

## VACUUM FLUCTUATION IN A 2×3 TANDEM MILKING PLANT IN DEPENDENCE ON THE VACUUM CONTROL METHOD

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### Abstract

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Vacuum fluctuation was measured using three different vacuum control methods. Firstly, the use was made of a control valve delivered by the manufacturer; then, an additionally installed frequency converter was used. Lastly, a frequency converter fitted with the stabilisation device prototype was used. First, the control sensitivity according to ISO was measured in all three alternatives. Then the vacuum fluctuation during milking was measured. To conduct the measurements under objectively identified conditions, another measurement was conducted with the air feed during milking being replaced with a precisely defined variable flow rate.

The conducted measurement confirmed the fact that when the frequency converter is used, the vacuum fluctuation in the stabilised condition is at the same level as when the control valve is used. If there are sudden changes in the flow rate and the frequency converter is used, the vacuum fluctuation increases. The proposed stabilisation device prototype can reduce the fluctuation.

Keywords: vacuum fluctuation, vacuum control methods, frequency converter

### INTRODUCTION

Presently, frequency converters are commonly applied to drive the milking machine vacuum pumps as this result in major electricity cost reduction. Their frequent application is encouraged by their relatively low price and the resulting short payback periods. Rasmussen (2005) states that the payback period is approx. 4.8 years. Later Olejník and Pavelková (2008) gave a payback period of 2 years. Since then, the prices of frequency converters have dropped even further and their payback period is currently even less than one year (Kudělka *et al.*, 2012). The use of frequency converters results in power cost reduction ranging around 50%. Olejník and Pavelková (2008) give a cost reduction value of 50–58%. To a certain extent, the reduction percentage is affected by the vacuum pump delivery given the size of the milking plant.

If an unnecessarily high performing vacuum pump is selected, the reduction appears to be high, too. To compare various systems, the reduction should be calculated in relation to the performance of the vacuum pump defined in accordance with the standard ISO 5707. Rasmussen measured the absolute reduction and states that the automatic milking system DeLaval VMS showed a saving of 20 kWh of electric power over 24 hrs of frequency conveyer-driven vacuum pumps being in use (Rasmussen, 2005). The vacuum pump revolution control has been dealt with for a relatively long time (Dunn, 1996) and research in the field of milking has focused on vacuum control in the individual teat cups (Ströbel *et al.*, 2012; Ströbel *et al.*, 2013). In practice, certain problems are still encountered when using the frequency converters.

Vacuum control by changing the revolutions entails certain deterioration in the vacuum stability.

Vacuum fluctuation is reflected in the deformation curve of the teat liner. The teat liner deformation curve in dependence on vacuum was described by Karas *et al.* (2003a, 2003b). Greater vacuum fluctuation is determined by the fact that air flow rate changes, i.e. during the teat cup application, occur very fast and changes in the electric motor and vacuum pump revolutions take place at a slower pace, which is caused by the rotating part inertia. Therefore, milking machines with frequency converters are also fitted with a conventional control valve, which is set to a value that is by ca. 1 kPa higher than the vacuum level set for the frequency converter control. If the air flow rapidly drops, the vacuum would be increasing for a short period of time. The control valve prevents from the increase exceeding 1 kPa. Contrariwise, when the flow rate increases, no system preventing from the vacuum drop is available and the vacuum changes depend on the time over which the vacuum pump revolutions reach the desired value.

Therefore, the objective of this study is to validate the applicability of the manufactured stabilisation device prototype in a milking plant using a frequency converter to control the vacuum.

## MATERIAL AND METHOD

To validate the proper functioning of the stabilisation device, vacuum fluctuation was measured in a tandem milking plant 2×3. Selection was intentionally made of a small milking plant as it has a well-tested system installed as a modified lab-scale model and therefore it was advisable to use it in a smaller-scale milking system. The milking plant is equipped with a rotary paddle vacuum pump with an actual delivery of 945 lmin<sup>-1</sup> at a 50 kPa vacuum. The milking machine vacuum system capacity (milk pipe, air pipe, air tank, collection vessel) totals 112 l. Three vacuum control alternatives were measured:

1. Control valve delivered by the manufacturer.
2. Additionally installed frequency converter.
3. Frequency converter complete with the stabilisation device prototype.

Firstly, control sensitivity according to the ISO standard was measured for all three alternatives. Each measurement was conducted three times and the mean value was calculated. Secondly, the vacuum fluctuation during milking was measured. The vacuum fluctuation measurement was conducted by means of the Pulsator tester PT IV instrument measuring the vacuum for a period of 60 s and over this time interval we determined the maximum, average and minimum vacuum values. The vacuum fluctuation was then calculated as a difference between the maximum and minimum value.

Given the fact the air flow rate in the milking device changes in the course of milking in dependence on the operations being performed, the course of the changes is irregular and also depends on the skills of the milkers. To get comparable

results, the measurements of each alternative were divided into the two following groups:

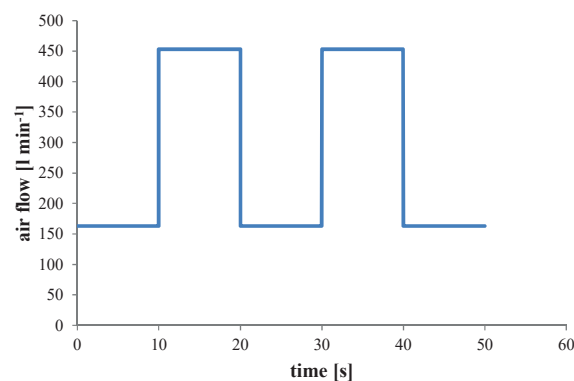
- a) milking performed only during the measurements,
- b) milking and teat cup application performed during the measurements.

In the group a) there were at all times six milked dairy cows because individual replacement of dairy cows occurs in the tandem milking plant and once the milking of one cow is completed, another one takes its place immediately. In the group b), this was about installing teat cups in one of the six boxes while milking was taking place in the other five boxes. In the group a) as well as in the group b), a total of ten measurements were performed and statistically processed by the Tukey test in order to assess the statistical significance of differences among all the measurement combinations.

Although intervals with an approximately identical activity were selected during milking, the air flow was not absolutely the same. In particular, when attaching the teat cups, the flow rate values may strongly differ and the application time may also be different. To conduct the measurements in objectively identical conditions, another measurement was carried out with the air consumption during milking being replaced by a precisely defined variable flow rate, see Fig. 1.

An electromagnetic valve connected instead of the collector to the central suction piece provided for the variable flow. The operation of the electromagnetic valve was controlled by a time relay 10 s opening intervals alternated with 10 s closing intervals. Once in the open position, the valve sucked 290 lmin<sup>-1</sup>. The total air flow was then gradually increased by activating pulsators and sucking in air via two different calibrated openings. More air got into the milking machine vacuum system through the leaking spots. The measurement determined that each activated pulsator sucked in 18 lmin<sup>-1</sup>, the calibrated openings sucked in 100 lmin<sup>-1</sup> and 200 lmin<sup>-1</sup> respectively, leakage sucked in 55 lmin<sup>-1</sup>. The milking machine setup for the measurement is shown in Tab. I.

Each measurement was repeated ten times and the measured values were statistically processed. To



1: Volume of air sucked in by the milking machine

I: Milking machine setup for the measurement

Measurement	Milking machine setup	Minimum air flow l min <sup>-1</sup>	Maximum air flow l min <sup>-1</sup>
1	1 pulsator	73	363
2	3 pulsators	109	399
3	6 pulsators	163	453
4	6 pulsators + 100 l min <sup>-1</sup>	263	553
5	6 pulsators + 200 l min <sup>-1</sup>	363	653

process the data, a use was made of the dispersion analysis which was employed to determine the statistical significance of the difference between the measured values determined by the individual vacuum control methods. The method of subsequent testing using the Tukey range test assessed the statistical significance of differences between all the measurement combinations.

## RESULTS AND DISCUSSION

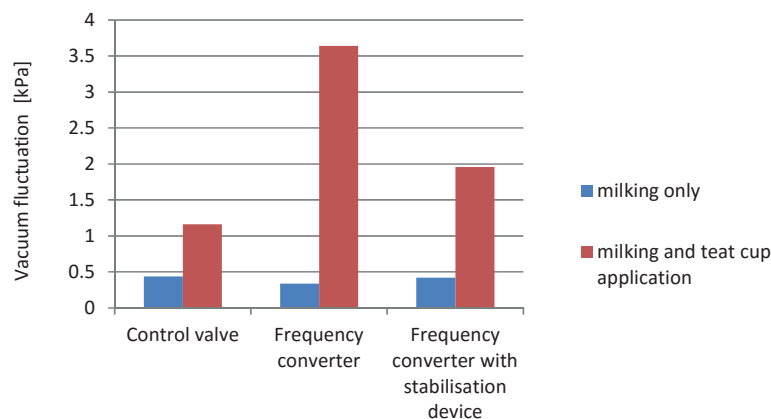
The control sensitivity measurement conducted according to ISO 6690 resulted in the following average values. When the control valve was used, the value totalled 0.17 kPa; when the frequency converter was used, the value totalled 0.33 kPa and when the frequency converter with the stabilisation device was used, the value was 0.23 kPa. Reaching the very low values resulted from the fact that this milking plant is very small. Furthermore, the control valve is not located at the vacuum pump, but directly in the milking parlour. The frequency converter vacuum sensor is also fitted in the milking parlour. The differences are minimal and this measurement is better in assessing the functioning of the control in a stabilised condition. Olejník and Pavelková (2008) stated that the use of a frequency converter improved the sensitivity by 15%. Our results did not confirm this. In our measurements, the measured values were very low and the differences were not statistically significant in any of the cases.

The results of the vacuum fluctuation measurement are shown in Fig. 2. The blue column shows the fluctuation during milking without attaching

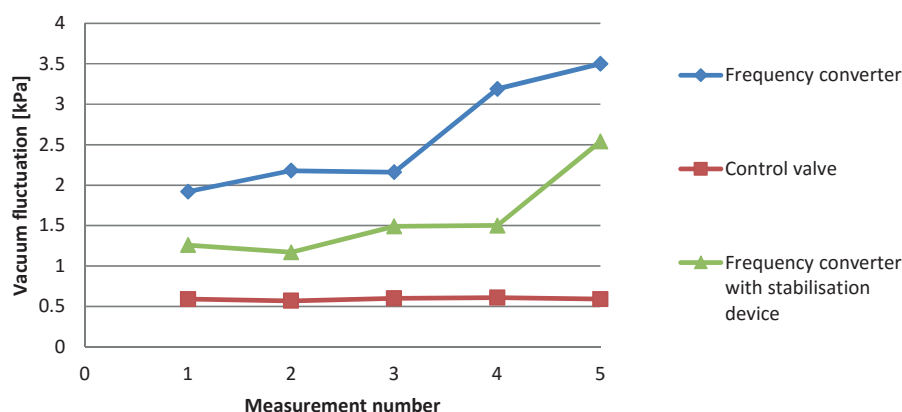
the teat cups during the measurement. In these cases, the vacuum fluctuation is very low. The lowest value of 0.34 kPa was achieved with the frequency converter control. Values below 0.5 kPa were also achieved in the other measurements, though. The differences were not statistically significant in any of the cases.

Completely different results were achieved when the teat cups were applied during the vacuum fluctuation measurement. The best results were achieved when using regulation based on the control valve when the mean vacuum fluctuation value reached 1.16 kPa. When the frequency converter was used, this value rose to 3.64 kPa. By applying the stabilisation device, the mean vacuum fluctuation value dropped down to 1.96 kPa. Differences between all the values are statistically highly significant. Olejník and Pavelková (2008) state that the vacuum fluctuation during the frequency converter control goes up to 2 kPa but they do not specify conditions under which the values were measured. Kukla (2007) gives the vacuum fluctuation up to 2.5 kPa. Vrba (2009) state that the vacuum fluctuation during laboratory measurement ranged between 1.1 kPa–1.8 kPa. Our measured results are worse. The vacuum fluctuation below 2 kPa was only achieved when the stabilisation device was applied.

When the vacuum fluctuation measurement was carried out under a precisely defined variable air flow rate, the lowest values were achieved when the control valve was used. The difference between the maximum and minimum vacuum value regardless of the milking machine setup was approximately



2: Vacuum fluctuation at milking



3: Vacuum fluctuation at a variable flow rate

0.6 kPa. The frequency converter control clearly indicates that the fluctuation magnitude depends on the air flow rate through the milking machine. During the first three measurements, the vacuum fluctuated around 2 kPa. With the increasing flow rate, it increased to values exceeding 3 kPa and the measurement number 5 reached a value of 3.5 kPa. By connecting the prototype of the stabilisation device it was possible to reduce the vacuum fluctuation over the entire measured range. In measurements no. 1–4 the fluctuation ranged between 1.2 kPa–1.5 kPa. In measurement No. 5,

when the flow rate was the highest, the fluctuation increased to a value of 2.5 kPa.

To process the data, we employed the dispersion analysis based on which we determined the statistically highly significant difference in the measured values between the individual vacuum control methods. After that, we tested the differences between the specific control methods at the identical flow rate. The testing method – Tukey test – revealed statistically highly significant differences between all measurements combinations at all the set flow rates.

## CONCLUSION

Vacuum fluctuation was measured using three different vacuum control methods. Firstly, the use was made of a control valve delivered by the manufacturer; then, an additionally installed frequency converter was used. Lastly, a frequency converter fitted with the stabilisation device prototype was used. First, the control sensitivity according to ISO was measured in all three alternatives. Then the vacuum fluctuation during milking was measured. To conduct the measurements under objectively identified conditions, another measurement was conducted with the air feed during milking being replaced with a precisely defined variable flow rate. Using this mode, we measured a total of five different levels of fluctuating flow rates. Using the control sensitivity measurement according to ISO, we reached values below 0.5 kPa and the differences between the individual control methods were statistically non-significant. The results of the vacuum fluctuation measurement during milking were first evaluated during ongoing milking without attaching the teat cups during the measurement. In all cases, the vacuum fluctuation was below 0.5 kPa. The differences between the average values were not statistically significant. When the teat cups were attached during the measurement, the average value of the vacuum fluctuation using the control valve regulation was 1.16 kPa. When the frequency converter was used, this value increased to 3.64 kPa. By connecting the stabilisation device, we managed to reduce the average vacuum fluctuation value to 1.96 kPa. The differences between all the values were statistically highly significant. When the vacuum fluctuation was measured under precisely defined variable airflow rate values and a control valve was used, the vacuum fluctuation reached approximately 0.6 kPa regardless of the milking machine setup. When a frequency converter was used for the control purposes it was identified that the fluctuation depended on the airflow rate through the milking machine. At lower flow rates, the vacuum fluctuation ranged around 2 kPa. The increasing flow rate entailed an increase to values going beyond 3 kPa. By connecting the stabilisation device prototype, the vacuum fluctuation was reduced in the entire measured range down to values between 1.2 kPa–1.5 kPa. Only during the measurement with the highest flow rate did the fluctuation rise to 2.5 kPa. The mutual differences between all values were statistically highly significant. The conducted measurement confirmed the fact that when the frequency converter is used, the vacuum fluctuation in the stabilised condition is at the same level as when the control valve is used. If there are sudden changes in the flow rate and the frequency converter is used, the vacuum fluctuation increases. The proposed stabilisation device prototype can reduce the fluctuation.

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