Electromotor and vacuum pump set up and measurement of basic parameters by frequency converter Siemens G-120 for milking equipment

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Abstract: Usage of rotary vane vacuum pumps is currently prevailing to ensure the desired vacuum pressure in the milking equipment. This vacuum pump is driven by a squirrel-cage induction motor. Vacuum pressure regulation was until recently done by a main mechanical regulator set to a desired vacuum pressure and sucking the ambient air into the system during the milking process itself and during other activities. With this type of vacuum pressure regulation the electric motor and vacuum pump worked at full power and that leads to big electric energy consumption. The technical solution of energy saving was achieved by a development of frequency converters and their comparatively cheap investment purchase costs. The frequency converters control the operation of the asynchronous induction motor in the way that the actual vacuum pump delivery is in proportion to a volume of the air sucked into the vacuum pipe system. Frequency converters supplied by the manufacturers have a universal set of input parameters that do not respect the individual requirements of the milking system. This paper is dedicated to a correct setting of input parameters of frequency converter control unit using a Siemens STARTER 4.04 software. This paper describes determination and setting of asynchronous induction motor basic parameters using frequency converter. This paper also shows flow characteristics for different vacuum pump speeds.

Key-Words: Rotary vane vacuum pump, vacuum pressure, milking equipment, asynchronous induction motor, frequency converter, Siemens G-120.

Introduction

Development and research on the field of milking technology was in the past mainly aimed at problems of technological parameters of milking machines. That led to the effort to adapt the operation of milking machines to individual requirements of dairy cows. [1] On one hand it is important to accept the priority of this problem because suction device of the milking machine directly affect the milk gland of the cow during the milking process. On the other hand it is important to pay attention to the technical execution of the whole milking machine and mainly the efficiency of the vacuum pump, regulation of vacuum pressure and energy requirements.

Usage of rotary vane vacuum pumps is currently prevailing to ensure the desired vacuum pressure. Vacuum pumps suck in the air with pressure lower than atmospheric and compress it to the pressure that is slightly higher than atmospheric. [2]. Vacuum pump is driven by a squirrel-cage induction motor. Vacuum pump has to be able to cover operational requirements for desired vacuum pressure. The efficiency of vacuum pump during the milking process is not limiting, the efficiency during the disinfection and cleaning is.

Regulation of vacuum pressure is based on vacuum pump characteristic with constant rotation speed. If we want to achieve constant vacuum pressure, there has to be a constant amount of air flowing through the vacuum pump. Whereas the amount of air sucked in the milking machine is variant in time, there would be significant fluctuation of vacuum pressure without using any regulation device. Vacuum pressure regulation was until recently done by a main automatic mechanical regulation valve. It sucks in such amount of the air into the system that the sum of the air sucked in per unit of time by regulation valve and milking machine is constant. Because of the way the milking units work (they almost never work in the same time) and the fact that asynchronous motor works at full power, the immediate power consumption of milking machine with this solution is significantly lower than efficiency of vacuum pumps. It is said that energetic loses caused by this inconvenient form of regulation is up to 60% of the whole power consumption. [6]

From the technical point of view, there is a need to achieve a stable vacuum pressure with optimal working parameters of asynchronous induction motor. Those are motor rotation speed, torque, power consumption. [3] For this purpose we can use frequency converter that allows us to regulate motor speed to desired values. In this way the total power consumption drops. [4] The power consumption drop using the control system with frequency converter is caused by a fact that the vacuum pump sucks in only the air that was created by the milking machine with optimal working parameters of asynchronous motor. [5]

The main goal of this paper is to describe assembled reference milking machine that is located in the laboratory in Mendel's University in Brno. Then to describe the methodology of measurement and to show the real parameters of vacuum pump and electromotor set. Then to calibrate and compare measured parameters with theoretical values of the device. Equally important goal is to inform the reader about the setup of the Siemens Sinamics G120P BT frequency converter with the SINAMICS PM 230 power unit in the Siemens STARTER 4.4 software.

Material and Methods

Characterization of laboratory milking machine

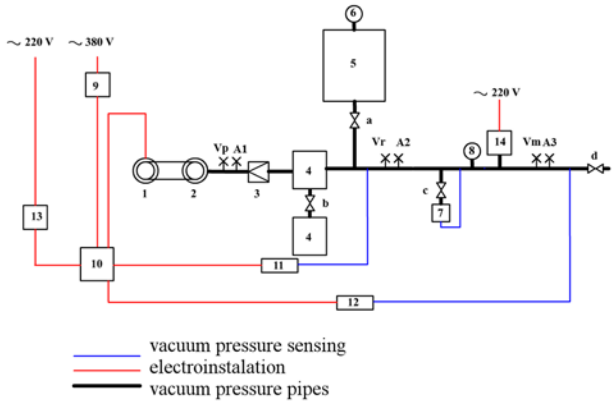
The reference milking machine was assembled in Mendel's University in Brno for finding the solutions for the problems of stability of vacuum pressure and power needs of vacuum pump and electromotor sets. This machine allows to simulate milking process and rinsing with various vacuum pressure regulation setups. The main block schema is in Fig. 1.

The main functional part of milking machine consists of rotary vane vacuum pump SACCO 1600 with theoretical power of 26.6 $dm^3 \cdot s^{-1}$, that is driven by asynchronous induction motor Siemens with theoretical mechanical power of 4.1 kW.

Stability of vacuum pressure in the system pipes can be set up and controlled by:

- To set input parameters in control unit of the frequency converter (Siemens SINAMICS G120)

Fig. 1 Main block schema of reference milking machine



1. electromotor; 2. vacuum pump; 3. check valve; 4. small air eliminator; 5. large air eliminator; 6. vacuum gauge; 7. membrane regulatory servo valve; 8. vacuum gauge; 9. electrometer; 10 frequency converter with PID regulator and control unit; 11 control pressure sensor; 12. check pressure sensor; 13. PC; 14. cycler (simulation of atmospheric presssure suction)

- Mechanically with automatic regulation diaphragm valve (Fullwood servac 3500)
- Combination of the above.

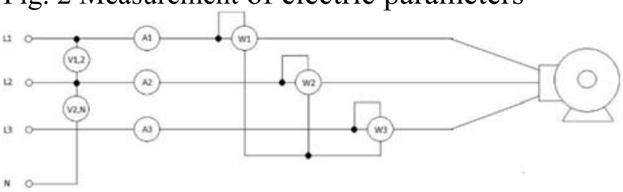
Parameter setup in STARTER 4.4 program was done in online mode when the converter was connected to a computer running the STARTER program. Needed parameters were inputted with setup wizard or they were accessible through *Expert list*. Expert list is a list of all the variables in the system. Basic motor setup includes input of rated voltage, (P0304), rated frequency (P0310), rated power (P0307), rated power factor (P0308), rated speed (P0311). Motor rotation speed limit was set up in P1001 [13].

Vacuum was measured with a linear pressure sensor BD-Sensors with range from -100 kPa to 0 kPa and with 4-20 mA output connected into the analogue input 1 of the Siemens converter. Data from pressure sensor were stored in variable r7521. Power consumption was stored in variable R39.

The indirect method was used for measurement of three phase asynchronous motor Siemens with theoretical power of 4.1 kW that was used to drive rotation vane vacuum pump. This method allows to measure only electrical parameters (current, voltage, power input) and to calculate other parameters such as mechanical shaft power, slip, speed or effectivity. Whole measurement was conduct in compliance with technical standard CSN 350301 [11]. Motor was connected in the star configuration.

The multifunction clamp ammeter Chauvin Arnoux F27 with 1% accuracy in range 1000 V was used for the measurement of current, power and power factor. Measurement was done with the circuit in Fig. 2. There were two states measured – with no load and with blocked rotor. For every state the current, power and power factor in every phase was measured. Result of the measurement were used to create circle diagram of induction motor that was made in custom made graphical program. [12]

Fig. 2 Measurement of electric parameters



Technical standards ISO 6690 [7] and ISO 5707 [8] were used for the measurement of the actual performance of vacuum pump for various rotation speeds and calculations about the reference milking machine. Actual flow amount of the air was recorded with flowmeter SAC FLOWING METER with accuracy 5 $dm^3 \cdot min^{-1}$ in the place V_p. Measured values of air flow were calibrated with gas meter for measurement of actual air flow with accuracy 0,001 m^3. Air flows measured with gas meter were converted with correlation computation for atmospheric pressure (1) that was measured in the laboratory with digital manometer Kimo MP55 with accuracy 0.2 kPa. Vacuum pressure in the system was measured in the point A_1 with a vacuum gauge RAMSES EN 837-1 with accuracy 0.5 kPa. All the measured values were calibrated by the mercury column in the U tube.

$$Q_{SV} = \frac{p_a - p_n}{p_a \cdot t} \cdot 1000 \;\; [dm^3 \cdot s^{-1}] \qquad (1)$$

Where:
p_a – atmospheric pressure [kPa]
p_n – vacuum in the system [kPa]
t – time for amount of 1 m^3 of pressured air to flow through gas meter. [s]

Rotation speed of the vacuum pump were set up in the control unit of the frequency converter in the STARTER 4.4 program and then checked with the rotations of the rotor of the vacuum pump with infrared Tachometer Model CA 27 with accuracy 0.1 rpm. Electromotor rotations were set up in range from 1450 rpm to 800 rpm. The actual input power was measured in the STARTER 4.4 program during changing flow rate of the air through the vacuum pump and the total power consumption for the nominal value of vacuum pressure of 50 kPa. This value is common in milking machines. Measured values of input power, total power consumption, actual air flow through vacuum pump and additional parameters were evaluated in the MS Excel. Statistical method – regression analysis. Determination coefficients (R^2) explains the percentage of variability (reliability) of the graphs and they are calculated by the equation (2).

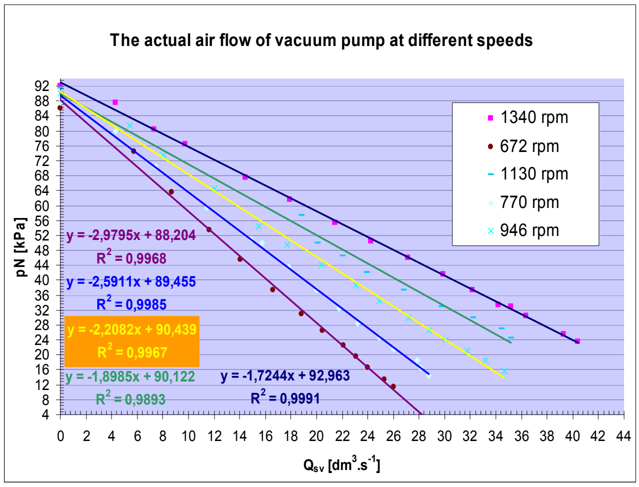
$$R^2 = 1 - \frac{\sum_{i=1}^{N} (y_i - y(x_i))^2}{\sum_{i=1}^{N} (y_i - m(y))^2} \qquad (2)$$

$y(x_i)$ – curve smoothing function
$m(y)$ – average of y

Results and Discussion

Dependency between the amount of air flow coming into the vacuum pump SACCO 1600 and the value of vacuum pressure for different rotation speed of vacuum pump (Fig. 1) was based on the methodology for the measurement of actual performance of vacuum pump above and was in compliance with the technical standard ISO 6690 [8]. Atmospheric pressure was 99.2 kPa therefore the correction of measured values according to (1) was needed. This measurement was done with varying vacuum pressure therefore the flow meter with calibration curve for different pressure levels had to be used.

Fig. 3 The actual flow of vacuum pump at different speeds



There is evident fact in Fig. 3 that the actual air flow of vacuum pump (performance) decreases with decreasing rotations of vacuum pump rotor. The lower performance vacuum pump is sufficient to achieve desired vacuum pressure (40-50 kPa), that is needed for the milking process and other associated activities. This will cause the lowering of the total power consumption. [9] When we look in Fig. 3, we can say the used vacuum pump SACCO 1600 with theoretical power of 26.6 $dm^3 \cdot s^{-1}$ is in good technical condition because its actual power with rated rotation speed is 25.1 $dm^3 \cdot s^{-1}$.

Actual input power was measured during varying air flow of vacuum pump and varying motor rotation speeds with the SINAMICS PM 230 and Siemens STARTER 4.4 software. In Fig. 4 the actual power consumption drops with the growing performance of the vacuum pump. Measured values of power consumption were fitted with quadratic equation and we can say that equations are statistically significant. Coefficients of determination R^2 are in range from 0.91 to 0.96. The actual input power of electromotor drops down from 4.41 kW (for 1450 rpm) to 1.89 kW (for 718 rpm) when we are comparing actual input power with various rotation speeds and nominal vacuum pressure (p_n=50 kPa). Actual power saving is therefore 58%. This confirms that energetic losses consequent to oversized design of milking machine can be up to 60% as was described in the beginning. [6] Because of this it is important to design input parameters in the control unit of frequency converter in the way that rotation speed is as low as it is possible with stable vacuum pressure in the system. [10]

Next measurement was focused on total power consumption in the system. Milking machine was set up for the 50 kPa vacuum pressure with the regulation valve Fullwood servac 3500. Frequency converter Siemens SINAMICS G120 can save up to 2.64 kW·h per an hour of work (Fig. 5). Measurements were done for rotation speed from 1450 rpm to 718 rpm.

Fig. 4 Actual power consumption at different motor speeds

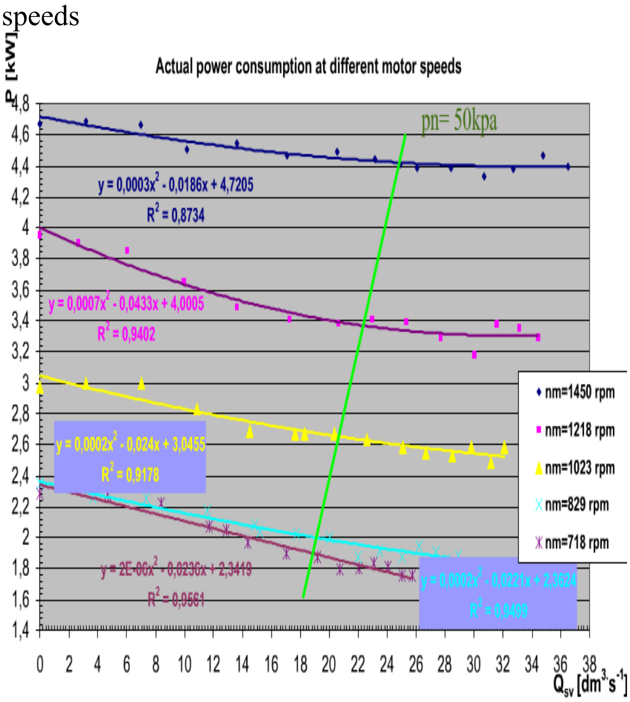
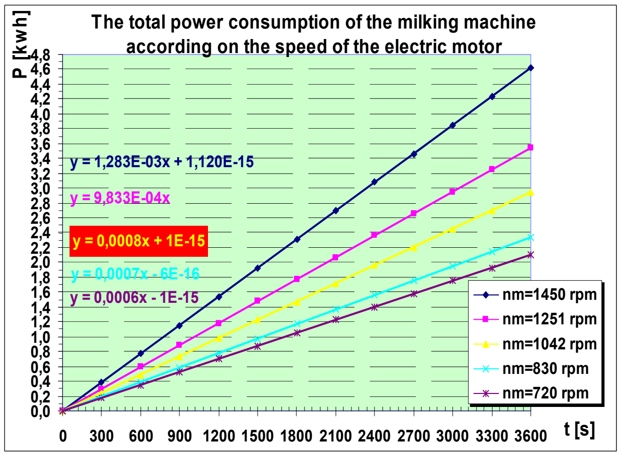


Fig. 5 The total power consumption of the milking machine according to the speed of the electric motor



The circle diagram of induction motor (Fig. 6) was created from measured electrical values. Measured values are in Table. 1 and Table. 2.

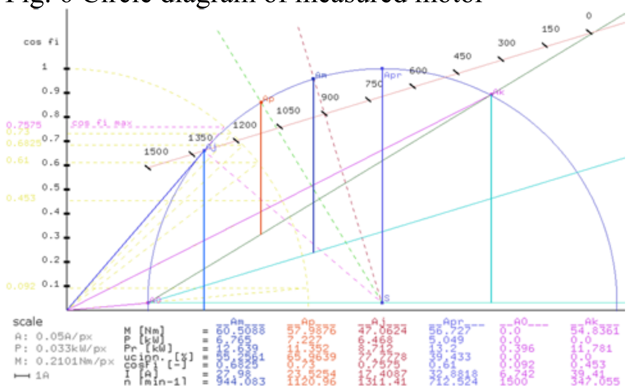
Table. 1 No load

I_0	cosφ	P	S	Q
A	-	W	VA	VAr
6.742	0.092	412.000	4470.167	4437.500

Table. 2 Blocked rotor

I_k	cosφ	P	S	Q
A	-	W	VA	VAr
39.410	0.453	549.667	1224.667	1088.667

Fig. 6 Circle diagram of measured motor



Motor has rated values: $\cos\varphi_j$=0.79; P_m=4.1 kW; I_j=8.9 A and rotation speed 1410 rpm. Point A_k in the circle diagram is situated in the right part of the circle and lies behind the point A_{pr}. That means the motor is in a good operational state. The maximal power factor in A_j is lower than rated power factor by 0.0325. This value should be in theory bigger or equal but for the common working conditions it is an acceptable value.

Conclusion

Siemens STARTER 4.4 showed as a good tool for measurement, setting and recording of input and output parameters of used asynchronous induction motor.

Measurements allowed us to describe the main characteristics of described milking machine. These characteristics will be used in future to design better control of vacuum pressure stability. Values from the circle diagram can be used to create torque, current and power characteristic of motor for its identification.

Values of actual air flow of vacuum pump SACCO 1500 and values from the circle diagram shows the vacuum pump and electromotor set is in good working condition.

Up to 58% of input electrical energy can be saved on the reference laboratory milking machine with correctly selected method of regulation of vacuum pressure (with frequency converter) while maintaining the vacuum pressure stability.

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