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Reduction of erosion duration for electrical discharge drilling using a nature analogue algorithm with nested strategy types

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Abstract
The required high economic efficiency, combined with the corresponding high quality demands, in the aerospace industry as well as in mould and tool making, motivate the necessity of finding suitable parameter combinations for the process of electrical discharge machining (EDM), e.g. when introducing new materials. To counteract this, various methods are being investigated in research for the optimisation of EDM. One new method is the stochastic optimisation procedure evolution strategy (ES). Due to its metaheuristic approach, this optimisation method is excellently suited for very complex processes in which the interrelationship of the individual influencing variables is not known. This publication presents the results of the investigation of the suitability of the ES optimisation method using the example of electrical discharge drilling. For this purpose, two nested ES-types were investigated. The electrode materials used were brass for the tool and stainless steel X5CrNi18-1 for the workpiece. As a result, the erosion duration could be reduced by 30 %. This investigation forms the basis for the use of nested ES types in electrical discharge drilling.

EDM, nature analogue algorithm, optimisation

1. Introduction

In order to fulfil the constantly growing requirements for compact and high-performance products in aerospace as well as in mould and tool making industry, hard and wear-resistant materials are primarily used. A process commonly used for machining these materials is electrical discharge machining (EDM). Considering the high complexity and the non-linear process behaviour, there are still no comprehensive findings or models on the inherent interactions of the process parameters of the EDM process. However, due to the high industrial relevance, huge efforts are being made in industry and research to optimise as well as model the EDM process [1]. In general, the common target values of the process cannot be influenced independently of each other.

Common approaches to process parameter optimisation are based on statistical design of experiments (DoE), e.g. based on a response surface method (RSM) and multicritically optimising the obtained quadratic model with the Derringer-Suich-Method in a case of sinking EDM [2]. However, DoE is restricted to narrowly defined limits. Auerbach et al. [3] proposed a separation of model and optimisation because an optimisation of non-linear production processes by use of models was not practicable. This approach allows the application of optimisation methods, where the correlations between individual process parameters and process results may be unknown [3].

Due to its metaheuristic concept, the stochastic optimisation method evolution strategy (ES) is well suited for complex processes such as EDM, see Figure 1. Analogue to nature, new parameters are generated as children of a parent parameter by mutation and recombination. New parameter sets are applied in real experiments, whereupon the results obtained are evaluated with regard to the optimisation criterion. Meeting a termination criterion such as a specific objective function value, a fixed number of generations γ_{max} or the absence of significant improvements will end the ES [4].

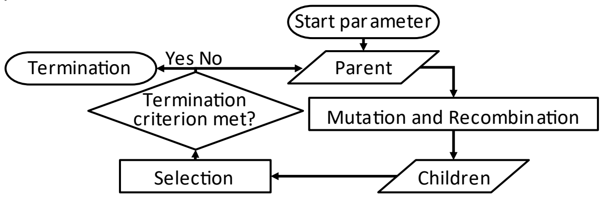

Figure 1. General procedure of the ES according to Rechenberg [4]

2. Materials and method

The hybrid machine tool "MicroDrill" was used for the investigations to optimise electrical discharge drilling by use of the ES [5]. Applying deionised water as the dielectric for internal flushing and a static pulse generator, multi-channel brass electrodes with an outer diameter of d_o = 0.90 mm were used to drill through holes in the stainless steel X5CrNi18-1 with a height of h = 3 mm. For the target values erosion duration t_{ero} and linear wear of the tool electrode Δl_E, the discharge duration t_e, the pulse interval time t_0, the discharge current i_e and the open-circuit voltage $\hat{u}_i$ were considered as process parameters to be varied.

Based on the work of Streckenbach et al. [6], two types of ES, a nested (1,4)-ES and a nested (1+4)-ES, with a number of parents of μ = 1 and a number of children of λ = 4 for each generation were applied for this study. The nested ES-types work according to the same principle as the simple ES-types. The step size is reduced with progressive evolution, which also reduces the search domain from generation to generation. For both types of nested ES a generation with four children each is generated by the algorithm, then experimentally executed and finally evaluated with regard to the erosion duration t_{ero} and the linear wear of the tool electrode Δl_E. For this purpose, the target value erosion duration t_{ero} is weighted with 70 % and the linear wear of the tool electrode Δl_E with 30 % respectively. In this way, it is possible to calculate quality points q_C, according to Equation 1 and use these for the validation of the ES applied. This process is repeated up to and including the fifth generation.

$$q_C = 0.7 \cdot \frac{t_{ero}^{child}}{t_{ero}^{start}} + 0.3 \cdot \frac{\Delta l_E^{child}}{\Delta l_E^{start}} \qquad (1)$$

After the fifth generation, the starting point for the sixth generation is determined by selecting the best children out of all five previous generations. Furthermore, the step size is reset to its initial value. This makes it possible to shift the search range and adjust the step size in the direction of a possibly better local optimum. From this new starting point, five more generations are generated and experimentally executed.

In the nested (1,4)-ES, the parent vector eroded in the previous generation is not taken into account for the selection procedure. In the nested (1+4)-ES however, the best child of the previous generation, i.e. the parent vector of the current generation is checked again and additionally issued with the three generated children. Thus outliers can be excluded and hence a search in the wrong direction can be prevented. This may result in a degradation of the subsequent generations, but it allows the algorithm to find further local optima.

3. Results

Figure 2 visualises the determined quality points q_C after triple execution of the nested (1,4)-ES as well as the nested (1+4)-ES for the optimisation of electrical discharge drilling. The mean value of the first parent with quality points $q_C = 1$ and the mean values calculated from the best three children out of all generations of the respective strategy types are shown.

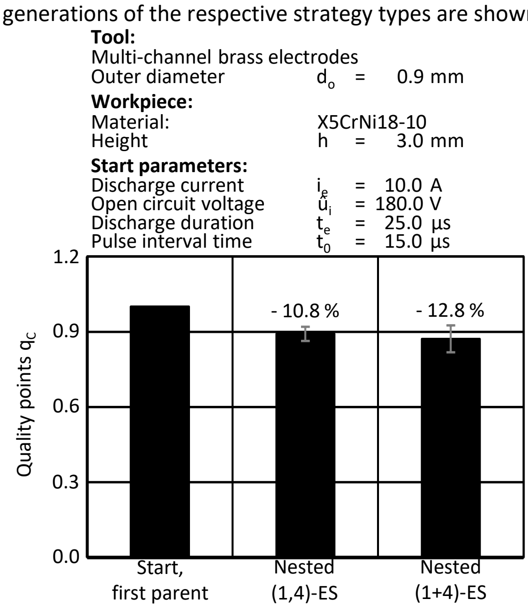

Figure 2. Comparison of quality points q_C before and after optimisation

The results show that improvements of the quality points q_C by 10.8 % and 12.8 % could be achieved, using the nested (1,4)-ES or the nested (1+4)-ES respectively. It should be noted that the target values taken into account via a quality function are offset against each other and an improvement of one target value compensates for the deterioration of another target value, as stated in the introduction. This fact results in the need of a differentiated consideration of the respective target values, visualised in Figure 3. The mean values of the erosion duration t_{ero} and the linear wear of the tool electrode Δl_E are calculated from the best three offspring of the respective strategy types. The values of the first parent are shown for comparison.

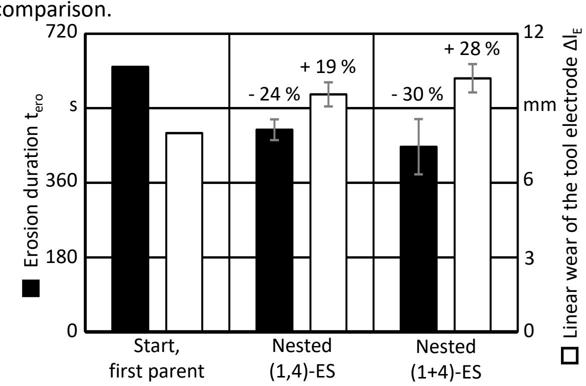

Figure 3. Comparison of the target values before and after optimisation

Using the nested (1,4)-ES, the erosion duration could be reduced by 24 %, from $t_{ero} = 640$ s to $t_{ero} = 488$ s. However, in parallel, the linear wear of the tool electrode Δl_E increased by 19 %, from $\Delta l_E = 8.00$ mm to $\Delta l_E = 9.55$ mm. With the nested (1+4)-ES, the erosion duration was reduced from $t_{ero} = 640$ s to $t_{ero} = 447$ s, a reduction of 30 %. As with the nested (1,4)-ES, this was accompanied by an increase in the linear wear of the tool electrode Δl_E by 28 %, from $\Delta l_E = 8.00$ mm to $\Delta l_E = 10.20$ mm.

Although the linear wear of the tool electrode Δl_E has increased due to the weighting in the calculation of the quality points q_C, however within the framework of this investigation, it was thus possible to demonstrate that optimisation of electrical discharge drilling is possible using the nested ES-types.

4. Summary and Conclusion

Based on the presented investigations, it could be shown that electrical discharge drilling can be optimised using the natural analogue algorithm ES. Both algorithms of the nested ES show the potential to be used for the optimisation of EDM applications in the industry.

A comparison of the nested (1,4)-ES and the nested (1+4)-ES showed that the nested (1+4)-ES results in a slightly better process improvement, with reductions of the quality points q_C by 12.8 % and 10.8 % respectively. This led to a decrease of the erosion duration t_{ero} by 30 % and 24 % respectively.

In summary, it can be stated that electrical discharge drilling can be optimised using the nested ES. The knowledge gained from this investigation forms a basis for further research and successful application of the ES for EDM processes.

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