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Safety Considerations for Automatic Milking Systems

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Successful introduction of fully automatic milking systems requires safety measures to avoid cow and equipment damage due to the behaviour of cows and due to collisions of animals and milking equipment. Investigations are reported on parameters which could be used to solve this problem and on possibilities to prevent accidents by appropriate treatment of cows.

It was found that the activity of eating concentrates and variations of load on the hind legs were related to the frequency of leg lifting. As expected, leg lifting was observed to be mainly caused by collisions of milking equipment with different parts of the cow, especially with her legs. A considerable reduction of cow leg activity during the application of teat cups was observed after previous stimulation.

Suitable sensors for recording the behavioural parameters of cows are weighing devices to measure mechanical loads on hind legs and on the manger to measure concentrate consumption. Leg activity also can be monitored by pressure sensitive plates or mats, commonly used by industry. To avoid collisions during automatic milking operations, capacitive and ultrasonic proximity sensors have been used successfully.

1. Introduction

Experienced herdsmen know that in each herd there are always some cows which are more difficult to milk than others because of frequent kicking or other individual behaviour. In general, the operator is able to avoid this kind of trouble by observation of the animal and by appropriate reactions, since most cows give "warnings" before they act.

To make fully automatic operation of milking systems feasible, the herdsman's experience and ability to predict unwanted actions of the cow must be replaced by technical means. One way of doing this has been proposed by Middel and Oenema,[1] and Notsuki and Ueno.[2] They describe purely mechanical devices to keep the cow's legs in the desired position. This approach to solving the problem has at least two disadvantages. First, the device must be adapted to various cow sizes, so that it is unlikely that all cows can be kept in an optimal position; secondly, some cows will not accept the restriction and, in trying to free themselves, will cause even more trouble or, in voluntary milking systems, will reduce the frequency of visits to the installation.

A different approach to a solution was chosen by Montalescot.[3] He designed a robot arm which was able to withstand kicks from a cow. No details are known of this device but one problem is that the inertial mass of the arm must be extremely small if injuries to the cow's legs are to be avoided. Thus, advanced materials may be required to manufacture the arm. A more conventional solution is a soft surface, but that requires large dimensions to be useful.

Based on experience in earlier experiments (Ordolff[4]) investigations were started in the Institute for Milk Production at the Federal Dairy Research Centre, Kiel, on parameters and devices to replace human skill in predicting unwanted or dangerous actions of a cow, to eliminate the necessity for applying mechanical restrictions to animals at automatic stations.

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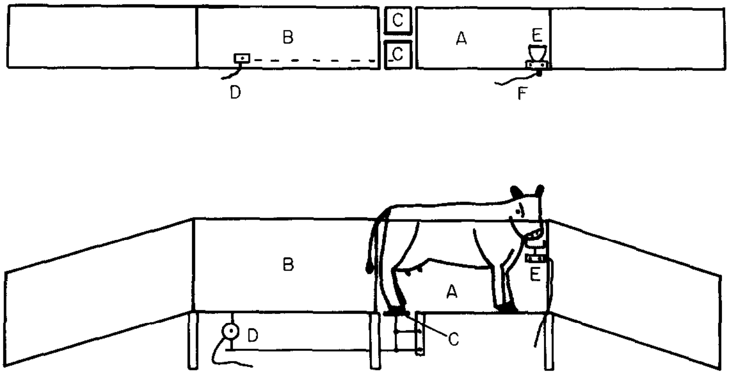

Fig. 1. Experimental installation for monitoring leg activity and eating behaviour. A, milking stall; B, preparation stall; C, weighing platform; D, scale with electrical signal output; E, manger; F, position transducer

Two obvious types of safety problem existed. The first one is related to the cow's behaviour and it arises when she enters the automatic milking station. At this time, it must be decided if milking can be carried out without undue risk of damaging the cow or equipment. The second type of risk is caused by accidental events which may happen when the equipment collides with the cow.

2. Experiments and results

2.1. *Monitoring cow activity*

An experimental milking station was equipped with weighing platforms for the hind legs of a cow (*Fig. 1*). Weight was converted into an electrical signal.

To monitor the cow's intake of concentrates the manger was mounted on an elastic suspension (*Fig. 2*). Mechanical oscillations, caused by the cow, were picked up by a position-transducer. Both signals were recorded on a two-channel chart recorder. Each

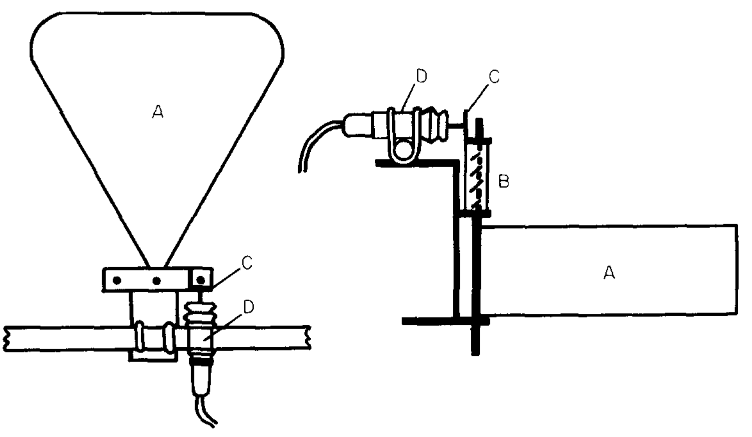

Fig. 2. Installation for monitoring the eating activity. A, Manger; B, elastic suspension; C, position indicator; D, position transducer

Table 1
Sequence of treatments

Treatment	Time, s	Action
1	0–60	Cow on station, undisturbed eating
2	60–90	Dummy robot moving under the cow
3	90–150	Touching and spraying teats
4	150–210	Cow on station, undisturbed eating
5	210–240	Tapping legs with a piece of wood
6	240–300	Dummy robot touching cow's legs, udder
7	300–360	Retracting dummy robot, cow undisturbed

record contained sequences of single events, e.g. motion of the hind legs or action of the tongue in the manger, providing information about the following parameters:

variations of weight on hind legs <40 kg (events/experiment),
variations of weight on hind legs >40 kg (events/experiment),
lifting hind legs (events/experiment),
eating time (s/experiment),
eating activity (events/experiment).

To test the reactions of cows, a sequence of different treatments was incorporated in an experiment (Table 1), which was repeated three times on different days. Twenty-one cows participated in this investigation, providing a total of sixty-three test sequences.

It was found that the level of activity differed considerably between cows (Table 2).

Table 2
Global activity of cows

	Parameter				
Cow	Eating time, s	Eating activity (events)	Weight <40 kg (events)	Weight >40 kg (events)	Lifting hind legs (events)
896	116	119	51	13	8
C91	158	187	53	1	1
D23	172	155	11	3	1
D43	242	178	41	5	2
D64	36	35	22	15	3
D76	247	133	18	9	3
E26	255	288	45	8	11
E74	256	114	48	9	3
E76	294	404	83	12	10
E95	339	253	8	5	5
E109	188	200	18	5	1
F64	314	160	46	2	1
F74	269	249	30	3	1
F99	341	288	27	11	7
F100	262	262	50	10	13
G1	112	45	30	12	8
G62	255	163	14	4	3
G64	323	216	18	6	4
G111	189	251	37	3	2
G200	86	85	24	4	5
Z7	196	218	106	20	4

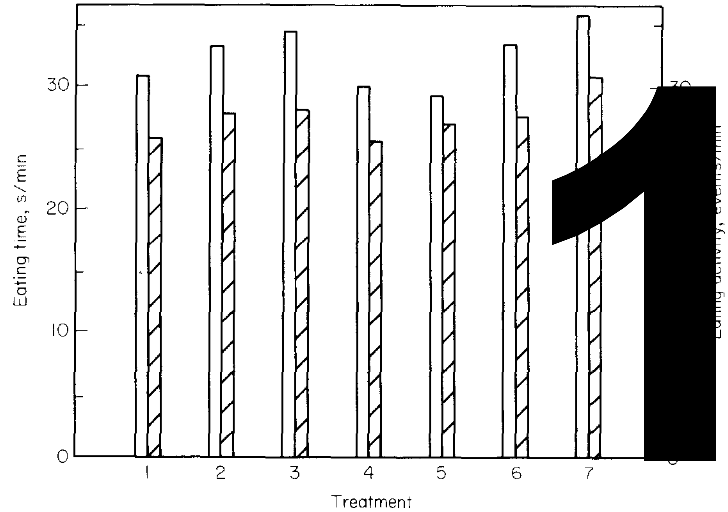

Fig. 3. Influence of different treatments on cow's average eating time (left column) and eating activity (right column)

Signals indicating eating behaviour and variations of weight up to 40 kg were received continuously. Variations of weight of more than 40 kg and lifting legs were observed less regularly. They probably represented cows' reactions to treatments.

For general assessment of the activity of cows, values were collected per treatment and per experiment and then the average level of activity in each treatment was calculated. Treatment 1 can be used as a reference for the level of activity.

No clear influence of treatments on eating behaviour was found (*Fig. 3*). The activity of legs, represented by signals of weight and by frequency of leg lifting, responded more obviously to the sequence of treatments (*Fig. 4*).

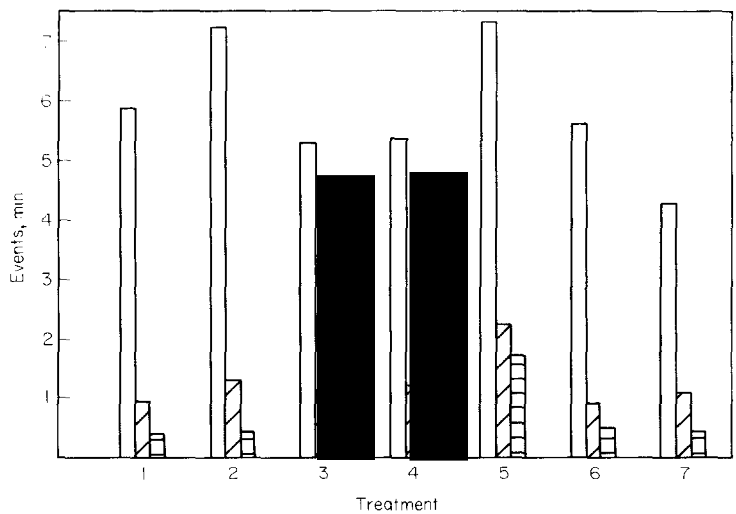

Fig. 4. Influence of different treatments on cow's leg activity: load variation below 40 kg (left column), load variation above 40 kg (central column), leg lifting (right column)

Table 3

Correlations between different parameters of cow activity

	Parameter				
	Eating time, s	*Eating activity (events)*	*Var. of weight <40 kg (events)*	*Var. of weight >40 kg (events)*	*Lifting hind legs (events)*
Eating time	1·00	0·63	−0·002	−0·19	0·12
Eating activity		1·00	0·34	0·03	0·47
Variation of weight <40 kg			1·00	0·52	0·28
Variation of weight >40 kg				1·00	0·48
Lifting legs					1·00

Degrees of freedom: 20, $r(P\ 0{\cdot}01) = 0{\cdot}53$, $r(P\ 0{\cdot}05) = 0{\cdot}41$

Treatments 2 and 5 caused an increase of weight signals <40 kg, which was not significant. As expected a significant increase of activity was found due to treatment 5 as far as weight signals >40 kg and the frequency of leg lifting were concerned.

Correlations between activity levels of different parameters within cows were calculated (Table 3). Eating time and eating activity were highly correlated. Variation of weight <40 kg and >40 kg, variations of weight >40 kg and lifting legs, and eating activity and lifting legs were also found to be correlated. There seemed to be a certain coincidence between high eating activity and leg activity of a cow.

2.2. *Influence of udder preparation on cow behaviour*

The same station was used for a further experiment to investigate the influence of preparation of cows on their behaviour during the procedure of attaching the teat cups. For this purpose cows were milked alternatingly without mechanical contact prior to attaching the teat cups (reference) and after conventional manual stimulation (experiment). Activity levels were recorded according to methods previously described.

The experiment included four periods:

(1) no action (30 s);
(2) manual stimulation (60 s), experiment only;
(3) attaching teat cups (30 s);
(4) no action except milking (60 s).

General activity of cows was found to be rather low, so the only useful information was the signal for load variation on the hind legs up to 40 kg. The frequency of events observed during the reference procedure decreased continuously from 4·5 events/min (*Fig. 5*) during the first period down to about 2 events/min during the last period. Activity during attachment of teat cups was approximately 3 events/min.

During the first period of the experimental procedure 3 events/min were observed. Then activity decreased and the lowest level of only 0·5 events/min was observed while teat cups were attached. Activity increased again during the last period.

2.3. *Sensors*

To avoid collisions of mechanical equipment with the cow various types of sensors are available. In general, remote sensing devices will be appropriate. During the work on

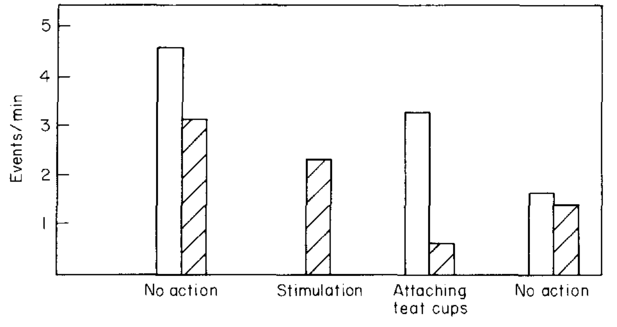

Fig. 5. Influence of stimulation on leg activity (load variations below 40 kg). Left column: without stimulation, right column: with stimulation

automatic milking experience was gained mainly in using capacitive proximity sensors and ultrasonic sensors.

Capacitive sensors worked up to a distance of 70 mm (Table 4). They were not affected by dirty surfaces of the animal, but their sensitive area must be kept dry and clean to avoid false alarms. When the sensor was set to its highest sensitivity the distance to switch it off was about twice the distance to switch it on (Table 5). Reduction of sensitivity level to a distance of 50 mm or less versus a cow's body resulted in a better defined response of the unit.

Experiments with an ultrasonic range finder gave reliable response up to a distance of about 400 mm, as long as the transmitter–receiver diaphragm was dry and clean, if the cow's surface was approximately parallel to the active diaphragm of the device. This working range was shorter than the nominal range of about 3 m when the unit was presented to surfaces such as wood, stone or metal. It seems likely that the hair covering the cow caused diffuse reflection of the ultrasonic beam which could not be read correctly by the measuring device at longer distances. The thin layer of heated air close to the surface of the cow may have had an additional influence on the resulting signal, explaining the different levels of zero distance signals observed (Table 6).

3. Discussion

Based on the results of the investigations described here the frequency of leg lifting is probably the most suitable parameter to indicate dangerous situations due to cow

Table 4

Maximum working distance of a capacitive proximity-sensor type "efector KB 3020-BPOG"*

Object	*"On" distance, mm*
Dry wood	50
Metal (Al)	35
Cow's body	70
Cow's leg	55
Udder	60
Teat	40

* Manufactured by IFM Electronic, D-4300 Essen, Federal Republic of Germany

Table 5

Distance for switching the capacitive sensor "on" and "off" at various settings of sensitivity. Object: cow body

On, mm	*Off, mm*
70	140
60	115
50	60
40	45

behaviour. It was found to be related to variations of weight on the hind legs exceeding 40 kg and to the activity of eating concentrates. So, by monitoring one or both parameters, the global risk of damage caused by a particular cow can be estimated.

Appropriate sensors for this purpose are available commercially. For both, eating activity and weight on legs, weighing systems have proved to be suitable. They need not be very precise, unless the weight of the cow or the amount of concentrates in the manger has to be measured accurately.

The mobility of legs can also be monitored by pressure sensitive plates or mats, frequently used in industry (Schreiber *et al.*[5]). Simple devices provide a binary output (on–off signal), more sophisticated products with an output proportional to the load are also available. They are able to discriminate different levels of load variation on the legs.

A second type of risk generally is due to collisions of the mechanical equipment with the cow. Obviously the legs are the most sensitive parts to be avoided, but there are other areas of the animal which should not be touched without previous warning by technical components.

Appropriate sensors, such as capacitive proximity transducers and ultrasonic range finders, were successfully used to prevent undesirable collisions of the equipment with the cow. But it was also found that preparing the cow for manipulations to follow can also reduce the risk of accidents.

During the experiments it was observed several times that cows obviously feeling uncomfortable at the experimental device did not move at all, but suddenly started kicking. For these cows an exceptionally low level of activity was recorded which was linked to a relatively elevated frequency of leg lifting. This was true especially for cows G200, G1 and to a certain extent for cow 896 (Table 2).

Monitoring cow behaviour and avoiding collisions will not completely eliminate the risk of accidents with automatic milking equipment. It can be recommended under all

Table 6

Relation of distance to output signal (V) of an ultrasonic range finder, type "Seleprox SU UCVA-8002 K"*

Surface	*Minimum signal, V*	*Signal proportional to distance, V/cm*
Wood	0·60	0·051
Cow's body	0·40	0·051
Teat	0·44	0·055

* Manufactured by Selectron Lyss AG, CH-3250 Lyss, Switzerland

circumstances to provide some initial mechanical contact with the cow, such as udder preparation, before the teat cups are attached. Thus it appears desirable to mimic the approach of human operators who, in general, talk to cows and touch them somewhere before starting manipulations at the udder.

4. Conclusions

Although it may be possible to design automatic milking equipment which will not be affected by kicks of the cow, care should be taken to avoid such events since they may hurt the animal. It is equally undesirable to restrict free space for the cows on automatic milking stations more than is necessary. When the system is based on voluntary visits for eating concentrates, this might well reduce the frequency of visits to a lower level than is required for proper function.

The investigations presented in this report indicated some facilities that might use the behaviour of the cow to indicate the likelihood of unwanted reactions of the animal. Monitoring the activity of eating and fluctuations of load on the hind legs was shown to be useful. It also became clear that minor collisions with the cow increase the risk of kicking, especially when the equipment hits the legs. Not all the results can be clearly interpreted, so the investigations will be continued.

Mechanical contact with the cow through udder preparation can reduce her activity during application of the teat cups. This function therefore may be used to prevent accidents.

Sensing elements, such as pressure sensitive mats or plates are available commercially and may be used to observe load variations on legs. Simple weighing devices monitor eating and leg activity. Industrial sensors, such as capacitive or ultrasonic transducers, can sense the distance between mechanical equipment and the cow. When linked to quickly reacting control units and robotic arms, these devices may be used to avoid collisions and so contribute to the comfort of cows and men in automated dairies.

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