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Performance of Electronic Pulsation Control Systems and Pulsation Control Problems for Milking Machines in Turkey

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Abstract: In this study, performances of three different electronic pulsator control unit were determined to overcome the problems faced especially by pneumatic pulsators. For this reason, three different pulsation control units, one with conventional components (PCU₁), one with PIC (PCU₂) and one with PLC (PCU₃) were used. All of the three units were designed to control a solenoid valve system and connected to a mobile milking machine performed milking for measurement of pulsation characteristics. A pulsator test equipment was used to determine the pulsation characteristics. Tests were carried out at 40, 45 and 50 kPa vacuum levels and 50, 55 and 60 min⁻¹ pulsation rates. Variance analysis and Duncan tests were performed on experimental data, which can be effective on changes. Based on the result of statistical analysis, changes of different levels and interactions between pulsation rate and vacuum level were determined. It was determined that, most of these interactions were caused by structural properties of control units and solenoid valve. However, it was seen that pulsation characteristics obtained by each of three pulsation control unit were accordance with international standards at all vacuum levels and pulsation rates. In additional, results of detail statistical analysis showed that, PCU₂ had more suitable characteristics than PCU₁ and PCU₃.

Key words: Milking machine, pulsator, PIC, PLC, pulsation rate, limping

INTRODUCTION

Milking machines are the most essential tools for the intensive dairy enterprises. With the help of this machine, mechanization of milking can be provided, milking productivity can be increased and milking can be performed in conditions that are more hygienic. In addition, udder deformations occurring in hand milking usually don't exist in machine milking.

Vacuum produced by pump in milking machines and facilities are applied to udders in a controlled manner by a pulsator. Thus, milk flow and massage phases are performed. Pressure change of teatcups in vacuum chamber is shown in Fig. 1.

In this Fig. 1 'a' shows increasing vacuum phase, 'b' shows maximum vacuum phase (milking phase), 'c' shows decreasing vacuum phase and, 'd' is the minimum vacuum phase (massage phase).

Based on the international standards, the term $(a+b)/(a+b+c+d) \times 100$ is called pulsator ratio (ASAE, 1996a,b; ISO 3918, 1997). Pulsator ratio often varies from country to country or from machine to machine in same country. The most commonly used pulsator ratios are 60 and 70%. Beside that, pulsator ratio and vacuum levels can also be

varied. For the milking machines used in Turkey, usually vacuum levels of 40-50 kPa, 50-60 min⁻¹ pulsation rates and pulsator ratio of 70% are applied.

Some of the pulsation parameters of milking must be with in the international standard (ISO 5707, 1983). These are,

- Phase "b" of the pulsation chamber vacuum record shall be not less than 30%.
- Phase "d" of the pulsation chamber vacuum record shall be not less than 15%.
- In alternately pulsation, the difference in the pulsator ratio between two teatcups in the same cluster (limping) shall not deviate by more than 5 units of percentage from the value stated by the manufacturer.
- The pulsator ratio shall be within ± 5 units of percentage of the value stated by the manufacturer.

According to 2003 data, there are 5522 stationary and 102 616 portable type milking machines in Turkey. Thus, a ratio of 66 cows per machine exists. However, milking machine industry is fast growing sector and the number of milking machines increased 29.2 times in during the last

Table 1: Pulsation characteristics of milking machines with pneumatic pulsator

Machine	No. of pulsator	Vacuum (Kpa)	Pulsation rate (min ⁻¹)	Pulsator ratio (%)	Pulsation phases (%)				Limping (%)
					a	b	c	d	
1	1	36.2	29.9	76.2	6.7	69.5	10.7	13.1	19.3
2	1	47.7	66.6	63.5	20.8	42.7	13.2	23.3	0.3
3	1	53.7	57.1	59.2	24.9	34.4	16.7	24.1	2.9
4	1	47.7	65.4	55.2	14.9	40.3	12.2	32.6	7.2
5	2	53.3	37.5	59.1	7.8	51.3	9.6	31.3	7.6
	1	50.0	64.2	64.7	11.3	53.3	9.6	25.7	5.4
6	2	48.5	68.5	61.6	19.0	42.6	14.0	24.5	2.6
	1	45.6	71.4	59.2	11.6	54.7	14.8	18.9	16.6
7	2	48.0	56.1	66.3	16.8	42.4	18.0	22.9	11.8
	1	50.3	58.3	69.8	13.5	53.8	10.9	21.8	4.0
8	1	53.2	75.9	57.8	13.0	49.6	11.5	25.9	4.6
	2	47.5	58.0	62.4	19.0	43.4	12.9	27.1	1.0

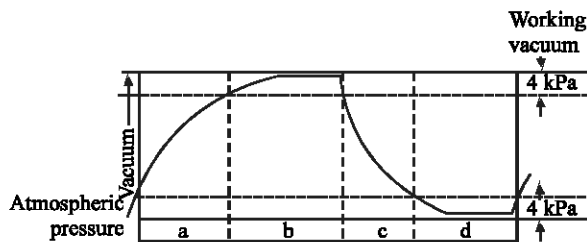


Fig. 1: Pulsator phases (ASAE, 1996a)

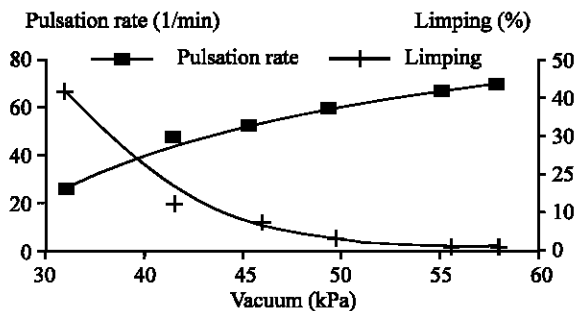


Fig. 2: Pulsation rate and limping changes in different vacuum levels for pneumatic pulsator used in practice (Vatandas and Gurhan, 1997)

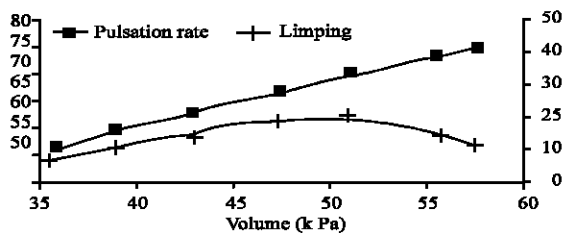


Fig. 3: Pulsation rate and limping changes in different vacuum levels for hydraulic pulsator used in practice (Vatandas and Gurhan, 1997)

five years (State Institute of Statistics 2004). On the other hand, machinery milking is almost absent for small

ruminant. Pulsators used in milking machines are generally pneumatic type and produced in Turkey.

Cetin (1997) measured operational parameters of milking machines used in dairy enterprises in the province of Tokat. Alfa Laval Tester Mk IV was used for measurement. Pulsation characteristics of milking machines with pneumatic type pulsator were shown in Table 1.

Vatandas and Gurhan (1997) evaluated pulsation rates and limping changes of pneumatic and hydraulic type pulsators in different vacuum levels. Pulsation rate and limping changes were shown in Fig. 2 for pneumatic type pulsator and Fig. 3 for hydraulic type pulsator.

Based on the international standards Table 1 and Fig. 2 and 3 were evaluated as follows:

- Milking vacuum levels of the most of the machines were not stable. The reason for that, poor maintenance and cleaning, leakage of vacuum system and regulation problems. Changes in vacuum levels usually increase risk of infection (Jones, 1999).
- Pulsation rate values were dependent on system vacuum levels. This occurs in all of the pneumatic and hydraulic type pulsators. Increasing the system vacuum level enhances pulsation rate for pneumatic and hydraulic type pulsators. The deviations in pulsation rate were out of the standards.
- Accordance with the international standards for 'b' and 'd' phases was obtained except only one machine. However, values for transition phases 'a' and 'c' were considerably high. High values for these phases cause the extension of milking time since they shorten the milking and massage phases.
- Limping parameter showing the difference between pulsator ratios of each half of teatcup was usually above the limits established by international standards. This causes an unstable alternative pulsation and vacuum fluctuations.

The milking machine has little effect on mastitis if properly operated and functioning according to manufacturer's specifications. Nevertheless, it is very difficult to do this in many dairies. The use of malfunctioning pulsators can cause teat end damage and increase the rate of new infection (Bray and Shearer, 1994). The mastitis survey indicated that only 25% of all dairies in Florida had all pulsators working properly (Bray *et al.*, 1998). Same conditions are also seen in Turkey. These all of irregular operating conditions and bad functional specifications are increase bacterial penetration of the teat duct. This factor is determined that one of the ways of the development of mastitis (National Mastitis Council, 1996).

This study was conducted to provide solutions for some of the above mentioned problems for milking machines. Among them was to develop a pulsation control system in which pulsation rate is independent of vacuum levels and pulsation phases and limping parameters are in accordance with international standards and to determine the operational performance of this system. In this study, three different type electronic control units were used. First of them is a conventional electronic control unit (PCU₁). Second of them is a programmable PIC (Peripheral interface controller, PCU₂) and third of them is a PLC (programmable logic controller, PCU₃) which commonly used in industrial automation.

Programmable pulsation control is important to obtain the different pulsation conditions easily and the application of this in milking systems is not a new concept. This process, which was done by, complicated electronic circuits without any software (Cant and Reitsma, 1979). In this study, applications was performed by a low cost integrated circuit (PIC). In addition, a programmable pulsation control unit can also suitable for sensors connection and perform stimulated milking. It was determined that stimulated milking was effective for milking yield in all phases of milking (Hamann and Tolle, 1980).

The aims of this study were to determine alternative electronic pulsators which will easily be adopted to milking machines widely used in dairy managements in Turkey and preserve the obtained data unchanged for a long time of period and to compare available pneumatic pulsators in deciding the more suitable one.

MATERIALS AND METHODS

This study was performed in Agricultural Machinery Department of Ankara Universtiy at 2004. In this study, three different pulsation control units (PCU₁, PCU₂ and PCU₃) were used with a selenoid valve unit. Pulsation

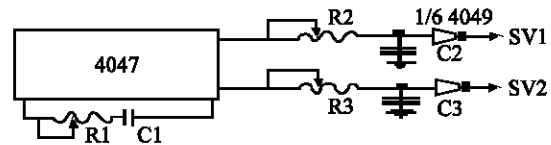


Fig. 4: Simplified diagram of PCU₁

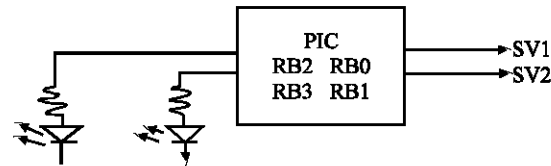


Fig. 5: Simplified diagram of PCU₂

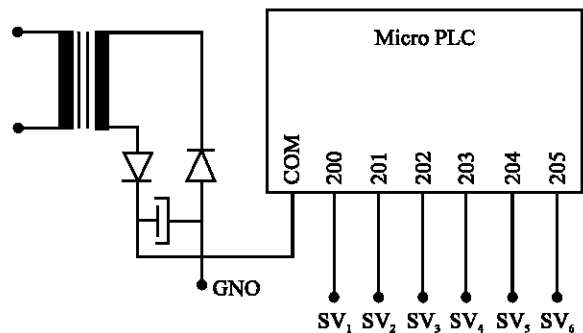


Fig. 6: Simplified diagram of PCU₃

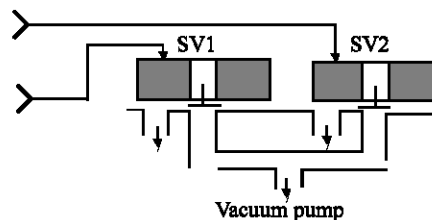


Fig. 7: Selenoid valve

signals from pulsation control unit was applied to selenoid valve and thus, different vacuum levels in teatcup were obtained. The pulsation control units are shown in Fig. 4, 5 and 6 and selenoid valve unit was shown in Fig. 7. PCU₁, PCU₂ and PCU₃ control units were all designed to provide alternately pulsation.

4047 integrated circuit used in the control unit in Fig. 4 is operated as a monostable multivibrator. With the R₁ and C₁ components connected to circuit for time constant was obtained and R₁ adjust the pulsation rate. Then, the obtained signals were applied to buffers in 4049 integrate circuit. R₂-C₂ and R₃-C₃ components in circuit provide the pulsator ratio for each half of the teatcup.

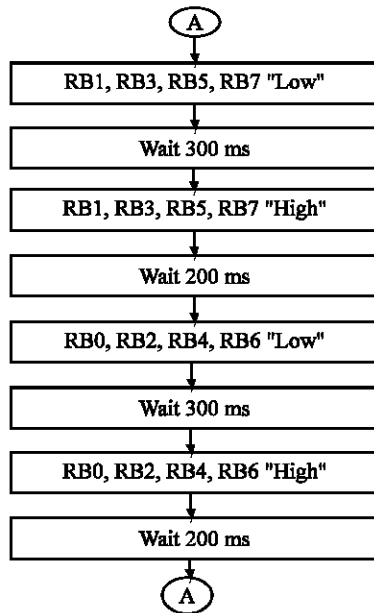


Fig. 8: Flowchart for classical pulsation control software developed for PIC 16F84

A programmable integrated circuit was used as a control unit in Fig. 5. This integrated circuit is a 16F84 type PIC. Two different pulsation control software were developed and edited in PICBASIC programming language (Micro Engineering Labs, Inc., 1999) and were loaded to PIC by a computer. One of this software provides a 70% pulsator ratio and 60 min⁻¹ pulsation rates and, the flowchart was given in Fig. 8. The other one was to provide a stimulated pulsation control and given in Fig. 9. The pulsator ratio was the same as the first one and, the pulsation rate was changed regularly from the nominal value to 200 min⁻¹ By this way, it was aimed to provide a periodical stimulation for dairy cows.

A micro PLC was used as a control unit shown in Fig. 6. PLC is a commonly used programmable device in industrial application. Instead of PCU₁ and PCU₂ units are low cost, PCU₃ with PLC costs more than them. However, it was possible to control more than one selenoid valves

with this device and thus suitable for milking stations. PLC used in this study has six outputs and the number of outputs can be increased by relays. Flowchart for PLC software developed was shown in Fig. 10.

The experimental data were recorded during the milking process performed by milking machines with the control units connected. Alfa Laval Alfatronic Tester Mk IV was used for this purpose. With this device, vacuum changes in pulsation chamber of teatcup, vacuum level and pulsation rate were measured and recorded. The pulsation curves can be obtained from tester's printer.

To compare the performance of pulsation control units used in this study, a commercial type electronic pulsator was also tested. This will be helpful during data analysis of the control units. On the other hand, results were statistically analyzed to show the differences between pulsation control units.

RESULTS AND DISCUSSION

Performance of control units: In Table 2-4 data recorded for each half of the teatcup were given one under the other. A pulsation characteristic of a commercial type pulsator was also given in Table 5.

Results of statistical analysis: Evaluation of differences between pulsation control units, based on the pulsation characteristics obtained under the most commonly used vacuum of 50 kPa and pulsation rate of 60 min⁻¹ for the control units of PCU₁, PCU₂ and PCU₃, the following statistical evaluations were performed:

- Maximum vacuum level phase 'b' and minimum vacuum level phase 'd' for all three units were in accordance with the international standards. However, limping parameter was highly below the limits given by the international standards. This shows that all three-control units had stable pulsation characteristics. Based on the statistical analysis results, it was concluded that the difference between the maximum vacuum phase 'b' values of

Table 2: Pulsation characteristics of the control unit PCU₁

Pulsation rate (min ⁻¹)	Vacuum (kPa)																				
	40							45							50						
	Characteristics (%)							Characteristics (%)							Characteristics (%)						
	a+b	a	b	c	d	Limping		a+b	a	b	c	d	Limping		a+b	a	b	c	d	Limping	
50	70.1	10.2	59.9	9.8	20.1	0.1		70.0	11.3	58.7	10.5	19.5	0.1		69.9	12.9	57.0	10.1	20.0	0.1	
	70.0	11.0	59.0	9.3	20.7			70.1	11.1	59.0	9.9	20.0			70.0	14.0	56.0	9.4	20.6		
55	71.1	11.1	60.0	9.0	19.9	0.2		70.1	10.7	59.4	10.7	19.2	0.5		70.4	12.7	57.7	12.6	17.0	0.5	
	70.3	10.6	59.7	10.6	19.1			70.6	13.4	57.2	10.5	18.9			69.9	10.2	59.7	12.1	18.0		
60	69.9	9.8	60.1	10.7	19.4	0.5		69.7	13.7	56.0	11.4	18.9	0.1		70.0	12.4	57.6	10.0	20.0	0.1	
	70.4	10.9	59.5	9.9	19.7			69.8	13.6	56.2	11.5	18.7			70.1	12.0	58.1	9.8	20.1		

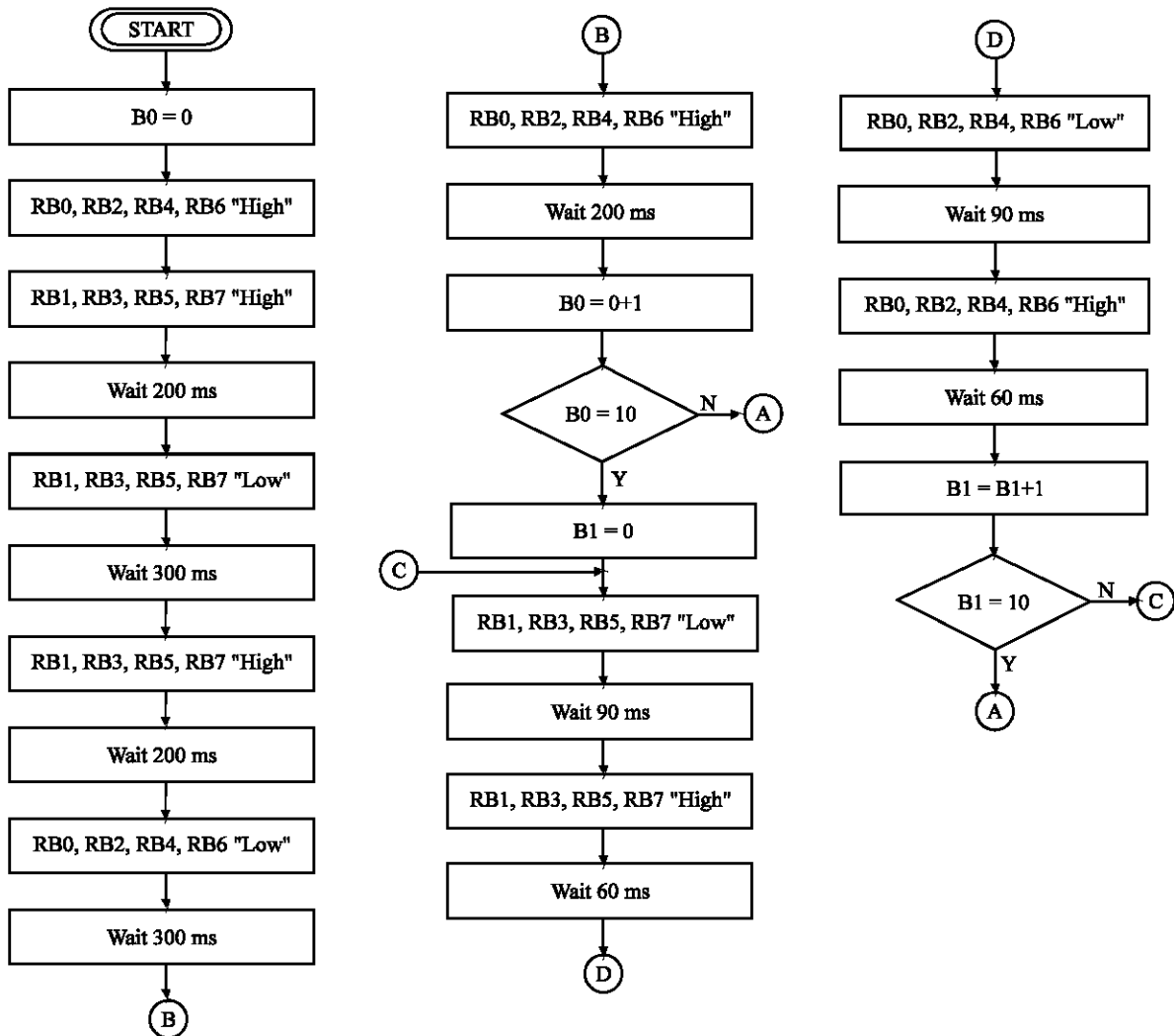


Fig. 9: Flowchart for simulated pulsation control software developed for PIC 16F84

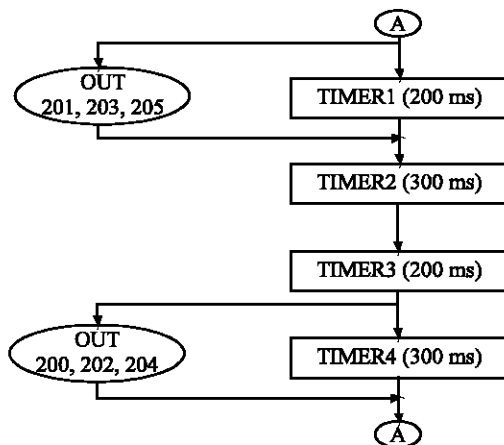


Fig. 10: Flowchart for pulsation control with PLC

PCU₁ and PCU₂ pulsation control units was not statistically important, but the difference between them and PCU₃ and commercial type pulsation control unit was found to be statistically important ($p < 0.01$). On the other hand, the difference between minimum vacuum phase 'd' values of PCU₁, PCU₃ and commercial type was not statistically important; but the difference between PCU₁ and PCU₂ was found to be statistically important ($p < 0.01$).

- Increasing vacuum phase 'a', which was designed to be small during the all-milking periods, was determined to be considerably lower for PCU₁ and PCU₂ pulsation control units than PCU₃ and commercial type pulsation unit ($p < 0.05$).
- Decreasing vacuum phase 'c', which was also designed to be small during the all-milking periods,

Table 3: Pulsation characteristics of the control unit PCU₂

Pulsation rate (min ⁻¹)	Vacuum (kPa)																	
	40						45						50					
	Characteristics (%)						Characteristics (%)						Characteristics (%)					
	a+b	a	b	c	d	Limping	a+b	a	b	c	d	Limping	a+b	a	b	c	d	Limping
50	71.4	13.1	58.3	10.7	17.9	0.2	71.0	14.8	56.2	10.9	18.1	0.2	70.8	13.7	57.1	12.1	17.1	0.4
	71.2	12.8	58.4	10.8	18.0		71.2	14.8	56.4	10.8	18.0		70.4	12.3	58.1	11.8	17.8	
55	70.4	11.3	59.1	11.5	18.1	0.5	69.9	12.2	57.7	12.3	17.8	0.3	70.1	11.4	58.7	11.8	18.1	0.4
	70.9	12.6	58.3	11.4	17.7		70.1	12.0	58.1	10.8	19.1		70.5	12.6	57.9	11.5	18.0	
60	71.0	13.1	57.9	11.1	17.9	0.3	70.1	13.0	57.1	11.9	18.0	0.1	70.0	11.8	58.2	11.7	18.3	0.1
	70.7	12.5	58.2	11.1	18.2		70.2	11.1	59.1	11.6	18.2		69.9	11.5	58.4	12.2	17.9	
200*	69.9	14.0	55.9	12.1	18.0	0.3	70.8	14.7	56.1	11.8	17.4	0.6	70.2	12.2	58.0	11.7	18.1	0.3
	70.2	14.0	56.2	12.2	17.6		70.2	13.2	57.0	10.8	19.0		70.5	13.1	57.4	11.0	18.5	

*Stimulated pulsation control

Table 4: Pulsation characteristics of the control unit PCU₃

Pulsation rate (min ⁻¹)	Vacuum (kPa)																	
	40						45						50					
	Characteristics (%)						Characteristics (%)						Characteristics (%)					
	a+b	a	b	c	d	Limping	a+b	a	b	c	d	Limping	a+b	a	b	c	d	Limping
50	70.4	18.3	52.1	7.3	22.3	0.4	71.0	20.0	51.0	7.9	21.1	0.6	69.9	18.8	51.1	10.4	19.7	0.4
	70.0	15.8	54.2	8.1	21.9		70.6	18.4	52.2	5.4	24.0		70.3	18.2	52.1	9.6	20.1	
55	69.7	14.7	55.0	4.1	26.2	0.8	70.0	17.0	53.0	7.6	22.4	0.9	70.6	17.5	53.1	5.8	23.6	0.7
	70.5	16.6	53.9	5.5	24.0		70.9	18.7	52.2	6.0	23.1		69.9	17.8	52.1	5.9	24.2	
60	70.0	14.0	56.0	5.0	25.0	0.6	70.2	15.5	54.7	5.6	24.2	0.4	70.9	17.9	53.0	10.2	18.9	1.0
	70.6	15.4	55.2	5.5	23.9		70.6	14.6	56.0	6.8	22.6		69.9	14.9	55.0	10.9	19.2	

Table 5: Pulsation characteristics of a commercial type electronic pulsator

Pulsation rate (min ⁻¹)	Vacuum (kPa)																	
	40						45						50					
	Characteristics (%)						Characteristics (%)						Characteristics (%)					
	a+b	a	b	c	d	Limping	a+b	a	b	c	d	Limping	a+b	a	b	c	d	Limping
60	69.8	15.7	54.1	10.4	19.8	0.3	70.0	15.2	54.8	9.9	20.1	0.2	69.9	14.9	55.0	10.1	20.0	0.2
	70.1	15.9	54.2	10.0	19.9		70.2	15.1	55.1	10.1	19.7		70.2	15.0	55.2	10.3	19.5	

was lower for PCU₃ than the others and the difference was found to be statistically important ($p < 0.01$).

Evaluation of pulsation control units, PCU₁, PCU₂, PCU₃
PCU₁: The increasing vacuum phase 'a' of PCU₁ pulsation control unit was 40 kPa. The difference between values at this vacuum level was found to be statistically important ($p < 0.05$) regardless of pulsation rate difference. For the maximum vacuum phase 'b' values, difference between 40 and 45 kPa vacuum levels at 50 min⁻¹ pulsation rate was statistically unimportant, on the other hand the difference at 50 kPa vacuum level was found to be statistically important ($p < 0.05$). The difference between vacuum levels at 55 min⁻¹ pulsation rates was not statistically important. The difference between 45 and 50 kPa vacuum levels at 60 min⁻¹ pulsation rates was not statistically important but the difference between 40 kPa and the others at same pulsation rate was found to be statistically important. Again, for the maximum vacuum

phase 'b' values, difference between all pulsation rates at the 40 kPa vacuum level was not statistically important. The 'b' values of 60 min⁻¹ pulsation rates at 45 kPa vacuum level were found to be statistically different and lower than the other. For the 50 kPa vacuum level, the 'b' values of 50 and 55 min⁻¹ pulsation rates were found to be different from the 'b' values of 60 min⁻¹ pulsation rates. The maximum 'b' values were obtained at 55 min⁻¹ pulsation rates.

For the decreasing vacuum phase 'c' values, some statistically important differences were found for PCU₁ pulsation control unit at different pulsation rates and vacuum levels ($p < 0.01$). The 'c' values at 50 and 60 min⁻¹ pulsation rates have not showed a statistically important difference for all vacuum levels. However, for 55 min⁻¹ pulsation rates, the 'c' values at 50 kPa vacuum level were statistically different from the others. A statistically important difference between 'c' values was observed only at 50 kPa vacuum level and 55 min⁻¹ pulsation rate. The 'c' values of this pulsation rate were higher than the others.

For the minimum vacuum phase 'd' values, also some statistically important differences were found for PCU₁ pulsation control unit of different pulsation rates and vacuum levels ($p < 0.01$). The 'd' values at 50 and 60 min⁻¹ pulsation rates have not showed a statistically important difference for all vacuum levels. On the other hand, the difference between 'd' values at 55 min⁻¹ pulsation rates and 50 kPa vacuum levels were statistically different from the other. It was observed that the difference between 'd' values at 40 and 45 kPa vacuum levels was not statistically important for all pulsation rates. A statistically important difference between 'd' values was observed at 50 kPa vacuum levels for 55 min⁻¹ pulsation rates.

PCU₂: For the increasing vacuum phases 'a' value of PCU₂ pulsation control unit, statistically important difference was determined only at 50 min⁻¹ pulsation rates ($p < 0.01$). The value at this pulsation rate was higher than the other two pulsation rates.

For the PCU₂ pulsation control unit, the differences between maximum vacuum phase 'b' values and the difference between minimum vacuum phase 'd' values were not found to be statistically important for all pulsation rates and vacuum levels.

For the decreasing vacuum phase 'c' values, the difference between 'c' values at 40 and 45 kPa vacuum levels were statistically important ($p < 0.05$). The 'c' values at this vacuum levels were smaller than 50 kPa vacuum level.

PCU₃: For the PCU₃ pulsation control unit, the difference between increasing vacuum phase 'a' values at 50 and 60 min⁻¹ pulsation rates were statistically important ($p < 0.01$). For the maximum vacuum phase 'b' values, difference at various vacuum levels was statistically important ($p < 0.05$) and difference at various pulsation rates were statistically important ($p < 0.01$). The pulsation rates with statistically important differences were 50 and 60 min⁻¹ values and vacuum levels with statistically important differences were 40 and 50 kPa. For the decreasing vacuum phase 'c' values, a statistically important difference ($p < 0.01$) was observed for different pulsation rates based on different vacuum levels. The vacuum level with this statistically important difference was 50 kPa vacuum levels. On the other hand, the 'c' values at 60 min⁻¹ pulsation rates were statistically different for 50 kPa vacuum levels from the others. It was also determined that the 'c' values 55 min⁻¹ pulsation rate at 50 kPa vacuum level were statistically different from the ones for the other two pulsation rates.

For the minimum vacuum phase 'd' values, statistically important ($p < 0.05$) differences between

various vacuum levels and different pulsation rates and vice verse were observed. The difference between 'd' values for all vacuum levels except 45 kPa and at all pulsation rates except 55 min⁻¹ pulsation rate was found to be statistically important.

CONCLUSIONS

The following conclusions were drawn based on the pulsation control units and the result of statistically analysis.

Pulsation rate-vacuum level interactions obtained from pulsation phase transition of PCU₁ pulsation control unit was due to the structural properties of the system. Especially for the interactions from the transition phases 'a' and 'c' were caused by the inertia of the metal core pin located in solenoid valve during the displacement of this pin in these two phases. Because different displacement velocities occurs at different pulsation rates and vacuum levels based on the mass of the metal core pin. This restriction can be partially eliminated by a reduction in the mass of metal core pin. On the other hand, performance can be affected the characteristics of the components in control unit caused by the parameters such as heat, current and etc. Here, characteristics of the components of R₂-C₂ and R₃-C₃ were considered important.

For the PCU₂ pulsation control unit, the same conditions were observed for the transition phases of 'a' and 'c'. However, the differences observed were lower than the ones observed with PCU₁ and they were beyond the nominal operational values. On the other hand, it was noticeable that the values of the most important phases (b and d) of pulsation could be determined independent of pulsation rate and vacuum level parameters. This results shows that the time based control process with a PIC was highly stable.

For the PCU₃ pulsation control unit, beside the above mentioned factors an additional factor was observed due to the solenoid valve. The relay type outputs of PLC used in this control unit have brought an additional inertia and mechanical contact problems. That is why; there were many interactions at pulsation phases of this unit.

In spite of the fact that the total time spent for the experiments in dairies was not too long, there were not any behavioral changes and infections on dairy cows during the all experimental period. In addition, after a full veterinarian control at the end of the experimental period, it was observed that there was not only mastitis on udders of the cows.

The results of this study were; to determine PCU₂ pulsation control unit which will preserve the obtained data unchanged for a long time of period and to compare

the other pulsation units and easily be adopted to milking machines widely used in dairy managements in Turkey.

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