VACUUM CONTROL OF MILKING MACHINES BY USING THE FREQUENCY CONVERTER AND THE REDUCING VALVE

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Abstract: *The article deals with the milking machine vacuum system which is designed for the vacuum level control with a special reducing valve. Vacuum Milking machines with the vacuum pumps without frequency converter have the constant rotation speed and vacuum level is controlled by the control valve. By using the frequency converter for controlling electric motor of vacuum pump the electric energy consumption significantly decreases but the vacuum fluctuation is higher. The vacuum pump of the designed vacuum system is connected to the air container. The vacuum level of the air container is controlled by the frequency converter on a higher level than the level of the milking vacuum. Newly designed reducing valve is placed between the air container and the vacuum pipeline system of the milking machine. The reducing valve controls the air which flows through it and the vacuum is reduced on the required level and is stabilized. But the energy consumption is a little bit higher.*
KEY WORDS: MILKING MACHINES, VACUUM PUMP, VACUUM LEVEL CONTROL, FREQUENCY CONVERTER

1. *Introduction*

If a constant vacuum is to be obtained by applying a standard regulation method of vacuum magnitude, the control valve must suck so much atmospheric air into the vacuum system that the sum of the air amount sucked in by the milking machine and the control valve within a time interval is constant. The vacuum pump works at a full efficiency irrespective of the actual consumption by the milking machine. For this presently, frequency converters are commonly used to drive the vacuum pumps of milking machines as this result in major electricity consumption reduction. Their frequent using is encouraged by their relatively low price and the resulting short payback periods. Rasmussen states that the payback period is approx. 4.8 years [RASMUSSEN, 2005]. Olejník later gave a payback period of 2 years [OLEJNÍK et al., 2008]. Since then, the prices of frequency converters have dropped even further and their payback period is currently even less than one year. Kudělka features already only about 200 days [KUDĚLKA et al., 2012]. The use of frequency converters results in power consumption reduction ranging around 50 %. Olejník gives a cost reduction value of 50 - 58 % [OLEJNÍK et al., 2008], Kudělka features 57 % [KUDĚLKA 2016]. 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 capacity vacuum pump is selected, the reduction appears to be high, too. 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 converter-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.

2. *Prerequisites and means for solving the problem*

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 [KARAS et al., 2003]. 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.

To validate the proper functioning of the stabilisation device, vacuum fluctuation was measured in a tandem milking parlour 2x3 with very good results [FRYČ et al., 2016]. The same device was tested in large herringbone milking parlour 2x13, but results was not satisfactory [FRYČ et al., 2015]. Therefore, was made other newly designed reducing valve. The objective of this study is to validate the applicability of the manufactured stabilisation device prototype in laboratory.

3. *Solution of the examined problem*

One of the basic demands for milking machines is to maintain a constant vacuum level if air consumption by milking machine is changed. The reduce valve prototype was manufactured by Utility model 14020 [FRYČ, 2004], but was modified for higher air flow rate. To validate the proper functioning of the stabilisation device with reduce valve, vacuum fluctuation was measured in laboratory, where was installed milking machine by Fig. 1.

The vacuum pump of the designed vacuum system is connected to the air container AC1. The vacuum level of the air container AC1 is controlled by the frequency converter on a higher level than the level of the milking vacuum. Newly designed reducing valve is placed between the air container AC1 and the vacuum pipeline system of the milking machine (air container AC2 at experimental device). The reducing valve controls the air which flows through it and the vacuum is reduced on the required level and is stabilized. The experiment milking plant is equipped with oil lubricated rotary vane vacuum pump with an actual delivery of 1564 $l.min^{-1}$ at a 50 kPa vacuum. Working vacuum in experiments was 45 kPa.

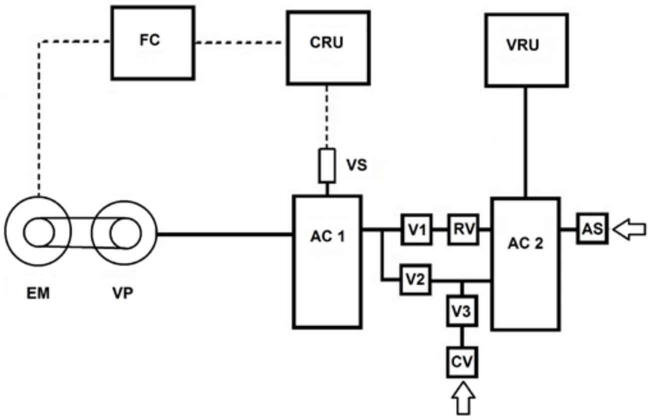

Fig. 1 *Scheme of experimental device*

FC – frequency converter, CRU – control and record unit, VRU – vacuum record unit, EM – electric motor, VP – vacuum pump, VS – vacuum sensor, AC1, AC2 air container, V1, V2, V3 – closing valve, RV – redicing valve, CV – control valve, AS – air sucking control device

The milking machine vacuum system capacity (pipe lines, air containers) totals 254 l. Three vacuum control alternatives were measured:

1. Control valve
   (valve V1 closed, valve V2 open, valve V3 open)

2. Frequency converter
   (valve V1 closed, valve V2 open, valve V3 closed)

3. Frequency converter complete with the stabilisation device (reducing valve prototype)
   (valve V1 open, valve V2 closed, valve V3 closed)

The vacuum fluctuation measurement was conducted by means of the Pulsatortester 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.

To conduct the measurements in objectively identical conditions, measurement was carried out with the air consumption by a precisely defined variable flow rate (Q_1, Q_2, Q_3) see Fig.2. 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. 15 s opening intervals alternated with 15 s closing intervals. Once in the open position, the valve sucked 100 l min^{-1}. The total air flow was then gradually increased by sucking in air via three different calibrated openings. More air got into the milking machine vacuum system through the leaking spots. The calibrated openings sucked in 400 l min^{-1}, 600 l min^{-1} and 800 l min^{-1}. The measurement determined that leakage sucked in 22 l min^{-1}.

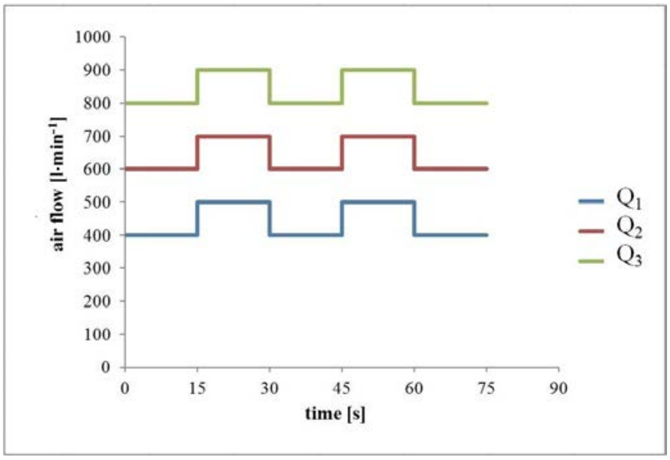

Fig. 2 *Variable flow rate of air sucked in by the milking machine*

Pressure difference is necessary for reduce valve using. The vacuum level of the air container AC1 is controlled by the frequency converter on a higher level than the level of the working vacuum. Three different levels of vacuum were tested 48 kPa, 51 kPa and 54 kPa. Electric energy consumption was recorded during all experiments.

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

4. *Results and discussion*

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 average difference between the maximum and minimum vacuum value was 1.1 kPa.

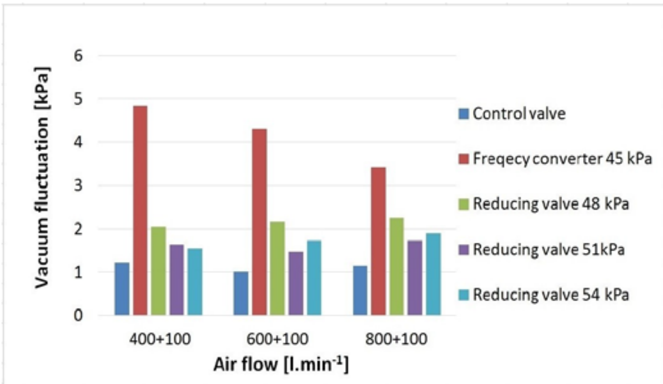

Fig. 3 *Vacuum fluctuation at measurement*

During frequency converter control the first measurement (flow rate Q_1) was fluctuation 4,8 kPa. With the increasing flow rate, it decreased to values 4.3 kPa (flow rate Q_2) and 3.4 kPa (flow rate Q_3). By connecting the prototype of the stabilisation device with reducing valve was indicated that the vacuum fluctuation is independent on air flow rate, but depends on the vacuum level at air container AC 1. When the vacuum level in the air container AC 1 is

48 kPa the average fluctuation is 2.1 kPa. When the vacuum level in the air container AC 1 is 51 kPa the average fluctuation is 1.6 kPa. When the vacuum level in the air container AC 1 is 54 kPa the average fluctuation is 1.7 kPa. Olejník and Pavelková and other authors state that the vacuum fluctuation during the frequency converter control goes up to 2 kPa when being used on farms [OLEJNÍK et al., 2008]. The comparison of our results with the experiments on farms isn't appropriate. The resembling measurements like ours were carried out by Kudělka and his results are similar [KUDĚLKA 2016].

To process the data, we employed the dispersion analysis based on which we determined that differences in the measured values between the individual vacuum control methods are statistically significant. We obtain following results: We determined the statistically highly significant difference in the measured values between the individual vacuum control methods. Difference between individual measurements with reducing valve are statistically significant only between vacuum levels 48 kPa and 51 kPa. Between other vacuum levels there are not statistically significant differences.

Comparison of electric energy consumption was carried out between vacuum control by frequency converter and vacuum control by reducing valve variations. The results of the electric energy consumption measurements are shown in Fig. 4. When the vacuum level increases the electric energy consumption increases as well. With the increasing flow rate, the differences between values of electric energy consumption increase. The use of frequency converters on farms results in power consumption reduction 50 % or more. [OLEJNÍK et al., 2008], [KUDĚLKA 2016]. We calculated the expected saving of the energy consumption. We supposed that the energy saving is 50 % in case the frequency converter is used for a vacuum control. The calculated energy saving is 46.5 % when vacuum level at air container AC1 is 48 kPa. The calculated energy saving is 42.7 % when the vacuum level at air container AC1 is 51 kPa. The calculated energy saving is 38.2 % when vacuum level at air container AC1 is 54 kPa.

To process the data, we employed the dispersion analysis based on which we determined the statistically 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 significant differences between all measurements combinations at all the set flow rates.

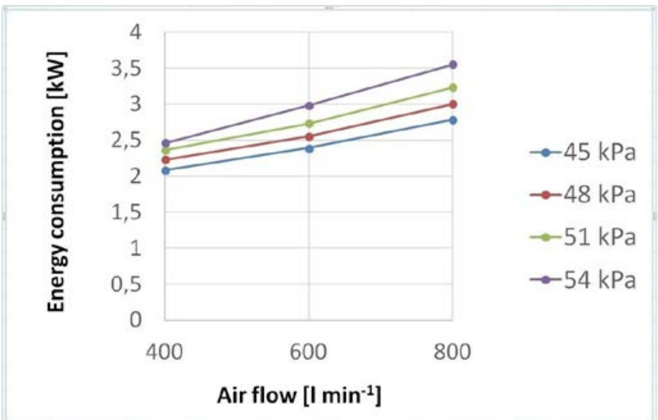

Fig. 4 *Energy consumption of vacuum pump electric motor*

5. Conclusion

The measurement we performed confirms that if a frequency converter is used, the vacuum fluctuation is at higher level as in case a control valve is used. Likewise it has been demonstrated that the proposed prototype of the stabilisation device can reduce the fluctuation. The achieved results are not as good as in case the control valve is used. On the other hand the vacuum fluctuation reduction nearly by 50 % is satisfactory. Higher energy consumption is the disadvantage of the vacuum control device with reducing valve. Saving of the energy consumption decreases from 50 % to 46.5 % in the best case. We have to choose a convenient variant with optimum vacuum fluctuation and energy consumption saving.

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