Machining Efficiency Prediction in ECM with a Spiral Shaped Electrode Based on Fuzzy Evaluation

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Abstract: Electron-Chemical Machining (ECM) by using a spiral shaped electrode is a new technological method for the machining of guide boles on the machine parts of hard material. Based on the theory of the fuzzy mathematics, a model of fuzzy evaluation on the efficiency of spiral shaped electrode ECM is set up. As an example, the evaluations on the efficiency of the machining process are carried out. The results indicate that the model is practical.

1. PREFACE

A manufacturing technology applying a special spiral-fluted electrode in traditional ECM (Electro-chemical Machining) is a new technology for expanding holes in hard metal materials parts. The machining theory of the hole expanding process by spiral-fluted electrode is similar to that of the general fixed negative electrode. It is also a process of metal removal in which electrolytic action is utilized to dissolve the work piece metal[1][2][3]. The machining process is illustrated in Fig.1. Workpiece is put into fixture, connects to the positive terminal of a DC supply, the tool (the cathode) mounted in a spring clip of the electrode head, connects to the negative terminal of the DC supply, electrode head is mounted under spindle of the machine, its rotation motion follow with spindle. The gap between tool and work piece is full of electrochemical solution provided with cycle system. After adjusting machine to make electrode go into certain depth of work piece, switch on the power, the metal of guide hole (the anode) is removed continually by arc erosion, outcome result of electrolysis is taken away by electrochemical solution, controlling machining time may meet to the demand of expanding hole at given voltage. At a result of “screw pump” effect producing by tool and guide hole of the work piece, it enhances the effect of supplying electrolyte and sweeping away of the electrolytic outcome, it improves machining efficiency and machining accuracy, superior to expanding hole by using fixed negative electrode and it can use low cost electrochemical cycle system to replace that of conventional ECM equipped with high pressure (0.5~2MP), high speed (5~50m/s). Experiments results indicate that the accuracy and quality of the machined surface and the machining efficiency could be improved greatly by applying spiral-fluted electrode in ECM. This project has been evaluated, currently, products are been developed.
In order to achieve proper technological properties in developing new product applied the novel method, a set of valid technological parameters is should provided. The technological performance of Electron-Chemical Machining (ECM) by using a spiral shaped electrode is a fuzzy conception, some conceptions, such as ‘high’, ‘higher’, ‘low’, ‘lower’ of machining efficiency have not absolute limit. Moreover, the factors influenced technological properties exist fuzzy properties with much uncertainty. For example, current $I$ is one of factors affected machining efficiency, while it is hard to say how much is belong to high efficiency.

Therefore, it is convincing result using fuzzy evaluation on performance with a spiral shaped electrode in EMC applied fuzzy mathematics and method, at the same time, it provides a new thinking for realizing optimization of technological parameters\cite{4}\cite{5}\cite{6}.

The main targets reported technological performance using a spiral shaped electrode in EMC are machining efficiency, machining precise, surface quality and machining cost and so on, and the several of discharging process are influenced on the various targets, so the fuzzy evaluation of technology using a spiral shaped electrode in EMC a spiral shaped electrode in EMC is a two level problem in fact. The first step is evaluation on each target, and the result is seen as single factor evaluation; then the second level evaluation is been carried out when every target seen as coexisted and weight factor. Due to limited space, the construction of fuzzy evaluation model about the machining efficiency is analyzed here.

2. MATHEMATICS MODEL OF FUZZY EVALUATION

2.1. Construction Factor Sets Influenced Machining Efficiency of ECM Using a Spiral Shaped Electrode

The evaluation factors set is a variety of factors collection impacted judged object. Here, the machining efficiency of ECM using a spiral shaped electrode is defined as: the amount of metal corrosion of guide hole in radial direction per unit time, unit’s of mm/min. According to the results of lots of tests and theory analysis, factors sets affected machining efficiency in ECM using a spiral shaped electrode is constructed:

$$U = \{u_1, u_2, u_3, u_4, u_5\}$$

(1)

here $u_1$ is the current density(A/cm$^2$), $u_2$ machining initial gap(mm), $u_3$ electrode helix angle (°), $u_4$ electrode rotational speed(r/min), $u_5$ electrolyte concentration (%).

2.2. Construction Evaluation Target Sets

The first, The evaluation about various factors is classified as different levels, then the sets formed by various evaluation from the evaluator which is called evaluation target sets is constructed. Here, the
evaluation target sets for the machining efficiency of ECM using spiral electrode can be expressed as follows:

\[ V = \{v_1, v_2, v_3\} \]  
(2)

Where \(v_1\) means machining efficiency is low, \(v_2\) machining efficiency is medium, \(v_3\) machining efficiency is high.

2.3. Membership Function

In the use of fuzzy evaluation method to solve practical problems, quantitative description of the data needs to be transformed into the membership on the fuzzy sets, thus a properly constructed fuzzy membership function is the key. There are several ways to determine membership functions, including the F statistical test, Trichotomy, F distribution method and the dual contrast sorting, the method of reasoning also can be used. Considering simplicity on trapezoidal function expression and calculation, combining the further of experiments data, F distribution method which adopted distribution of semi-trapezoid and trapezoid on real area is used, and this method can meets the real-time prediction requirement on performance. The membership functions of fuzzy sets defined as follows:

1. the membership functions of machining efficiency which classified ‘high’, ‘medium’, ‘low’ to current density \(I\).

\[
\begin{align*}
\mu_{v_1}(x) &= \left\{ \begin{array}{ll}
0.1x + 1, & 0 \leq x \leq 10 \\
0, & x > 10 \\
0.08x, & 0 \leq x < 12.5 \\
2 - 0.08x, & 12.5 \leq x < 25 \\
0, & x \geq 25 \\
\end{array} \right.
\end{align*}
\]  
(3)

2. the membership functions of machining efficiency which classified ‘high’, ‘medium’, ‘low’ to machining initial gap.

\[
\begin{align*}
\mu_{v_2}(x) &= \left\{ \begin{array}{ll}
1.25x, & 0 \leq x < 0.8 \\
1, & x \geq 0.8 \\
2.5x, & 0 \leq x < 0.4 \\
2 - 2.5x, & 0.4 \leq x < 0.8 \\
0, & x \geq 0.8 \\
\end{array} \right.
\end{align*}
\]  
(4)

\[
\begin{align*}
\mu_{v_3}(x) &= \left\{ \begin{array}{ll}
0, & 0 \leq x < 32 \\
0.0125x, & x \geq 32 \\
\end{array} \right.
\end{align*}
\]  
(5)

3. the membership functions of machining efficiency which classified ‘high’, ‘medium’, ‘low’ to the electrode helix angle.

\[
\begin{align*}
\mu_{v_4}(x) &= \left\{ \begin{array}{ll}
-0.25x + 1, & 0 \leq x \leq 4 \\
0, & x > 4 \\
x/6, & 0 \leq x < 6 \\
1.6 - x/6, & 6 \leq x < 16 \\
0, & x \geq 16 \\
\end{array} \right.
\end{align*}
\]  
(6)

\[
\begin{align*}
\mu_{v_5}(x) &= \left\{ \begin{array}{ll}
0, & x \geq 16 \\
0.0625x, & 0 \leq x < 16 \\
\end{array} \right.
\end{align*}
\]  
(7)

4. the membership functions of machining efficiency which classified ‘high’, ‘medium’, ‘low’ to the electrode rotational speed.

\[
\begin{align*}
\mu_{v_6}(x) &= \left\{ \begin{array}{ll}
-0.01x + 1, & 0 \leq x \leq 100 \\
0, & x > 100 \\
\end{array} \right.
\end{align*}
\]  
(8)
Due to the different influence degree for each factor to machining efficiency, it is necessary to weigh on each factor. According to the experimental result and expert experience, current density and electrolyte concentration are the greatest impact factor, the second one is helix angle electrode, machining initial gap and electrode rotational speed have the least impact, so weight set can be expressed as followed:

\[ A=(0.3, 0.1, 0.2, 0.1, 0.3). \]

(5) the membership functions of machining efficiency which classified ‘high’, ‘medium’, ‘low’ to the electrolyte concentration.

\[
\begin{align*}
u_{i2}(x) &= 0.2x + 1, & 0 \leq x \leq 5 \\
&= 0, & x > 5 \\
\end{align*}
\]

\[(15)\]

\[
\begin{align*}
u_{i3}(x) &= 3 - 0.2x, & 0 \leq x < 10 \\
&= 0, & x \geq 15 \\
\end{align*}
\]

\[(16)\]

\[
\begin{align*}
u_{i4}(x) &= 1, & x \geq 16 \\
&= 0.0625x, & 0 \leq x < 16 \\
\end{align*}
\]

\[(17)\]

2.4. Fuzzy Evaluation Matrix

\[ R = \begin{pmatrix} r_{i1} & r_{i2} & r_{i3} \\ r_{i1} & r_{i2} & r_{i3} \\ r_{i1} & r_{i2} & r_{i3} \end{pmatrix} \] \[= \begin{pmatrix} \mu_{i1}(y_{i1}) & \mu_{i2}(y_{i1}) & \mu_{i3}(y_{i1}) \\ \mu_{i1}(y_{i2}) & \mu_{i2}(y_{i2}) & \mu_{i3}(y_{i2}) \\ \mu_{i1}(y_{i3}) & \mu_{i2}(y_{i3}) & \mu_{i3}(y_{i3}) \end{pmatrix} \]

Assuming \( X=(x_{1}, x_{2}, x_{3}, x_{4}, x_{5}) \) is one of parameters of technological scheme \( u_{i} \) which evaluating machining efficiency in ECM using spiral electrode. For each technological scheme been evaluated \( x_{i} \), the comment about number \( i \) should be in the fuzzy set \( R=(r_{i1}, r_{i2}, r_{i3}, \ldots, r_{in}) \) of evaluation index set. \( n \) indicators should be a subset of \( n \)-reviews, so the single factor of total reviews \( u_{i} \) about \( 5 \) indicators may be expressed using a fuzzy matrix as followed:

Where \( \mu_{i}(x_{i}) \) represent for the degree of \( u_{i} \) subject to the level \( V_{i} \)

2.5. Weight Distribution

Due to the different influence degree for each factor to machining efficiency, it is necessary to weight on each factor. According to the experimental result and expert experience, current density and electrolyte concentration are the greatest impact factor, the second one is helix angle electrode, machining initial gap and electrode rotational speed have the least impact, so weight set can be expressed: \( A=(0.3,0.1,0.2,0.1,0.3). \)

2.6. Set B of Fuzzy Evaluation

Fuzzy evaluation set is the membership of the evaluation index set \( V \) to the allover objective taken into account all the evaluation factors \( U \) and their weights \( A \), denoted \( B=(b_{1}, b_{2}, b_{3}) \), where \( b_{j} \) indicates the membership of evaluation target number \( j \) to the allover objective. According to the relative theory about fuzzy mathematics, fuzzy evaluation sets can be expressed as follows:

\[ B = A \circ R \] \[(19)\]

3. EVALUATION INSTANCE

ECM machine is used for carrying out experiments on a workpiece of carbide YG8, the diameter of this machined guide hole is 12mm, and the technological parameters are showed as follows:

- Current density \( I=14.35A/cm^{2} \),
- machining gap \( \Delta=0.386mm \),
- electrode helix angle \( \theta=18.0^{\circ} \),
- electrode rotational speed \( n=190.0r/min \),
- electrolyte concentration is 12%.

The evaluation matrix \( R \) can be calculated using the expression given below:

\[ R = \begin{bmatrix} 0 & 0.852 & 0.448 \\ 0.4825 & 0.965 & 0 \\ 0 & 0 & 1 \\ 0 & 0.4375 & 0.475 \\ 0 & 0.6 & 0.75 \end{bmatrix} \] \[(20)\]
Evaluation may be calculated using the expression given below:

\[
B = A \cdot R \\
= \begin{pmatrix} 0.3, 0.1, 0.2, 0.1, 0.3 \end{pmatrix} \times 
\begin{bmatrix} 0 & 0.852 & 0.448 \\ 0.4852 & 0.965 & 0 \\ 0 & 0 & 1 \\ 0 & 0.4375 & 0.475 \\ 0 & 0.6 & 0.75 \end{bmatrix} \\
= \begin{pmatrix} 0.04825, 0.5785, 0.6069 \end{pmatrix} 
\]

The final result after normalized can be expressed:

\[
B = (0.039, 0.468, 0.493) 
\]

The result of calculation is showed that the membership of this group machining parameters of the technological plan belonged to ‘low machining efficiency’ is 0.039, the membership belonged to ‘medium machining efficiency’ is 0.468, the membership belonged to ‘high machining efficiency’ is 0.493. Evaluation result shows that this group of machining parameters of the technological can assured high machining efficiency. This result is agreed with the experimental result completely.

4. CONCLUSIONS
1) The factors affected technological performance of ECM using spiral electrode and evaluation targets are of the characteristic of fuzzy. It is favor for overcoming the shortcomings of inaccurateness and one-sidedness applied fuzzy mathematics in evaluation.
2) The process of evaluation is a digital analyzing process; its algorithm can be accomplished easily by computer, which provides condition for realizing machining parameter optimization.
3) The weighted average model is adopted to evaluation equation so as to distinguish influence with different technological parameters, thus the evaluation is relatively exhaustive, the evaluation result is closed to experimental data.
4) Inner hole machining on carbide materials with ECM using spiral electrode is a new technology, the determination to membership function and the distribution of weight is the key to assure of accuracy for evaluation result. In this paper, the adopted method is relatively simple, it needs discussing deeply and continuously improving, then evaluation accuracy is increasing and directing production.

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