Comparison of the operation of milking machine control valves and a newly designed regulating device

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ABSTRACT: One of the basic demands for milking machines is to maintain a constant vacuum level if air consumption by milking machine is changed. The author designed a device with reducing valve for vacuum level regulation and a simultaneous vacuum pump control enabling electric power to be reduced. The paper deals with a comparison of the operation of standard control valves with the newly designed device used for vacuum regulation from the viewpoint of dynamic properties. When measuring vacuum stability by applying various regulation methods and a subsequent statistical evaluation of the results obtained it was proven that the function of the newly designed regulating device was comparable with the best reducing valves used so far.

Keywords: milking machine; vacuum control; control valve; vacuum stability

In conjunction with the prepared launching of the IPPC (Integrated Pollution Prevention and Control) Law (ANONYMOUS 1999) it is necessary to reduce, in all branches of the human activity and thus also in agriculture, material and electric power consumption and to apply environment-friendly technological procedures. The measurements carried out at our workplace (FRYČ 2001) proved that the air flow through the milking machine vacuum pump markedly exceeded the average consumption of the milking machine. The efficiency of the vacuum pump is namely based on the maximum permissible air consumption by the milking machine to which moreover a reserve of the vacuum pump efficiency is added being comparable with the consumption of the milking machine. With respect to these facts we endeavoured to find whether the vacuum pump run could be controlled, which would result in a reduction of electric power.

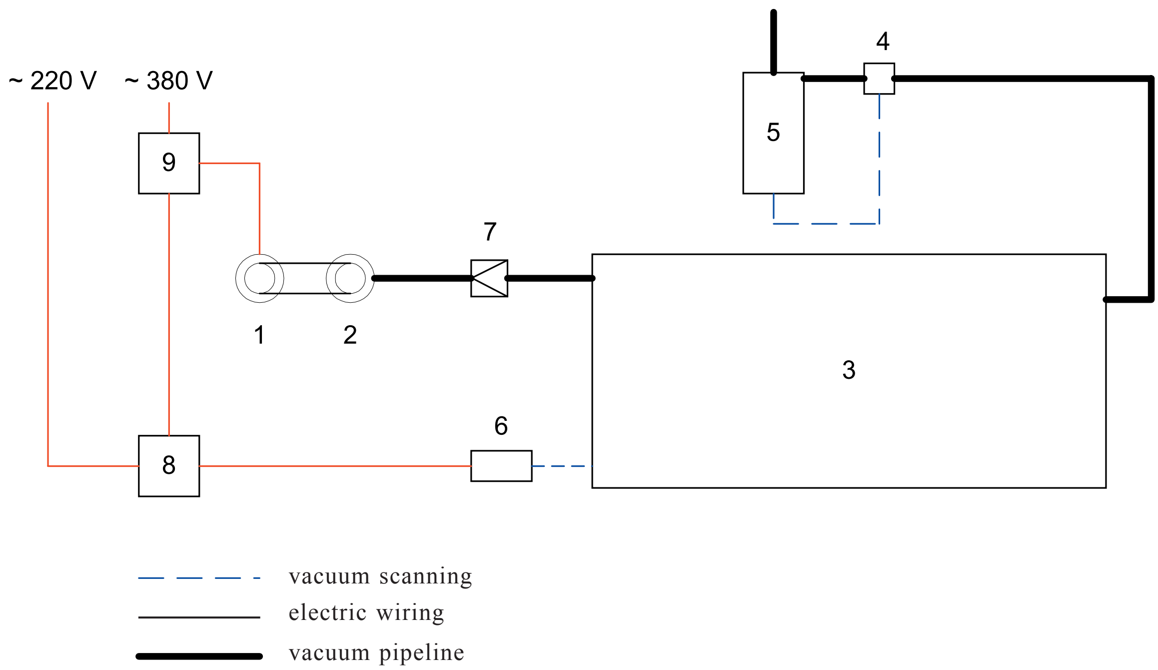

Fig. 1. Control unit with pressure-reducing valve – Functional diagram
1 – electric motor; 2 – vacuum pump; 3 – big air chamber; 4 – pressure-reducing valve; 5 – small air chamber; 6 – vacuum transducer; 7 – back-pressure valve; 8 – electronic control unit; 9 – electric motor control

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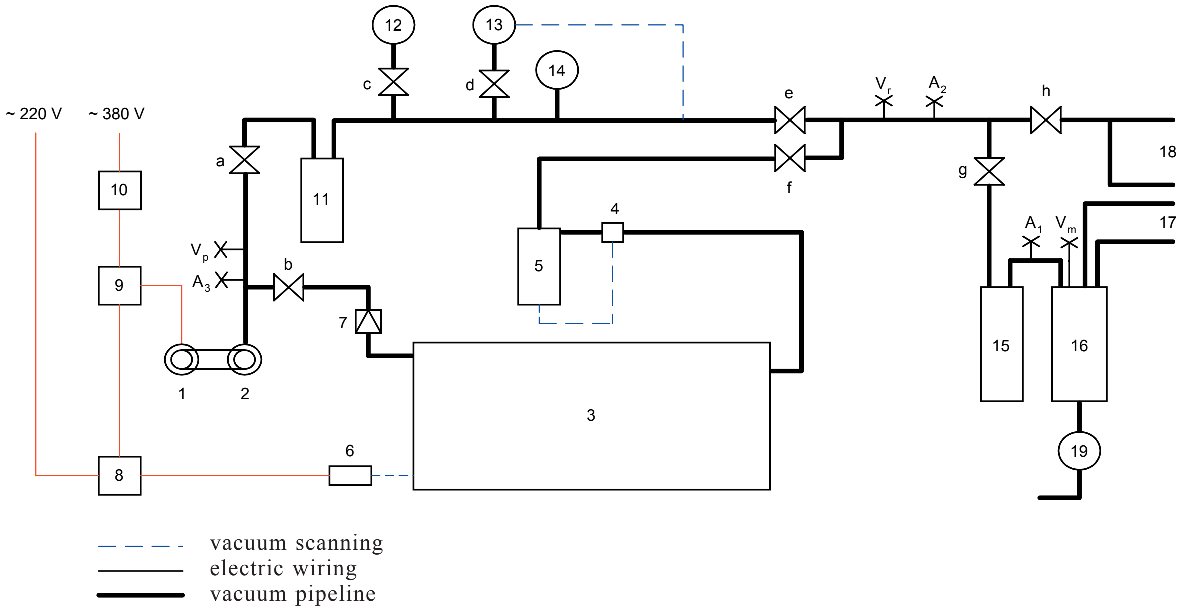

Fig. 2. Laboratory measurement installation – Functional diagram
1 – electric motor; 2 – vacuum pump; 3 – big air chamber; 4 – pressure-reducing valve; 5 – small air chamber; 6 – pressure transducer; 7 – back-pressure valve; 8 – control unit; 9 – electric motor control; 10 – electrometer; 11 – air chamber; 12 – control valve with weight; 13 – diaphragm control servo-valve; 14 – vacuum gauge; 15 – sanitary trap; 16 – receiver; 17 – milk pipeline; 18 – air pipeline; 19 – milk pump
a – h – cocks; A – air flow rate measuring points; V – vacuum measuring points

MATERIAL AND METHOD

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 reason a device for vacuum regulation was designed which does not suck any atmospheric air. Only the air from the milking machine passes through the vacuum pump, its run depending on the instantaneous air consumption. The device is designed to control vacuum pump run by a frequency converter. To verify theoretical presuppositions and the function of the regulating device with reducing valve vacuum pump electric motor switching on and off was first used. Device principle is illustrated in Fig. 1. Vacuum pump set is directly connected to a large capacity air chamber (hereinafter designated as a "big air chamber"). Connecting piping between the vacuum pump and the big air chamber is provided with a non-return valve so that no vacuum pump reverse run takes place by the effect of big air chamber vacuum resulting in undesirable air sucking. In the big air chamber an vacuum within the chosen range of p_{n1} up to p_{n2} $(p_{n1} > p_{n2})$ is maintained, its minimum value (p_{n2}) being higher than the working vacuum of the milking machine (p_{np}). Basic device parameters were specified by the author (FRYČ 2002).

Device function was very satisfactory at a steady-state regime (FRYČ, KUKLA 2002). It was necessary to test device operation at dynamic changes which can occur during milking. With respect to a different principle in the function of regulating device with reducing valve no diagnostic measurements in accordance with the Standard ISO 6690 could be carried out. For this reason vacuum stability was measured being not compulsory based on the Standard ISO 6690 in force, however, its previous versions involved the measurement and recommended it for a comparison of different regulation methods. Measurements by applying the newly suggested regulation method were made and for a comparison also a standard measurement of vacuum regulation with weight control valve and a diaphragm control servo-valve was carried out. The measurements proceeded both in laboratory conditions and on the milking machine at a stable. In either case adapted pipe-type milking machines ZD 2-020 manufactured by Agrostroj Pelhřimov and connected based on the diagram in Fig. 2 were used. The laboratory milking machine was of the following parameters: milking piping up to collecting vessel was 24 m long, total air piping length up to vacuum pump being 27 m. Vacuum pump efficiency was 7.8 dm^3/s. Losses caused by milking and air piping leakages measured in accordance with the Standard ISO 6690 amounted to 0.3 dm^3/s.

The measurements were carried out at the reconstructed cowshed K 174 of the agricultural enterprise GenAgro Ostrovačice Říčany, the cowshed being a six-row, through stable with three independent milking machines, model ZD 2-020. For experiments the milking machine of the best technical condition was chosen (the highest vacuum pump efficiency and the lowest losses by leakages). Milking piping length up to collecting vessel was 122 m, total air piping length up to vacuum pumps being 154 m. The efficiency of both vacuum pumps totalled 19.0 dm^3/s. Losses caused by milking and air piping leakage were 2.5 dm^3/s based on the Standard ISO 6690.

The measurements were carried out as follows:

1. The milking machine was put into operation in the following way: vacuum pump was switched on and all milking units intended for milking were connected to the milking machine. Portable milking units were located in the most distant place. Teat-cups were closed by stoppers and all checking devices set for milking. All additional devices making use of vacuum were connected including those being inactive during milking.
2. The vacuum pump was allowed to run for at least 15 minutes prior to measuring.
3. The value of the atmospheric pressure and milking machine working vacuum was recorded.
4. Adjustment of cocks for individual measurements was made as follows (Fig. 2):
   Measuring the control valve with weight: cocks a, c, e – opened; cocks b, d, f – closed. Measuring the diaphragm control servo-valve: cocks a, d, e – opened; cocks b, c, f – closed. Measuring the regulating device with reducing valve: cocks b, f – opened; cocks a, e – closed.
5. The milking hose of the most distant milking unit was throttled, disconnected and connected to the vessel with atmospheric pressure. The capacity of this vessel was large enough to hold 10 l of air from the milking machine after releasing milking hose throttle – measured at atmospheric pressure.
6. A device intended for vacuum recording was connected to the adjacent milking unit by means of a T-piece in a short milking hose.
7. Device for vacuum recording was put into operation and the milking hose throttling was quickly opened.
8. Maximum value of vacuum drop in kPa and the time in seconds within which the vacuum returned to its initial value were read and both quantities multiplied between each other.

In dependence on the atmospheric pressure and the value of working vacuum set the vessel capacity based on Item 5 was determined. Air amount V_{10} sucked into the vacuum system of the milking machine is based on the difference between the vessel capacity V_N and the air volume V_Z remaining in the vessel after generating nominal vacuum p_n converted to atmospheric pressure p_a and is expressed by the relation:

$$V_{10} = V_N - V_Z \qquad (m^3) \qquad (1)$$

while V_Z can be expressed by the relation:

$$V_Z = V_N \frac{p_a - p_n}{p_a} \qquad (m^3) \qquad (2)$$

and after substituting into the relation (1) V_{10} can be adjusted as follows:

$$V_{10} = V_N - V_N \frac{p_a - p_n}{p_a} = V_N \,.\, (1 - \frac{p_a - p_n}{p_a}) \quad (m^3) \qquad (3)$$

By adjusting V_N can be expressed as:

$$V_N = \frac{V_{10}}{1 - \dfrac{p_a - p_n}{p_a}} \qquad (m^3) \qquad (4)$$

Laboratory measurements were carried out at the atmospheric pressure of 99.0 kPa. In dependence on the atmospheric pressure the capacity of the closed vessel intended for a single air inlet of 10 dm^3 was computed based on the relation (4) as follows:

$$V_N = \frac{V_{10}}{1 - \dfrac{p_a - p_n}{p_a}} = \frac{10}{1 - \dfrac{99 - 50}{99}} = 19.8 \text{ dm}^3 \qquad (5)$$

Cowshed measurements were made at the atmospheric pressure of 101.5 kPa. Closed vessel capacity was calculated based on the relation (4) as follows:

$$V_N = \frac{V_{10}}{1 - \dfrac{p_a - p_n}{p_a}} = \frac{10}{1 - \dfrac{101.5 - 50}{101.5}} = 20.3 \text{ dm}^3 \qquad (6)$$

Milk can with cover was used as closed vessel. The can was fully filled with water and by means of a graduated vessel its capacity measured. Prior to the measurement the can was filled with a specified amount of water so that the air volume in the can exactly corresponded to the capacity computed. Vacuum drop (magnitude) and the time of its duration were recorded by means of the instrument Pulsator tester PT IV operating based on the method of Item 2. Then the maximum value of vacuum drop in kPa was subtracted together with the time in seconds within which the vacuum returned to its initial value and both quantities were multiplied between each other.

RESULTS AND DISCUSSION

In accordance with the Standard ISO 5707 the product of the vacuum drop in kPa and the time in seconds within which the vacuum returns to its initial value shall not exceed 20 kPa/s. The results of the laboratory measurements are listed in Table 1. The best result, i.e. the lowest average value (7.1 kPa/s) was obtained when using a diaphragm control servo-valve. Regulating device with reducing valve revealed slightly worse parameters (9.3 kPa/s). The worst results of an average value of 18.2 kPa/s approaching the permissible maximum were obtained when using a weight control valve.

The results of the stable measurements are listed in Table 2. The best result, i.e. the lowest average value (12.5 kPa/s) was obtained when using a diaphragm

Table 1. Measured and computed values of vacuum stability found at laboratory

No.	Veight control valve			Diaphragm control servo-valve			Device with reducing valve		
	drop (kPa)	drop time (s)	product (kPa/s)	drop (kPa)	drop time (s)	product (kPa/s)	drop (kPa)	drop time (s)	product (kPa/s)
1	3.8	4.9	18.6	3.8	1.8	6.8	3.8	3.1	11.8
2	3.8	4.9	18.6	4.6	2.2	10.1	3.8	2.6	9.9
3	3.8	4.9	18.6	3.8	2.0	7.6	3.8	2.6	9.9
4	3.8	4.4	16.7	3.1	2.2	6.8	3.1	2.6	8.1
5	3.8	4.9	18.6	3.1	1.8	5.6	3.8	3.1	11.8
6	3.8	4.9	18.6	3.0	1.8	5.4	3.8	2.2	8.4
7	3.8	4.9	18.6	3.1	2.2	6.8	3.1	2.6	8.1
8	3.8	4.9	18.6	3.8	2.2	8.4	3.1	2.2	6.8
9	3.8	4.4	16.7	3.1	2.2	6.8	3.8	2.2	8.4
10	4.1	4.4	18.0	3.8	1.8	6.8	3.8	2.6	9.9
Average	3.83	4.75	18.182	3.52	2.02	7.120	3.59	2.58	9.286
Variance			0.564			1.652			2.430
s.d.			0.751			1.285			1.559

s.d – standard deviation

Table 2. Measured and computed values of vacuum stability found at stable

No.	Veight control valve			Diaphragm control servo-valve			Device with reducing valve		
	drop (kPa)	drop time (s)	product (kPa/s)	drop (kPa)	drop time (s)	product (kPa/s)	drop (Pa)	drop time (s)	product (kPa/s)
1	2.8	8.3	23.2	2.5	4.0	10.0	3.1	4.4	13.6
2	3.1	7.9	24.5	2.8	3.9	10.9	3.1	4.0	12.4
3	2.4	11.5	27.6	3.6	4.2	15.1	3.0	4.4	13.2
4	2.4	12.0	28.8	3.1	4.3	13.3	2.9	4.4	12.8
5	2.5	8.8	22.0	3.1	4.8	14.9	3.1	4.2	13.0
6	2.3	11.5	26.5	3.0	4.0	12.0	3.0	4.6	13.8
7	2.3	10.3	23.7	3.1	4.4	13.6	3.1	4.4	13.6
8	2.9	9.5	27.6	2.8	3.9	10.9	3.1	4.2	13.0
9	2.4	11.6	27.8	3.1	4.2	13.0	3.0	4.6	13.8
10	2.5	10.2	25.5	2.5	4.4	11.0	2.9	4.4	12.8
Average	2.56	10.16	25.716	2.96	4.21	12.483	3.03	4.36	13.204
Variance			4.707			2.853			0.220
s.d.			2.170			1.689			0.469

control servo-valve. Regulating device with reducing valve revealed a little worse parameters (13.2 kPa/s). The worst results of an average value of 25.7 kPa/s were found when using a weight control valve. The milking machine provided with this control valve does not comply with the value specified.

CONCLUSION

Both in laboratory and stable measurements the differences in the values between the diaphragm control servo-valve and the regulating device with reducing valve were statistically insignificant. The differences in the values between the weight control valve and the diaphragm control servo-valve are statistically significant. Also the differences in the values between the weight control valve and the regulating device with reducing valve are statistically significant. Based on the measurements made and their evaluation it can be stated that the newly designed regulating device with reducing valve is comparable with the present control servo-valves from the viewpoint of the dynamic properties.

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Porovnání činností regulačních ventilů dojicích strojů a navrženého regulačního zařízení

ABSTRAKT: Jedním ze základních požadavků na dojicí stroje je udržování konstantní úrovně podtlaku při změnách spotřeby vzduchu dojicím strojem. Autor příspěvku navrhl zařízení pro regulaci úrovně podtlaku s redukčním ventilem při současném řízení chodu vývěvy, což umožňuje snížit spotřebu elektrické energie. Příspěvek se zabývá porovnáním činnosti běžně používaných regulačních ventilů s navrženým zařízením pro regulaci podtlaku z hlediska dynamických vlastností. Jak při měření v laboratoři, tak i při měření ve stáji bylo zjištěno, že rozdíl hodnot mezi membránovým regulačním servoventilem a regulačním zařízením s redukčním ventilem není statisticky významný. Rozdíly hodnot mezi závažovým regulačním ventilem a membránovým regulačním servoventilem nebo mezi závažovým regulačním ventilem a regulačním zařízením s redukčním ventilem jsou statisticky významné. Na základě provedených měření a jejich vyhodnocení lze tvrdit, že navržené regulační zařízení s redukčním ventilem je z hlediska dynamických vlastností srovnatelné se současnými regulačními servoventily.

Klíčová slova: dojicí stroj; regulace podtlaku; regulační ventil; stabilita podtlaku

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