Fuzzy logic system applied to drive pivot mechanism of the arm with buckets of an medium size excavator ERC 1400

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Abstract: This paper presents the design of a numerical algorithm for speed control of AC motor using fuzzy logic algorithm, that can be used to drive pivot mechanism of the arm with buckets of an medium size excavator ERC 1400, excavator very common in the lignit careers in Oltenia Energy Complex. In this paper are presented characteristic stage for synthesis fuzzy algorithm (fuzzification of the firm information, base rules building, the inference and composition of the rules, defuzzification), suitable for speed control of the pivot mechanism of the arm with buckets of an medium size excavator ERC 1400.

Key Words- Fuzzy, automatic adjustment, medium size excavator

1 Presentation of the technological flow in the coal quarries

To easily understand the technological flow of a quarry we present technological flow for a particular case, namely the technological flow for Tismana I (Rovinari) quarry.

Technology working in this quarry consists of 5 technological lines for excavation and 3 lines for landfill, as shown in Fig.1.

According to the provisions, the quarry was equipped with four SchRs. 1400 excavators, an SRS. 1300 excavator, two dump machines with a capacity of 6500 m³/h each and a dump achine with a capacity of 4400 m³/h. Dump sterile is made in the indoor and outdoor dump.

Length of the circuits consists of 24.5 km transporters with belt widths ranging between 1400 and 800 mm, equipped with electric motors of 425 kW and 630 kW. Running speed of the walking is up 5.3 m/s.

1.1 The appearance and development of the excavators with rotor

Excavators with wheel and buckets are the newest types of excavators, whose using in mining began in the beginning of 20th century. Wheel with bucket is used in oldest times. Set in motion by the stream of water directed through channels and troughs, this put in motion in turn toothed gears wooden who acted millstones, stamps, mill, mills, etc.. The activity with reverse action, as old, was achieved by gearing maneuvered by people or animals, that put in function the wheel with bucket who take water from the basins and directed by troughs or channels to irrigation. This principle was taken by inventors of the excavators with wheel and bucket, but in this case the bucket engagement is through forces of the motors and the reducers. Although the principles are very ancient, the excavators with wheel and bucket were the last that occurred as a means of excavation.

Data on the excavators with wheel and bucket were found in the documents left by Leonardo da Vinci, which referred to a rotor with diameter of 12 m, designed to operate underwater to rectify the bed of navigable rivers and the deepening them. Specialists in the former R.F.G. developed a classification at the excavators with wheel and bucket in 5 generations according to the
daily capacities of the mining mass excavated, namely:
- first generation (less than 40000 m$^3$/day);
- second generation (less than 60000 m$^3$/day);
- third generation (less than 110000 m$^3$/day);
- fourth generation (less than 240000 m$^3$/day);
- fifth generation (from 300000 m$^3$/day at 500000 m$^3$/day);

Because of the hardly working regime for the organ for excavation from ERC, this is currently actuated with asynchronous motors with rotor winding (ring) useful for hard start regime, where to start it is use a metallic rheostat in $3 \div 4$-speed steel, generally asynchronous motor with three phase of 630 kW, 6 kV, 71 A, 988 rev/min. Lately, instead the asynchronous motor with wound rotor was introduced squirrel cage asynchronous motor and hydraulic coupling, which has a simpler maintenance (eg for ERC 1400 drive of wheel with bucket is made with squirrel cage induction motor of 500 kW). For situations where the technological process requires regulation of the speed of rotation of the arm with bucket, will present an algorithm for making this automat regulation.

Block diagram of the system for regulating the speed of AC motor using fuzzy logic design is shown in Fig. 2. Regulating law (using fuzzy logic) of designed system is software implemented using development environment LabWindows CVI. For this implementation we need to design an acquisition system for acquisition of the AC motor’s speed, this value been read with an tachogenerators and the current of the AC motor, respectively for transmission to execution element of the elaborated control by the regulating law implemented software.

The current of AC motor during consumption, it is sent to the computer by static frecqvency converter, via the second analog input channel of acquisition system. The MITSHUBISHI inverter can be commanded with an extern voltage signal (0÷5V), and it give at his output an sinusoidal signal with variable frequency and magnitude, the variation range of frequency been 0÷60 Hz. AC motor’s stem is coupled to flexible common stem of a voltage generator and a tachogenerators. Voltage generator is the AC motor’s task, the system perturbation actuate when at the voltage generator terminals are connected one or more users.

Fig. 2. Block diagram of the system for regulating the speed of AC motor

2. The synthesis of the Fuzzy regulator

2.1. The fuzzyfication of the ferm information and creating the rules base
We’ll start to materialize a fuzzy regulator for adjusting the speed of AC motor.

The nominal revolution of the AC motor is 1500 rot/min, and the domain for adjustment is 0÷1500 rot/min.

For the revolution adjustment of AC motor we’ll define 3 linguistic variables, associated to the input quantities (the statoric current, the revolution error) and to the output quantity (the command):

- the revolution error – which varies between -1500÷1500 rot/min;
- the statoric current witch has values between 0÷3,5 A;
- the command which takes values in the interval 0÷5 V.

The linguistic variable revolution error can be vaguely characterized through the following linguistic terms:

- low revolution error with belonging function: \( \mu_{W_{\text{m}}} = (l_{1500}, l_{1500}, l_{1000}, 0) \);
- moderated revolution error with belonging function: \( \mu_{W_{p}} = (l_{1000}, 0, 1000, 0) \);
- high revolution error with belonging function: \( \mu_{W_{M}} = (0, 1000, 1500, 1500) \).

For the linguistic variables revolution and current error, the shape of the belonging function afferent to the linguistic term from the middle, as is seen in fig. 4.

![Fig. 4](image)

Next will be exemplified the way in which the degrees of belonging are determined for a firm value \( W_{0} = 700 \) at the defined linguistic terms are:

\[ W_{0} = \{ \mu_{W_{\text{m}}}(W_{0}), \mu_{W_{p}}(W_{0}), \mu_{W_{M}}(W_{0}) \} \]

We will calculate then the values of the belonging degrees.

For the \( W_{\text{m}} \) linguistic term we have:

\[ \mu_{W_{\text{m}}}(W_{0}) = \begin{cases} 0, & \text{for } W_{0} > D \\ \frac{A-B}{C-A}, & \text{for } A \leq W_{0} \leq C \\ 1, & \text{for } C < W_{0} \leq B \end{cases} \]

For the \( W_{p} \) linguistic term we have:

\[ \mu_{W_{p}}(W_{0}) = \begin{cases} 0, & \text{for } W_{0} < A \\ \frac{B-A}{C-B}, & \text{for } A \leq W_{0} \leq B \\ 0, & \text{for } B < W_{0} \leq C \\ \frac{D-C}{D-B}, & \text{for } C < W_{0} \leq D \\ 1, & \text{for } D < W_{0} \end{cases} \]

The afferent values of the belonging degrees of the firm value \( W_{0} = 700 \) at the defined linguistic terms are:

\[ W_{0} = \{ \mu_{W_{\text{m}}}(700), \mu_{W_{p}}(700), \mu_{W_{M}}(700) \} \]

For the command linguistic variable we’ll consider 3 linguistic terms:

- low command with the belonging function: \( \mu_{U_{\text{m}}} = (0, 0, 2,5) \);
- moderate command with the belonging function: \( \mu_{U_{\text{md}}} = (0, 2,5, 5) \);
- high command with the belonging function: \( \mu_{U_{M}} = (2,5, 2,5, 5) \);

According to the relation (3) we have the 3-louple:

\[ W_{0} = \{ 0, 0, 3, 0, 7 \} \]

Similary for the fuzzy variable current, the values afferent to the degrees of belonging of the firm values \( Y_{0} = 0,82 \) A, at the defined linguistic terms are:

\[ Y_{0} = \{ 0,785, 0,214, 0 \} \]

The rules base after whitch the fuzzy regulator works can be simple.
defined considering as a premise the revolution error as follows:

\[
\begin{align*}
R1: \text{IF } (e=Wm) \text{ AND } (y=Ym) \Rightarrow (u=Um); \\
R2: \text{IF } (e=Wp) \text{ AND } (y=Ym) \Rightarrow (u=Umd); \\
\ldots \\
R9: \text{IF } (e=WM) \text{ AND } (y=YM) \Rightarrow (u=Umd);
\end{align*}
\]

2.2. The inference and composition of the rules

Each rule from BRF framework represents a logical expression built with the conjunction operator AND. Therefore the intersection operation of the fuzzy multitude is applied, after which at the output is obtained a punctual minimum of the belonging function domain of the output variables.

And so, for a rule from BRF framework as:

\[
R8: \text{IF } (e=Wp) \text{ AND } (y=YM) \Rightarrow (u=Umd);
\]

we have: \( \omega_{Umd} = \text{MIN}(0.3, 0) = 0 \), where \( \omega_{Umd} \) is the scalar value for activating the fuzzy multitude \( U_{md} \).

As it follows, we retain only the useful rules (significant) for the given numerical case which are 4:

\[
\begin{align*}
R2 \rightarrow \omega_{Umd} &= \text{MIN}(0.3, 0.7) = 0.3 \\
R3 \rightarrow \omega_{UM} &= \text{MIN}(0.7, 0.7) = 0.7 \\
R5 \rightarrow \omega_{Umd} &= \text{MIN}(0.3, 0.2) = 0.2 \\
R6 \rightarrow \omega_{Umd} &= \text{MIN}(0.7, 0.2) = 0.2
\end{align*}
\]

We observe that in the inference process the rules may have as result the same fuzzy multitude as output, generally activated with different \( \omega_i \) coefficients. This is the case of rules R2, R5 and the R6 from the example we analyze. So, the operation of inference is finalized at the level of the whole BRF through a technique of composition of the results of the elementary inferences. In our case, we adopt the method of composition known as MAX, after which the rules which have the same fuzzy multitude for output, it is activated with the maximum values of the coefficient \( \omega_i \). So for the rules R2, R5, R6, the output fuzzy multitude \( U_{md} \) will be pondered with the coefficient \( \omega_{Umd} \) calculated as follows:

\[
\omega_{Umd} = \text{MAX}(\omega_2, \omega_5, \omega_6) = \text{MAX}(0.3, 0.2, 0.2) = 0.3
\]

Further in this example we applied the operation of inference with correlation through product as is shown in the graphics in fig. 5.

\[
O = \text{MAX}(\omega_2, \omega_5, \omega_6) \cdot m_{UM} + \omega_2 \cdot m_{Umd}
\]

As is done the inference with correlation through product and for R3, R5 and R6.

The performed operations until this point are represented. For the example considered fuzzy output of the system is:

\[
O = \text{MAX}(\omega_2, \omega_5, \omega_6) \cdot m_{Umd} + \omega_2 \cdot m_{Umd}
\]

which, geometrically speaking, sums up to the reunion of the surfaces limited by fuzzy multitudes as result of codification as in fig. 6.
2.3. Defuzzyfication

In case of this application I chose the most used defuzzyfication method which offers the most substantial results, the method of the gravity center (centroid). Adequate to it, if the fuzzy multitudes are determined through the method of inference with correlation through product, then it may be calculated the global gravity center on the basis of the local gravity centers of each I rule from BRF.

In this case: \( u_k = 3.88 \).

3. Experimental results

The fuzzy regulator was software implemented, the communication between computer ant the AC motor being made through like in fig. 1. The answer of the system commanded with a fuzzy regulator when at input is applied an variable (step) signal is presented in fig 7.

![Fig. 7. Process response](image)

4. Conclusions

Adjustment system designed include the following benefits:

- as can be seen on the graph in Fig. 7, transient response duration and stationary error are very small fitting into acceptable limits;
- the system offers the possibility to easily change the controller parameters and reference speed;
- the system designed and implemented allow also monitor other parameters of the AC motor (current, temperature, torque).

BIBLIOGRAPHY