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MODELLING OF THE NEGATIVE PRESSURE SET VALUE SIGNAL IN AN AUTONOMOUS MILKING CLUSTER WITH ARTIFICIAL INTELLIGENCE METHODS

Summary

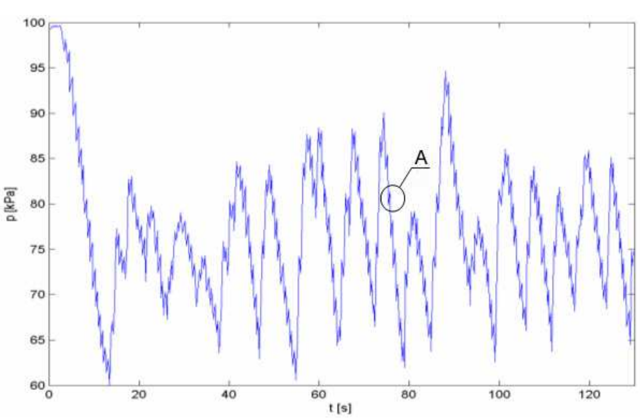
The course of calf suction process was mapped with artificial intelligence methods in terms of negative pressure control in an autonomous milking cluster. A Sugeno-type fuzzy model was applied. The parameters were selected with the training method based on actual process graphs. Findings of a computer simulation in the MATLAB-Simulink® program were illustrated graphically, reflecting the nature of the phenomena. The model error of 6% shows its positive verification.

1. Introduction

The automatic control of a cow milking cluster should reflect the natural calf suction process. Therefore operation parameters of milking clusters designed should be referred to this process taking account among others of pressure, milk volume and process time. At present the operation parameters of these devices are static. In most technical solutions a change in the negative pressure value in teat chambers and pulsation chambers occurs after going to individual phases of milking, which affects the cow's udder, and thus the quantity and quality of the milk obtained. Uncontrolled changes in the negative pressure in teat chambers of teat cups are another important issue. Automatically controlled negative pressure with values closely related to milk outflow, measured independently for each quarter of the cow's udder would be the optimum solution of the milking cluster design. The objective of the study is to present pressure modelling in the teat chamber of an autonomous milking cluster on the basis of physical parameters of the calf suction process, using artificial intelligence methods.

2. Assumptions for modelling

Pressure graphs from the calf suction process were used for developing of a model calculating the suction pressure set value signal in an autonomous milking cluster [1]. The courses of distinguished individual phases: the initial, actual and final phase were analysed. The pressure values ranged from 60 kPa to 95 kPa.



Reference: [1]

Fig. 1. An example of the pressure course for the initial phase

The recurring course components observed on the graph, one of them designated as the "A" detail, are suctions during which a calf consumed a portion of milk. The estimated milk mass values were applied to development of the process model. The pressure values exceeding 85 kPa were rejected at the model training stage. Pressures at this level in the teat chamber would result in an automatic slip of the teat cup off a teat.

3. Pressure Modelling

The formulation of a classic mathematical model is usually a difficult and complex issue. However, having a tool like fuzzy logic and test results describing the phenomenon analysed, you can dispense with the need for developing a model with analytical methods in favour of a model using fuzzy logic [3, 4, 6]. Therefore a fuzzy model was developed in the Matlab-Simulink environment, calculating the set value signal for the process of control of the absolute pressure course in the teat chamber of a teat cup. A Sugeno-type fuzzy model was applied.

The Matlab Fuzzy Logic Toolbox environment library enables Sugeno fuzzy model parameters to be selected with training methods used in neural networks. An algorithm consisting in a transformation of a Sugeno fuzzy model into a self training neural network was applied to selecting of the model parameters. This algorithm is represented by the ANFIS Editor [2] interface presented in fig. 2.

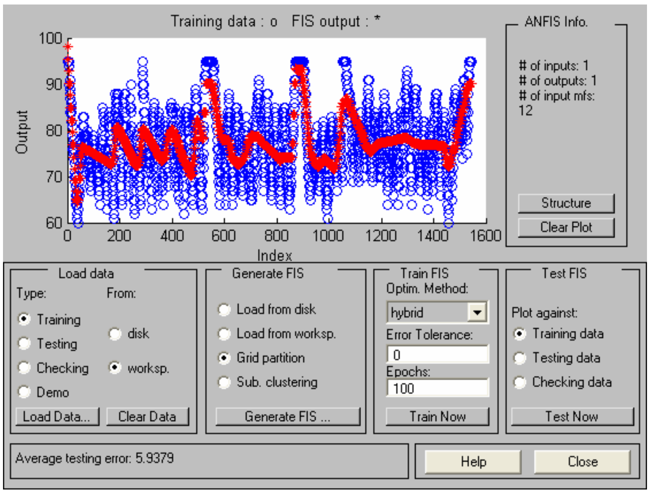


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Fig. 2. The ANFIS Editor interface window with the visualisation of training data

According to the parameter selection algorithm, the fuzzy model was transformed into an equivalent six-layer neural network (fig. 3).

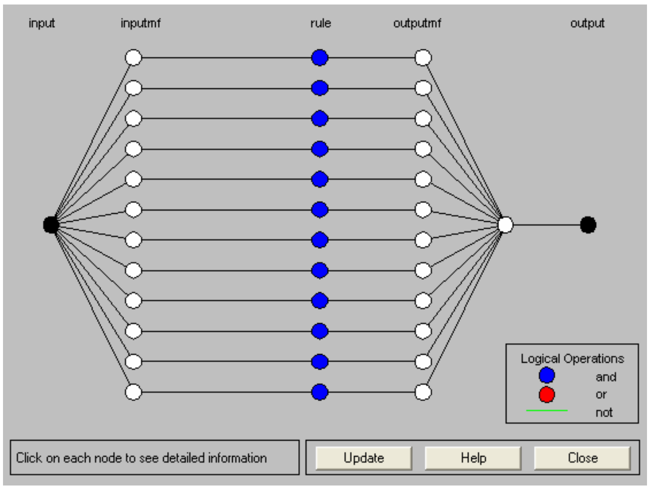

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Fig. 3. The Anfis Model Structure with visualisation of the fuzzy model described by 12 rules after transformation into a neural network

The subsequent neural network layers visible in the window perform the following functions: the first layer (input) means the input value, the second layer (inputmf) is responsible for fuzzification of the input value, the third layer (rule) represents rules. The subsequent layers (outputmf and output) are responsible for defuzzification (crispening) [5].

A matrix containing the milk mass values and the absolute pressure course in the calf suction process was used as the training data for the neural network. The applied algorithm enabled Sugeno-type fuzzy model parameters to be selected. The model input-output diagram is presented in Fig. 4.

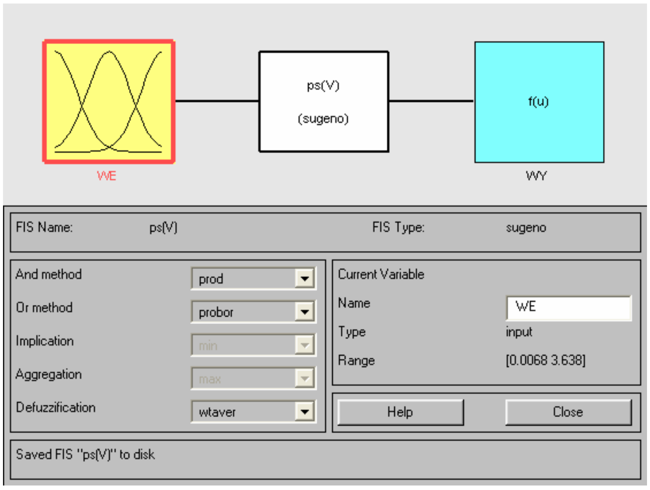

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Fig. 4. The FIS Fuzzy Logic Toolbox editor window - the fuzzy model input-output diagram

The mass of milk flowing out of a teat was declared the input parameter WE. The course of absolute pressure changes in the calf suction process *WY* constituted the output parameter. The linguistic (fuzzy) variable was determined by a set of 12 membership functions (pimf). The number of functions was determined in an arbitrary manner (Fig. 5).

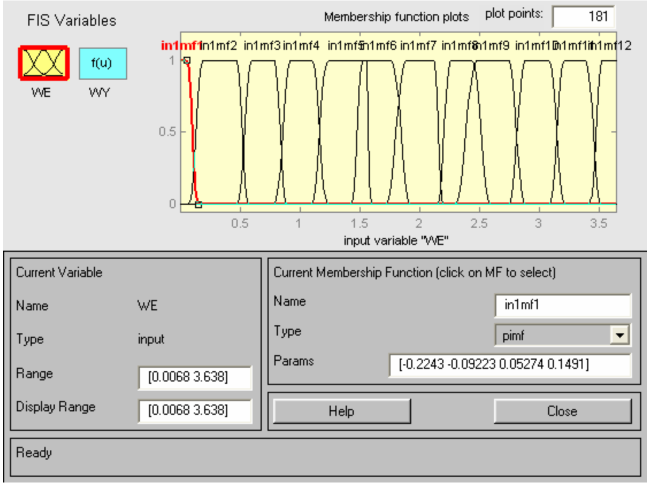

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Fig. 5. The window of the course of the membership function of the input parameter belonging to the subsets

Relationships between the input and output parameters were described with a rule base formulated with the algorithm used for selection of the model parameters (Fig. 6).

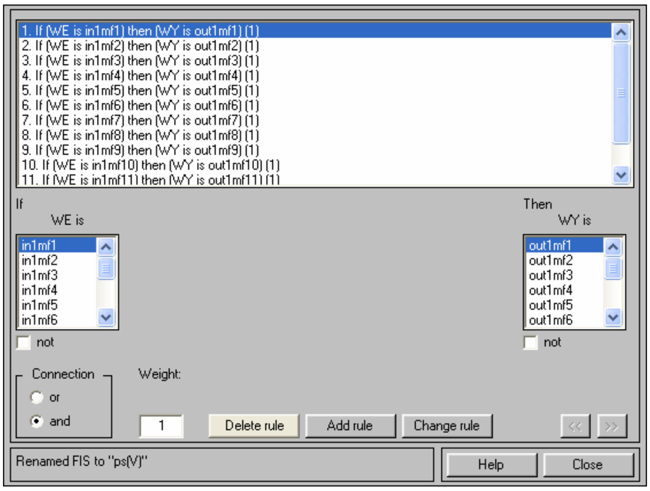

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Fig. 6. The rule base window

The conditional sentence table presented in the rule base window reads:

1. If (WE is in1 mf1) then (WY is out1 mf1) (1),
2. If (WE is in1 mf2) then (WY is out1 mf2) (1),
3. If (WE is in1 mf3) then (WY is out1 mf3) (1),
4. If (WE is in1 mf4) then (WY is out1 mf4) (1),
5. If (WE is in1 mf5) then (WY is out1 mf5) (1),
6. If (WE is in1 mf6) then (WY is out1 mf6) (1),
7. If (WE is in1 mf7) then (WY is out1 mf7) (1),
8. If (WE is in1 mf8) then (WY is out1 mf8) (1),
9. If (WE is in1 mf9) then (WY is out1 mf9) (1),
10. If (WE is in1 mf10) then (WY is out1 mf10) (1),
11. If (WE is in1 mf11) then (WY is out1 mf11) (1),
12. If (WE is in1 mf12) then (WY is out1 mf12) (1).

4. The verification of the pressure set value model

To verify the developed model, the course of the process of determination of the absolute pressure set value in a milking cluster, with a reference to calf suction process graphs, was computer simulated. The model developed in the MATLAB-Simulink environment according to the diagram (fig. 7) was subject to simulation.

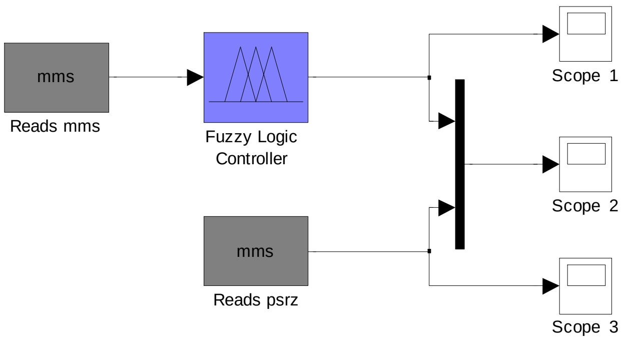

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Fig. 7. The control module simulation diagram

The Sugeno-type fuzzy model is represented by a Simulink block called "Fuzzy Logic Controller". The values of mass changes m_{ms} of milk flowing out of the cow's teat during milking were put into the model input (Fig. 8).

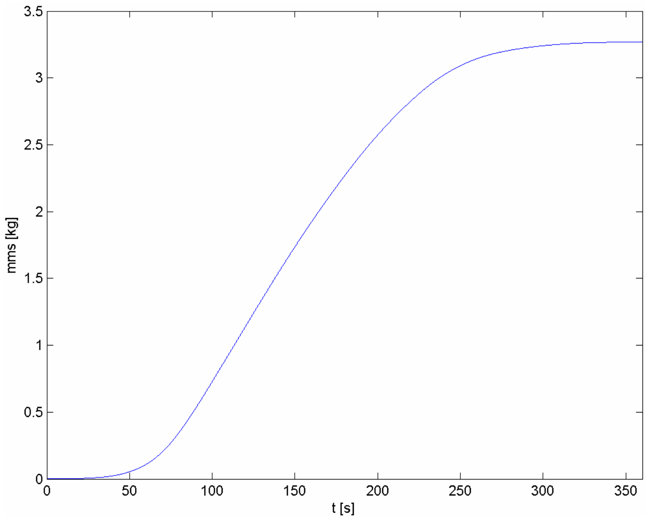

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Fig. 8. The mass of milk flowing out of the cow's teat

This course was obtained after integrating over time the calculated mass flow rate value changes of the liquid representing milk in the calculations (Fig. 9).

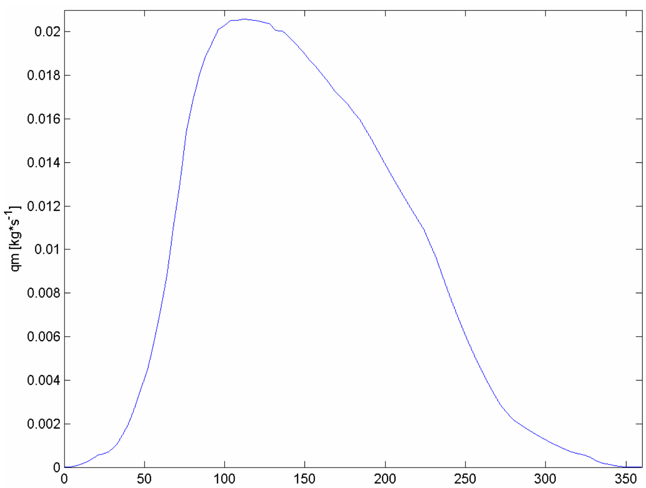

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Fig. 9. The mass flow rate of milk flowing out of a teat

The Matlab workspace data were read in with a block designated "Reads m_{ms}". The course of absolute pressure changes in the calf suction process calculated with the model was output. This constituted the set value for pressure control in the milking cluster. The values of actual absolute pressure in the calf milk suction process were taken from a worksheet to the MATLAB workspace through the block "Reads p_{srz}". The actual course and the course obtained from the model were compared. The "Scope" type blocks presented in the diagram were used for visualisation of the values compared. Fig. 10 shows the course of suction process absolute pressure, calculated according to the fuzzy set rule (the "Fuzzy Logic Controller" block).

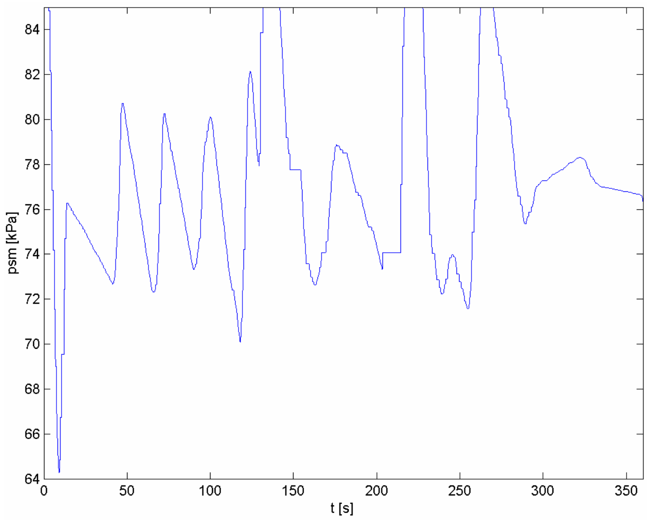

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Fig. 10. Mapping of the absolute pressure changes during the three phases of the suction process

The graph shows the modelled course of absolute pressure changes in the calf suction process versus time. This course constitutes the set value signal for the pressure in the milking cluster. The presented absolute pressure values in the time interval analysed are within the range (65–85) kPa. The graphs in fig. 11 are presented to illustrate the comparison of actual course and the other course resulting from the modelling.

The graph presented above shows the courses: the actual one "1" p_{srz} (green) and the simulated one, represented by the number "2" p_{sm} (blue).

To evaluate the model quality, the average absolute prediction error *MAPE* (1) was calculated on the basis of the actual data and the values obtained from the modelling: were:

$$MAPE = \frac{1}{m}\sum_{t=1}^{m}\left|\frac{y_t - y_t^p}{y_t}\right| \quad (1)$$

y_t - the actual values of calf suction pressure in kPa,
y_t^p - the values of suction pressure obtained in the model in kPa,
M - number of observations.

The average absolute prediction error *MAPE* is equal to ca. 6%, so it is reasonable to state that mapping of the course of the absolute pressure of the calf suction process with a Sugeno-type fuzzy model is correct.

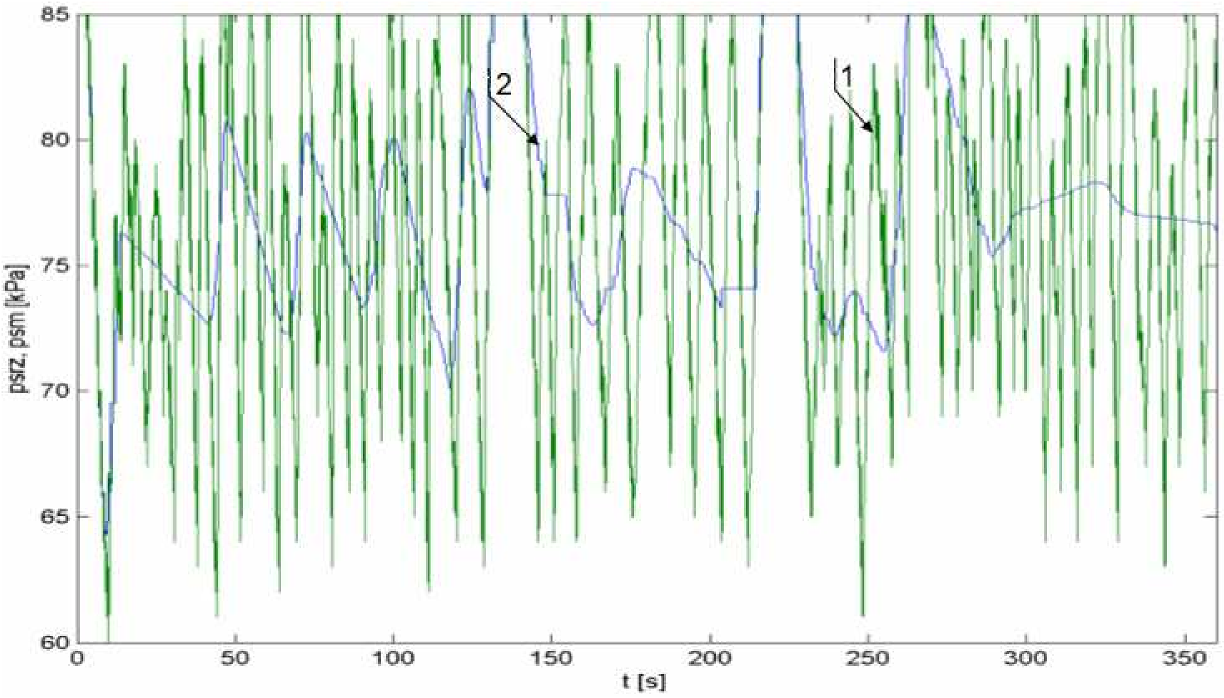

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Fig. 11. The comparison of changes in the actual absolute pressure in the calf suction process and in its mapping

5. Conclusions

1. The developed Sugeno-type fuzzy model allows the course of changes in absolute pressure in the calf suction process to be mapped versus the mass of the milk flowing out from the cow's teat. The average absolute prediction error *MAPE* is ca. 6%.

2. The applied model enables the absolute pressure set value signal in a milking cluster to be determined with a reference to the calf suction process.

3. This presented algorithm provides the set value signal for control of the absolute pressure course in an autonomous milking cluster.

6. References

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