Dynamic tests during cow milking with different types of milk meters

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Summary

This study is related to the POM - Measure 2 - Project B15 «Veterinary services computerization and technical support to livestock farms», in which innovative plants solutions has been introduced to recognize the single animal to measure the quantity of produced milk, to centralize and automate the management, in different cow and sheep and goats breedings in Puglia and Basilicata regions. The experimentation has foreseen dynamic tests, during the real milking of the cows, in an apulian plant in which different measurers of the quantity of milk have been installed: weigh jar, electronic weighing «bascule» milk-meter, electronic proportional milk-meter. In a mechanical point of view, the vacuum level and the vacuum fluctuations in three different milk pipe sections have been valued: at short milk tube, downstream from the claw, prior to the milk meter. Comparing the results, authors deduced that the electronic milk-meters, like the electronic proportional milk meter, allows inferior vacuum degree variations and less mechanical solicitations in cow udder; such situation is particularly evident with higher milk flow. The study also underlines that the vacuum drops during milking can be very critical if not immediately compensate with a suitable planning and periodic revision of the plants.

Keywords

Dynamic tests - Milk meters - Milking plants - Vacuum fluctuations - Weight jar.

Introduction

Different theoretical studies were carried out to define the optimal and critical air/milk flow conditions in milk pipelines (5, 7, 8). They highlight that because of mechanical stresses due to a rapid backflow of milk in the pipeline, bacteria may infect the teat channel of the cow being milked. This is much more evident when the milk flow is such to prevent the overlying air flow to compensate for the variations in pressure (5, 7, 8).

The analysis of the variations in the working vacuum during milking has only been investigated over the last few years and so far only laboratory trials have been carried out (12). On one hand, laboratory trials allow isolating numerous variables that can affect such a complex phenomena, but it is equally true that cow milking is difficult to be reproduced in environments other than the real one; therefore, the currently available results require remarkable verifications on real scale plants (1, 2).

From the sanitary point of view, the influence of mechanical milking in developing new mammary infections has not been fully assessed so far, though it is proved that, because of milking, a high percentage of such infections can occur if the number of bacteria on the teat is already high (6, 8, 10). Similarly, from the

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sanitary point of view, it is not known yet if an impulsive and intense stimulus, or a less intense stimulus but with relatively long intervals is more harmful (14).

This paper investigates how different milk meters connected to each single cow do influence the vacuum degree and thus the functionality of the plant.

Table I
Characteristics of the test milking plant.

Type of plant	Herringbone milking room with 5 stations
Vacuum pipe	Q = 11500 dm³/min; n =1270 giri/min; Engine: P =3kW
Vacuum pipe	Material: PVC Diameter est. = 63 mm, int.= 57 mm
Sanitary trap	Material: PVC; Capacity: 5 dm³
End tank	Type: closed Material: vetro; Capacity: 50 dm³
Milk extraction pump	Q = 200 dm³/min; n = 1400 rpm Engine: P =0,6 kW
Pulsators	Company: Interpuls (mod. LP20-electtronic); n. 5 Pulsation ratio: 60/40; Pulsation rate: 1 Hz
Sheats	Type: long; Material: rubber
Short milk tubes	Material: alimentary rubber; Diameter int.= 8 mm; Lenght =15 cm
Claw	Company: Interpuls (mod. Orbiter-electronic) capacity: 350 cm³
Long milk tubes	Material: alimentary rubber Diameter int. = 18 mm Middle lenght = 900 cm
Milkline	Material: steel AISI 304 Diameter: est. 50 mm; int. = 46 mm
Washline	Material: steel AISI 304 Diameter: est. 38 mm; int. = 35 mm
Milk measuring system before October 2000	n. 5 glass weigh jars of 33 dm³s each
Milk measuring system after October 2000	n.5 glass weigh jars of 33 dm³ each
Vacuum regulator	Company: Milkline Type: servomechanism
Detach type	Company: Milkline; Type: simple rope

Materials and methods

The main characteristics of the investigated plant are reported in table 1. The measuring systems (3, 9) of the milk produced by each single cow being milked were:

- weigh jar (Figure 1a);
- electronic weighing «bascule» milk meter (Figure 1b);
- electronic proportional milk meter (Figure 1c).

The tests were performed upon milking of cows, at the following cross-sections of the milk circuit (Figure 2):

A) the short milk tube;

B) the long milk tube, downstream from the claw;

C) the long milk tube, prior to the milk meter or the jar.

Six cows from the fifth to the seventh lactation week were selected: three of them with a maximum yield of about 60 kg/day and the others with a maximum yield not greater than 26 kg/day. These cows were milked every 24 h at a milking unit where one of the three investigated milk meters had been installed; the vacuum variations were thus determined at each milking machine. This procedure allowed to obtain standard milk flow conditions, as well as two different values of flow in the milk pipe: a medium one and a higher one.

As a whole, 55 milking measurements for each selected cow were taken.

The trials were carried out using a digital pressure transducer Ecotronics – DASM (Star Ecotronics, Milano, Italia). The gauging chain consisted of a pressure sensor directly inserted at the gauging cross-section, a data logger connected to a portable computer and the data processing software with maximum error of ±0.5% with respect to the performed measurement, a measurement accuracy of the

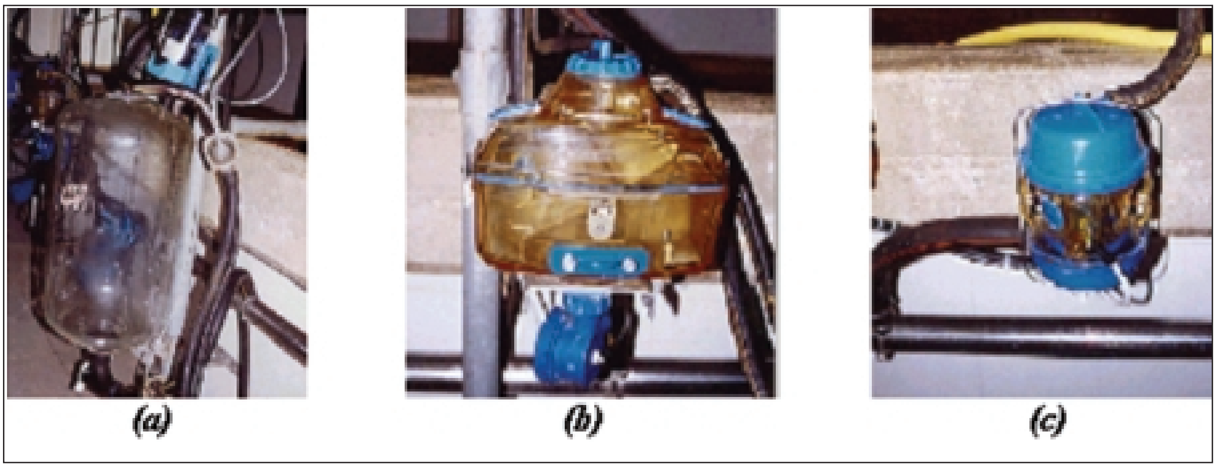

Figure 1
Studied milk-meters: (a) weigh jar, (b) electronic weighing "bascule" milk meter, (c) electronic proportional milk meter

vacuum level equal to ±0.5% and a sampling frequency of 2000 Hz per channel, in a pressure range from 100 to 250 kPa. Thus, the accuracy was about ten times greater than what required by ISO standards 6690 (2, 11).

At each gauging cross-section, the instantaneous vacuum levels and their fluctuations were determined; the latter were calculated though the following formula applied by the software, at 5 s intervals,

$$F = \sum_{i=1}^{N} \frac{P_{iMax}}{N} - \sum_{i=1}^{N} \frac{P_{iMin}}{N}$$

where:

• P_{iMax} (kPa) is the ith relative maximum of instantaneous vacuum drop, measured at 5 s sampling;

• P_{iMin} (kPa) is the ith relative minimum of instantaneous vacuum drop, measured during the 5 s of sampling.

Therefore, the vacuum fluctuation, F, allows making a further analysis of the instantaneous values since it more clearly highlights the distribution of the vacuum variations at the measuring cross-section over time; thus, it is an indicative parameter of the vacuum level uniformity as well as of the type of stress effectively generated because of its drop (12).

In the course of the measurements, due care was taken to make the teat cup cluster to adhere perfectly to the udder and prevent any undesired external air admission to the milk pipes; moreover, before performing the dynamic tests, the plant was constantly subject to static tests in accordance with the ISO standards 6690, by replacing and/or recording any component that might cause accidental losses, in such a way to guarantee always the

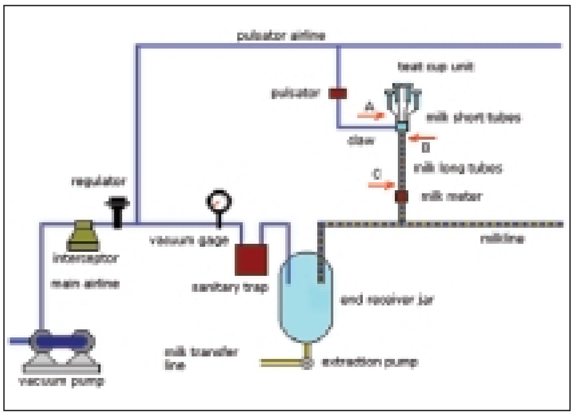

Figure 2
Milking plant scheme; the arrows point out the sections in which vacuum fluctuations have been measured

same effective reserve of vacuum and the same technical-operational conditions of the plant (Table II).

The latter procedure allowed having the milk meters and the milk flows from the milked cows as only variables in the course of the dynamic tests..

Results

Figures 3, 4, 5, 6, 7 and 8 report the instantaneous values of vacuum levels and the corresponding fluctuations, at the A, B, C (Figure 2) cross-sections, respectively, for a cow with high (Figures 3, 5 and 7) and medium-to-low milk flows (Figures 4, 6 and 8). The graphs refer to a single milking but they are representative since they recurred during most of the tests performed (Table III). In fact, the middle values in Table III (instantaneous maximum and minimum values, so also fluctuations) are of the same order as those reported in the graphs; they are middle values of 165 milking measurements that, for each gauging cross-sections and each flow conditions, were taken (55 milking measurements for each selected cow) and standard deviation and middle value rates are lower than 10 %.

In some cases, see Figures 3, 4, 5, 6, 7 and 8, at the end of milking, sudden and instantaneous drops in the working level are recorded – quite evident at the short milk tube (Figures 3-Ia, 3-Ib) and generally observed, at a lower intensity, also at the downstream cross-sections (Figures 5-Ib, 7-Ib, 6-Ib and 8-Ib). Sometimes, for instance during the trials with weigh jar, variations of this type during the same milking are evident at the short tube and not at the claw or at the attachment of the meter (Figures 3-Ia, 5-Ia and 7-Ia; 4-Ia, 6-Ia and 8-Ia).

For each gauging cross-section, when sharp and sudden drops in instantaneous vacuum levels are observed, fluctuations tend to increase (Figures 3-Ia and 3-IIa, Figures 8-Ia and 8-IIa).

The analysis of all the graphs highlights that greater drops in vacuum levels and greater fluctuations occur at the short milk tube (Figure 3), and this confirms what is reported in the literature (5,7,9). Generally, the intensity of instantaneous values tends to increase further after the early 100 s of milking, i.e. when the cow releases the highest amount of milk, as well as in the cases of high milk ejections (Table III, Figures 3, 5 and 7); whereas, fluctuations tend to increase when the maximum milk release from the milked cow is to start or, more often, to end.

If a weight jar is installed in the milk line, instantaneous vacuum drops at the short tube are the highest, both at high (Figure 3-Ia) and smaller ejections (Figure 4-Ia); in both cases such drops reach even 35 kPa, though showing a rather uniform pattern over time. In fact,

Table II
Milking plant operational parameters, verified with static tests (ISO standards 6690-3918) before dynamic tests

Pulsation curve characteristics (at pulsators)		
Vacuum level (kPa)	45	
Pulsation rate (cycles/min)	60	
Pulsation ratio	0,6	
Limping (%)	0,1	
Time (ms)	1080	
Elements of the plant	**Air flow at 50 kPa (dm³/min)**	**Air consumtion (dm³/min)**
Vacuum pump	1200	/
Vacuum line	1020	180
Milk line	1010	10
Milking units	910	20/pulsator
Milking units	810	20/unit
Vacuum effective reserve (dm³/min)	810	

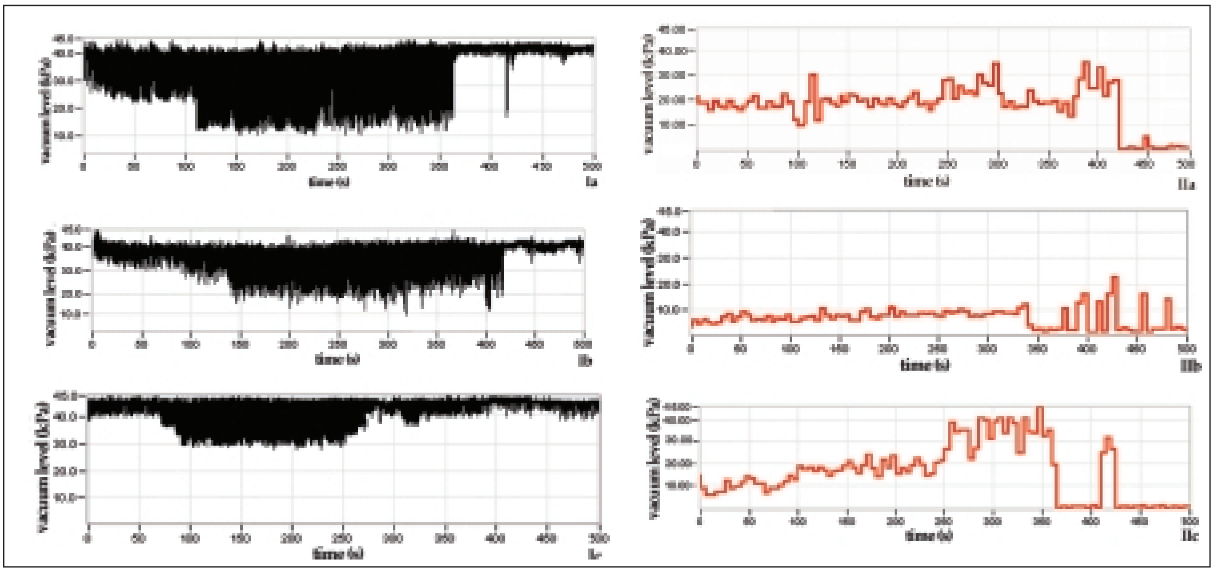

Figure 3
Section A (Fig. 2): instant vacuum level (I) and fluctuations (II) with high milk flow. Test positions: (a) with weigh jar; (b) with electronic weighing "bascule" milk meter; (c) with electronic proportional milk meter

fluctuations reach very high values, of the order of 45 kPa, only when maximum milk release starts to end, whereas at the previous phase they are reduced by half and show a basically constant pattern, which is less traumatic to the udder. The minimum value is recorded more frequently at the final milking phase, except the cases where though milk flow and vacuum level have become stable, an impulsive variation of the latter causes a very high and evident though shorter fluctuation.

During the operation of the weighing «bascule» milk meter, the analysis at the short milk tube basically confirms what observed with the

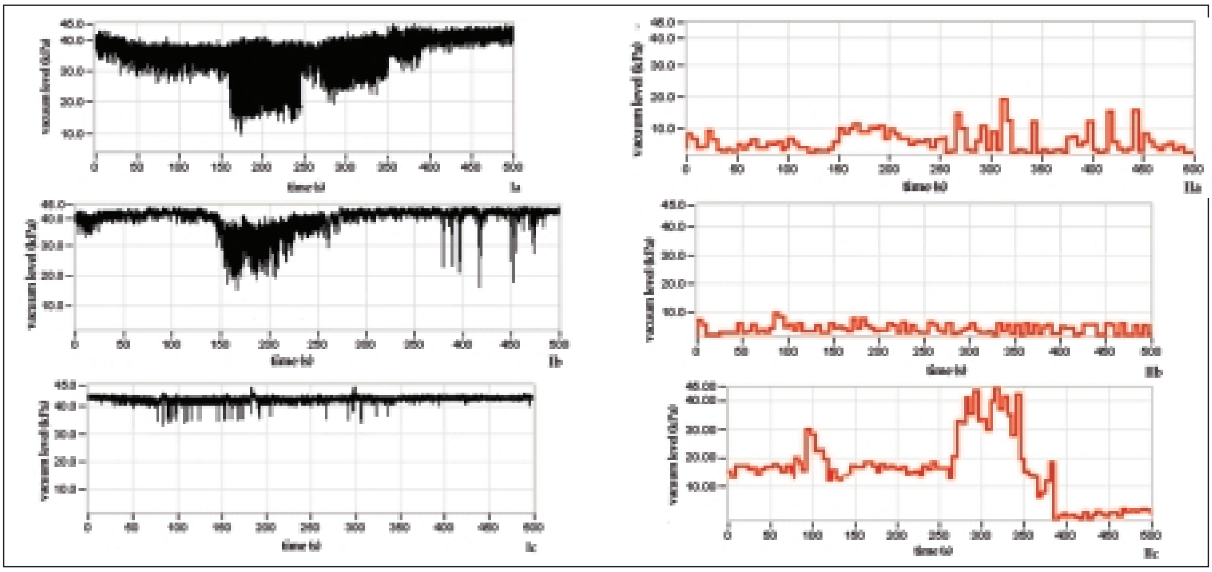

Figure 4
Section A (Fig. 2): instant vacuum level (I) and fluctuations (II) with middle-low milk flow. Test positions: (a) with weigh jar; (b) with electronic weighing "bascule" milk meter; (c) with electronic proportional milk meter

weigh jar, with an appreciable reduction of the instantaneous vacuum drops that always remain below those measured by the weigh jar, assuming maximum values not exceeding 27 kPa, for both the investigated ejections (Figures 3-Ib and 4-Ib); in particular, for smaller ejections, the increase in the instantaneous vacuum drop occurs in a much shorter time, i.e. corresponding to a less intense release of the maximum amount of milk by the animal (Figures 4-Ib, 6-Ib and 8-Ib). The vacuum fluctuations measured by the weighing «bascule» milk meter maintain a pattern quite similar to the weigh jar, with a reduction in maximum values that, for high ejections, do not exceed 35 kPa (Figure 3-IIb); whereas for more reduced ejections, as compared with the jar, the fluctuation pattern is less uniform, although maximum values do not exceed 20 kPa (Figure 4-IIb).

If the proportional milk meter is installed in the milking unit, the analysis of the measurements taken at the short milk tube highlights low values both with a high or reduced flow; instantaneous values (Figure 3-Ic and 4-Ic) reach 5-15 kPa as compared with the vacuum level established through the static mechanical tests (45 kPa), whereas fluctuations are of the order of 5-15 kPa (Figures 3-IIc and 4-IIc). Similar to other investigated cases, the maximum values refer to the trials with high milk flows.

When the measurement is taken at the claw (Figures 5,6) and at the inlet of the meter (Figures 7,8), the differences observed in the short tube tend to reduce; this occurred both during the same milking - although the pattern of instantaneous values is quite similar to the one of the previous cross-sections - and between milkings with the different metering systems. Attenuation is particularly evident for the vacuum variations measured with the jar (Figures 3a, 5a and 7a; 4a, 6a and 8a) that, in terms of instantaneous values and fluctuations, tend to be smaller in the long tube, thus becoming of the same order as those measured with the milk meters (Figures 5b, 5c, 7b and 7c, 6b, 6c, 8b and 8c).

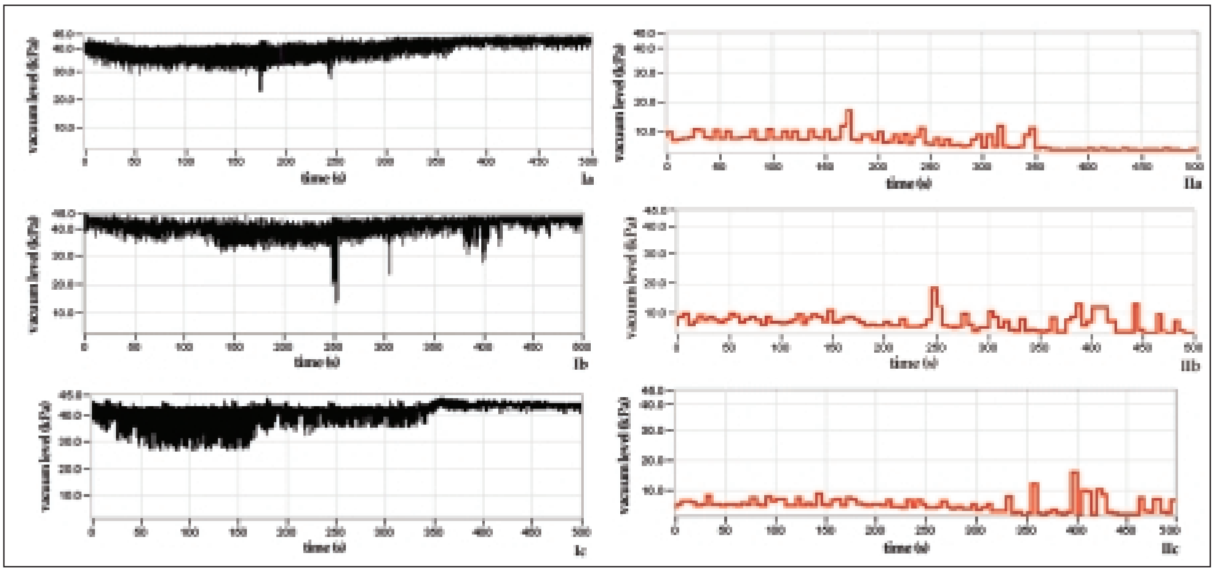

Figure 5
Section B (Fig. 2): instant vacuum level (I) and fluctuations (II) with high milk flow. Test positions: (a) with weigh jar; (b) with electronic weighing “bascule” milk meter; (c) with electronic proportional milk meter

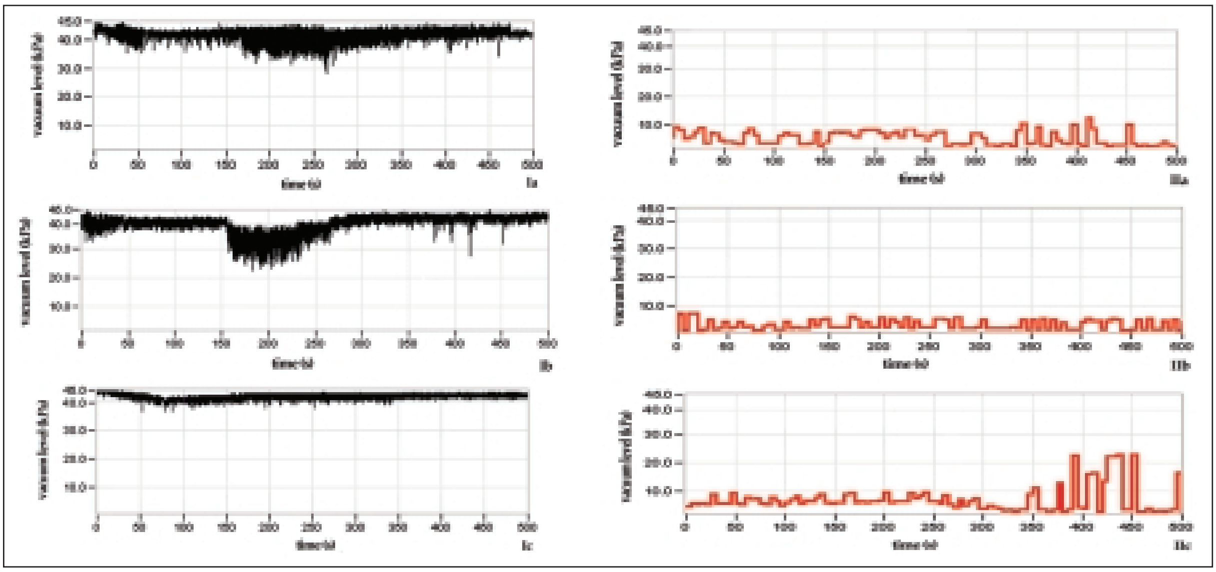

Figure 6
Section B (Fig. 2): instant vacuum level (I) and fluctuations (II) with middle-low milk flow. Test positions: (a) with weigh jar; (b) with electronic weighing “bascule” milk meter; (c) with electronic proportional milk meter

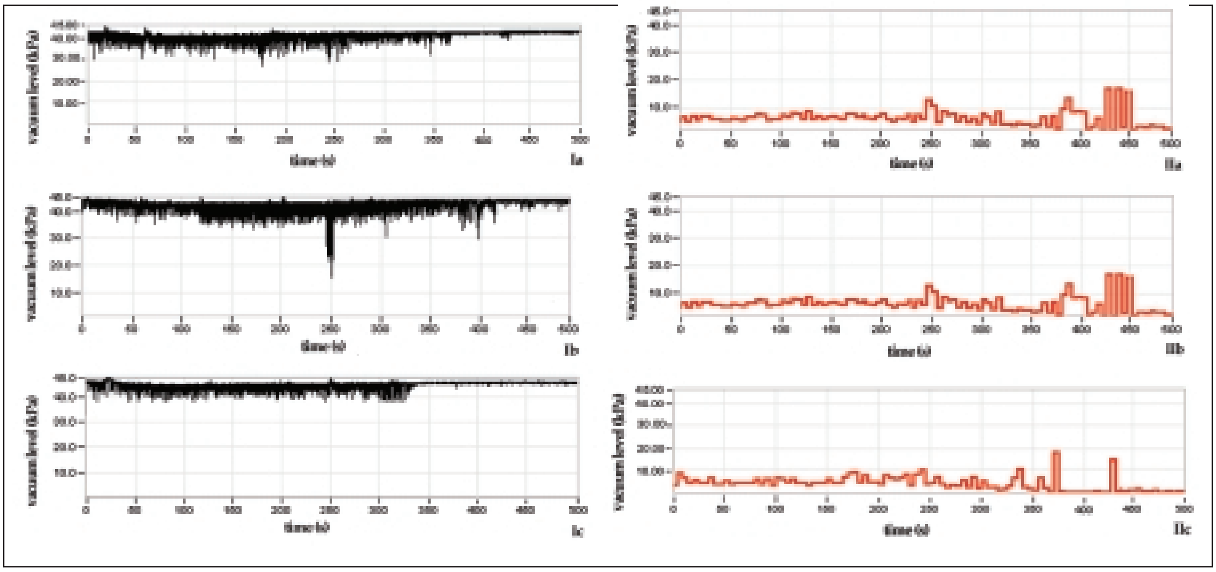

Figure 7
Section C (Fig. 2): instant vacuum level (I) and fluctuations (II) with high milk flow. Test positions: (a) with weigh jar; (b) with electronic weighing “bascule” milk meter; (c) with electronic proportional milk meter

Milk meters exhibit much smaller fluctuations and, in some cases, at the attachment with the long tube, vacuum fluctuations of the same intensity as those measured at the upstream sections are observed. In particular, at the end of milking, at the inlet of the milk meter, vacuum fluctuations not greater than 20 kPa (Figures 7-IIb, 8-IIb and 7-IIc) do occur and, though not being excessive, they are slightly greater than those measured at that very moment at the claw (Figures 5-IIb, 6-IIb and 5-IIc). The overall analysis of data (Table III) gives comparable results for the jar, both with high milk flows and with smaller ones, whereas, for electronic milk meters, critical operational conditions, greater than 2.7 kg/min, do occur upon very high milk ejections. In such cases, with respect to smaller flow conditions, the increase in average fluctuations at the short tube is 111.6% for the electronic weighing «bascule» milk meter and 76.2% for the proportional milk meter (Table III); the increase for the same values measured at the inlet of the milk meters is smaller: 35.4% for the electronic weighing «bascule» milk meter and 58.3% for the proportional milk meter (Table III). The latter is the one presenting the least deviation of the minimum vacuum value from the working vacuum level: not greater than 23.5 kPa at the short tube and 13 kPa at the other measuring cross-sections. In the two other cases, such a deviation is greater and, at the same cross-sections, it is greater than the corresponding one of the proportional milk meter by about 10 kPa, with very high peaks (Table III)

Table III
Measurements summarizing chart (middle of 165 values)

High level milking: middle flow 3,18 kg/min (s = 0,18)						
Section of measure	Minimum vacuum instantaneous level (kPa)	σ	Maximum vacuum instantaneous level (kPa)	σ	Fluctuation (kPa)	σ
A-proportional milk-meter	20.80	2.13	44.20	0.92	7.40	0.54
B-proportional milk-meter	34.67	1.46	43.93	0.36	5.00	0.35
C-proportional milk-meter	30.81	2.38	44.73	0.60	3.80	0.36
A-weighing “bascule” milk-meter	9.88	0.71	44.80	1.40	14.60	1.20
B-weighing “bascule” milk-meter	12.21	0.44	44.43	1.29	7.20	0.40
C-weighing “bascule” milk-meter	13.43	0.42	44.07	0.24	6.50	0.37
A-weigh jar	3.77	0.37	44.50	1.04	15.50	0.73
B-weigh jar	13.97	0.94	43.46	1.28	7.10	0.54
C-weigh jar	15.85	1.78	44.90	0.56	5.00	0.49
Low level milking: middle flow 1,57 kg/min (s = 0,07)						
Section of measure	Minimum vacuum instantaneous level (kPa)	σ	Maximum vacuum instantaneous level (kPa)	σ	Fluctuation (kPa)	σ
A-proportional milk-meter	30.81	3.35	44.73	0.84	4.20	0.25
B-proportional milk-meter	25.27	2.31	43.90	0.41	3.60	0.28
C-proportional milk-meter	31.01	1.51	44.07	0.31	2.40	0.16
A-weighing “bascule” milk-meter	14.39	1.14	43.40	1.40	6.90	0.36
B-weighing “bascule” milk-meter	23.59	2.19	44.58	1.29	5.20	0.24
C-weighing “bascule” milk-meter	26.15	2.25	44.58	0.24	4.80	0.37
A-weigh jar	4.50	0.37	44.20	1.04	11.80	0.57
B-weigh jar	18.31	1.13	43.71	1.28	7.20	0.27
C-weigh jar	17.85	1.80	44.07	0.56	2.40	0.23

Discussion

The graphs of the instantaneous vacuum level (figures 3-I, 5-I, 7-I, 4-I, 6-I and 8-I) highlight the drops occurred over very short time periods, that are generally adjusted in equally short time periods by the effective vacuum reserve, and are to be attributed to the admission of undesired air to the measuring milking unit or adjacent ones. An example of this type are the vacuum variations due to the introduction of air at the end of milking, from the teat cup cluster to the short milk tube.

This emphasises, in particular, the difficulty of taking this type of measurements, though full care was taken to prevent the accidental admission of air; these trials are equally important for the global assessment of the plant, since they point out to constraints that might not be detected in the absence of cows being milked and milk flowing through. Greater intensity and frequency of instantaneous vacuum level drops, at the short milk tube and as a result of high ejections, are mainly due to the occurrence of turbulent flow in the milk pipelines plus, in case, milk back-flow to the udder. On the other hand, the cross-section of the short tube is much smaller and the influence of cyclic fluctuations (due to the opening and closing of liners) is much greater. Whereas, the occurrence of vacuum level drops at the attachment with the milk meter or the weigh jar could be due to turbulence or the admission of air at the metering cross-section.

Therefore, referring to the vacuum variations in the time intervals during which the cow releases maximum milk flow, the considerable reduction of total values downstream of the short milk tube leads to state that in this specific case, the cyclic fluctuations are the highest as compared with all the other measured ones and that, in the investigated plant, the pump allowed to re-establish the working vacuum in generally acceptable time periods. On the other hand, the extent of

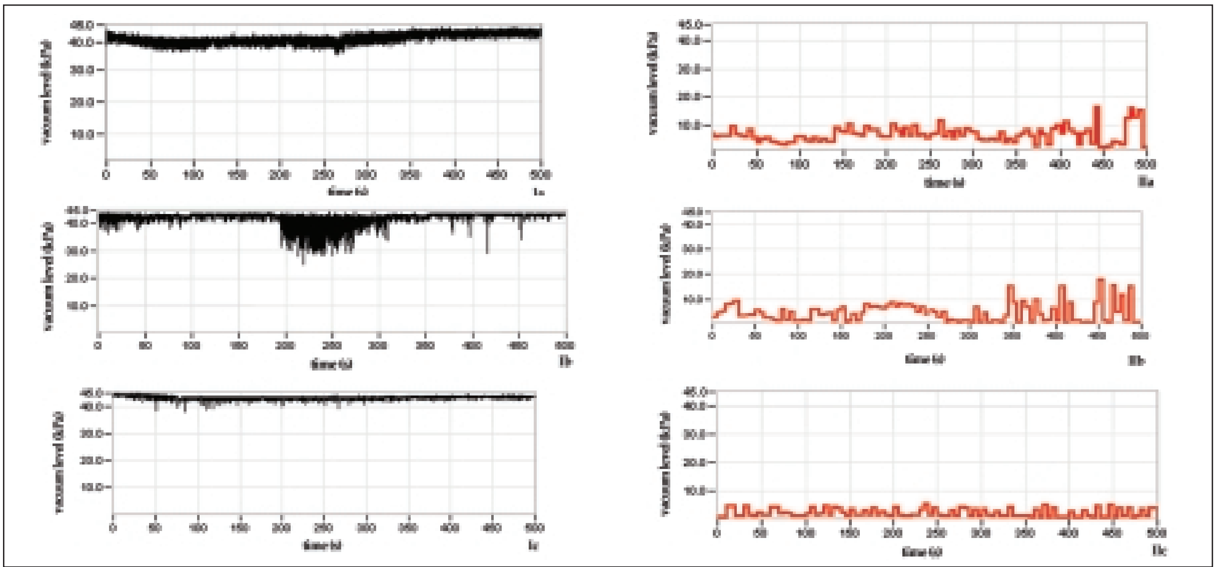

Figure 8

Section C (Fig. 2): instant vacuum level (I) and fluctuations (II) with middle-low milk flow. Test positions: (a) with weigh jar; (b) with electronic weighing “bascule” milk meter; (c) with electronic proportional milk meter fluctuations at the same gauging cross-section varies depending on the investigated gauging system; therefore, we can infer that the insertion of the meter in the milk pipe, since it is an obstacle to the milk flow, has generated acyclic fluctuations of different extent depending on the type of gauge installed.

Critical working conditions of electronic milk meters with flows greater than 2.5 kg/min are due to the milk flow conditions through the meter; in the weighing «bascule» milk meter, a very high flow tends to emphasize the «shaking» effect due to the alternate movement of the tipping tray. Whereas in the proportional milk meter, milk may flow back as a result of greater opening and closing frequency of the inlet valve to the measuring chamber.

As for the vacuum fluctuations, the weigh jar maintains rather constant performance in both the investigated flow conditions; this indicates that such a solution brings a minimum effective vacuum reserve just downstream from the teat cup cluster. But, such an advantage was not sufficient to prevent the weigh jar from producing the highest vacuum variation values, especially at the short tube. The main reasons of the latter constraint are the head losses at the components usually present in such plants, like the flow indicator, as well as more chances for the external air to enter through fittings and valves at the attachment cross-section.

As from the above, it is evident that the observed acyclic vacuum fluctuations, in the case of a wrong design of the plant or its inadequate management during maintenance and milking, could reach much higher values and be seriously harmful to the sanitary state of the udder if they are not immediately compensated through the effective vacuum reserve.

Therefore, the milking data meter has to be conceived and designed to oppose the least obstacle to the air-milk flow and to minimize the risk of external air admittance at the gaskets and fittings; to this purpose, of special importance is the fluid-dynamic study of the path and/or the cross-section where the measurement of the amount of milk is taken.

In view of that, an innovatory type of milk flow measurement upon milking is the infrared system (Figure 9) where the measurement is taken through a sensor working in the near infrared. The air-milk mixture flows through a

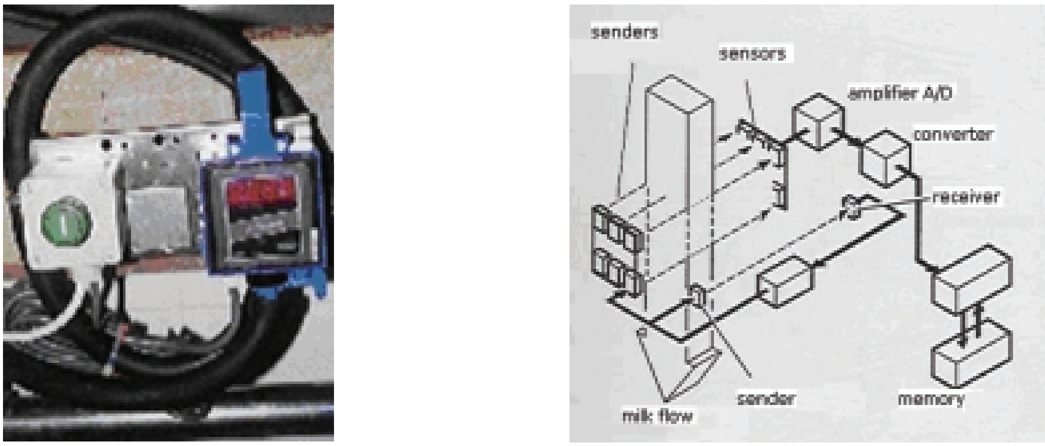

Figure 9
Infrared electronic milk-meter (diagram) (DELAVAL, Tumba, Sweden -mod. Flo Master FF)

measuring cell without interfering with any moving part.

Milk yield is estimated by dividing the flow into micro-layers, and a rapid internal processor with a frequency exceeding 90 000 Hz samples the flow rate, the duration and layer density. However, in such milk meters if, for essentially for measurement accuracy reasons, the fluid were obliged to follow a tortuous path or to slow down suddenly, very high head losses would occur.

Finally, this study points to the need of defining national and international reference technical standards also for the dynamic test of milking plants and their components, as it is the case for the sizing and static test.

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