Representation of Process Parameters Pump Stations by Term Set with a Rectangular Shape of the Membership Function

A. A. Yemekeev
Almetyevsk state oil institute
Almetyevsk, Russia
e-mail: emekeev@gmail.com

A. M. Sagdatullin
Almetyevsk state oil institute
Almetyevsk, Russia
e-mail: Saturn-s5@mail.ru

E. A. Muravyova
Ufa State Petroleum Technical University
Sterlitamak branch
Sterlitamak, Russia
e-mail: muraveva_ea@mail.ru

Abstract[1]

In order to improve the pump station control quality a special case of fuzzy controllers has been suggested to use, in which both the input and output variables are represented by a set of mutually non-overlapping terms of the rectangular shape of the membership function (precise terms). As it has been found out there is only one term in this set at any moment of time that is equal to a logical unit, whereas in the production rules system operating such terms, at any arbitrary moment of time, only one production rule antecedent is equal to a logical unit. This allows without losing of the control adequacy in each controller production system scanning cycle not to execute it completely, but solely as far as the rule, whose antecedent at a given moment is equal the logical unit, which also offers immense opportunities to increase the controller speed. In fuzzy controllers with precise terms, unlike the conventional fuzzy controllers the control precision has been shown to be invariant with respect to the complexity of the production rules conditional part structure. It is now clear that precision of fuzzy controllers with precise terms in the control systems as represented by verbal models is compatible with PID-controllers precision while using them to control the linear process facilities.

1. Introduction

The pump station (PS) are functionally designed to both maintain pressure in pipelines at the preset level and to remove preliminarily water and mechanical impurities from oil. They look like a tank of about 200 m^3 capacity ((10 × 4 × 5) m) with inlet and outlet pipelines, equipped with centrifugal pumps with variable frequency asynchronous motors and controllable valves [1, 9, 10].

As it follows from the conceptual model of the BPS, shown in Fig. 1, its input variables are the flow rate of the crude oil emulsion Q_1 and Q_2 throught a control valve and the pressure pump respectively, whereas output variables are

L_l – well fluid level in tank;

Q_{out} and H_{out} – respectively flow rate and pressure in the pipeline after the BPS.

The broken lines in Fig. 1 show that the parameter Q_1 only affects the L_1 while Q_2 affects all BPS controllable parameters.

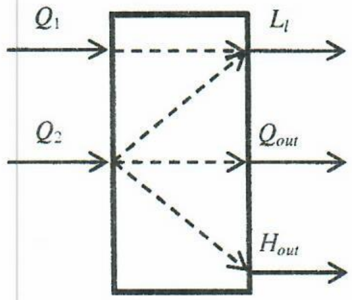

Fig. 1. Conceptual model of pump station

The BPS control task is confined to maintaining real-time preset point of controllable process parameters at essentially uneven debit of oilfields producing wells. The above description follows that the BPS is a multiply, nonlinear, nonstationary dynamic control object with both two input and three output parameters. As is known [2, 3], development of adequate mathematical model for such process facilities is a challenge.

Proceedings of the 16[th] international workshop on computer science and information technologies CSIT'2014, Sheffield, England, 2014

Here is why the widespread control of pump stations on the basis of PID-controllers, which are related to the number of the classical linear automation tools used for nonlinear process facilities, does not provide adequate control quality, which leads to additional power losses in BPS electric drives. On the other hand, the BPS verbal models as professional experience of experts in the domain are deprived of above drawbacks. Even though they are always available for control systems developers their implementation based on PID-controllers is impossible.

2. Interpretation peculiarities of pump stations process parameters by the set of precise terms

Existing theory and practice of control systems development [4, 8] strongly recommends in such cases to use the fuzzy controllers (FC), in which the input and output variables are presented by a set of terms of triangular, trapezoidal and bell-shaped membership functions. In this case their related terms along the universal numerical axis overlap to thus give rise to redundant uncertainties.

Let us explain the thesis stated by the example of interpretation of a continuous parameter p (for BPS input and output variables similarly) by set of n fuzzy terms $T_{1f} - T_{nf}$ of a triangular shape of the membership function $\mu(p)$, shown in Fig. 2. The arrangement of terms $T_{1f} - T_{nf}$ along the universal numerical axis gives rise to the following uncertainties:

- on the interval $(0 - p_1)$ the parameter p physical values are defined by term T_{1f} as a particular value of the membership function;
- on the intervals $(p_1 - p_2)$, $(p_2 - p_3)$, etc. the parameter p physical values depending on the value of the membership function and fuzzy logic operation (min or max) being used determined by terms T_{1f} or T_{2f};
- the parameter p physical value at the point p_2 is interpreted by terms T_{1f} and T_{2f} simultaneously with the same value of the membership function, which requires at FC software implementation specifying which of these terms is the priority.

The disadvantage of interpretation discussed is in the excessive amount of uncertainties, increasing the complexity of the defuzzification procedure and as a consequence – reducing the control precision which in its turn leads to increased electro power losses. To eliminate these disadvantages in the BPS control FC input and output variables are suggested to be interpreted by the set of non-overlapping terms of the rectangular shape of the membership function $T_{1c} - T_{nc}$ (Fig. 3) [5], which will further on be referred as precise terms.

As a result of such interpretation there is only one of the above enumerated uncertainties remaining which is the uncertainty inside the interval along the universal numerical axis which interval is being overlapped by each precise term.

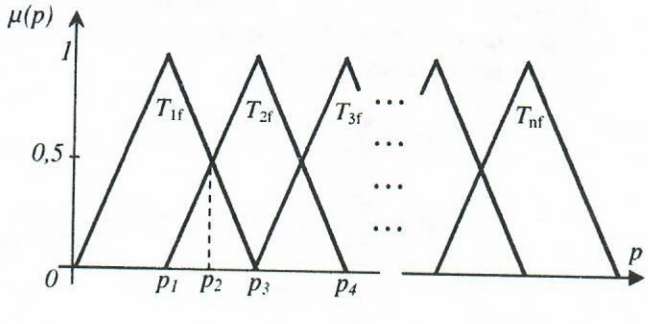

Fig. 2. Interpretation of the p parameter by the set of n fuzzy terms of the triangular shape of the membership function

As a result of the above we get a special case of the conventional FC, whose input and output variables are interpreted by the precise terms set, and the terms $T_{1c} - T_{nc}$ having a rectangular shape of the membership function (inside each precise term $\mu(p) = 1$), following the course of their logical nature transformed into binary logical arguments. Therefore, the following relationship is valid for each of them:

$$\mu_{Ti}(p) = \begin{cases} 1, if \quad p_{i-1} \le p < p_i, i.e. p \in T_i; \\ 0, if \quad p_{i-1} > p \ge p_i, i.e. p \notin T_i, \end{cases} \tag{1}$$

where $i = \overline{(1 \div n)}$ is the number of the term of the physical quantity p. For example, for a term T_1 $i = 1$, $\mu_{p1}(p) = 1$ at $0 \le p < p_1$. Otherwise $\mu_{p1}(p) = 0$.

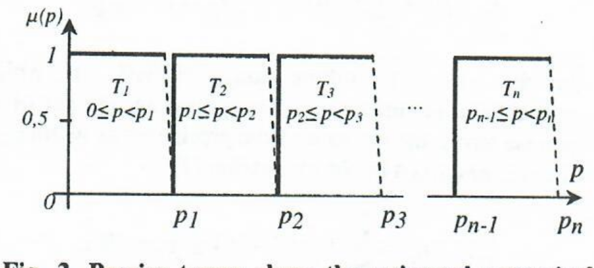

Fig. 3. Precise terms along the universal numerical axis

Analytically basic term-set, shown in Fig.3, looks like:

$$\begin{aligned} T(p) = \{ & T_1(0 \le p < l), T_2(l \le p < 2l), T_3(2l \le p < 3l), \ldots \\ & T_i((i-1)l \le p < il), T_n((n-1)l \le p < nl)\}, \end{aligned} \tag{2}$$

where l is the width of each term.

In number of cases, it is more convenient to use the shortened form of expression (2):

$$T(p)=\sum_{i=1}^{n}T_i((i-1)l \le p < il). \qquad (3)$$

Expression (3) for the n-dimensional FC with representation of controllable parameters $p_1 - p_n$ by the set of m precise terms looks like:

$$\begin{cases} T_1(p_1)=\sum_{j=1}^{m}T_1((j-1)l \le p_1 < jl); \\ T_2(p_2)=\sum_{j=1}^{m}T_2((j-1)l \le p_2 < jl); \\ \dots \\ T_i(p_i)=\sum_{j=1}^{m}T_i((j-1)l \le p_i < jl); \\ \dots \\ T_n(p_n)=\sum_{j=1}^{m}T_m((j-1)l \le p_n < jl). \end{cases} \qquad (4)$$

The summation sign in expressions (3) and (4) means the precise terms set.

From Fig. 3 it follows that the FC with precise terms (FCwPT) control error is defined by the precise terms width used in the models of the controller input and output variables. It is suggested to decrease / increase (roughening) control errors by reducing (2.6) / increasing (2.7) in k times terms precise width interpreting FCwPT input and output variables.

$$T_{k1}=\sum_{i=1}^{n/k}T_{ki}((i-1)lk \le p < ikl). \qquad (5)$$

$$T_{1/k}(p)=\sum_{i=1}^{kn}T_{\frac{1}{k}i}((i-1)\cdot l/k \le p < il/k). \qquad (6)$$

In the case of n-dimensional FCwPT in which controllable parameters are interpreted by the set of m precise terms, the increase of the precise terms width by k times is described by the expression (7):

$$\begin{cases} T_{1kl}(p_1)=\sum_{j=1}^{m/k}T_{1kj}((j-1)lk \le p_1 < jlk); \\ T_{2kl}(p_2)=\sum_{j=1}^{m/k}T_{2kj}((j-1)lk \le p_2 < jlk); \\ \dots \\ T_{ikl}(p_i)=\sum_{j=1}^{m/k}T_{ikj}((j-1)lk \le p_i < jlk); \\ \dots \\ T_{nkl}(p_n)=\sum_{j=1}^{m/k}T_{mkl}((j-1)lk \le p_n < jlk), \end{cases} \qquad (7)$$

whereas decrease of their width by as many times is described by expression (8):

$$\begin{cases} T_{1 1/k}(p_1)=\sum_{j=1}^{mk}T_{1\frac{1}{k}j}((j-1)\, l/k \le p_1 < jl/k); \\ T_{2 1/k}(p_2)=\sum_{j=1}^{mk}T_{2\frac{1}{k}j}((j-1)\, l/k \le p_2 < jl/k); \\ \dots \\ T_{i 1/k}(p_i)=\sum_{j=1}^{mk}T_{i\frac{1}{k}j}((j-1)\, l/k \le p_i < jl/k). \end{cases} \qquad (8)$$

The summation sign in expressions (5) – (8) means the precise terms set.

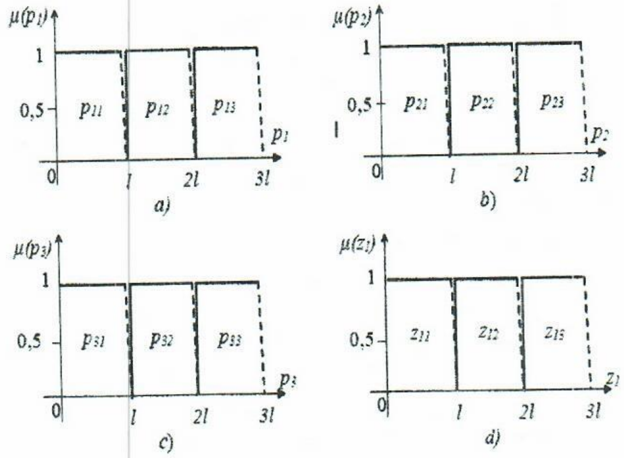

Fig. 4. Precise terms of variables p_1, p_2, p_3, z_1 along the universal numerical axis

From these arguments it follows that the most important feature of the model of a physical value as a precise terms set, is the presence at any given moment of time incorporated in it is one term only whose value is equal to the logical unit. Therefore, in the production rules system operating with precise terms, at any given time, only one production rule antecedent is equal to the logical unit. The latter circumstance allows without loss of control adequacy in each scanning cycle to execute not the entire production rules system, but solely as far as the rule whose conditional part at a given moment is equal to the logical unit. The arrangement of such a rule at the beginning of production systems (for example, using anytime-algorithm [6]) allows to increase the FCwPT speed manifold.

However, the most significant FCwPT advantage is their high control precision of verbally specified objects parameters, which can be comparable with the PID-control precision of linear processes. To illustrate this statement, consider the executing procedure of the following production rule:

$$IF \quad P_1=P_{11}\cap P_2=P_{22}\cap P_3=P_{31}\cup P_1=P_{13}\cap P= \\ =P_{21}\cup P_3=P_{33}, THEN \quad Z_1=Z_{11}. \qquad (9)$$

The term set of FCwPT input p_1, p_2, p_3 and output variables z_1 model and logical inference for rule (9) are presented in Fig. 4 and 5, respectively.

According to the laws of the binary logic [7], and regardless of the complexity of rule (9) antecedent, the result of its scanning will be a precise term z_{11}, but not as in a conventional FC is membership function of complex shape, whose defuzzification yields greater error and takes a lot of CPU time. In the suggested case defuzzification is confined to the elementary procedure, such as determining of a variable's precise value as the middle of the term interval. In addition, in order to increase control precision the width of terms can be reduced down to a value of quantization discreteness of FCwPT analog-to-digital and digital-to-analog converters.

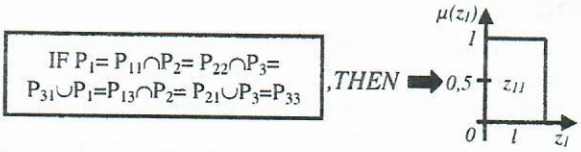

Fig. 5. Logical inference model for rule (9)

3. Conclusions

- Regardless of the number of production rules antecedent arguments with precise terms the result of logical inference is a (unique) fuzzy controller with precise terms output variable term, whose width defines its precision. In this case the limit of this width reduction is the quantization discreteness of element base analog to digital and digital to analog converters, on which the controller is created.
- In the fuzzy controllers it is sufficient to execute without losing control adequacy in each scanning cycle not the entire system of production rules, solely as far as the rule, whose antecedent at a given moment is equal to the logical unit.

References

1. Fattahov R.B., Sobolev S.A., Tronov V.P. Optimization batch operation of pumping stations operating conditions in pumping fluid in one pipeline / / *Oil industry*. 2012. № 3. PP. 83–86.
2. Guzairov M.B, Muravyova E.A. Process control using on precise logic controllers. Monograph. *Mashinostroyeniye*, 2012. 305 p.
3. Verevkin A.P., Kiryushin O.V. Automation of processes and industries in oil refinary and petrochemical industries. – *Ufa: publishing office UGNTU*, 2005. – 171 p.
4. Vasilyev V.I., Ilyasov B.G. Intelligent control systems. Theory and Practice: Textbook. – M.: *Radiotechnika*, 2009. - 392.
5. Muravyova E.A., Kayashev A.I., Gabitov R.F. *The precise logic controller for process control.* RF patent № 2445669. Published on: 3/20/2012. Bulletin. Number 8.
6. Kayashev A.I., Murayeva E.A. Any-time Algorithm for Fuzzification of Physical Quantities on tht Basis of Crisp Sets. CSIT'2011. Proceedings of the 13th Internanional Workshop on Computer Science and Information Technologies. Germany, Garmisch-Partenkirchen, September 27 – October 02, 2011. Volume.
7. Kayashev A.I., Muravyova E.A. Logical structures synthesis of chemical processes based on multicycled equations. *Bashkirian Chemical Journal*, V. 13 № 3, 2006.
8. Vasilyev V.I. Intelligent information security systems: tutorial. *Mashinostroyeniye.*
9. Kayashev A.I., Yemekeev A.A., Ziatdiov A.M. Analysis of automation systems energy efficiency of pumping station high-voltage electric drive. *Journal "Gas industry"*, № 12, 2013. PP. 47-50.
10. Kayashev A.I., Yemekeev A.A., Ziatdiov A.M. Analytical research of electric drive pumping station automation systems. *Journal "Oil Industry"*, № 1, 2014, PP. 94-97.