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VALIDATION OF A MODEL OF THE NEGATIVE PRESSURE SET VALUE SIGNAL FORMATION IN THE COW MACHINE MILKING

The validation of the suction absolute pressure set value signal formation in an autonomous milking cluster was conducted using the Mamdani linguistic model as a setter in an automatic control system. The computer simulation was conducted in the MATLAB-Simulink® programme. The calculation results were illustrated with graphs reflecting the nature of the phenomena.

1. Introduction

The automatic control of a cow milking cluster should approximate the machine milking parameters to their ontogenic features. From the control process point of view the optimum solution is a close relationship of the suction pressure values with the flow rate of milk flowing out of the cow's teat. Therefore in the Department of Power Engineering and Automation of Agricultural Processes of the University of Agriculture in Krakow an engineering project on an autonomous milking cluster with separated suction pressure and milk conveying pressure has been undertaken. This cluster milks cow's udder quarters individually. A part of the project is a concept of an automatic control system using the linguistic model calculating the suction pressure set value. The control system validation was conducted in the project, by a simulation experiment on a linguistic model. The course of the absolute suction pressure set value signal obtained from the model for an autonomous milking cluster in individual milking phases was compared with expectations based on the theoretical and empirical knowledge.

2. Objective and scope of the project

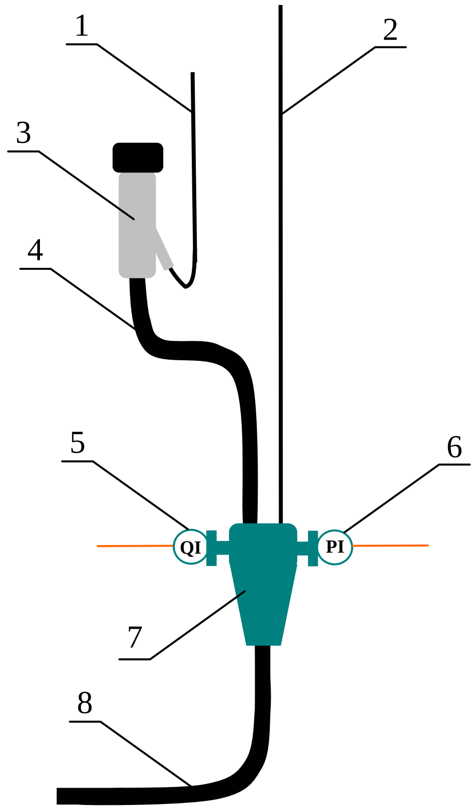
The objective of work was to perform validation of the process of forming the absolute suction pressure set value signal in an autonomous cow milking cluster with a Mamdani linguistic model.
The scope of the project covers developing of a linguistic model performing the role of setter of the suction pressure set value in an autonomous milking cluster and a computer simulation of its operation in the MATLAB-Simulink program.

3. Characteristics of the controlled system

The controlled system is an autonomous milking cluster with separated suction pressure and milk transport pressure. The controlled process involves the suction pressure, which changes in relationship to the mass flow rate of milk flowing out of the cow's teat. Fig. 1 presents a segment of an autonomous milking cluster for milking a cow's udder quarter.

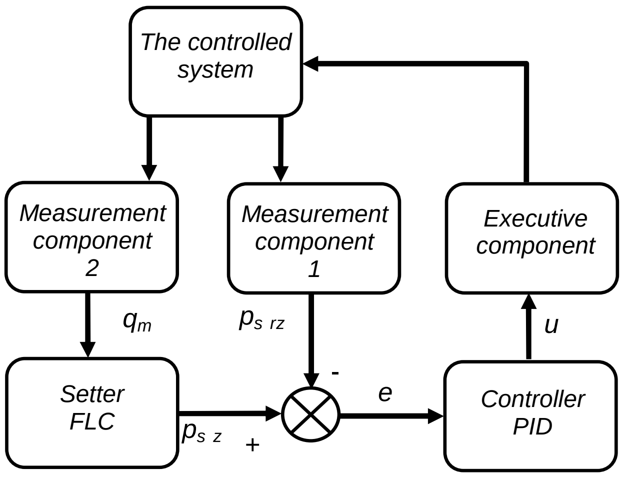
4. Control system

The automatic control system requires two measurement components to be placed in the controlled system in order to determine the value of the suction pressure p_s and the mass flow rate of milk flowing out of the cow's teat q_m. The suction pressure constitutes the controlled variable. However, the mass flow rate of milk is the variable that is the basis for shaping of the controlled variable set value signal on the basis of the Mamdani linguistic model. The control system diagram is presented in Fig. 2.



Reference: Own research of the authors
Fig. 1. A simplified diagram of the controlled system: 1 - pulsation line, 2 - absolute suction pressure tube p_s, 3 - teat cup, 4 - short milk tube, 5 - milk mass flow rate measurement sensor, 6 - absolute suction pressure sensor, 7 - autonomous milking cluster claw, 8 - long milk tube

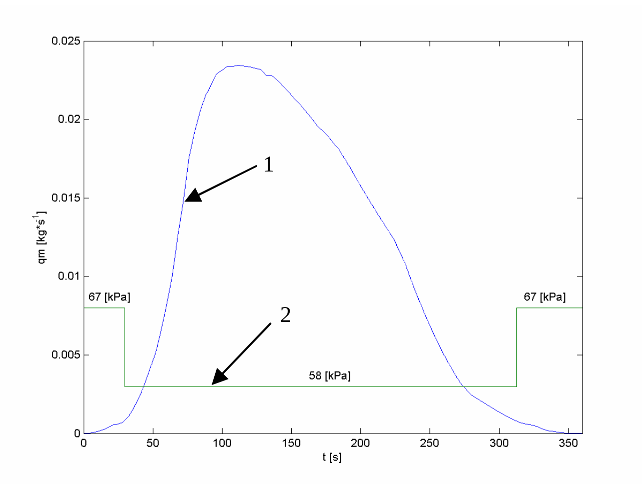
The operation of the control system is as follows: the measurement component 2 generates a signal containing information on the mass flow rate of milk flowing out of the cow's teat q_m. This is the basis for calculation of the suction pressure set value in the milking cluster $p_{s\,z}$ with a Mamdani-type linguistic model (*FLC setter*). The set value signal goes to the summing node input, where it is compared with the signal from the measurement component 1 (actual suction pressure in the autonomous milking cluster $p_{s\,rz}$). The difference calculated in the summing node is the control error *e*. The signal that represents it, is entered into the input of the *PID* controller, which calculates feedback on the controlled system, executed by the executive component - the valve [5].



Reference: Own research of the authors
Fig. 2. Block diagram of the suction pressure control system

5. Assumptions for modelling of the set value signal

To calculate the signal of the absolute suction pressure p_s set value in an autonomous milking cluster, on the basis of the milk mass flow rate q_m, it was necessary to determine the relationship between these variables. It was determined on the basis of theoretical and empirical knowledge (fig. 3).



Reference: Own research of the authors
Fig. 3. The mass flow rate of milk flowing out of the cow's teat with the line of suction pressure set value

The graph above illustrates two courses concerning the setter. The first one designated with number 1 (the blue line) is the mass flow rate of milk flowing out of the cow's teat - the signal from the measurement component 2 (fig. 2). It was calculated according to reference data [2]. The second course designated with number 2 (green line) is the course of the set value signal p_s assigned to the first course on the basis of authors' knowledge on the milking process. The following assumptions were made: the suction pressure value p_s should change depending on the value of mass flow rate of the fluid, representing in calculations the milk flowing out of the cow's teat q_m in the following manner: at the fluid outflow rate $q_m \leq 0{,}0008$ kg·s^{-1} the suction pressure is 67 kPa, while at $q_m > 0{,}0008$ kg·s^{-1} it is equal to 58 kPa [3].

6. Process Modelling

Methods falling within artificial intelligence are successfully used in agricultural engineering. Probabilistic-Bayesian networks are used for description of agricultural production and management of food production chains [4]. The Bayesian network technology enabled among others a milk production process line reliability model to be constructed [1].

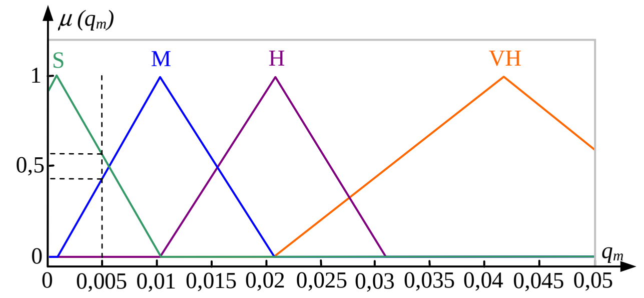
In this case a fuzzy Mamdani model (*FLC setter* in fig. 2) was used to determine the set value of the absolute suction pressure on the basis of the flow rate of milk flowing out of the cow"s teat. Its operation is based on fuzzy inference, or drawing conclusions on outputs on the basis of inputs*wy=f(we)*, based of relationships between these variables created according to fuzzy inference principles. The model consists of three basic modules: fuzzification, inference, defuzzification. The first of the said modules is responsible for fuzzification of inputs. This process is executed by relating input variables to the linguistic values along with the assigned fuzzy sets. The sets may be described by a number of available membership functions. The second module - "inference" processes inputs in linguistic variable categories into the relevant output signal value. The inference process takes place on the basis of a rule base describing the relationships occurring between the inputs and the outputs. The output is determined [6, 7, 8, 9, www.mathworks.com] in the last "defuzzification" module.

To illustrate the operation of the mathematical algorithm of a Mamdani-type linguistic model, used for generating of the set value signal p_s, a calculation example for one input value (q_m) is presented below. This variable was fuzzified. During the linguistic inference stage the corresponding output fuzzy values were determined, and next the outputs were defuzzified. The described calculation operations were presented in the three modules below.

6.1. The Fuzzification Module

In the fuzzification module the fuzzification operation was performed, that is calculation of membership of the input variable q_m to individual fuzzy sets. Based on the knowledge on the milking process, the input q_m value set was divided into 4 subsets: small values S, middle values M, high values H and very high values VH. Membership function values were assigned to subset members. The course of the membership function of the set members q_m to the subsets S, M, H and VH is presented on fig. 4.

Next the input values q_m were fuzzyfied for its randomly indicated point – 0,005. It required an auxiliary line to be drawn from the value of 0,005 perpendicularly to the X-axis (fig. 4). Auxiliary lines to the Y-axis were drawn from the points of intersection of the auxiliary line with the lines of value subsets, the small ones S and the middle ones M, and the values of the membership function for these subsets were read.



Reference: Own research of the authors

Fig. 4. The course of the membership function of members of the input set q_m to the subsets

They were 0,57 for the subset S and 0,43 for the subset M respectively. By analysing the presented graph in this way we can find that a member of the input set q_m of 0,005 belongs or does not belong:

1. It belongs to the S small value subset with the membership function equal to 0,57

$\mu_{qmM}(0{,}005) = 0{,}57$

2. It belongs to the M small value subset with the membership function equal to 0,43

$\mu_{qmS}(0{,}005) = 0{,}43$

3. It does not belong to the H high value subset, therefore the membership function is equal to 0

$\mu_{qmW}(0{,}005) = 0$

4. It does not belong to the VH very high value subset - the membership function is equal to 0

$\mu_{qmNW}(0{,}005) = 0$

After the linguistic coding of a crisp input (q_m = 0,005) carried out in this manner, the sum of the obtained values of the membership function of the set members to the subsets is: 1 (1):

$$\mu_{qmM}(0{,}005) + \mu_{qmS}(0{,}005) + \mu_{qmW}(0{,}005) + \mu_{qmNW}(0{,}005) = 0{,}57 + 0{,}43 + 0 + 0 = 1 \qquad (1)$$

6.2. The Inference Module

Within the operations performed in the linguistic inference module, the output p_s set was divided into 4 subsets: small values S, middle values M, high values H and very high values VH. Each member of the set p_s was assigned values of membership function of this member of the set to the subsets (fig. 5).

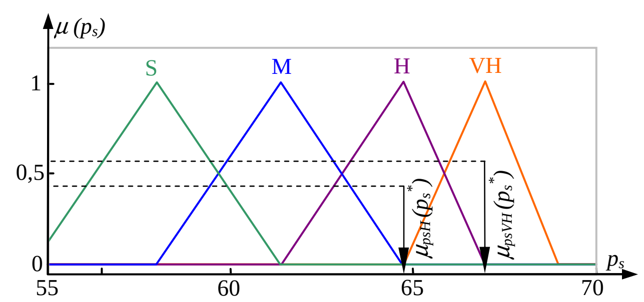


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Fig. 5. The course of the membership function of members of the output set p_s to the subsets

To determine the fuzzy values of output signals on the basis of fuzzy input signals, a rule base, constituting a representation of the knowledge on the milking process was developed. The rule base is a governing table containing a set of fuzzy rules describing the relationships occurring between inputs and outputs. The governing table describing the relationships between the mass flow rate of milk flowing out of the cow's teat q_m and the absolute suction pressure p_s in an autonomous milking cluster has the following form:

1. If the milk mass flow rate q_m is small (q_mS), the absolute pressure value p_s is very high (p_sVH).
2. If the milk mass flow rate q_m is medium (q_mM), the absolute pressure value p_s is high (p_sH).
3. If the milk mass flow rate q_m is high (q_mH), the absolute pressure value *ps* is small *(ps*S).
4. If the milk mass flow rate *qm* is very high (*qm*VH), the absolute pressure value *ps* is small *(ps*S).

Then on the basis of conditional statements of the resulting rule base the conclusions were formulated.

1. In accordance with the first conditional statement of the rule base you can conclude that for the input q_m at a level of 0,005, which belongs to the S small value subset with the membership function of 0,57, the output parameter level p_s will be the highest of the declared VH with the probability equal to the membership function value – 0,57. On this basis you can state that the value of the membership function of the output variable p_s to the VH subset is 0,57.

$$\mu_{psVH}(p_s^*) = 0{,}57$$

2. Based on the second conditional statement of the governing table you can draw a conclusion that for the input q_m at a level of 0,005, also belonging to the M medium value subset with the membership function equal to 0,43, the output value p_s will be the high, with the probability equal to the membership function value at a level of 0,43. Thus you can state that the value of the membership function of the output p_s to the H subset is 0,43.

$$\mu_{psH}(p_s^*) = 0{,}43$$

3. It follows from the third conditional statement of the rule base that the values of the input q_m from the H subset corresponds to the output values p_s in the S subset. However the mass flow rate of milk flowing out of the cow's teat q_m of 0,005 does not belong to the H high value subset, so you can conclude that the searched value of the suction pressure p_s does not belong to the S small value set.

$$\mu_{psS}(p_s^*) = 0$$

4. The value q_m at a level of 0,005 does not belong to the VH very high value subset as well, so you can conclude on the basis of the fourth conditional statement, that the searched value of the suction pressure p_s in this case also does not belong to the S small value subset.

$$\mu_{psM}(p_s^*) = 0$$

Thanks to the performed linguistic inference a fuzzy form of the searched absolute suction pressure value p_s in an autonomous milking cluster p_s has been obtained.

6.3. The Defuzzyfication Module

In the defuzzification module a singleton method was used for calculation of the crisp output value. In accordance with this method the values of the membership function of the set members to a specific subset of the outputs p_s were replaced with single-member sets - singletons. They were in a place for which the membership function of a specific subset is equal to 1. In fig. 5 singletons are designated with arrows perpendicular to the X-axis. The axis for the VH subset indicates point 66.96, while for the H subset, the second arrows points out 64,76. The activation degrees for the singletons discussed are 0,57 for the first one and 0,43 for the other. After replacing the fuzzy sets with the relevant single-member sets the crisp output values p_s were calculated with the dependency (2) [9]:

$$p_s^* = \frac{\sum_{i=1}^{m} p_{si} \cdot \mu_{p_s i^*}}{\sum_{i=1}^{m} \mu_{p_s i^*}} \qquad (2)$$

where:

p_s^* - the air absolute suction pressure in an autonomous milking cluster,

$\mu_{p_s i^*}$ - the degree of activation of the i-th singleton by a given rule,

p_{si} - the value of the output variable in the place of location of the i-th singleton,

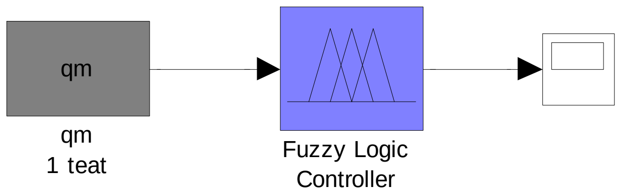
M - the number of rules.

The calculated value of the absolute suction pressure p_s in an autonomous milking cluster for the mass flow rate of milk flowing out of the cow's teat q_m of 0.005 is:

$$p_s^* = \frac{66{,}96 \cdot 0{,}57 + 64{,}76 \cdot 0{,}43}{0{,}57 + 0{,}43} = 66{,}02$$

7. Simulation tests

The computer simulation of the operation of the developed linguistic model, which is to perform the role of a setter in the automatic control system, was carried out in the MATLAB-Simulink environment according to the diagram shown in fig. 6.

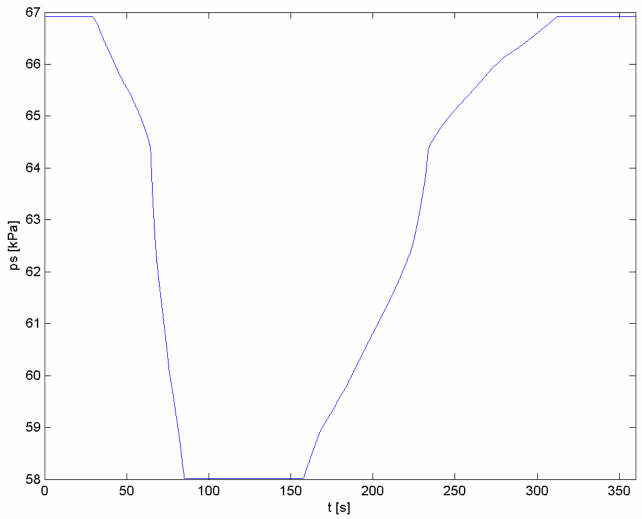


Reference: Own research of the authors

Fig. 6. The diagram for module operation simulation

The developed Mamdani-type fuzzy model is represented by a Simulink block called "Fuzzy Logic Controller" on the presented block diagram. The calculated course of mass flow rate of milk flowing out of the cow's teat q_m, read in from the Matlab environment workspace with the "qm 1 teat" block was entered to its input. The entered course is marked in fig. 3 with number 1. The values from the "Fuzzy Logic Controller" block output were visualised with an "Oscilloscope" type block. The calculated signal of the set value of absolute suction pressure p_s is presented in fig. 7.

Analysing this graph you can observe that in the beginning of the milking simulation the signal of the absolute suction pressure set value p_s stays at a level assumed for the initial phase of milking and is equal to 67 kPa. Then it gently declines to the level appropriate for the actual milking i.e. 58 kPa, and in the end of the simulation it reaches the level corresponding to the final phase of milking, which is again 67 kPa. It stays at this level to the end of the simulation.



Reference: Own research of the authors

Fig. 7. The signal of the absolute suction pressure set value p_s versus time

8. Conclusions

1. The Mamdani model simulation tests indicate it is reasonable to use the model for calculations of the set value of suction pressure in the cow milking process.
2. The presented automatic control system will enable the absolute suction pressure to be shaped in the function of the flow rate of milk flowing out of a quarter of the cow's udder.
3. The developed linguistic model will be used for selection of technical parameters of an autonomous milking cluster.

9. References

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