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INVESTIGATING THE IMPACT OF CURRENT, PULSE ON TIME, AND PULSE OFF TIME ON EDM PERFORMANCE

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ABSTRACT

High Carbon High Chromium Steel (HCHCR) parameter optimization for Electrical Discharge Machining (EDM) is an important goal in the field of precision manufacturing. Because of its unusual properties, such as high hardness and wear resistance, HCHCR requires careful EDM parameter optimization. This work aims to quantify the influence of three design factors—current, pulse on time (Ton), and pulse off time (Toff)—on HCHCR machining specifications like material removal rate (MRR) and surface integrity characteristics like average surface roughness (Ra). These factors are most connected to the EDM process and its control. All trials followed the L9 orthogonal array protocol. The Ampere rating, pulse on time, and pulse off time were among the variables varied between the experiments..

Keywords: Surface roughness, Pulse, Discharge, Electrode, Current

I. INTRODUCTION

When working with difficult materials like High Carbon High Chromium Steel (HCHCR), optimizing parameters in Electrical Discharge Machining (EDM) is essential for improving machining productivity and precision. When it comes to EDM applications, HCHCR, with its legendary hardness and wear resistance, offers both distinct obstacles and possibilities. Optimization of EDM settings becomes crucial as companies demand increased precision and efficiency. In the industrial business, Electrical Discharge Machining (EDM) is a popular non-traditional machining technology for shaping and molding conductive materials with complex geometries. Electrical discharge machining (EDM) is a high-precision machining process that allows for the cutting of complicated forms without using a tool that comes into direct contact with the workpiece. The procedure entails making electrical sparks between the electrode and the workpiece, which produces high-temperature radiation that either melts or evaporates the material. Therefore, as a crucial technique in the manufacture of precision components, EDM is especially well-suited for materials with high hardness and difficult-to-machine characteristics.

Of the many difficult materials used in machining, high carbon high chromium steel stands out. This alloy is highly sought-after for its numerous tool, die, and mold applications because to its remarkable hardness, wear resistance, and capacity to maintain sharp cutting edges. The high carbon and chromium concentration in the steel's distinctive composition makes it robust and resistant to abrasion, corrosion, and deformation. On the other hand, HCHCR's desired qualities also make it difficult to machine. When working with HCHCR, conventional procedures can be inefficient, thus more sophisticated approaches, such as electrical discharge machining (EDM), are required for best results. When dealing with the complex job of machining HCHCR, the need of optimizing EDM settings becomes clear. The rate of material removal, surface finish, and overall machining efficiency are heavily influenced by parameters including pulse length, discharge current, and electrode material. Maximizing EDM's potential while minimizing HCHCR's drawbacks requires striking the correct balance among these elements. For example, the amount of energy released during each discharge is controlled by the duration of the pulse, which in turn influences the depth of material removal and the area impacted by heat. Instead, the strength of electrical discharges, which in turn affects the rates of material removal and the surface integrity, is controlled by discharge current. Because it affects tool wear, machining precision, and process stability as a whole, choosing the right electrode material is equally crucial.

An organized and thorough procedure is required for the optimization of EDM settings during HCHCR machining. In order to modify the procedure according to the unique properties of HCHCR, researchers and practitioners must take into account the complex interaction between several factors. Striking the right balance between material removal and workpiece integrity requires careful control of several parameters, including pulse on time, pulse off time, peak current, and flushing conditions. Optimizing these parameters to increase machining efficiency while avoiding surface quality degradation, micro-cracking, and heat damage is a formidable problem. The constant need for efficiency and accuracy in today's industrial processes motivates the search for optimal EDM settings for HCHCR machining. Cutting tools, metal forming dies, and plastic injection molds are just a few of the many uses for HCHCR components. Tighter tolerances, better surface finishes, and shorter lead times are becoming necessities in various businesses as they develop. With careful optimization of the parameters to address the unique problems of HCHCR, EDM, known for its micron-level accuracy, is well-positioned to fulfill these needs.

II. REVIEW OF LITERATURE

Patel G C, Manjunath et al., (2021) Industries require precise standards for cost-effective machining of high carbon high chromium (HcHcr) steel, while maintaining good surface quality. The objective of electrical discharge machining (EDM) for HcHcr steel is to minimize machining expenses by maximizing the material removal rate (MRR) and minimizing the tool wear rate (TWR), while also achieving a high-quality surface finish by minimizing surface roughness (SR). A comparative research was conducted to investigate the electrical discharge machining (EDM) of HcHcr D2 steel (DIN EN ISO 4957). The study employed the Taguchi L18 experimental design, which included many factors including

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electrode materials (copper, graphite, and brass), dielectric fluids (distilled water and kerosene), peak current, and pulse-on-time. An analysis was conducted on the process performances in terms of material removal rate, surface roughness, and tool wear rate. Pareto analysis of variance was utilized to determine the relevance of the process variables and their ideal values in order to achieve reduced SR and TWR, as well as increased MRR. The ideal EDM parameters were determined using the Hybrid Taguchi-CRITIC-Utility and Taguchi-PCA-Utility techniques. The graphite electrode achieved a higher material removal rate (MRR) of 0.0632 g/min, as well as a lower surface roughness (SR) of 1.68 µm and tool wear rate (TWR) of 0.012 g/min, while using distilled water as the dielectric fluid. This performance was superior to that of the brass and copper electrodes. In addition, a metallographic investigation was conducted to examine the surface integrity of the machined surfaces. Micrographic study of the ideal circumstances revealed reduced surface roughness and a decreased presence of flaws, such as impressions, waviness on the surface, and micro-cracks, in comparison to the worst conditions.

Sahoo, Sarat et al., (2019) Wire electrical discharge machining (WEDM) is a sophisticated unconventional machining technique designed particularly for achieving intricate three-dimensional shapes in tough materials with exceptional precision. The current study examines the impact of several process factors, including pulse on time, pulse off time, wire feed, and servo voltage, on response variables such as cutting speed, material removal rate, kerf width, and surface roughness during the machining of high carbon high chromium steel. The experiment was designed using Taguchi's L9 orthogonal array, which consists of four components and three levels. The selection of the best level of machining parameters has been accomplished by implementing a unique strategy called the order preference by similarity to ideal solution (TOPSIS) approach. An analysis of variance (ANOVA) was performed to examine the impact of process factors on the overall performance of machining. The proposed optimum condition is confirmed to be effective by the confirmatory test. The findings of this study emphasize that the parameters of pulse on time and servo voltage have a major impact on machining performance.

M., Dastagiri et al., (2018) Electrical Discharge Machining (EDM) is a distinctive and very accurate production technique. It may be used to create complex or simple forms and geometries in components and assemblies. Yield and quality are crucial factors in manufacturing processes that have become significant concerns in today's highly competitive industry. Most industrialized units primarily focus on these specific areas in terms of techniques and procedures. Thus, in this study, the approach of 'multi-objective optimization' is employed to simultaneously enhance the quality and yield of the EDM operation on rail. The four selected input process parameters for this approach are: Discharge current (IP), Pulse on time (Ton), Discharge voltage (v), and Inter Electrode Gap (IEG). These factors will be analyzed at three distinct levels. I will evaluate the Material Removal Rate (MRR), Surface Roughness (Ra), and Tool Wear Rate (TWR) as output variables and quantify them for each experimental run. This article aims to demonstrate the optimization of Mean

Reciprocal Rank (MRR) to increase productivity, reduce Surface Roughness to enhance offline quality, and simultaneously minimize Tool Wear Rate of the electrode. Consequently, the Heuristic technique has been employed to predict the aforementioned outcomes.

Gonchikar, Ugrasen et al., (2015) Wire Electrical Discharge Machining (WEDM) is a precise thermo-electrical machining technique that can properly form components with different levels of hardness or intricate geometries. This study aims to optimize the process parameters in wire electrical discharge machining (EDM). The work material used was HCHCr. The work material underwent machining using various process parameters, which were determined using Taguchi's L27 orthogonal array. The parameters, including pulse-on, pulse-off, current, and bed speed, were adjusted. The factors analyzed include surface roughness, volumetric material removal rate, and accuracy. An analysis of variance (ANOVA) was conducted to determine the extent to which a component influences the outcome. In addition, a verification experiment was conducted to validate the effectiveness of the optimal settings.

Bhattacharya, Anirban et al., (2011) The objective of this study was to determine the optimal parameter settings for rough and finish machined surfaces of EN31, H11, and high carbon high chromium (HCHCr) die steel materials in a powder-mixed electric discharge machining method. An experimental design and analysis of variance were used to investigate the impact of seven process factors and their interactions, employing a dummy-treated approach. The material removal rate (MRR), tool wear rate, and surface quality were monitored and assessed after each experiment. The parameter configurations for rough and completed machining processes were acquired. EN31 had the highest Material Removal Rate (MRR) when compared to the other two materials under comparable process conditions. The utilization of a copper (Cu) electrode containing suspended aluminum inside the dielectric material resulted in the optimization of the Material Removal Rate (MRR). The act of suspending powder in the dielectric led to the alteration of the surface. Graphite powder exhibited a reduced Material Removal Rate (MRR) while enhancing the quality of the surface finish. HCHCr necessitates increased current and pulse settings to initiate a machining cut effectively. It performs well when used in conjunction with a tungsten-Cu electrode and graphite powder, resulting in an enhanced finish. The mean removal rate (MRR) for H11 is lower than that of EN31 but much greater than that of HCHCr under the same process conditions.

III. RESEARCH METHODOLOGY

The studies were conducted utilizing an electric discharge machine, with a copper electrode and an HCHCR D3 STEEL work piece. The current was applied in a straight polarity direct current, with the electrode serving as the anode and the workpiece as the cathode. The IPOL is controlled by a servo system and uses a dielectric fluid. The 32 mm diameter HCHCR D3 steel is cut into nine equal circular pieces using a band saw. The electrolytic copper tool (99.9%) is the material utilized for the experiment. This tool electrode has a diameter of 20 mm and a total length of 25 mm. There are three process parameters that may be adjusted:

pulse on time, pulse off time, and gap current.

Figure 1: Experimental setup

Work piece material: Air-hardening tool steel with a high carbon and chromium content is known as HCHCR D3. Its resistance to wear and abrasion is great. In its annealed state, it is machinable and heat treatable, yielding hardness values between 55 and 62 HRC. Hardening HCHCR D3 steel properly results in little deformation. Hardened HCHCR D3 steel has moderate corrosion resistance due to its high chromium content.

Machining time: Machining time is the amount of time it takes to process a work item in order to change its dimension. The machining time is recorded by means of a stop watch.

Surface roughness: A surface's roughness may be determined using the central line average technique (Ra). The average absolute departure of the roughness abnormalities from the mean line throughout one sampling length is what this number shows. Surface roughness may be measured with the Talyor Hobson Talysurf equipment.

Material removal rate: It is calculated by the formula

$$MRR = \frac{W_i - W_f}{\rho_w T}$$

Where Wi = initial weight of work piece before machining

Wf = final weight of work piece after machining

ρw = density of the work piece

T = machining time

IV. DATA ANALYSIS AND INTERPRETATION

The findings were created after the tests were conducted using the combinations received from the Mini tab software's design of experiments.

Table 1: Results for Machining Time using ANOVA

Source	Seq SS	Adj MS	F	P	% of contribution
Time On	0.2448	0.1227	0.12	0.910	1
Time Off	31.0059	15.5030	12.51	0.074	53
Gap Current	24.2641	12.1323	9.79	0.093	42
Error	2.4836	1.2419			4
Total	57.9984				100

Results for machining time at time on (1), time off (53) and gap current (42) are shown in the above table as percentages. The machining time is significantly affected by the time off. Based on the data provided, it is evident that time off is the primary component that has to be carefully chosen in order to achieve the minimal machining time, since this study is a parameter based optimization design.

Table 2: Results for Surface Roughness using ANOVA

SOURCE	SEQ SS	ADJ MS	F	P	% of contribution
Time- On	20.891	10.450	3.15	0.240	59
Time- Off	5.340	2.670	0.83	0.560	15
Gap Current	2.449	1.227	0.35	0.729	7
Error	6.685	3.340			19
Total	35.372				100

Based on the data in the table, we can see that the surface roughness values at pulse on time (59), pulse off time (79), and gap current (7) made up the percentage contribution. There is a strong correlation between the pulse on time and surface roughness. The following data make it very evident that pulse on time is the most important parameter to pick successfully in order to achieve the minimal surface roughness, which is expected given that this study is a parameter based optimization design.

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Table 3: Results for MRR using ANOVA

Source	Seq SS	Adj MS	F	P	% OF CONTRIBUTION
Time on	0.000012	0.000004	43.00	0.024	11
Time off	0.000059	0.000034	277.00	0.006	59
Gap current	0.000037	0.000020	151.00	0.005	30
Error	0.000000	0.000000			0
Total	0.000107				100

The numbers for material removal rate during time on (11), time off (59), and gap current (30) are shown in the above table as % contributions. Surface roughness is shown to be significantly affected by the amount of time off. From the above results, it is evident that time off is the primary element that has to be set effectively to acquire the greatest material removal rate. This study is based on a parameter-based optimization approach.

V. CONCLUSION

Pulse length, discharge current, and electrode material are three EDM parameters that have been studied because of their complex interaction and their impact on material removal rates, surface finishes, and machining efficiency in general. To fully use EDM and reduce problems like heat damage and micro-cracking that come with HCHCR, it is crucial to find the sweet spot between these parameters. To achieve the best possible balance between material removal and workpiece integrity, it is necessary to fine-tune the flushing conditions, peak current, pulse on time, and pulse off time. Advanced machining solutions are in high demand due to the increasing accuracy and efficiency requirements of modern businesses. Electrode machining (EDM) is a key technology in this context. A wide variety of products rely on HCHCR components, such as cutting tools and plastic injection molds. Getting better surface finishes, shorter lead times, and tighter tolerances is becoming more and more important as industries change.

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