euspen's 21st International Conference & Exhibition, Copenhagen, DK, June 2021
www.euspen.eu

Concept for an actuated variable tool electrode for use in sinking EDM

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Abstract
Typically, a large number of individual tool electrodes has to be used in sinking electrical discharge machining (sinking EDM) to successfully machine a single workpiece. Due to non-uniform wear and insufficient flushing of the working gap electrode geometries have a significant effect on the process efficiency. This paper discusses the use of an actuated variable tool electrode for sinking EDM to reduce the number of required tool electrodes and to increase the overall process efficiency. A miniaturised linear actuator was developed to individually move electrode segments to form the target shape for the tool electrode. The coordinated actuation of bundled electrode segments introduces new methods for the active flushing within the working gap, which cannot be implemented in conventional sinking EDM. Intelligent sinking strategies can further improve process efficiency by creating and sinking sub-geometries into the workpiece offering improved flushing conditions compared to the original geometry.

EDM, sinking EDM, micro-actuator

1. Introduction

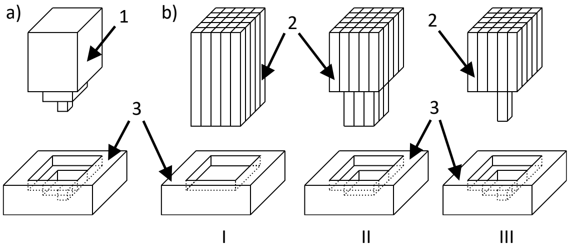
A great challenge in manufacturing of injection moulds by sinking EDM is the large number n of individual tool electrodes typically required. This results from the fact that those processes are characterised by considerable tool wear and complex geometries, which are processed by applying differently shaped tool electrodes. Up to several hundred machining steps have to be repeated until the target workpiece geometry is reached, each requiring an individually manufactured tool electrode. This results in a considerable amount of time needed for the manufacturing of the tool electrodes as well as for the tool electrode change. Therefore, the total time t and cost c of production for each workpiece are high [1]. An approach for reducing the number n of required tool electrodes and the time needed to produce the tool electrodes is the use of segmented tool electrodes. Each segment has few geometric features and can ideally be taken from stock material. The bundling of multiple segments creates a more sophisticated geometry, comparable to individual pixels in a digital picture.

Several publications have shown that tool electrodes made up of multiple individual segments can improve process conditions in sinking EDM [2, 3]. Channels in the centre of the segments enable active flushing of the working gap s, which can only be implemented in solid electrodes with considerable effort. All approaches published in the literature need adjustments of the segments before the erosion process to create the geometry for the tool. This adjustment is time intensive and leaves potential for improvement. In this paper the concept for a new kind of segmented tool electrode is presented. In addition, to using multiple segments in a fixed configuration, the application of actuators is discussed to move individual electrode segments during the erosion process. Firstly, this enables the automated precise and quick positioning of the segments to form the desired geometry to be transferred into the workpiece. Secondly, the actuation of segments during the erosion enables dynamic flushing in the working gap s, which cannot be achieved in conventional sinking EDM in this way. In order to realise the actuation of the segments, a dedicated electric linear drive is developed with a minimised geometry.

2. Subdivided erosion process for improved flushing

Dynamic adaptation of the tool geometry does not only reduce time in the machine setup. Additionally, completely new erosion strategies are possible. Taken the pyramid geometry as seen in Figure 1 a, the flushing of the working gap s with conventional strategies becomes significantly less efficient the larger the erosion depth d_e. Due to several sharp edges around the pyramid steps, the erosion particles get trapped in the working gap s. A possible improvement for the flushing conditions is depicted in Figure 1 b. In step I, the top plateau of the pyramid is transferred into the workpiece. In step II the outer ring of the tool electrode segments is retracted, so that the inner 3 x 3 segments are exposed. In the final step III, only the innermost segment is exposed to erode the final step of the pyramid. In each step this leaves more space around the top level of the geometry for particles to be removed from the working gap s.

To prove the hypothesis, that the erosion duration t_{ero} of steps I - III is significantly shorter than the one of the process shown in Figure 1 a, experiments were carried out on the machine tool Genius 1000 The Cube by ZIMMER & KREIM, Brensbach, Germany. EDM 3 graphite, by POCO GRAPHITE INC., Decatur, USA, was used for the tool electrodes and ELMAX steel, by VOESTALPINE AG, Linz, Austria, as the workpiece material. For the first experiment a solid tool electrode as seen in Figure 1 a was used. The second experiment was carried out according to Figure 1 b. For this experiment, the electrode segments were mounted statically. A combination of the strategy shown in Figure 1 b and the dynamic, synchronised movement of the electrode segments with the help of the actuators is believed to further improve the flushing in the horizontal direction inside the frontal working gap s_F and therefore shorten the erosion duration t_{ero}.



1 Solid tool electrode
2 Bundled tool electrode segments
3 Workpiece

Figure 1. Example of a pyramid geometry sunk into the workpiece; a) conventional process; b) with a segmented tool electrode

3. Miniaturised linear direct drive with weight compensation

To dynamically generate complex depth profiles for highly adaptable tool geometries the linear actuator is required to generate a static working stroke of $L = 30$ mm. Furthermore, the actuator is utilised to generate the oscillating wave movements for the flushing strategy, which demands a slider-amplitude of about $A = 1$ µm and a frequency of up to $\omega = 5$ Hz. Accordingly, the required maximum force amplitude F_A to accelerate the tool electrode with a mass $m = 10$ g is calculated given in Equation 1.

$$F_A = m\,(\omega^2 A + g) = 0.108 \text{ N} \qquad (1)$$

Energy-dissipating effects, like friction between the electrodes, are initially neglected in this concise calculation. The main part of 91 % of the required force amplitude F_A is used to counteract the static gravitational force $F_g = 0.098$ N of the tool electrode. The required dynamic force $F_d = 0.01$ N thus accounts for only 9 % of the total force. Since the width of an electrode segment is $w = 5$ mm, the outer diameter of the miniaturised linear actuator is limited to $d \leq 5$ mm. The major challenge in designing the linear actuator is to ensure a high force density D_F for robust control dynamics despite the small installation space and the large working stroke L. In this regard, the concept of a miniaturised electric linear drive including a permanent magnetic weight compensation was developed. This concept is shown in Figure 2.

The objective of the permanent magnetic weight compensation is to passively counterbalance the electrode mass m over the specified process stroke of $L = 30$ mm. As shown in Figure 2, this is realised by integrating a diametrically magnetised permanent magnetic slider into a soft magnetic stator. Thereby a position-independent force of $F_g = 0.098$ N can be generated closely [4].

To provide the dynamic force with an amplitude of $F_d = 0.01$ N, a two-phase linear synchronous motor was developed. The actuator is based on the physical principle of the LORENTZ force F_L. Two axially magnetised permanent magnets penetrate the stator coils with a radial magnetic field B and thus generate an axial force F_L on the slider, see Equation 2.

$$F_L = \iiint j \times B \, dV \qquad (2)$$

The opposing permanent magnets in the slider create an alternating radial magnetic field B in the stator coils. The current densities j_i in the stator coils are adjusted in dependence of the slider position x_L to provide current densities j_i proportional to the local radial magnetic field. Providing a current density amplitude of $\hat{j} = 5$ A/mm² a LORENTZ force of $F_L = 0.05$ N is generated. The force F_L is calculated using the multiphysics simulation software COMSOL.

The generated force $F_L = 0.05$ N exceeds the required dynamic force $F_d = 0.01$ N by $\Delta F = 0.04$ N. The resulting force reserve ΔF can be utilised to compensate for occurring disturbing forces F_d, which have been neglected, when deriving the demanded actuator force F_A in Equation 1. Thereby, a sufficient actuator force F_A for a robust and dynamic position control is guaranteed.

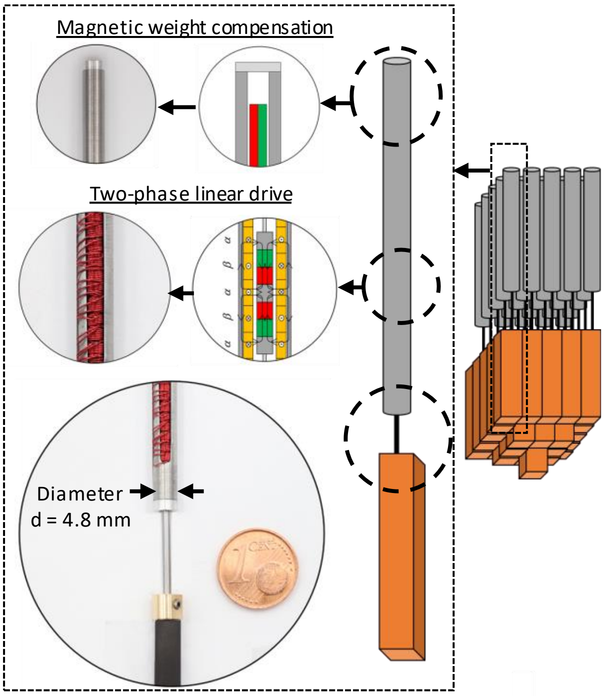


Figure 2. Miniaturised electric linear drive with permanent magnetic weight compensation

4. Conclusion

Within this paper the potential of the actuated variable tool electrode regarding optimisation in sinking EDM was presented. The automated generation of bundled tool electrode geometries by variable electrode-segments and innovative flushing strategies allow for a significant decrease of the EDM process time $t_{process}$. Moreover, the concept of a miniaturised linear direct drive with permanent magnetic weight compensation has been developed to ensure robust control dynamics despite the limited installation space.

In future work the realisation and experimental validation of the designed actuator will be investigated. An essential topic in this respect are intensive investigations after combining the segmented tool electrode with the linear drive requiring the design of an appropriate positioning control. Furthermore, the flushing strategy will be optimised by simulation and validated experimentally. In this regard, the excitation strategy, amplitude A and frequency ω will be investigated and optimised in respect to diverse workpiece geometries and materials. Innovative erosion strategies will be derived as well as means of the compensation of the relative linear wear ϑ_l by adjusting the positions of the electrode segments will be investigated.

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