Development of Acupuncture-and-Moxibustion Needle Made of Co–Cr–Mo Alloy Prepared for Medicinal Functions

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Abstract
Two objectives were demonstrated in this study. One was the development of a complete processing technique to generate numerous small-diameter holes using electrical discharge machining (EDM) for Co–Cr–Mo alloy needles, for which processing conditions are unknown. Another objective was to develop a precise control technique to elute a chosen quantity of medicine. Results show that many advantageous effects on EDM were produced through precision processing: σ 0.9 μm (hole diameter variance (mm)) and low reduction of electrode wear ratio, 32% (tool consumption length (mm) / processing hole depth (mm)). The processing efficiency was high: 6 min 46 s per hole.

1 Introduction
Advanced processing technologies are necessary for manufacturers to satisfy design demands and develop products with high efficiency. Requirements for this product were the following: "Generate as many minute holes as possible in part of the 15 mm range the top-end forward to root direction of needle side-plane made from Co–Cr–Mo alloy and having φ0.25-mm-diameter." This study demonstrated the technology to generate numerous minute holes of Co–Cr–Mo alloy needle side-plane.

2 Experiment plan
2.1 Input–Output Relations
A processing method by which the hole diameter levels were changed was obtained by electrode swinging. A small hole was generated from more than φ0.1 mm to less than φ0.2 mm when using a φ0.1 mm rod electrode with added circle swinging behaviour. It was set as presented in Fig. 1. The characteristic of the input value was the ideal removal volume (M; mm^3). That of y: the output value was the actual removal volume (y; mm^3) and the noise factor was the circle swinging radius (mm). Sensitivity β and SN ratio η (db) are indexes of processing efficiency. Here β indicates the processing time

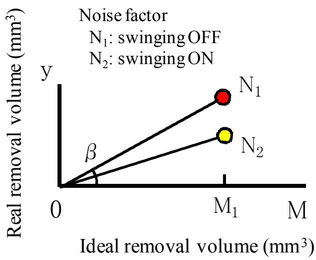

Figure 1: Input–output relation.

(mm^3/s) to generate a hole. The SN ratio indicates the processing stability to evaluate the input–output linear relation.

2.2 Signal factor

Signal factors were set so that the ideal removal volume for level 1 was 0.0079 mm^3. The signal factor was set to only one level because the priority was selected for efficient experiments. However, if many levels of signal factors were set, it was possible to obtain dynamic characteristics with added high robustness.

2.3 Control factors

The control factors were set to eight levels of characteristics to produce a matrix table L18 arrangement. Factor A, Factor B, and Factor C are circuits used to adjust the microprocessing power supply. The auxiliary power (AUX) of factor E was charge resistance (Ω) in the case of a capacitor power supply. Therefore, the charge-resistance value controlled the charging time. The electric discharge phenomenon stopped time. The F circuit (GAP) of factor F was used to supply the voltage (V) for the capacitor circuit. It represents a processing power index. The processing adjustment (GAIN) of factor G was used to set the return speed (mm/s) to escape from the unsuitable electrical discharge phenomena. The adjustment value was set sufficiently high to contribute to efficient processing.

2.4 Noise factor and processing conditions

The noise factor was set as one characteristic. It was then divided into two levels to obtain dynamic stability in cases of a changing nominal value to represent the removal volume or hole diameter. Level 1 was set with the swinging radius as 0 mm. Level 2 was set with the swinging radius as 0.025 mm. The electrode's lower feed quantities of noise factor two levels were adjusted to set equal removal volumes because of the difference from the hole's circular area. Level 1 was set to the 0.4444 mm feed depth direction. Level 2 was set to 0.1000 mm feed. An EDM device was used as the micropower supply (EDSCAN8E; Mitsubishi Co., Ltd.). The workpiece was a Co–Cr–Mo alloy for which minute hole processing was conducted against a flat top plane of a cubic block. The processed holes were 36 pieces that were representative of 18 experiments (matrix table L18), doubled (noise factor 2 levels).

3 Experiment results and consideration

3.1 Processing results

The relative linear wear was calculated for the electrode wear length per unit of processing hole depth and multiples 100 (%). Therefore, the removal ratio between the electrode and workpiece was presented. The inverse proportion between the processing hole depth and electrode wear length was readily apparent.

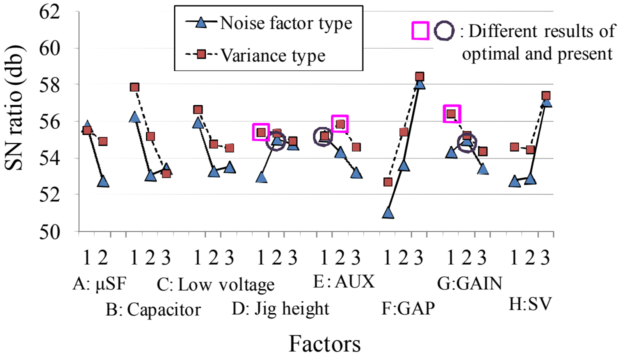

Figure 2: Factor effects of SN ratio.

3.2 Calculation of SN ratio

Sufficient robustness was not obtained if numbers of signal factors and noise factors were not fully reflected. The optimal condition was obtained that combined to computation using two methods of SN ratio calculation methods for the type of noise factor effect used and the type of total variance effect used[1]. The factor effect graph presented in Fig. 2 shows two SN ratio calculation methods. The optimal condition of noise factor type was included A1, B1, C1, ***D2***, ***E1***, F3, ***G2***, H3, another total variance type was included A1, B1, C1, ***D1***, ***E2***, F3, ***G1***, H3. Three factors were calculated, yielding different results using the two SN ratio calculation methods. The three factors are shown in bold and italic text above as factors D, E, and G. Final conclusions of optimal condition were determined to ascertain the level at which high precision and high efficiency were obtained. Therefore, the final combinations were A1, B1, C1, D2, E2, F3, G2, and H3. The minute hole processing of about φ0.1 mm was stabilized to high SN ratio in case of ON conditions that were factor A, factor B and factor C grouped microprocessing circuits. It was apparent that the circuits were necessary to attain high-stability processing.

3.3 Confirmation experiment

Processing to produce numerous minute holes was performed for a flat plane on a cubic block workpiece made of Co–Cr–Mo alloy, for which processing conditions were set as two types (optimal and present). The processing results are depicted in Fig. 3. The present conditions were set according to the manufacturer, showing the processing conditions database. The microprocessing circuit of factors A, B, and C is inferred to be necessary on a φ0.1 mm level minute hole processing. The two indexes of the SN ratio were not equal between estimates of the expected value 17.7 db and the experimental value of 3.3 db. Therefore, the difference was 14.4 db, which is not reliable. Regarding sensitivity, it was nearly equal between the estimated expected value of 2.4 db and the experimentally obtained value of 2.0 db. Their difference was

0.4 db. However, when the absolute value of sensitivity is small, then the reliability is low.

4 Verification experiment

The minute hole processing which was planned for continuous ten pieces holes for needle side-plane was tried to obtain optimal condition on the matrix table experiment. The experiment condition was set that workpiece was a needle of φ0.25 mm of Co–Cr–Mo alloy and the pitch between one hole's centre and the next hole's centre was 0.4 mm. Other conditions were the same as those used for the matrix table experiment. Photographs of needles after minute hole processing are presented in Fig. 4. Results show that ten piece holes having sharp edges and precise roundness were generated in optimal conditions. Results also showed that whole through holes were only four pieces, so six holes were not generated through holes in the present condition. Comprehensive processing results of the verification experiment are presented in Table 1. The results were obtained under optimal conditions in which the average hole diameter was ϕ 0.1087 mm, indicating the precise reverse forming electrode diameter because the lateral gap was 8.7 μm, which is very small, and the variance of the hole diameter was 0.9 μm, which indicates high precision. Therefore the results show that precise processing was demonstrated. Moreover, the relative linear wear was indicated as 36.2%. Another, in the present processing condition, showed average hole diameter of φ0.1245 mm so that the lateral gap was 24.5 μm diameter, the hole diameter variance (σ) was 3.2 μm, and the relative linear wear was calculated as 96.8%. However, results show that the present performance was superior for processing speed because the optimal value was 0:06:46 (h:m:s), whereas the achieved time was 0:00:25 (h:m:s).

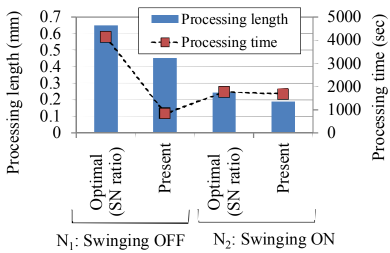

Figure 3: Results of confirmation experiment.

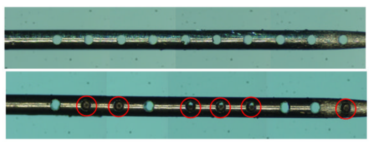

Figure 4: Photograph of verification experiment (upper, optimal; lower, present).

Table 1: Results of verification experiment.

Average (10 holes)

Item	Optimal	Present
Diameter of hole (mm)	0.1087	0.1245
Lateral gap (diameter, μm)	8.7	24.5
Processing time (h:m:s)	0:06:46	0:00:25

Total (10 holes)

Item	Optimal	Present
Total electrode wear length (mm): p	0.8162	2.1896
Total processing length (mm): q	2.5000	2.2623
Total relative linear wear (%): p／q×100	32.6	96.8
Variance of diameter (σ, μm)	0.9	3.2
Total processing time (h:m:s)	1:07:43	0:04:11

5 Conclusions

Confirmation experiment was conducted. The two indexes of SN ratio were not equal between those of estimates of the expected value 17.7 db and the experimented value of 3.3 db. Therefore the difference of 14.4 db was not very reliable. Results showed that ten piece holes having sharp edges and precise roundness were generated in the optimal condition. Moreover, stability processing of low relative linear wear was 36.2%. In addition, a method of elution control for administration of a chosen quantity of medicine is being tested at pressent using potentiostat electrical and chemical measurement systems, in addition to inductively coupled plasma spectroscopy.

Reference:

[1] Hiroshi Yano: A guide of quality engineering calculation, Japanese Standards Association, pp. 262-266 (1998).