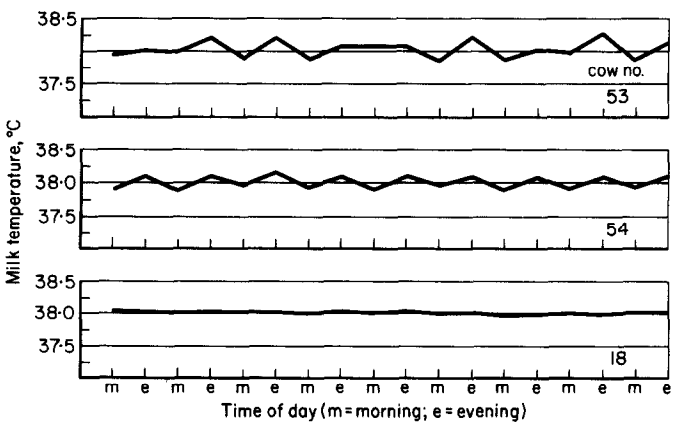

Fig. 8. Graph of the milk temperature of different animals

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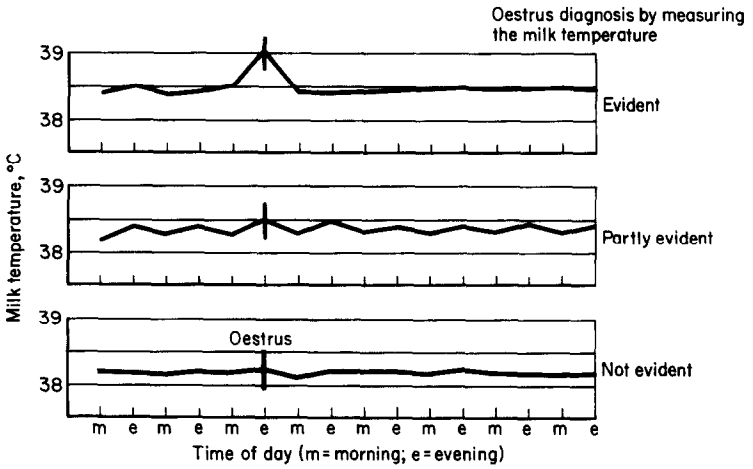

Fig. 9. Milk temperature before, during and after the oestrus

3.2. *Oestrus reactions*

After Ball *et al.*[8] the body temperature of a cow in oestrus can be shown in a typical time history which is marked by the fact that the body temperature increases directly before oestrus and decreases again afterwards. Similar results were found by continuous measurement of the rectal temperature by means of a contact thermometer.

By automatic measuring of the milk temperature only in the morning and in the evening it is possible to miss the oestrus, because normally the period of the oestrus peak is short. Therefore, a continuous measurement of the milk temperature is necessary (*Fig. 9*). Thus in 2 years of experiment the optimum stage of oestrus could be detected only in the case of at most 42% of the animals.

3.3. *Pathological variations*

More evident results could have been shown by the measurements for pathological variations in the animals (*Fig. 10*). For example, the onset of mastitis is mostly preceded by

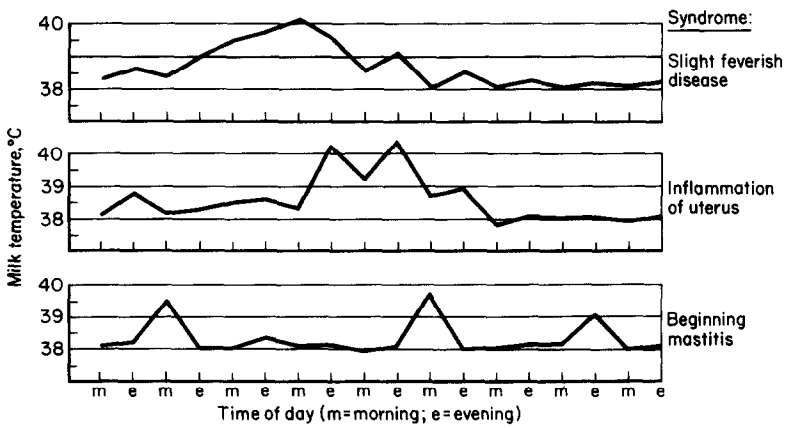

Fig. 10. Temperature graphs of dairy cows with different diseases

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considerable variations in temperature which are far beyond the tolerance of the measurement of the other "normal" variations.

The experiments have shown that mastitis usually starts in one quarter, irrespective of the fact that the milk temperature also increased in the other udder quarters at the same time. Therefore, proof of separately diseased quarters is impossible by measuring the milk temperature. For the monitoring of udder diseases measurements by a sensor per cluster unit is sufficient.

Inflammations of the genital organ also lead to an increase in milk temperature. In *Fig. 10* the temperature graph of mastitis is demonstrated. After initial irregularities in temperature there is a considerable rise in temperature which became normal after a successful treatment in a short period of time.

3.4. *Experiences of animal monitoring by milk temperature measurements*

In cases of increase in temperature of the animals a veterinary surgeon was consulted. During the years of experiment the following diseases of the animals could have been diagnosed by him: mastitis 5%, metabolic disorder 11%, uteritis 15%, inflammation of claws and limbs 5%.

Rises in temperature were caused in 26% of the cases by the oestrus of the animals, in 16% they were the results of medicinal treatments and in 22% no diseases could be proved despite higher temperatures.

Fig. 11 shows the success rate which has been achieved by the scientific workers during their thoroughly carried out animal monitoring every day. One hundred percent represent the daily diagnosis carried out by a veterinary surgeon. The hatched columns show the percentage of the temperature changes proved by measurement.

This comparison shows that with regard to mastitis and uteritis a success rate of 100% through automatic control is achieved. This does not go for metabolic disorders, inflammations of claws and above all for the oestrus diagnosis.

The experiments made up to now show that no specific disease or oestrus diagnosis is possible by exclusively milk temperature measurement. Such a diagnosis can only be achieved by synchronous recording of various physiological parameters.

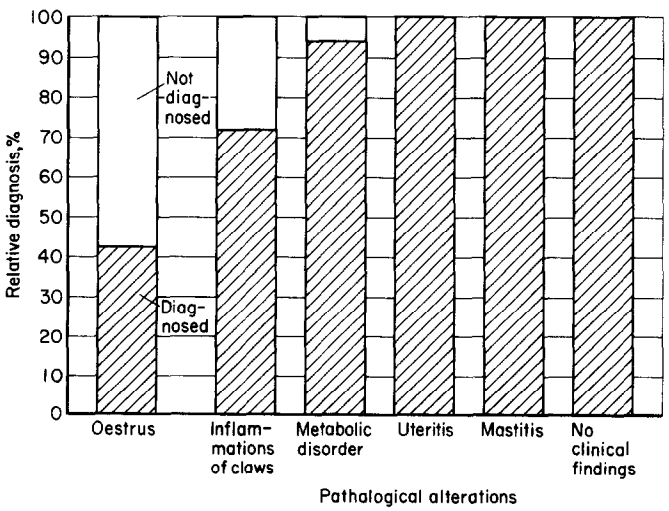

Fig. 11. Herd control by milk temperature measurement

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4. Early diagnosis of subclinical mastitis of cows

4.1. *Selection of suitable parameters*

A distinct early diagnosis is necessary above all in case of udder diseases. For investigational purposes mastitis was induced in certain animals by an intra cisternal application of a germ suspension.[9] The course of the disease was observed by continuous measuring of the reference value "bacterial cell content of the milk". In the uninfected udder quarters the average cell content showed values of about 100 000 cells/ml milk during the whole duration of the experiment. In the infected quarters, the values of cell content rose considerably directly after the infection. In order to investigate the disease the physiological associated reactions were recorded by means of the following sensors:

milk temperature,
electrical conductivity of the milk,
changes in the milk quantity, and
changes in the water consumption.

The cell content of the milk determined by laboratory measurements was related to the measured results achieved by the sensors (*Fig. 12*). In these experiments a rapid increase of the values of the cell content of the milk was observed immediately after infecting the cows. At the same time the measurements of the electrical conductivity after the infection have also shown a clear rise which became normal for a short time on the second day. After the third day of experiment another increase in the values was measured.

The milk temperature reacted 12 h after the infection with an increase of 0·8 K and reached a higher level in the further experiment.

The milk quantity was measured and a yield depression of about 5 kg was observed after the infection was triggered. There was a relatively late indication of a clear influence on the water consumption and a relation with mastitis could only be assumed.

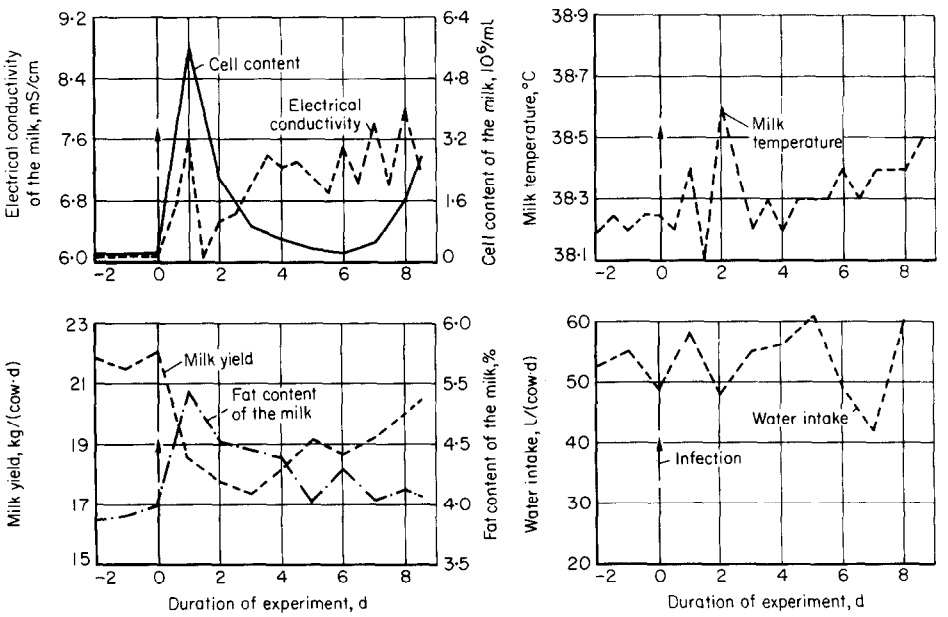

Fig. 12. Graphs of different physiological parameters in case of mastitis

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4.2. *Limiting values for the monitoring of the udder health*

As useful parameters for computer-assisted monitoring of udder health the electrical conductivity, the milk temperature, and the milk yield have been chosen. Subclinical mastitis cows have been assumed at a threshold value of 500 000 cells/ml milk.

4.2.1. *Limiting value for the electrical conductivity of the milk*

This parameter shows individual differences in healthy animals with values of electrical conductivity measured between 4·8 mS/cm and 6·0 mS/cm. These variations are caused by race and individuality of the cows. The results of Linzell *et al.*[10] have been confirmed according to which the electrical conductivity of healthy udder quarters can be considerably disturbed by an infection. Owing to the previous results differences of the values in the electrical conductivity of 0·6 mS/cm in a quarter compared with the healthy quarters can be judged as a proof of pathologically harmed udders (*Fig. 13*).

Higher values of the electrical conductivity are measured only in the initial milk flow of the infected udder quarters, later on the flow values become similar to those of the uninfected udder quarters. Therefore, the electrical conductivity of all four udder quarters must be recorded for an early diagnosis; it is only then that the focus of inflammation can be located through the differences of the values with the other udder quarters.

4.2.2. *Limiting value for the milk temperature*

The milk temperature reacts almost in the same way in all udder quarters in case of an infection of one single quarter (*Fig. 14*). Because of the individuality of the cows, it is impossible to define a limiting value of the change of the milk temperature.

An absolute fixing of a limit is impossible because of individual variations. Abnormal conditions, however, can be inferred from the absolute difference in temperature of the measurements of two consecutive milking times. If we assume an inevitable error in the milk temperature measurements of 0·2 K due to the sensors and normal variations of the animals of 0·2 K a difference value of 0·4 K for the milk temperature above the norm is required before any disease can be assumed. Due to the fact that this parameter also reacts to other abnormalities of the animal, it only allows definite statements about mastitis infection in connection with other parameters.

4.2.3. *Limiting value for changes in the milk yield*

In the experiments, correlations between udder infections and the yield have been shown which have been especially serious during the first three days after the infection (between 3

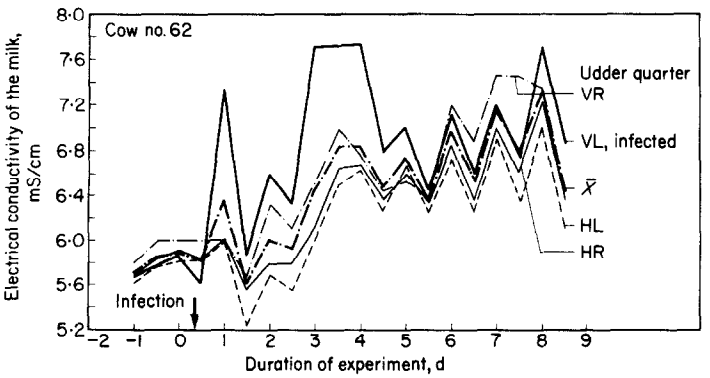

Fig. 13. Graphs of the electrical conductivity of the milk of all four udder quarters

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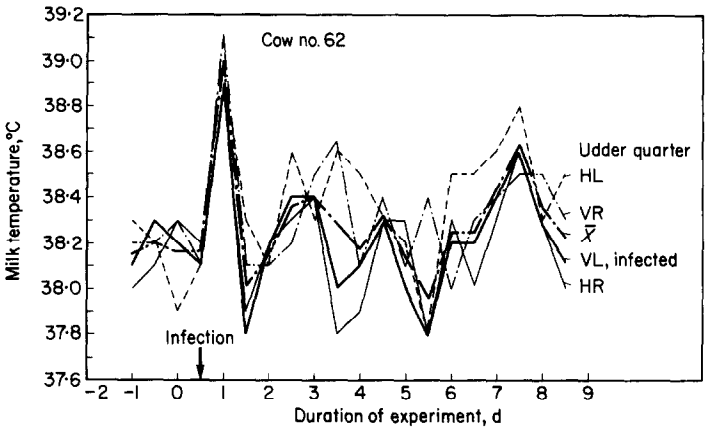

Fig. 14. Graph of the milk temperature of the four udder quarters. $\bar{X}$, mean value; VR, right before; VL, left before; HL, left behind; HR, right behind

and 7 kg change of absolute milk yield). Such evident production losses can be taken as a reliable indication of disorders of the organism. Because of the daily variations of the individual cow an absolute determination of a limiting value for this parameter cannot be determined. The parameter can, therefore, only be used in conjunction with records of the normal milk yield of the animal concerned.

5. Early diagnosis of metabolic disorders

Other experiments are being made on the early diagnosis of metabolic disorders. This syndrome makes up only 2% of all the early losses of cows, but it can lead to considerable problems with dairy livestock if the disease is noticed too late.

For the experiment six test cows were undernourished by 25%. By continuous recording of the milk quantity, live weight, milk temperature and electrical conductivity the different reactions and the intensity of the metabolic disorders on this parameter could be ascertained.

The increase in ketone which has been proved by aceto acetic acid in urine functioned as the indicator which indicated metabolic disorder from the third day of the experiment. Five out of six test animals showed clear reactions (*Fig. 15*).

This experiment led to an immediate and visible drop in milk yield and live weight in the animals with a ketosuria (to prove that there is ketone in the stall). With considerable delay the milk temperature reacted about 8 days after the beginning of the experiment whereas a clear rise in value of the electrical conductivity has already been noted on the third day of experiment. In contrast to mastitis, all quarters reacted. For fixing limiting values further experiments are necessary.

6. Oestrus monitoring by means of various parameters

Uncertain oestrus diagnosis is frequently the reason for poor success of fertilization in dairy farming. By current automatic recording of different parameters the possibilities of a computer based oestrus diagnosis have been examined. The oestrus synchronization of the animals was set at a determined time. As all the oestrus symptoms depend on the quantity of progesterone produced, this parameter was included in the experiments as a comparative value and for the exact description of the oestrus time and course. The tests have been carried out both in the tied stall barn and free stall barn.[11]

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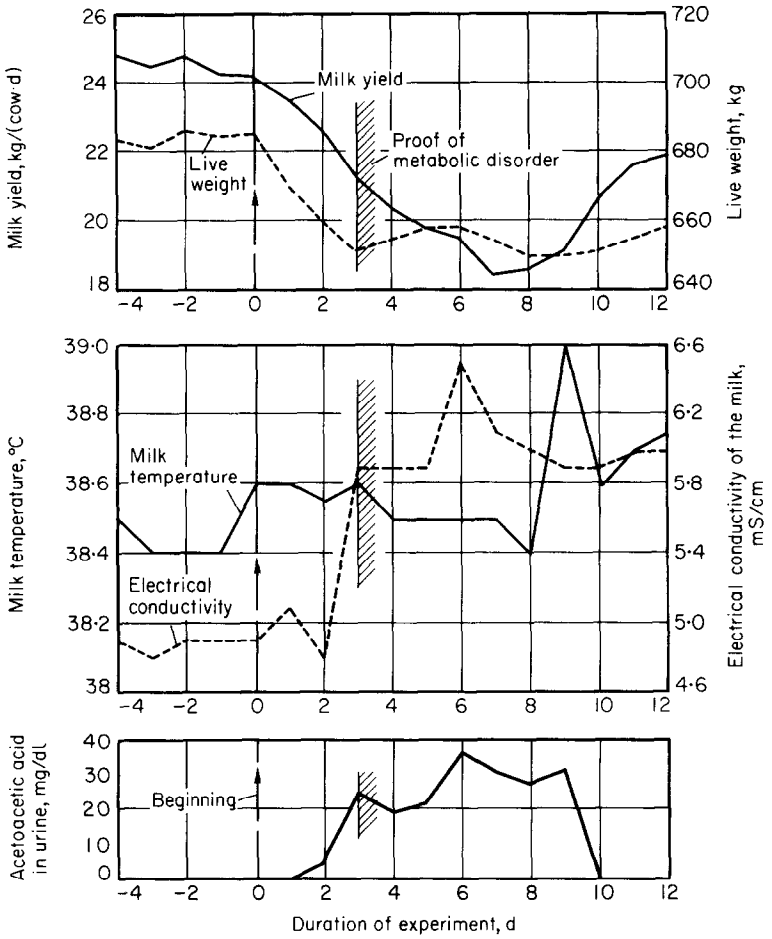

Fig. 15. The response of different physiological parameters for metabolic disorders

6.1. *Choice of suitable parameter*

The following automatically recorded parameters reacted clearly during the oestrus. The milk temperature showed at the oestrus day on average over the whole experiments an increase of 0·1 K to 0·4 K above the mean in the total cycle (*Fig. 16*).

A rise in temperature, however, could only be observed in 40 to 60% of the animals in the tied stall barn, whereas up to 90% of the cows in the free stall barn showed clear increases in temperature. Since a variety of factors have an effect on the milk temperature this parameter alone is not sufficient for oestrus diagnosis. Of the other parameters, recorded through the milk, only the fat content of the milk showed a definite reaction while the electrical conductivity gave no indication of the oestrus and the feed intake only in a few cases.

However, clear reactions were observed in the values marking the animal behaviour such as the frequency of steps and the pulse rate.[12] The tests on the frequency of steps have shown that the restricted number of steps in the tied stall barn has allowed an increase only of 10 to 14% during the oestrus, whereas the normally higher rate in the free stall barn (7300 steps per day) doubled during the oestrus (*Fig. 17*).

For the oestrus diagnosis the number of steps in the tied stall barn is not suitable as a

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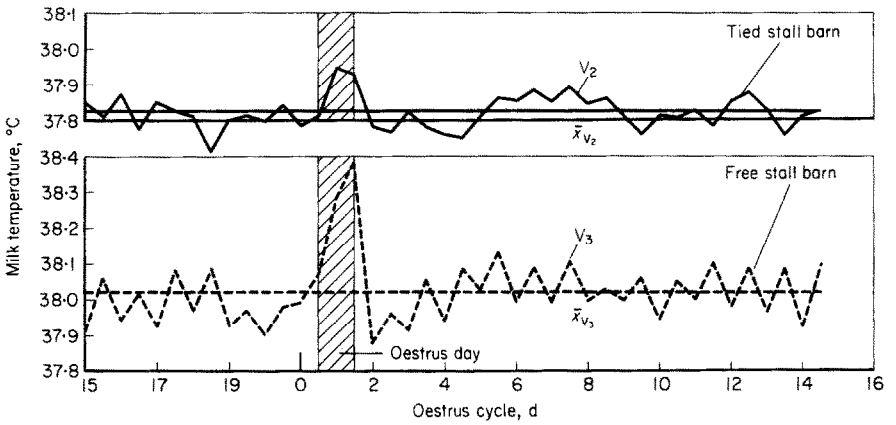

Fig. 16. Graph of the milk temperature during the oestrus cycle E2: n = 15/day; E3: n = 24/day (V_2 : V_3, Experiments 2 and 3; $\bar{x}$, mean value)

parameter of the animal behaviour so that in this barn system the pulse rate is recorded by an ear mounted sensor. It was ascertained that the absolute pulse rate per minute rose due to the oestrus on the daily average by about 7% from 68·5 pulse/minute to 73·5 pulse/minute and that simultaneously the number of interruptions of the rest period at night increased

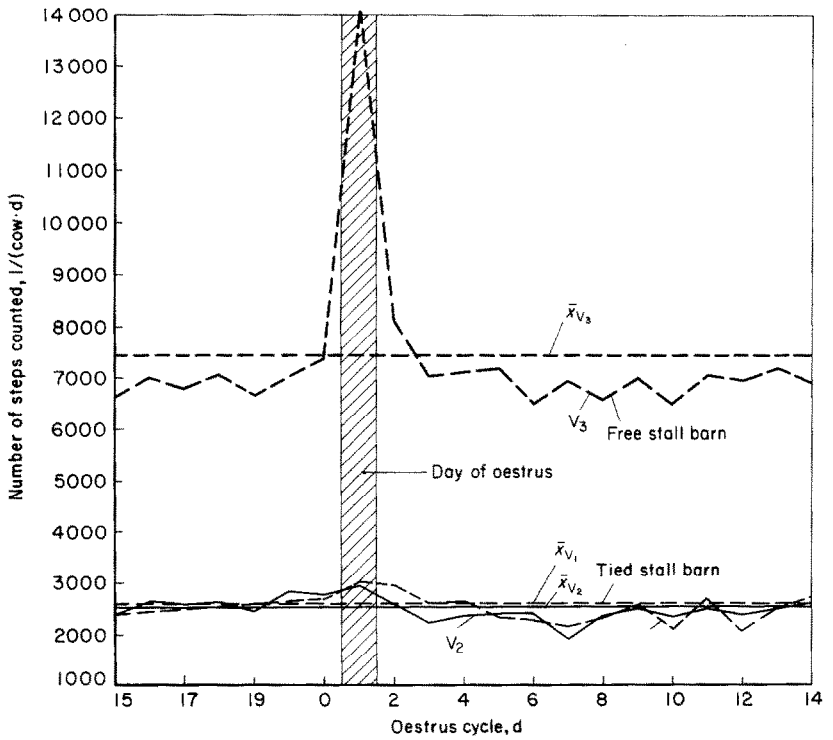

Fig. 17. Number of steps per day during the oestrus cycle. V1, Experiment 1; V_2, Experiment 2; V_3 Experiment 3

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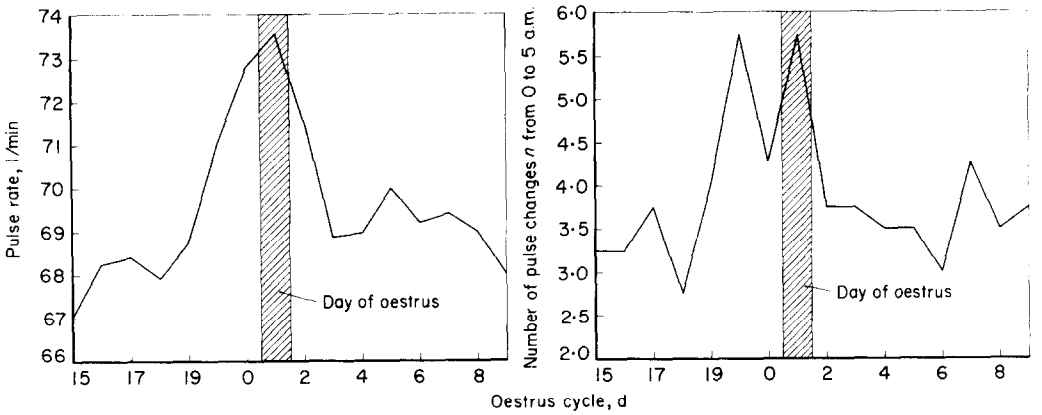

Fig. 18. Oestrus diagnosis by measuring the pulse rate

from about 3·5 to 5·0. According to the *t*-statistics, the two parameters point significantly to the oestrus (*Fig. 18*).

Both, the intra-vaginal electrical conductivity and the intra-vaginal pH value have turned out to be suitable parameters, but automatic recording of these is not possible at the present time.

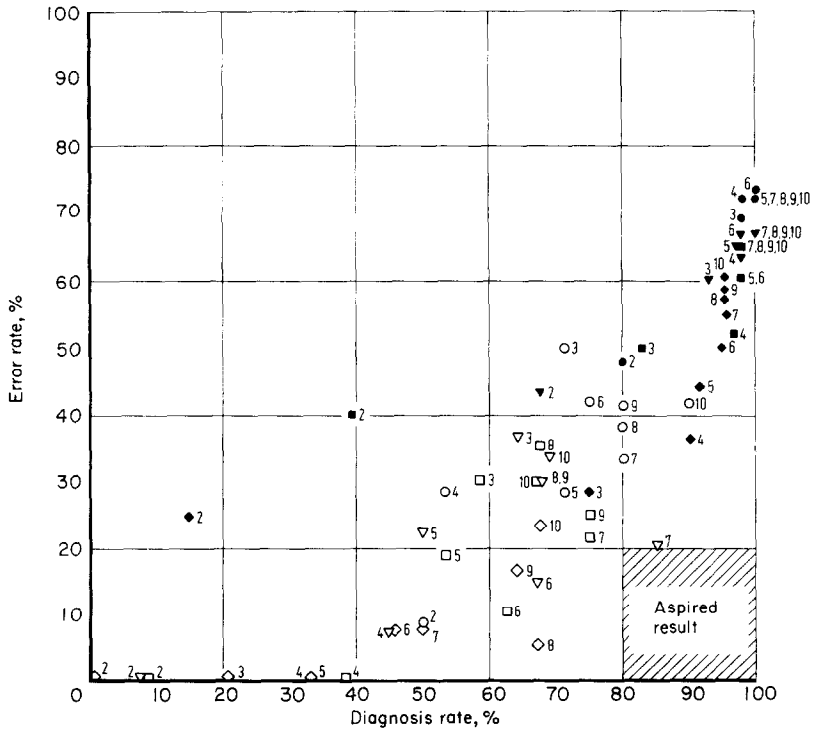

Fig. 19. Computer-based oestrus diagnosis in the free stall barn. Percentage of the diagnosed oestrus as well as error classifications for different confidence periods and level of error. One parameter-model of the number of steps: ●, 1%; ▼, 0·5%; ■, 0·1%; ◆, 0·01%. Four parameter-model: ○, 1%; ▽, 0·5%; □, 0·1%; ◇, 0·01%.

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6.2. *Evaluation of the oestrus parameters through an analysis by elimination*

Consideration of one single parameter leads to a higher percentage of false oestrus diagnoses (*Fig. 19*, full symbols). An analysis by elimination is proposed to reduce these false positive indications using the parameters "milk temperature", "number of steps", "milk yield", and "feed intake" (open symbols). The parameter of "electrical conductivity of the milk" serves for the elimination of oestrus or disease caused reactions. This is demonstrated in *Fig. 19* by the example of the free stall barn.

With a suitable combination of the variables more than 80% of all the oestrus cases can thus be diagnosed, simultaneously reducing the amount of incorrect information by about 20%. Compared with the conventional oestrus diagnosis the success rate has been increased by 50% by means of the presented model. The percentage of false oestrus diagnosis has halved. The sole observation on the frequency of steps brought a higher diagnosis rate, but the error rate still amounts to 60% and thus amounts to an unacceptable level in practice.

Acceptable results in the tied stall barn can be achieved by including the measurement of the pulse rate.

7. Conclusions

From present results of automated recording of physiological parameters by means of computer-aided systems for early diagnosis of pathological alterations or changes in reproduction of the animals, the following conclusions can be made.

(1) Selective measurements of single or more parameters do not give sufficient information to differentiate statements about certain diseases and the time of oestrus as this is only possible by continuous measurements of various parameters.

(2) The following parameters prove to be suitable for health monitoring.

mastitis:
- electrical conductivity;
- milk temperature;
- milk quantity;
- fat content of the milk.

metabolic disorder:
- live weight;
- milk quantity;
- electrical conductivity;
- fat content of the milk.

(3) The simultaneous recording of the following parameters is to be recommended for oestrus monitoring.

(a) for free stall barn:
- frequency of steps;
- milk temperature;
- milk yield;
- electrical conductivity.

(b) for tied stall barn:
- milk temperature;
- frequency of steps;
- milk yield;
- pulse rate;
- electrical conductivity.

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(4) A computer program has been proposed which is able to evaluate a combination of measured data in order to predict the onset of oestrus. The aspiration is to achieve a success rate of 90% and an error rate lower than 10%.

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