Synthesis of a fuzzy controller for identification and quantification of disturbances by trends

E A Muravyova and R F Imaev
Ufa State Petroleum Technological University, Branch in the City of Sterlitamak, Russia
E-mail: muraveva_ea@mail.ru

Abstract. This article describes the main stages of constructing a fuzzy controller that identifies disturbances in the automatic control system by trends on the example of the brine cycle, namely, heating the purified one going to electrolysis. This method can be implemented in perturbation control systems for the formation of control actions, as well as for diagnostic purposes. The aim of the study is to synthesize a fuzzy controller for identifying and quantifying perturbations by trends. The article proposes a method for estimating perturbations by trends. A mathematical model of processes implemented in the Mathcad environment is constructed. A conceptual model of a fuzzy controller for determining the perturbation is implemented. As a result of the research conducted on the basis of the proposed method, two fuzzy controllers were synthesized that quantify disturbances in the water heating cycle, namely: the deviation of the temperature of the purified brine entering the heat exchanger, as well as the deviation of the water temperature in the tank from the norm. The developed project is of practical importance, since the information about disturbances obtained as an output value from the fuzzy controller can be used in the diagnosis and assessment of the system state at any time, which, in turn, can be used for smoother control when applying a correction signal to the controller that controls the dampers and pumps, as well as to prevent accidents.

1. Introduction
Formation of perturbation control systems is hampered by difficulties of quantitative identification of perturbations. The article proposes a method for estimating disturbances by trends. To do this, it is proposed to develop a fuzzy controller (FC) based on expert information. The identification of disturbances is continuous, thereby ensuring the continuity of control action on the control object (OC). Works in which control systems [1-5] for disturbances are presented do not use the principles of fuzzy logic to identify them, their quantitative determination is not always accurate. Note that the synthesis algorithm described in [6-8] allows to generate output values of FC with the required static characteristic and minimal error, thereby making it possible to strictly estimate disturbing effects on the system.

2. Description of the control object
The section under consideration (figure 1), located in the brine preparation cycle, located at the production of JSC "BSK" in workshop No. 4, is designed to heat the finished and purified brine NaCl (sodium chloride) going for electrolysis. The section includes two shell-and-tube heat exchangers (pos. E-516 and E-506), centrifugal pump (pos. P-551) and cooling water tank (pos. TK-551).
Steam flow rate for water heating to heat exchanger pos. E-516 is supported by control valve pos. TY-583-3. Also in the scheme there are two more similar valves: pos. TY-535-3 (for control of heated water flow through bypass to tank with cooling water pos. TK-551) and pos. TY-535-4 (for control of heated water flow to heat exchanger pos. E-506).

3. **Mathematical model of processes occurring in the cycle of brine heating for electrolysis**

Consider the following key processes:

- Water heating in heat exchanger pos. E-516, [40÷100] °C;
- Temperature change in the tank pos. TK-551 as a result of the cyclicity of the process, [40 100] °C;
- Brine heating in heat exchanger pos. E-506, [40÷100] °C (theoretical value), [70÷85] °C (supported optimal value).

The course and nature of these processes depends on:

- Steam flow rate to heat exchanger pos. E-516 [0÷7500] of m³/h;
- Consumption of hot water through a bypass [0÷60] of m³/h;
- Flow water to heat exchanger pos. A-506[0÷60] of m³/h.

Modeling will be carried out in Mathcad - a computer algebra system from the class of computer-aided design systems, focused on the preparation of interactive documents with calculations and visual accompaniment, is easy to use and use for teamwork.

Set input parameters and write constants with explanations (figures 2-3). The value of the constants was found in the reference data [9-12].
Figure 2. Initial values and constants for simulating processes in the refined brine heating cycle.

The models presented in figures 3, 5, 7 are obtained by solving the thermal balance equations (the variables used in the construction of the model are taken from figure 2).

Mathematical model of processes implemented in the medium of MathCad occurring in the heat exchanger pos. Е-516 shown in figure 3:

\[
\begin{align*}
\text{Initial values and constants for simulating processes in the refined brine heating cycle:} & \\
\text{Water consumption for heat exchanger E-516, created by pump p-506, m}^3 & = 60 \ F_{\text{water}} \\
\text{Vapor density, kg/m}^3 & = 1 \ p_{\text{steam}} \\
\text{Steam consumption for heat exchanger E-516, m}^3/h & = 7500 \ F_{\text{steam}} \\
\text{Temperature in the tank TK-551 at start-up, °C} & = 2100 \ t_{\text{steam}} \\
\text{Heat capacity of steam, kg/(J/°C)} & = 115 \ c_{\text{steam}} \\
\text{Temperature of steam going to the heat exchanger E-516, °C} & = 2256000 \ t_{\text{cond}} \\
\text{Consumption, water through the bypass, m}^3/h & = 20 \ F_{\text{bypass}} \\
\text{Consumption, water for the heat exchanger E-506, m}^3/h & = 40 \ F_{\text{water}2} \\
\text{Water condensation temperature, °C} & = 100 \ t_{\text{cond}} \\
\text{Specific heat of condensation of steam, J/kg} & = 1250 \ c_{\text{cond}} \\
\text{Heat capacity of water, kg/(J/°C)} & = 4200 \ c_{\text{water}} \\
\text{Density of water, kg/m}^3 & = 1000 \ \rho_{\text{water}} \\
\text{Water volume of tank TK-551, m}^3 & = 12 \ V \\
\text{Heat capacity of the purified brine, kg/(J/°C)} & = 2700 \ C_{\text{pur}} \\
\text{Density of the purified brine, kg/m}^3 & = 1575 \ \rho_{\text{pur}} \\
\text{Density of water, kg/m}^3 & = 1250 \ \rho_{\text{water}} \\
\text{Water temperature at the inlet to the heat exchanger pos. E-506 at launch, °C} & = 53.75 \ t_{\text{vi}} \\
\text{Brine temperature at the outlet of the heat exchanger pos. E-506 at launch, °C} & = 49 \ t_{\text{vi}} \\
\text{Temperature in the tank TK-551, indicated in the cycle subroutine} & = Z
\end{align*}
\]

Mathematical model of processes occurring in the heat exchanger pos. E-516:

\[
\begin{align*}
\text{Mathematical model of processes occurring in heat exchanger pos. E-516:} & \\
\text{The model shown in figure 3 is the result of solving the following thermal balance equation:} & \\
\alpha_1 \cdot \rho_{\text{water}} \cdot F_{\text{steam}} \cdot \left( C_{\text{steam}} \cdot (t_{\text{steam}} - t_{\text{cond}}) + q_{\text{cond}} \right) + \frac{F_{\text{steam}} \cdot \alpha_1}{1000} \cdot \rho_{\text{water}} \cdot F_{\text{water}} \cdot (t_{\text{vi}} - t_{\text{v1}}) & = C_{\text{water}} \cdot \left( t_{\text{cond}} - t_{\text{vi}} \right),
\end{align*}
\]

where \( t_{\text{v1}} \) - the final temperature of the water exiting the heat exchanger to be found, the number 1000 in formula (1) shows that after the steam condensed in the heat exchanger, its volume decreased by 1000 times. Formula (1) shows how the water flows from the vessel pos. TK-551 and recirculated steam at a temperature of 115 °C.

Mathematical model of processes occurring in capacitance pos. TK-551 will be shown in figure 5:

\[
\begin{align*}
\text{Mathematical model of processes occurring in the capacity TK-551:} & \\
\text{The model shown in figure 5 is the result of solving the following thermal balance equation:} & \\
\frac{F_{\text{steam}} \cdot \tau \cdot t_{\text{v1}}}{1000} + V \cdot t_{\text{vi}} + V \cdot F_{\text{bypass}} \cdot \tau \cdot t_{\text{v1}} + F_{\text{water}2} \cdot \tau \cdot t_{\text{vi}} & = \frac{F_{\text{steam}} \cdot \tau \cdot t_{\text{v1}}}{1000} + V \cdot F_{\text{bypass}} \cdot \tau + F_{\text{water}2} \cdot \tau
\end{align*}
\]
Figure 5. Graph (tvi) illustrating the change in water temperature in the heat exchanger pos. Е-516 from time (t, min).

The model shown in figure 5 is the result of solving the following thermal balance equation:

\[ C_{\text{water}} \cdot \rho_{\text{water}} \cdot \frac{F_{\text{steam}}}{1000} \cdot t \cdot (t_{\text{cond}} - t_{\text{vhv}}) + V \cdot (t_{\text{vi}} - t_{\text{vhv}}) + F_{\text{bypass}} \cdot t \cdot (t_{\text{vi}} - t_{\text{vhv}}) + F_{\text{water}} \cdot t \cdot (t_{\text{vi}} - t_{\text{vhv}}) = 0, \]  

(2)

where tvi is the water temperature described by the model in figure 3, tri - is the water temperature (brine) described by the model in figure 6, tvhvvi is the final water temperature to be found, t is the time in minutes. The number 1000 in formula (2) shows that after the steam condensed in the heat exchanger, its volume decreased by 1000 times. Formula (2) shows how water flows from heat exchanger pos. Е516 passing through bypass TY-535-3 and cooled water from heat exchanger pos. Е506.

Figure 6. Graph (tvhvvi) illustrating the change of water temperature in tank TK-551 from time (t, min).

Mathematical model of processes occurring in heat exchanger pos. Е-506 will look like this

\[
T_{tr} \leftarrow \frac{C_{\text{pur}} \cdot ppur \cdot F_{\text{pur}} \cdot tipur + C_{\text{water}} \cdot F_{\text{water}} \cdot cx2 \cdot p_{\text{water}} \cdot tv1}{C_{\text{pur}} \cdot ppur \cdot F_{\text{pur}} + C_{\text{water}} \cdot F_{\text{water}} \cdot cx2 \cdot p_{\text{water}}}
\]

Figure 7. Mathematical model of processes occurring in the heat exchanger Е-506.

The model shown in figure 7 is the result of solving the following thermal balance equation:
\[ C_{вод} \cdot F_{рассол} \cdot \rho_{рассол} (t_{рассол,вход} - t_r) - C_{вод} \cdot F_{вод,вход} \cdot \rho_{вод,вход} (t_{вод,вход} - t_r) \cdot \alpha_2 = 0, \]  

(3)

where \( t_{вод,вход} \) is the water temperature described by the model in figure 3, \( t_r \) - is the final water temperature to be found. Formula (3) shows how water flows from heat exchanger pos. E516 and purified cold brine.

4. Fuzzy controller synthesis to identify and quantify perturbations

Before starting the synthesis of fuzzy controllers (FC), it is necessary to develop their conceptual models depicting the connection of inputs and outputs. The conceptual model shows the influence of input signals (brine temperature at the heat exchanger outlet pos. E-506 (figure 9, 10) and trend of deviations representing the difference of the model of brine temperature at the heat exchanger outlet (figures 9, 10) and the same model without disturbances (figure 11) to the result of fuzzy controller operation - its output value [13]. Only those FC inputs that affect its output are indicated. For the convenience of determining perturbations, we will use the following assumption: by determining one of the two possible perturbations, we omit the second perturbation (conditionally we believe that it is not).
In our case, the fuzzy controller will quantify the disturbances in the water heating cycle, namely, the temperature deviation of the purified brine entering the heat exchanger pos. E-506 (norm - 40 °C), deviation of water temperature in the tank, pos. TK-551 (figure 6) from the norm.

The model of the control object (brine temperature at the heat exchanger outlet, pos. E-506, described in figure 7) taking into account perturbations (figures 9, 10), as well as the trend of deviations, which is the difference between the model of the object taking into account perturbations (figures 9, 10) and the model of the object without taking into account perturbations (figure 11), expressed in degrees Celsius. The output values will be a numerical array containing perturbation data at each time point (deviation degree and sign).

Figures 12, 13 show conceptual models of fuzzy controller for identification and quantitative evaluation of perturbations of water temperature parameters in tank pos. TK-551 and inlet brine temperature.

Two trends are supplied to the input of the first fuzzy controller (figure 12): the trend of brine temperature at the outlet of the heat exchanger at the conditionally constant temperature of the incoming brine (figure 9) and the trend of deviations, which is the difference in the parameters (brine temperature) of the trend with disturbance (figure 9) and the trend of brine temperature at the outlet of the heat exchanger pos. E-506 without disturbances (figure 11).

Two trends are supplied to the input of the second fuzzy controller (figure 13): the trend of brine temperature at the outlet of the heat exchanger in the absence of disturbances of the water temperature parameter in the tank pos. TK-551 (figure 10) and deviation trend, which is the difference between the...
parameters (brine temperature) of the trend with disturbance (figure 10) and the trend of brine temperature at the outlet of the heat exchanger pos. E-506 without disturbances (figure 11).

Tr - brine temperature at the heat exchanger outlet, pos. E-506; tr - trend of deviations; g'T water capacity - disturbance (degree of deviation of water temperature in the tank TK-551 from the norm)

**Figure 12.** Conceptual model of fuzzy controller for determination of disturbance (water temperature in tank in pos. TK-551).

According to the mathematical model, a table of reference points through which the static characteristic of the FC should pass is compiled (table 1).

| tr off (40) | tr off (255) | tr off (30) | tr off (350) |
|------------|-------------|-------------|--------------|
| T1 (40)    | -3.17       | -3.54       | -4.11        |
| T2 (30)    | -1.37       | -1.72       | -2.14        |
| T3 (350)   | 0           | 0           | 2.03         |
| T4 (51)    | 1.34        | 1.6         | 2.51         |
| T5 (64)    | 2.94        | 3.21        | 3.79         |

Table 1: Perturbation reference points for FC synthesis (g'T brain input).

Table headers are a collection of reference points for input FC variables.

As can be seen from table 1, most perturbation values do not match the centers of term weights (figures 14 - 19). Therefore, in each rule, the output variable corresponds to two terms with different degrees of affiliation. That is, we will use production rules of the type:

*If <tr off> and <tr>, then g'T water capacities = g_i and g'T water capacities = g_j, where C_i, C_j - the degree of belonging of the variable to the terms g'T water capacities.*

tr off - deviation trend equal to the difference of the model of the object with disturbances (figures 9, 10) and without (figure 11).

To describe the input linguistic variables, "the temperature of the brine at the outlet of the heat exchanger pos. E-506 at conventionally constant temperature of brine entering heat exchanger pos. E-
506 "(Tr)," deviation trend at conventionally constant temperature of brine entering the heat exchanger pos. E-506 "(Tr\text{off})," brine temperature at heat exchanger outlet, pos. E-506 in the absence of disturbances of the temperature value in the tank pos. TK-551 "(Tr)," trend of deviations at absence of disturbances of temperature value in capacitance pos. TK-551 "(Tr\text{off})" will use five terms each (figures 14-17).

Figure 14. Linguistic variable "brine temperature at heat exchanger outlet pos. E-506 at conventionally constant temperature of brine entering heat exchanger pos. E-506".

Figure 15. Linguistic variable "trend of deviations at conventionally constant temperature of brine entering the heat exchanger pos. E-506".

Figure 16. Linguistic variable "brine temperature at heat exchanger outlet pos. E-506 in the absence of disturbances of the temperature value in the tank pos. TK-551".

Figure 17. Linguistic variable "trend of deviations in the absence of perturbations of temperature value in capacitance pos. TK-551".

To describe the output linguistic variables, "the degree of deviation of the temperature of the purified brine to the inlet to the heat exchanger pos. E-506 "(t_{water capacities}) and" the degree of deviation of the water temperature in the tank TK-551 from the norm "(t_{braininput}) will use the five terms shown in Figures 18-19. Extreme terms have a symmetric triangular shape. For any value of the function of belonging to the output variable to extreme terms, their center of gravity will not shift. This allows you to specify the
minimum and maximum values of the output function. These variables have a change range of \([-4.6; 4.6]\) °C.

**Figure 18.** Linguistic variable "degree of deviation of purified brine temperature to the heat exchanger inlet pos. E-506".

**Figure 19.** Linguistic variable "degree of deviation of water temperature in the tank TK-551 from the norm".

We will demonstrate how the belonging functions for the input variables "brine temperature" (figure 14) and deviation trend (figure 15) are located at values of input parameters 60 and 3 °C respectively.

**Figure 20.** Finding the function of belonging to the variable "brine temperature at the heat exchanger outlet pos. E-506 at conventionally constant temperature of brine entering heat exchanger pos. E-506".

**Figure 21.** Finding the function of belonging to the variable "trend of deviations at conditionally constant temperature of brine entering the heat exchanger pos. E-506".

As can be seen from figures 20, 21, the following values were obtained:

\[ T_r = 60 \, ^\circ C, \ \mu(T_r) = (T_{r1}, T_{r2}, T_{r3}, T_{r4}, T_{r5}) = (0; 0.6; 0.4; 0; 0). \]

\[ T_{r_{off}} = 3 \, ^\circ C, \ \mu(T_{r_{off}}) = (T_{r_{off1}}, T_{r_{off2}}, T_{r_{off3}}, T_{r_{off4}}, T_{r_{off5}}) = (0; 0; 0; 0.7; 0.3). \]

To determine the results of the aggregation, we find the minimum value of the degree of truth of the sub-conditions for each of the conditions.

Based on the results of fuzzification, it can be concluded that rules will work, the antecedent of which contains the following statements:

\[ T_{r2} \ \text{OR} \ T_{r3} \ \text{AND} \ T_{r_{off4}} \ \text{OR} \ T_{r_{off5}}. \]
Only 4 rules that worked. For the algorithm described in the draft, you need to find the degrees of truth of all rules. The result of the aggregation is represented as a matrix of the form:

\[
Z = \begin{pmatrix}
0.3 \\
... \\
0.4 \\
0.6 \\
... \\
0.3
\end{pmatrix}
\tag{4}
\]

consisting of 25 elements, 21 of which will be zero for our case, only 4 elements will be non-zero: 
\[z = (z_1; z_2; z_3; z_4) = (0; 0.4; 0.3; 0.6)\]

Let us demonstrate how the aggregation step is implemented using the example of rules, the antecedent of which contains the statement Tr\text{off} \_2 AND Tr\text{off} \_4 (figure 22).

![Implementation of the aggregation phase.](image)

As shown in figure 22, the minimum degree of truth will be 0.6.

Consider a rule of the form IF T = Tr\text{off} \_3 and Tr = Tr\text{off} \_5. In this rule, two values of the output variable \(t\_\text{brine input}2\) and \(t\_\text{brine input}3\) are implemented, with \(t\_\text{brine input}2 = -2.3\) and \(t\_\text{brine input}3 = 0\) (values of \(t\_\text{brine input}2\) and \(t\_\text{brine input}3\) are taken from the description of the linguistic variable \(t\_\text{brine input}\) (figure 19).

The value of the center of gravity \(g_2\) is -1.15.

\[
g_2 = \frac{-2.3 + 0}{2} = -1.15.
\]

The desired value of the output variable of the fuzzy controller, taken from Table 1 (Tr\text{off} = Tr\text{off} \_3 and Tr = Tr\text{off} \_5), is -1.37 (\(t\_\text{brine input} = -1.37\)).

Since \(g_2 = -1.37 < g_3 = -1.15\), then \(g_2\) is the basic consequent, \(g_3\) is the additional consequent. So, \(g_3 = g_2 = -2.3\) (\(g_0\) - is the basic consequent).

The output value will be 0.9:

\[
g^* = 1 - \frac{-1.37 + 1.15}{-2.3 + 1.15} = 1 - 0.1 = 0.9.
\]

The degree of truth of the additional consequent is determined from the graph depending on the relative value of the output value. According to the diagram shown in figure 23, the degree of truth of the additional preservative is 0.6 (s = 0.6).

Then it is fair to say that IF T = Tr\text{off} \_3 and Tr = Tr\text{off} \_3, THEN \(t\_\text{brine input} = t\_\text{brine input}2\) and \(t\_\text{brine input} = t\_\text{brine input}3\).
Figure 23. Dependence of the degree of truth of the additional preservative on the relative value of the output value.

Table 2 shows 25 production rules describing the effect of disturbances for the first controller:

| Rule | $T_{r1}$ | $T_{r2}$ | $T_{r3}$ | $T_{r4}$ | $T_{r5}$ |
|------|----------|----------|----------|----------|----------|
| 1    | $V_1$    | $V_1$    | $V_1$    | $V_1$    | $V_1$    |
| 2    | $V_{2,0.02}$ | $V_{2,0.03}$ | $V_{2,0.01}$ | $V_{2,0.001}$ | $V_{2,0.001}$ |
| 3    | $V_{2,0.15}$ | $V_{2,0.04}$ | $V_{2,0.002}$ | $V_{2,0.1}$ | $V_{2,0.11}$ |
| 4    | $V_{2,0.001}$ | $V_{2,0.05}$ | $V_{2,0.01}$ | $V_{2,0.1}$ | $V_{2,0.2}$ |
| 5    | $V_{2,0.0001}$ | $V_{2,0.01}$ | $V_{2,0.001}$ | $V_{2,0.004}$ | $V_{2,0.081}$ |
| 6    | $V_{3,0.01}$ | $V_{3,0.032}$ | $V_{3,0.00003}$ | $V_{3,0.4}$ | $V_{3,0.001}$ |
| 7    | $V_{3,0.001}$ | $V_{3,0.01}$ | $V_{3,0.035}$ | $V_{3,0.035}$ | $V_{3,0.01}$ |

If $t_{brine input}$ is a basic consequent, then the degree of truth of the term $t_{brine input}$ is equal to one, if $t_{brine input}$ is an additional consequent, then the degree of truth of the term $t_{brine input}$ is equal to the value “c.”

Using Table 2, construct matrix $B$:

$$B = \begin{pmatrix} 1 & \cdots & \cdots & 0 \\ 0.35 & \cdots & \cdots & 0 \\ 0 & \cdots & \cdots & 1 \\ 0 & \cdots & \cdots & 0.89 \end{pmatrix}$$

The matrix contains 25 columns for each rule and 5 rows for each term of the output parameter. The final step of activation is to calculate the ratio of the product of matrix $B$ (formula 5) and vector $z$ (formula 4) by the sum of the values of vector $z$ for each rule.

$$\mu(g) = \frac{Bz}{\text{sum}(z)}$$

Consider the activation step by example using the data obtained in formulae 4, 5:
sum(z) = z_1 + z_2 + z_3 + z_4 = 1.6.
Thus, we get:

\[ \mu(g) = \begin{pmatrix} 1 & \ldots & 0 \\ 0.35 & \ldots & 0 \\ 0 & \ldots & 0 \\ 0 & \ldots & 1 \end{pmatrix}_{1.6} \begin{pmatrix} 0.3 \\ \ldots \\ 0.4 \\ \ldots \\ 0.3 \end{pmatrix} = \begin{pmatrix} 0 \\ \ldots \\ 0 \\ 0.3746 \\ 0.4432 \end{pmatrix}. \]

**Figure 24.** Results of activation.

As a result, we obtain the area formed by the terms brine input_4, brine input_5 and horizontal lines corresponding to the values \( \mu(\text{brine input}) = 0.3746 \) and \( 0.4432 \).

In order to obtain quantitative values for each output variable, it is necessary to defuzzify using the formula:

\[ g' = \frac{\max_g \int g \cdot \mu(g) \, dg}{\int \mu(g) \, dg}, \]

where \( g' \) – disturbance (brine input);
\( g_{\text{max}} \) – maximum value of disturbance in the range of actuated term;
\( g_{\text{min}} \) – minimum value of disturbance in the range of the actuated term.

For the examples described above (figure 24) we will find:

\[ g''(T) = \frac{\max_g \int g \cdot \mu(g) \, dg}{\max_g \int \mu(g) \, dg} = \frac{\int 2.3\mu_4(g) \, dg + \int 4.6\mu_5(g) \, dg}{\int 2.3\mu_4(g) \, dg + \int 4.6\mu_5(g) \, dg} = 2.913^0 C. \]

Reference perturbation points for FC synthesis obtained by mathematical model of change of brine temperature at outlet (figure 9) are shown in table 3.

**Table 3. Reference Points for HP Synthesis (g’ water capacity).**

| \( T_{\text{off}} \) | \( T_{1(40)} \) | \( T_{2(55)} \) | \( T_{3(70)} \) | \( T_{4(85)} \) | \( T_{5(100)} \) |
|----------------|----------------|----------------|----------------|----------------|----------------|
| \( T_{\text{off}1(3)} \) | -3.27 | -3.34 | -3.67 | -3.95 | -4.24 |
| \( T_{\text{off}2(1.5)} \) | -1.13 | -1.45 | -1.86 | -2.14 | -2.62 |
| \( T_{\text{off}3(0)} \) | -0.43 | 0.56 | 0.78 | -0.37 | 0.49 |
| \( T_{\text{off}4(1.5)} \) | 1.19 | 1.36 | 1.79 | 2.14 | 2.57 |
| \( T_{\text{off}5(3)} \) | 2.76 | 3.03 | 3.41 | 3.83 | 4.04 |
Activation for \( g'_{\text{brain input}} \) has been described previously (formula (6)). In this case, we'll use the same algorithm.

Table 4 shows 25 production rules describing the effect of the disturbance of the brine temperature parameter on the inlet to the heat exchanger pos. E-506, for operation of the controller determining these disturbances:

| \( T_{roff1}(3) \) | \( T_{roff2}(1.5) \) | \( T_{roff3}(0) \) | \( T_{roff4}(1.5) \) | \( T_{roff5} \) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| \( V_1 \) | \( V_1 \) | \( V_2 \) | \( V_2 \) | \( V_2 \) |
| \( V_{2.000} \) | \( V_{2.7} \) | \( V_{2.66} \) | \( V_{2.56} \) | \( V_{2.88} \) |
| \( V_{2.028} \) | \( V_{2.0.9} \) | \( V_{2.54} \) | \( V_{2.81} \) | \( V_{2.98} \) |
| \( V_{2.034} \) | \( V_{2.92} \) | \( V_{2.12} \) | \( V_{3.38} \) | \( V_{3.57} \) |
| \( V_{2.42} \) | \( V_{0.76} \) | \( V_{2.56} \) | \( V_{3.68} \) | \( V_{3.0} \) |

5. Matlab Development of fuzzy controllers in Matlab environment

The next stage after the creation of the rule base is their implementation as part of fuzzy controllers.

To design a controller using fuzzy logic in the Matlab environment, use the fuzzy command. We will design a fuzzy FC2 controller. Set the number of input parameters to 4, output parameters to 3. Next, we denote the measurement ranges for each input and output parameter. In accordance with the ranges, we set the terms for the input parameters. Setting terms for output parameters is done in the same way.

This method designs fuzzy controllers FC1, FC3 and FC4.

Conclusion

Thus, a fuzzy controller was synthesized to identify and quantify disturbances on trends. Disturbance information obtained as an output value from a fuzzy controller will help in diagnosing and evaluating the state of the system at any time, which, in turn, can be used for smoother control when a correction signal is sent to the controller that controls the shutters and pumps, as well as to prevent emergency situations.

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