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Micro-machining of cylindrical parts by electrical discharge grinding

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Abstract

The electrical discharge machining of cylindrical components is decisively influenced by the process conditions resulting from the rotational movement of at least one of the two electrodes. This paper analyses the machining effects developing at high peripheral speeds. Focus of investigation is especially placed on the evaluation of the effects on process behaviour and surface topography. The process variants electrical discharge turning (EDT), electrical discharge grinding (EDG), and wire electrical discharge grinding (WEDG) are compared with respect to the influence by the above-mentioned effects and the resulting process planning.

Keywords: Electrical discharge machining; Micro-machining; EDG; WEDG

1. Introduction

Micro-manufacturing processes are not only used for the production of micro-systems but increasingly also for the machining of functional surfaces, the respective function of a surface being influenced by the dimensions and the shape of the integrated structures. “Textured”, “engineered”, or “micro-structured” surfaces can be distinguished according to the structural characteristics [1]. Textured surfaces are characterised by a defined roughness, waviness or topography. Engineered surfaces have a defined functionality through a characteristic sub-surface formation. In the case of micro-structured surfaces, the micro-structures are characterised by a defined shape and usually by a high aspect ratio giving the component a defined physical function. They are applied in optical, electronic, and procedural processes to reinforce certain physical effects, e.g. the heat transfer in radiator bodies. A frequent form of application are micro-structured foils with special optical properties such as reflector foils for traffic management systems manufactured through embossing or rolling.

The flexible manufacture of cylindrical components of hard materials, which are used for the mass production of micro-structured components by forming processes as forming tools (e.g. plate rolls), is a challenge in terms of production engineering. This holds especially true if the micro-structures must have a high aspect ratio and small edge radii. As an alternative to grinding technologies limited by the achievable precision, geometrical complexity, and minimum dimensions, different process variants of micro-EDM can be used as depicted in Fig. 1.

It is characteristic for micro-electrical discharge turning (μEDT) that a micro-structured tool electrode is reproduced in the rotating workpiece by linear feed. This process variant has been used mainly for the electrical discharge dressing of pin or disk electrodes, a dressed tungsten carbide block serving as the forming electrode [2]. In the case of micro-electrical discharge grinding (μEDG), a micro-profiled disk electrode is used, the geometry of the profile of the rotating disk electrode being transferred by a linear feed to the circumference of the rotating workpiece, too. Investigations into μEDG have already been carried out on the basis of the machining of planar workpieces for the manufacture of micro-channels [3–6]. Wire electrical discharge grinding (WEDG) can be used as a third process variant. It differs from the other two process variants mainly by the formation of the workpiece contour as the result of a path movement. The WEDG is an established process applied for many years for the manufacture of rotationally symmetrical pin electrodes with simple geometries [2,7]. Moreover, complex grinding wheel geometries in the conventional field are also profiled by WEDG [8]. Special machines or wire travelling units, which are integrated in die-sinking machines, have been used so far for WEDG.

All three process variants are characterised by the fact that a high speed relative movement between workpiece and

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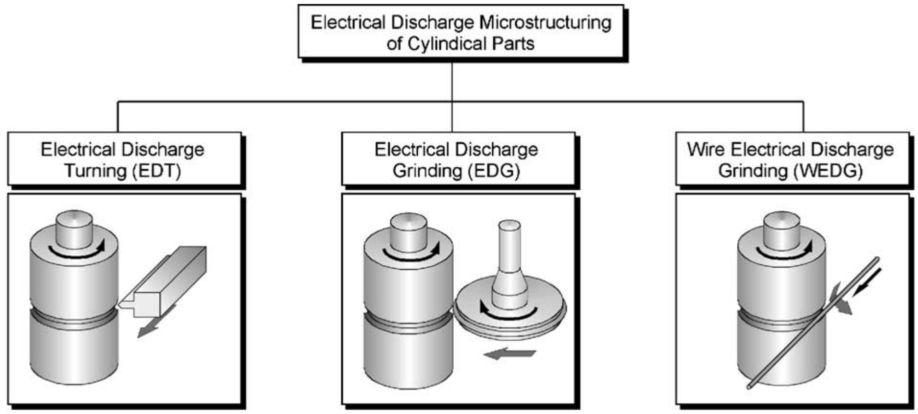

Fig. 1. EDM process variants for micro-structuring of cylindrical parts.

tool electrode as a result of the rotation of at least one of the working partners influences the machining process. Assuming that both electrodes rotate (EDG), the direction of rotation, too, might influence the process behaviour. Two cases can be distinguished here: synchronous rotation and counter rotation. The centre of attention within the scope of the investigations described in the following was placed on investigations into effects resulting from the rotation as well as the influence on the surface topography and on the process behaviour.

2. Analysis of process influences

2.1. Experimental setup

An AGIETRON COMPACT 1µ type die-sinking machine by AGIE SA, Losone (CH) was used as a test machine with a special generator for micro-EDM. The generator was operated in relaxation mode and was able to produce a minimum discharge energy of $W_e = 0.12\,\mu J$ ($t_e = 40\,ns$, $\hat{i}_e = 250\,mA$) at its smallest discharge capacity of $C_e = 100\,pF$. The further configuration is summarised in Table 1.

2.2. Determination of process influences

A direct effect of the rotational movement is the influence on the position and on the expansion of the plasma channel of a single discharge. Hereby, there are two different theories opposed to each other. On the one hand, it can be assumed that the foot points of the plasma channel move along with the initial positions on the surface of the rotation electrode. This means that the plasma channel is longitudinally expanded depending on the direction of rotation, circumferential speed, and discharge duration. If the expansion exceeds a boundary value, the plasma channel tears off leading to a disruption of the current flow. Considering the theory that the discharge energy W_e significantly determines the discharge crater geometry, it must be assumed that a plasma channel precociously breaks down with increasing circumferential speed ν_u. This would entail that the discharge crater becomes smaller in relation to its area and volume [9,10]. If this assumption was right, significant topography differences would have to occur in case of machining with counter rotation or synchronous rotation, respectively. On the other hand, it can be assumed that the position does not change independently of the electrode rotation. This leads to a shifting of the original position of the electrode surface, at which the plasma channel had developed. The heating up of the material surface is thus not stationary.

2.2.1. Analysis of the influence on heat conduction

The heat conduction is considerably influenced by the circumferential speed ν_u of the rotating electrode. To analyse and evaluate this effect with the help of a simple approach, the locally dependent temperature distribution can be determined in an infinitely expanded solid body starting from a steadily moved translatory heat source q''' in x-direction according to CARSLAW and JAEGER [11] as:

$$T(x, y, z, t) = \frac{q'''}{2k\kappa\pi^{3/2}}\, e^{Ux/2\kappa} \times \int_{R/2\sqrt{\kappa t}}^{\infty} e^{(-\xi^2-(R^2U^2/16\kappa^2\xi^2))}\, d\xi \qquad (1)$$

being $R^2 = x^2 + y^2 + z^2$ and $z = 0$, k the heat conductivity, t the considered point in time, U the translatory constant speed and κ the thermal diffusivity. The temperature of the developing plasma channel in the gap is assumed to be $T_p = 10{,}000\,K$ and that of the fluid $T_f = 20\,^\circ C$. The heat q''' is calculated from the 1st fundamental theorem of thermodynamics to $q''' = 2\rho c_p(T_p - T_f)$, c_p corresponding to the specific heat capacity and ρ to the density of the solid body. For simplification, heat transfer by convection will be neglected. The discharge duration is assumed $t_e = 1.2\,\mu s$. Due to the assumption that $t_e \ll 60/n_W$, the movement of the heat source is purely translatory. The results for the temperature distribution at the workpiece surface are presented in the following figures (Fig. 2).