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THE APPLICATION OF ARTIFICIAL INTELLIGENCE METHODS IN POLYETHYLENE FILM PRODUCTION PROCESS CONTROL

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Abstract

The paper presents the design of a fuzzy controller whose task is intelligent, linguistic rule based control of thickness of the extruded polyethylene film. The structure of the fuzzy controller was developed; then, its model was built in MATLAB SIMULINK program and simulations were run to verify its performance under laboratory conditions. Based on the investigation, it can be concluded that the developed controller enables precise adjustment of polyethylene film thickness, taking into account disturbances caused by internal and external factors.

Keywords

Fuzzy logic, production process control, simulation, Matlab, production system.

1. Introduction

Decision-making related to the process of production and control of production facilities is a complex technical issue. It is due to the necessity to take decisions based on a large, difficult-to-calculate number of factors influencing the control of the process and the facilities [1]. Many research institutions are involved in attempts to develop controllers which would be able to take decisions on the basis of fragmentary or imprecise input data. Fuzzy logic, one of the most important methods of artificial intelligence, has great potential in this respect [10]. Fuzzy logic imitates human reasoning, which involves the ability to make the right decisions and operate complicated machinery relying on imprecise terms (e.g., high speed, low temperature, poor visibility). The way of describing fuzzy sets presented in [18] allows for the definition of areas where a given element can simultaneously belong to two sets. The use of fuzzy inferencing facilitates reasoning with the use of rules formulated in near-natural language and operators integrating multiple linguistic rules.

In automatization of technological processes, the use of fuzzy inferencing brings the desired effects with regard to control [16]. It is currently used in many control systems; in particular, wherever classical logic is unable to effectively handle ambiguities and contradictions [10, 11]. Examples of application of fuzzy logic, for example for process control and optimization, include complex control systems where methods of standard control and fuzzy logic are combined [3, 12]. Fuzzy logic is increasingly used in electronic control systems, database exploration or design of expert systems. Literature of the topic also includes examples of industrial applications of fuzzy logic [4, 13, 15] as well as possibilities of machine learning and rule-based control [9]. In paper [17], the authors present the application of fuzzy genetic algorithms in controlling the temperature of a plastic extruder. Paper [19] reports a simulation study of a twin-screw extruder used for rubber processing, in which fuzzy inferencing was used for controlling the speed of the screw. Paper [14] in turn describes the application of a controller for adjusting temperature of a plastic processing twin-screw extruder.

The aim of this study is to present the design of a controller based on fuzzy reasoning used for automatic control of the thickness of the extruded polyethylene film and to determine the effects achieved thanks to this method. The project sought to find a way to enable such adjustment of thickness on the circumference of the film tube that uniform thickness is retained for minimum three work shifts.

At present, polyethylene film thickness control is done manually. This task is assigned to experienced machine operators, who make decisions related to adjusting the valves that regulate the flow of cooling air on the blow-molding unit/blower. However, because of three-shift work schedule, the control has to be carried out by three different operators, each of whom has a different knowledge and possibly a different approach. The process involves changes in raw material parameters, ambient temperature or requirements for the finished product. Frequently, errors arise from slow response to changing external conditions. Therefore, an objective was established to develop a controller which would enable prompt, rule-based control of cooling the blower and ensure continuation of production according to technological requirements. Due to the lack of predefined control algorithms and the possibility to use expert knowledge expressed in the form of linguistic rules, a decision was made to develop a fuzzy-reasoning based controller. In the assumed setting, a fuzzy controller is a decision-making module placed in the adaptive setting.

The paper is divided into five parts. The first part includes an overview of the existing literature on the use of artificial intelligence methods for production process control. Part two introduces the research problem related to process control in the field of polyethylene film production. The third part is devoted to the description of the fuzzy-logic controller design and development. Part four presents a MATLAB-based simulation study of the operation of the developed fuzzy controller. Part five contains a conclusion and recommendations for further research.

2. Description of the research problem

The object of the study is the blow molding production process used for manufacturing polyethylene film. Its principal task is to obtain uniform thickness of the film on the circumference while being within tolerance range stated by the customer. At present, the machine is operated by an operator. Thickness measurements are performed manually and followed by manual adjustment of the slit width of the nozzle. Actions taken by operators and the general production system are described in the authors' earlier works [6–8]. In [6] a schematic diagram of a blow-molding extrusion machine with automatic control of film thickness is presented, along with a‘ detailed description of the principle of the operation of a cooling ring with automatic sector adjustment.

Having performed thickness measurements, the operator is able to assess in which place the set screws should be manually adjusted to regulate the slit width of the nozzle in order to even out the thickness of the film on the circumference of the film tube. The adjustments of set screws are made according to the operator's knowledge and experience. It is therefore possible that each of the operators will make a different decision to solve the issue by machine adjustment. They have different knowledge and experience, so the actions they undertake may differ as well; consequently, the result may be different than expected. The time needed to obtain the desired film thickness may vary, too, which may lead to increasing amounts of production waste.

Another type of situation in which a problem connected with the thickness of the film on the circumference of the film tube may appear is the change in the ambient temperature over the three work shifts; for example, an overnight drop in temperature by 15 degrees Celsius. A way to regulate film thickness then is to set the cooling on the cooling ring. This, however, excludes the possibility of sector adjustment of film thickness only in required places. The cooling is increased or decreased around the entire circumference of the film tube.

Due to a relatively long response time, varying reactions to the necessity of adjustments depending on the human operator's knowledge and experience and limitations resulting from machine construction, a decision was made to develop and apply a controller based on fuzzy-reasoning in adjusting the thickness of the film.

3. Design of a fuzzy logic-based controller for controlling the process of polyethylene film extrusion

Fuzzy control systems enable the control of non-linear objects whose non-linearity makes it difficult to describe them by analytical methods. Characteristic features of fuzzy control include:

- the possibility of expressing a problem in a natural language on the basis of the "expert's" experience through an analysis of relationships between input and output data sets, which facilitates its understanding;
- the ability to model highly complex non-linear dependencies where analytical description is difficult or impossible;
- the use of adaptive parameter selection technique on the basis of learnable data (ANFIS – Adaptive Neuro-Fuzzy Inference Systems);
- flexibility and resilience to imperfect data;
- application of parallel computing;
- the possibility of combining with conventional control methods [2].

In order to utilize the expertise of the human operators controlling the process of polyethylene film production, the concept of a fuzzy controller suited to the process under consideration was proposed. A major challenge was to enable the application of existing linguistic rules to automatic, intelligent decision-making when the necessity to intervene in the manufacturing process arises. On the grounds of previous experience, it was concluded that remedial action is often delayed. Additionally, manual regulation prevents the possibility of adjusting film thickness in all sectors of the polyethylene tube. Consequently, it may happen that a large batch of the material is of inadequate quality – the thickness of the produced film is too low with regard to the customer's specifications. It is often the case that the thickness of the film is too high and although the customer does not raise objections, it needs to be borne in mind that higher thickness is reflected in additional costs generated by higher consumption of raw material and energy needed to heat it.

The experiments conducted on a test stand demonstrated that adequate control of film thickness primarily depends on the time of response to the occurring disturbances. It is also crucial to take regulatory action in the exact sector of the tube where the deviation beyond tolerance range occurred. For the purposes of concept development, it was suggested that a film thickness sensor should be installed directly on the machine. It was assumed that measurement readings would be transmitted to the main computer, where the data would then be verified based on a fuzzy-reasoning controller. Signals generated by the controller would be sent to the cooling ring at the bottom of the extruder. If the thickness was too high, the cooling should decrease; if the film was too thin, the cooling intensity should increase. Measurements should be performed throughout the entire period of production. Figure 1 shows the concept of application of Fuzzy Logic controller for automatic control of film thickness in the process of extrusion.

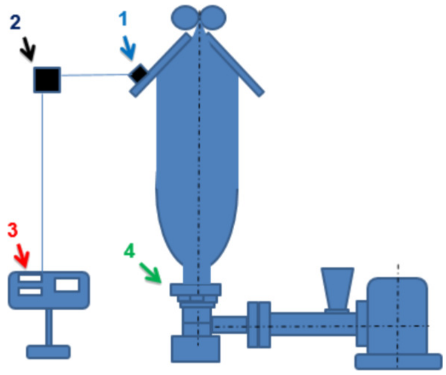


Fig. 1. The concept of application of Fuzzy Logic controller for automatic control of film thickness in the process of extrusion: 1 – film thickness sensor, 2 – measurand converter, 3 – control panel with Fuzzy Logic controller for film thickness adjustment, 4 – segmented cooling ring with automatic airflow regulation.

The tool used for film thickness measurement is a standard touch sensor (Fig. 2). A capacitive sensor is mounted on an air suspension arm and remains in continuous contact with the sheet.

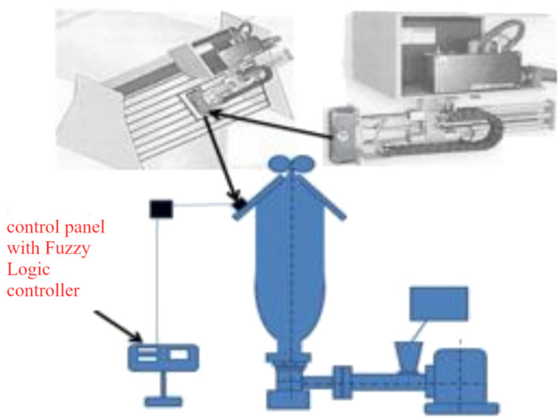


Fig. 2. Sensor used for film thickness measurement.

Measurement readings are transferred to the main computer, where they are verified and appropriate action is taken. Controlled cooling by means of airflow results in adjusting film thickness directly where it is necessary. Figure 3 presents a segment cooling ring with automatic regulation of film-cooling airflow.

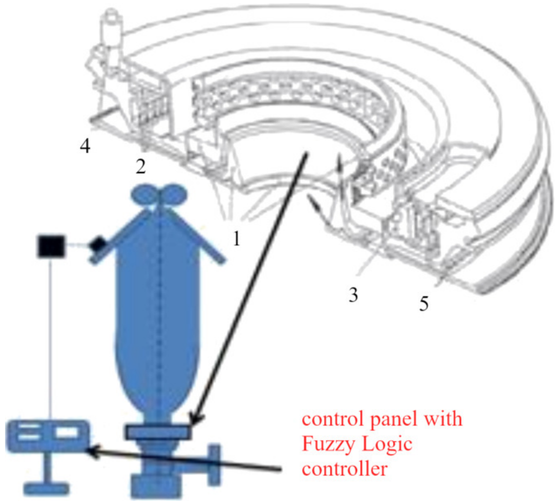


Fig. 3. Segment cooling ring with automatic regulation of film-cooling airflow: 1 – dual-flow cooling ring, 2 – adjusting actuators, 3 – actuator unit, 4 – actuator positioning drive, 5 – perimetric air inlet; arrows mark the outflow of air.

For the cooling ring to function properly, a sufficient airflow is necessary. During automatic operation, positions of the actuators are shown with regard to zero position. Before a new product is introduced or the machine is started, the cooling ring actuators should be set to neutral.

The system for adjusting film thickness operates continually. It retrieves information about the current state of the manufacturing system. Then reasoning is performed and subsequently a parameter is generated, which determines the accuracy of the decision to decrease or increase the cooling of the extruded film by the adjusting actuators on the cooling ring.

The fuzzy controller is developed on the basis of data concerning film thickness measurements performed directly on the extruder in conditions of mass production.

Three input variables were used for the fuzzy controller: x1, x2, and x3.

The first variable (x1) is the difference between the preset and the actual thickness of the film. The values of this variable may be positive or negative. The maximum negative value of the variable is -10, and the maximum positive value is $+10$. Assuming that the nominal thickness of the film is 15 μm and the current measurement of film thickness in the examined sample is 25 μm, the value of variable x1 is $+10$. Both maximum values, positive and negative, serve to indicate the range to be covered by the fuzzy sets.

The second variable, x2, is the position of the last measurement in the area indicated by six sigma. The values of this variable may be positive or negative. The maximum negative value of the last measurement position is −3. In this area, there are points whose value is below the center line of the control chart. The maximum positive value is +3. This area contains points whose value is above the center line of the control chart. The values of variable x2 are defined by the ranges of positions of points within the distance of +/– 3 sigma from the mean value of film measurements indicated on the control chart. It is very important in which zone, below or above the center line, the last measurement is because it may signal process deregulation, which may result in significant variation in film thickness on the perimeter.

The third variable, x3, is the ambient temperature. The possible values range from the minimum +10°C to the maximum +35°C. These represent the lowest and the highest ambient temperature recorded during the study. The ambient temperature matters as a change in temperature influences the thickness of the film extruded in a given moment.

The values of input variables were divided into intervals. Variables x1 and x2 were divided into 7 intervals: very large positive (bardzo duża dodatnia, bdd), large positive (duża dodatnia, dd), small positive (mała dodatnia, md), close to zero (bliska zeru, bz), small negative (mała ujemna, mu), large negative (duża ujemna, du), very large negative (bardzo duża ujemna, bdu). Variable x3 was divided into 5 intervals: very small (bardzo mała, bm), small (mała, m), medium (średnia, ś), large (duża, d) and very large (bardzo duża, bd).

The output variable is the degree of opening of actuators regulating the cooling in the automatic ring (y). As with variables x1 and x2, it was divided into 7 intervals.

The procedure based on fuzzy logic – in this case, the decision concerning the setting of actuators regulating the cooling – consists of three stages: fuzzification, i.e. converting input variables into fuzzy variables; inferencing with the use of linguistic rule base; and defuzzification, i.e., obtaining a single number from the output variable. Figure 4 presents the stages of the inferencing process based on fuzzy logic.

At the fuzzification stage, the particular input variable values are given the values of fuzzy sets that describe them. The input variable is interpreted here as a linguistic variable with appropriately defined values. A classic theory of sets assumes that any given element can "partially belong to a set" and this membership can be expressed by a real number from the range $(-0, 1)$ whose value is determined by a properly defined membership function [5].

Table 1 presents the particular linguistic variables and their assigned membership functions.

In fuzzy logic, inferencing is based on linguistic rules. These rules are composed of a conditional block (a premise, IF-statement) and a conclusion block Yj starting after the word THEN. The fuzzification process enables direct use of rules expressed in linguistic terms. Figure 5 shows sample linguistic rules used for assessing the degree of opening of the actuators regulating the cooling. In the controller's rule base there are 245 rules which determine the degree of opening of the actuators regulating the cooling in the automatic ring. The number of rules is the product of the numbers of fuzzy sets.

Figure 6 shows a graph of transfer function in the devised fuzzy controller. It is a simple way of establishing when the value of output variable will be the lowest and when the highest.

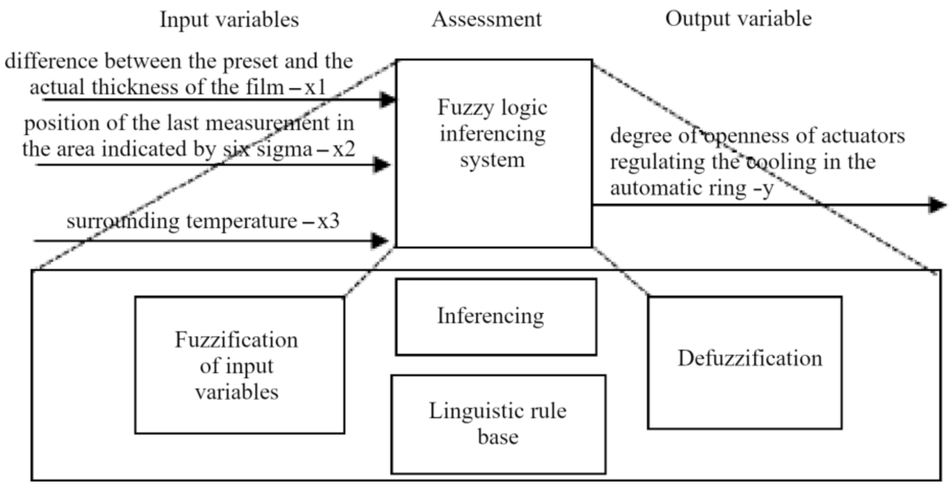
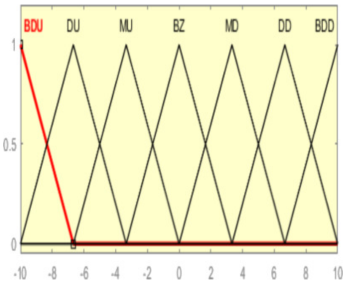
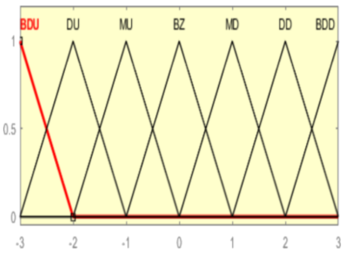
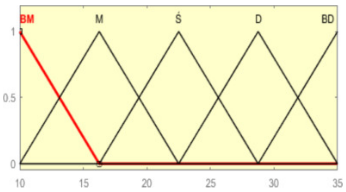
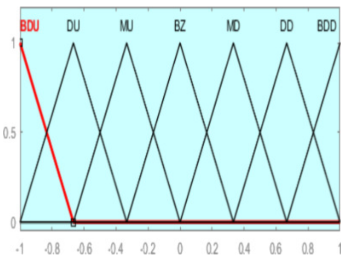


Fig. 4. Inferencing process based on fuzzy logic.

Table 1
Linguistic variables and their assigned membership functions for the FL controller under development.

Linguistic variable description	Membership functions
x1 – difference between the preset and the actual thickness of the film [μm]; values: very large positive (bdd), large positive (dd), small positive (md), close to zero (bz), small negative (mu), large negative (du), very large negative (bdu)	
x2 – position of the last measurement in the area indicated by six sigma; values: very large positive (bdd), large positive (dd), small positive (md), close to zero (bz), small negative (mu), large negative (du), very large negative (bdu)	
x3 – ambient temperature [°C]; values: very small (bm), small (m), medium (ś), large (d), very large (bd)	
y – degree of opening of actuators regulating the cooling in the automatic ring; values: very large positive (bdd), large positive (dd), small positive (md), close to zero (bz), small negative (mu), large negative (du), very large negative (bdu)	

1. If (x1 is BDU) and (x2 is BDU) and (x3 is BM) then (y is DD) (1)
5. If (x1 is BDU) and (x2 is BDU) and (x3 is BD) then (y is BDD) (1)
167. If (x1 is MD) and (x2 is DD) and (x3 is M) then (y is MU) (1)
241. If (x1 is BDD) and (x2 is BDD) and (x3 is BM) then (y is BDU) (1)
245. If (x1 is BDD) and (x2 is BDD) and (x3 is BD) then (y is DU) (1)

Fig. 5. Examples of rules used for assessing the degree of opening of the actuators regulating the cooling.

The fuzzy inference value is transferred to the defuzzification block. As a result of defuzzification the value is obtained for the degree of opening of the actuators regulating the cooling in the automatic ring. In the devised controller, defuzzification is performed by using the Mean of Maximum technique (MOM).

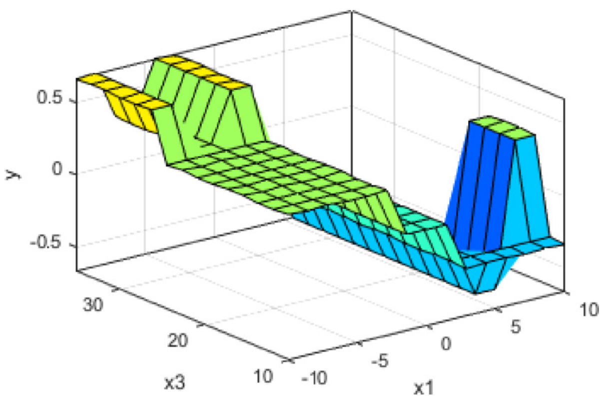


Fig. 6. Graphical presentation of transfer function in the fuzzy controller.

4. Simulation studies presenting the developed fuzzy controller's

Simulation studies were conducted with the use of Matlab program with Fuzzy Logic Toolbox and SIMULINK modules. Actual data obtained in the process of polyethylene film production were used in the studies.

Figure 7 shows the way in which the rules of fuzzy inference influence the data transferred to the fuzzy controller. Three vertical lines indicate the values supplied to the fuzzy controller: the difference between the preset and the actual thickness of the film = 10, the position of the last measurement in the area indicated by 6 sigma = 3 sigma, the temperature of the surroundings = 35°C. The yellow color indicates that the particular variable belongs to fuzzy sets. The blue color indicates that the output variable belongs to fuzzy sets. The value of this variable – here, the degree of opening of the actuators regulating the cooling – is determined during defuzzification. In this case, the degree of opening of the actuators regulating the cooling equals −0.66. This means that the opening of the actuators is reduced, which leads to a reduction of cooling airflow and consequently to a decrease in the thickness of the film.

Table 2 presents the results of the simulation. The first three columns include input variables. These input variables were: the difference between the preset and the actual thickness of the film (variable x1), the position of the last measurement in the area indicated by six sigma (variable x2), the ambient temperature (variable x3). The last column includes the output variable y determining the degree of opening of the actuators regulating the cooling. In the row below the variables, comments on the particular results can be found. In accordance with the accepted procedure, if there is no need for intervention through adjustment of airflow actuators, then the degree of opening of the actuators regulating the cooling equals 0. If the degree of opening is more than 0, then the airflow is increased, which influences the thickness of the film. In situations where the degree of opening is less than 0, the opening of the actuator is reduced and the airflow is consequently reduced, resulting in the decrease in film thickness.

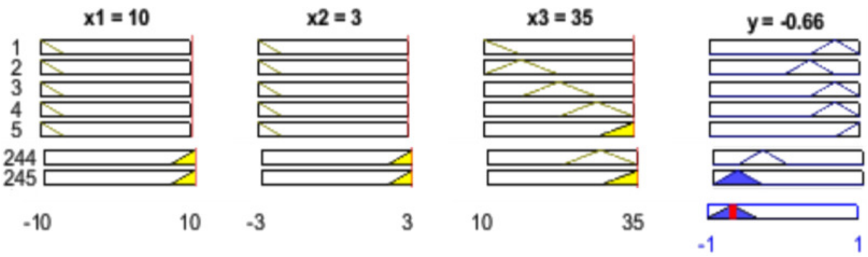


Fig. 7. Fuzzy controller operation example – the degree of opening of the actuators regulating the cooling.

Table 2
Exemplary results of simulation.

x1 the difference between the preset and the actual thickness of the film	x2 the position of the last measurement in the area indicated by six sigma [s]	x3 the ambient temperature [°C]	y the degree of opening of the actuators regulating the cooling in the automatic ring
+10	+3	35	−0.66
Comment	Reduction of the opening of actuators regulating the cooling is required, which will result in reduced thickness of the film		
+1	+1.5	20	−0.16
Comment	Reduction of the opening of actuators regulating the cooling is required, which will result in reduced thickness of the film		
+10	+3	10	−0.9
Comment	Reduction of the opening of actuators regulating the cooling is required, which will result in reduced thickness of the film		
−10	−3	35	+0.9
Comment	Increase in the opening of actuators regulating the cooling is required, which will result in increased thickness of the film		
−10	−3	10	+0.66
Comment	Increase in the opening of actuators regulating the cooling is required, which will result in increased thickness of the film		

5. Summary

The aim of the study was to develop a controller based on fuzzy reasoning used for automatic control of the thickness of the extruded polyethylene film. During the design works, the controller was devised and then a model was developed in the MATLAB SIMULINK program, followed by simulation studies. On the basis of the conducted studies it can be concluded that the developed controller allows fast reaction to emerging disturbances in the process of blow-extrusion of polyethylene film. It also allows the adjustment of film thickness, which in some cases cannot be done manually by the operator. Preliminary tests indicate that the implementation of the controller will lead to film quality improvement on every work shift, and by the same token, contribute to the reduction of production costs. Such implementation of a fuzzy controller will allow the operators' knowledge to be used and stored as a linguistic rule base. As part of further study, the authors plan to develop an adaptive controller and integrate genetic algorithm with fuzzy logic. Future plans also include extending the controller with additional input variables and developing a model of the whole process of film extrusion (with a polyethylene film blow extruder).

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