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Producing the vacuum in modern drawn milking systems

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Abstract. This paper deals with the measurement of the modern method of producing and regulating the vacuum in milking equipment which is currently in use. Individual measurements are primarily focused on evaluating the latest knowledge in the design, management and stabilization of the vacuum in modern milking systems. In the evaluation, emphasis was placed on economic efficiency with regard to energy consumption, environmental friendliness, high performance, operational reliability and ease of operation in the creation and control of the vacuum. The basic element of every milking system is the vacuum pump. This feature of the machine provides a vacuum for milking, milk transportation and for the activities of other devices whose task is, e.g., scanning the milking equipment or controlling movable barriers at milking parlours.

In this paper, a frequency converter was used, which is, used in milking technology for regulating and controlling the vacuum through changing the rotational speed of the vacuum pumps which do not require the use of centrifugal force to seal the working space to create a vacuum. The aim of the measurements using the above-mentioned inverter was to check the performance of the pump at different speeds and different vacuum levels to determine the actual air flow need over the milking cycle.

Key words: milking system, milking unit, vacuum system, vacuum regulation, vacuum air pump, frequency converter.

INTRODUCTION

The aim of this paper is to present the results of measurements and a modern method of acquisition and regulation of the under-pressure in milking equipment. As an essential machinery element of milking equipment, the vacuum pump provides under-pressure for milking, transport of milk and for the activities of other devices (scanning of the milking equipment, controlling movable barriers at milking parlours, etc.) (Walstra et al., 1999; Laurs & Priekulis, 2008). The drive of the vacuum pump is usually mediated by an electric motor and thus forms a machine set whose accessories include an air receiver, control valve, a vacuum gauge and a portion of an exhaust pipe that discharges the air sucked out by the vacuum pump (Pittermann, 2008; Pavelka & Zděnek, 2010). An oil separator is mounted at the end of the exhaust pipe at the bladed vacuum pumps, which also acts as a muffler. For vacuum pumps that do not have oil lubrication, a muffler is mounted at the end of the exhaust pipe. Standard ČSN ISO 3918 defines the terms used in the construction, manufacturing and use of milking machines for dairy cows.

Some milking equipment manufacturers have also recently begun utilizing for milking machines a vacuum pump for milking with two identical rotors with a sponge-shaped cross section, known as a Roots blower. The pistons are coupled by a pair of precisely-manufactured gears so that they have opposite direction of rotation. During rotation, spaces are created between the walls of the cylinder and the rotors connected either via a suction or discharge port; however, with regard to leakage losses, there may never be simultaneous connection to the suction and discharge. With increasing pressure ratio of p_2 p_1^{-1} leakage losses also increase, and thus a pressure ratio is selected up to a maximum of 1.8. Air vacuum pumps are widely used also thanks to substantial volume flows that can reach up to 9,000 l min^{-1} (the Roots blower with two-lobed rotors). In these vacuum pumps, the effect of leaks can also be corrected using high peripheral speeds (up to 100 m s^{-1}).

MATERIALS AND METHODS

Performance of vacuum pump – the amount of air sucked out by the vacuum pump at working temperature, specific rotations and under-pressure level at the input. It is expressed by the quantity of free air per minute (Fig. 1) (ČSN ISO 3918).

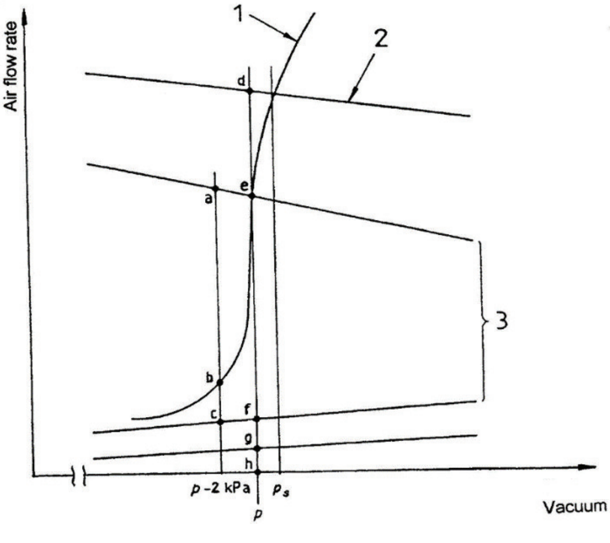


Figure 1. Relationship between pump capacity, air used by components, effective reserve, manual reserve and regulation characteristics (ČSN ISO 3918): 1 – regulation characteristic; 2 – vacuum pump capacity characteristic; 3 – air flow through regulator (spare capacity); *ab* – effective reserve; *ac* – manual reserve; *bc* – regulation loss; *dh* – vacuum pump capacity at working vacuum; *de* – air used by milking units; *fg* – air consumption of continuously operated components; *gh* – system leakage; *p* – working vacuum with all units operating; p_s – working vacuum with no unit operating.

According to ČSN ISO 5707, the vacuum pump must be able to ensure the operating requirements (milking and cleaning) of the milking equipment, including other equipment that is active continuously or intermittently during milking, which requires under-pressure for its activities and consume air. In order to ensure operating requirements, the vacuum pump should have sufficient performance so that the decrease in under-pressure in or near a collection container does not exceed 2 kPa during normal milking, including insertion and removal of cups, air leakage in teat sleeves, or if the milking equipment falls. Performance must be measured in accordance with ISO 6690.

Performance must be measured in accordance with ČSN ISO 6690. If more than one vacuum pump is installed, it must be possible to disconnect the vacuum pumps not being used.

The performance of a vacuum pump during a nominal atmospheric pressure of 100 kPa will be acquired by multiplying the measured performance of the vacuum pump by the K_1 (1) (Table 1) coefficient, which we calculate as follows:

$$K_1 = \frac{p_{\max} - p_{nom} \cdot \dfrac{p_a}{p_{an}}}{p_{\max} - p} \tag{1}$$

where: p_a – surrounding atmospheric pressure during measuring (kPa); p_{an} – nominal atmospheric pressure (kPa); p_{max} – maximum level of under-pressure with a fully-closed suction port of the vacuum pump during measuring (kPa); p – level of under-pressure in the suction port of vacuum pump (kPa); p_{nom} – nominal under-pressure level in the suction port of the vacuum pump (kPa).

Table 1. Correction coefficient K_1 for different atmospheric pressures (ČSN ISO 6690)

Surrounding atmospheric pressure during measuring p_a (kPa)	Correction coefficient K_1 for the vacuum level at the vacuum pump 50 kPa
100	1.00
95	1.07
90	1.16
85	1.28
80	1.45

The performance of vacuum pump during a nominal atmospheric pressure for a given elevation will be acquired by multiplying the measured performance of the vacuum pump by the K_2 (2) (Table 2) coefficient:

$$K_2 = \frac{p_{\max} - p \cdot \dfrac{p_a}{p_s}}{p_{\max} - p} \tag{2}$$

where: p_a – surrounding atmospheric pressure during measuring (kPa); p_s – normal atmospheric pressure for the elevation (kPa); p_{max} – maximum under-pressure level with a fully-closed suction port of vacuum pump during measuring (kPa); p – under-pressure level in the suction port of the vacuum pump (kPa).

Table 2. Correction coefficient K_2 for different atmospheric pressures (ČSN ISO 6690)

Surrounding atmospheric pressure during measuring p_a (kPa)	Correction coefficient K_2		
	Vacuum level at the vacuum pump (kPa)		
	40	45	50
109	0.94	0.92	0.91
106	0.96	0.95	0.93
103	0.98	0.97	0.96
100	1.00	1.00	1.00
97	1.03	1.03	1.04
94	1.05	1.07	1.09
91	1.09	1.11	1.14

Regulation of under-pressure via a change of vacuum pump rotations using a frequency converter – this method of regulation can be used in an under-pressure system with an air vacuum pump in which efficacy is not changed by changing the rotations, as it does not require the use of centrifugal force to seal the working parts. This regulation provides a way to reduce energy consumption and related costs. Most dairy farms use vacuum pumps with constant operation that continuously produce more under-pressure than is actually needed for the operation and cleaning of the milking system. Normally, one or two vacuum pumps are installed in a milking parlour in order to achieve a constant air flow of 170 l min^{-1} by one milking unit. The amount of air that is actually consumed for 'balanced' milking – when all of the milking units are deployed and there is no leakage, is approx. 30–60 l min^{-1} per one milking unit. Even the most advanced cleaning of a milking system requires only 60–70 l min^{-1} of air per one milking unit, if the CIP (Sanitation/cleaning station) system is well designed and balanced.

However, during milking there occur moments where an additional air flow is required due to excessive clinging, such as during the attaching the milking machine, if the teat cup does not rest against it, or if the teat cup slips from the teat of the cow.

During cleaning using the CIP method, this may, for example, occur when the air injector is in the phase of in-taking air into the piping.

The vacuum pump does not need to be operated with constant rotations in order to achieve maximum air flow, which is only required in short time intervals during milking and cleaning. Instead, it is possible to save significant amounts of electricity by equipping the vacuum pumps with a rotation regulator. Such a regulator can speed up or slow down the vacuum pump so that it produces the amount of air that is necessary for any phase of the milking or cleaning. A vacuum pump equipped with a regulator works only at approx. half of the rotations, as opposed to not being equipped with such equipment. If the vacuum pump operates at lower rotations, then it will be quieter. Due to the fact that steady milking does not require excessive air flow, a vacuum pump equipped with a regulator will operate at relatively low rotations most of the time during milking and cleaning. This will significantly contribute to reducing the noise of the vacuum pump. Running a vacuum pump at lower rotations has a positive effect on the bearings and other internal components of the vacuum pump, which contributes to prolonging its lifespan. This is one more reason why a vacuum pump should be equipped with a regulator.

In view of the above facts, a parallel milking parlour of the most commonly used size in the Czech Republic, 2 x 8, was selected for further evaluation.

Own measuring – measuring was carried out for a 2 x 8 parallel milking parlour (Table 3) with the following objectives:

1) To verify the performance of the vacuum pump declared by the manufacturer at various rotations of the vacuum pump (Tables 4, 5), and at various under-pressure levels;

2) To determine the current air flow requirement during the course of the entire milking cycle, and to ascertain the electricity demands for creating the necessary amount of under-pressure using a frequency convertor as an under-pressure regulator (Fig. 2) and without using a convertor, wherein a control valve regulates the under-pressure; compare the measured values and determine the percentage of electricity savings during individual milking phases.

Table 3. Basic parameters of measured milking parlour

Parameter	Value	Unit
Type of milking parlour	parallel with rapid withdrawal	-
Size of milking parlour	2 x 8	-
Performance of milking parlour specified by the manufacturer	80	Dairy cows h^{-1}
Working under-pressure	42	kPa

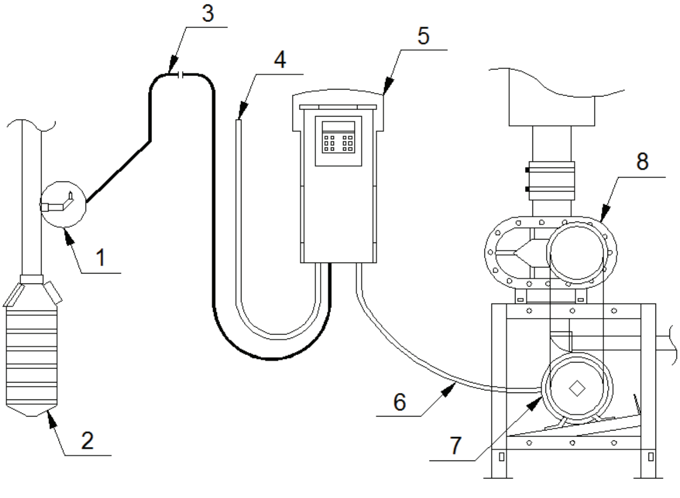


Figure 2. Connection diagram of frequency convertor (ACS 550-01-08A8-4) to the motor of the vacuum pump: 1 – sensor; 2 – separator; 3 – shielded cable; 4 – CYKY cable; 5 – frequency convertor; 6 – CYKY cable; 7 – motor; 8 – vacuum pump.

Table 4. Basic parameters of measured vacuum pump

Parameter		
Type	Bou-Matic AIR-STAR BP 140	
Model	GACHDPA 0040	
	Value	Unit
Minimal rotations	1,000	rotations minute^{-1}
Maximum rotations	3,000	rotations minute^{-1}
Nominal rotations	2,920	rotations minute^{-1}
Nominal performance at 50 kPa	1,960	L min^{-1}
Reduction ratio (vacuum pump/motor)	1.277	-

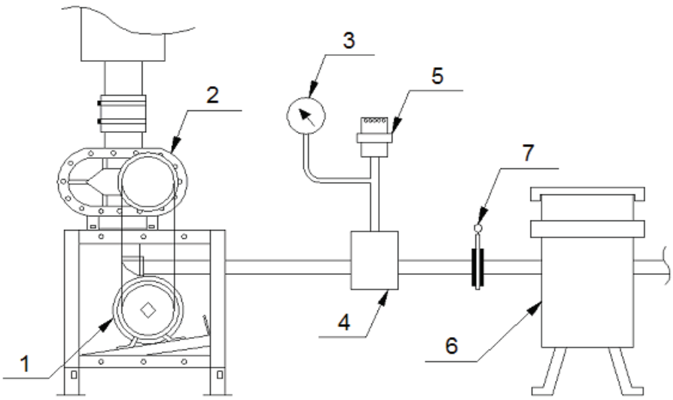


Figure 3. Diagram of the measurement of the performance of the vacuum pump: 1 – motor; 2 – vacuum pump; 3 – vacuum gauge; 4 – valve; 5 – flow meter; 6 – filter; 7 – slide.

Table 5. Basic parameters of vacuum pump motor

Parameter	Value	Unit
Nominal rotations	1,800	rotations minute^{-1}
Nominal performance	7.5	kW

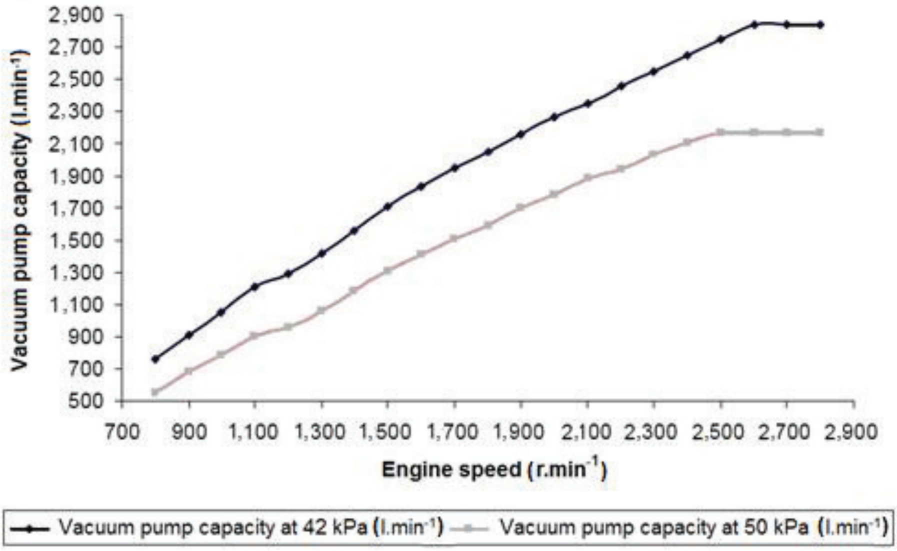
RESULTS AND DISCUSSION

The performance of the vacuum pump was measured using a frequency convertor by which the rotations of the motor were set from 800 rotations minute^{-1} intermittently by 100 rotations, up to the maximum permitted number of rotations of the motor, i.e. 2,820 rotations minute^{-1}.

Using a set for measuring the performance of a vacuum pump that contains a flow meter and vacuum gauge, the performance of the vacuum pump was measured at an under-pressure of 50 kPa, and at a working under-pressure of 42 kPa (Table 6). During this measurement, the under-pressure piping was closed using a slide in front of the air filter of the vacuum pump (Fig. 3). The values are specified in Graph 1.

Table 6. Values from measuring the performance of the vacuum pump

Rotations of motor	Rotations of vacuum pump	Frequency	Performance	Performance 42 kPa	Frequency	Performance	Performance 50 kPa
rotations minute^{-1}	rotations minute^{-1}	Hz	kW	l min^{-1}	Hz	kW	l min^{-1}
800	1,021	27.2	1.8	760	27.3	2.1	550
900	1,149	30.5	1.9	910	30.6	2.2	680
1,000	1,277	33.8	2.1	1,050	33.9	2.5	780
1,100	1,404	37.2	2.4	1,210	37.3	2.7	900
1,200	1,532	40.5	2.6	1,290	40.6	3.0	960
1,300	1,660	43.8	2.8	1,420	43.9	3.2	1,060
1,400	1,787	47.2	3.1	1,560	47.2	3.5	1,180
1,500	1,915	50.5	3.3	1,705	50.6	3.8	1,310
1,600	2,043	54.0	3.5	1,830	54.1	4.0	1,405
1,700	2,170	57.4	3.8	1,950	57.5	4.3	1,510
1,800	2,298	60.8	4.1	2,050	60.9	4.7	1,590
1,900	2,426	64.2	4.4	2,160	64.4	5.0	1,700
2,000	2,553	67.7	4.7	2,270	67.9	5.3	1,780
2,100	2,681	71.3	5.1	2,350	71.5	5.7	1,880
2,200	2,809	74.8	5.5	2,460	75.1	6.2	1,940
2,300	2,936	78.4	5.8	2,550	78.6	6.5	2,035
2,400	3,064	81.9	6.2	2,650	82.3	7.0	2,110
2,500	3,192	85.6	6.5	2,750	86.4	7.5	2,170
2,600	3,319	89.4	7.1	2,840	86.7	7.6	2,170
2,700	3,447	90.5	7.3	2,840	86.9	7.7	2,170
2,800	3,574	90.5	7.3	2,840	86.9	7.7	2,170



Graph 1. Graphical representation of measuring the performance of the vacuum pump.

The measured values show that the vacuum pump fulfils the performance declared by the manufacturer, as the actual measured performance during vacuum pump rotations of 2,920 rotations minute^{-1} is 2,020 l min^{-1} (this value is drawn from Graph 1).

The measured values also show that at a working under pressure of 42 kPa, there is no need to configure the frequency convertor so as to achieve the maximum permitted rotations of the motor of 2,800 rotations minute^{-1}, as the maximum performance of the vacuum pump is already achieved at 2,600 motor rotations minute^{-1}. The issue of energy savings when milking is very timely (Ahokas et al., 2013; Gaworski & Leola, 2014).

CONCLUSIONS

The measured values show that during the entire course of the milking cycle, it was never necessary to have more air than 2,050 l min^{-1}. This maximum was only necessary during rinsing; during own milking the maximum air consumption was 1,570 l min^{-1}.

In addition, the required performance to produce under-pressure did not exceed 4.2 kW. These values are drawn from measuring when a frequency convertor is connected. For the alternatives without a frequency convertor, the motor rotations are constant (nominal speed of 1,800 rotations minute^{-1}). At these speeds the vacuum pump performs at 2,050 l min^{-1}. The measurements showed that the average speed during milking regulated by a frequency convertor is 807 rotations minute^{-1}, which corresponds to an air flow of 770 l min^{-1}.

This means that during milking without a frequency convertor but using a control valve, the average of additionally-sucked air is 1,280 l min^{-1}.

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