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Process Optimization In Automated Hybrid Edm Using Rotational Workpiece Fixtures

Vijay D Patel[1], Sivaneasan Bala Krishnan[2], A Subrata Chowdhury[3], Prasun Chakrabarti[4],, Harshad C Patel[5]
[1] Post-doctoral Researcher- Singapore Institute of Technology, Singapore / Ganpat University, India.
[2] Associate Professor, Singapore Institute of Technology, SINGAPORE
[3] Sreenivasa Institute of Technology and Management Studies, INDIA
[4] Department of Computer Science and Engineering, Sir Padampat Singhania University, INDIA
[5] Assistant Professor Ganpat University, India

ABSTRACT
Electrical Discharge Turning (EDT) represents an innovative and efficient approach that merges the principles of Electrical Discharge Machining (EDM) with conventional turning operations. This hybrid method is particularly suitable for machining intricate cylindrical components made from difficult-to-machine materials such as H13 die tool steel. The core aim of this study is to evaluate the machinability of H13 steel using a specially designed rotating workpiece fixture mounted on a die-sinker EDM.
To replicate turning-like conditions during the EDM process, a custom rotational attachment was developed. The experimental framework was structured using Taguchi's Design of Experiments (DOE) method, with key process variables including pulse on time, pulse off time, peak current, and rotational speed. These parameters were systematically varied to analyze their influence on surface roughness (SR). The findings indicated that peak current was the most influential factor affecting on surface finish, followed by pulse on time.
An optimal surface roughness value of 7.647 µm was achieved under specific parameter settings. Overall, this research confirms that EDT, when implemented with a rotating fixture, offers a promising advanced manufacturing technique for producing high-precision cylindrical components from tough tool steels.

INTRODUCTION
Electrical Discharge Machining (EDM) is a well-known technique of working with hard materials and making complex shapes. More recently, new hybrid techniques have been developed-like Electrical Discharge Turning (EDT) which allows dielectric based electrical machining of rotating cylindrical workpieces. Of these innovations, the conversion of rotating fixtures to the standard die-sinker EDM machines holds a lot of promise in the manufacturing of cylindrical components, but is still under-researched.
At the same time, there is a significant improvement in surface properties in the development of EDM with powder-mixed dielectrics. As an example, Singh et al. (2024) have shown that the use of a graphite-loaded dielectric increased the microsurface hardness of H13 tool steel by 159%, which demonstrates the usefulness of the customized dielectric composition. On the same note, Nas et al. (2025) explored the enhancement of surface finish and wear resistance of untreated AISI H13 using advanced EDM techniques. It is in this light that the current study seeks to combine the rotational machining potential of EDT with surface-enhancing techniques in machining cylindrical parts made of H13 die steel. Taguchi methodology of design of experiment is used to find the optimum values of the key process parameters.

LITERATURE REVIEW
Electrical Discharge Machining (EDM) has gained a lot of recognition as a non-conventional process that can be applied in machining electrically conducting and difficult to machine material particularly when complex geometries have to be produced. Conventional EDM methods are usually limited to workpieces and profiles that are fixed and in 2D. But the combination of rotational capability has greatly expanded the range of functionality of EDM. Rotational Electrical Discharge Turning (EDT) and Wire EDM Turning (WEDT) are some of the techniques that have been developed to employ the best of the dimensional and finish capabilities in the production of cylindrical components. As an illustration, Khan et al. (2023) showed the ability of WEDT to hold dimensional tolerances up to 5 microns on rotating parts, whereas Gohil and Puri (2024) emphasized the decisive role of spindle speed in terms of roundness and dimensional accuracy.
In addition to the mechanical aspects, process parameters are critical in the improvement of the performance values like Material Removal Rate (MRR), Surface Roughness (SR), and tool wear. Bahgat et al. (2019)

investigated how such variables as pulse on time, current and electrode material influence the EDM of H13 die steel and reported that peak current had the greatest impact on MRR and tool degradation. Continuing on these findings, Singh et al. (2024) employed a graphite-enriched dielectric, and accomplished a surface hardness of H13 that was increased by an impressive 159 percent, thus confirming the performance advantage of powder-mixed dielectric fluids. In a similar study, Cu cermet electrodes (CuTiC) were used, and pulse current was found to be the major influential parameter on the surface roughness; the models developed were very much in line with the experimental results.
Other new trends in the field of EDM studies are the application of external energy fields and nanomaterial additives. Recent studies by Jadidi et al. (2020) and others have shown that the magnetic-field-assisted EDM increases the flushing and debris removal, decreases the overcut, and supplements rotational mechanisms when machining high-strength alloys, including H13 and EN24.
In order to optimize these processes, powerful statistical and computational tools including Taguchi Design of Experiments (DOE), Response Surface Methodology (RSM) and Grey Relational Analysis (GRA) are commonly used. Siddiqui et al. (2024) used these frameworks to machine Ti6Al4V, whereas Sana et al. (2024) applied AI to powder-mixed EDM configurations to predict multi-objective results with great precision. These developments point to the growing significance of predictive modeling and intelligent systems in the planning of the EDM processes.
These findings are supported by the detailed reviews conducted by Pop and Titu (2023) and Kumar et al. (2024) with the authors noting that the impact of discharge current and pulse on time remains consistent across various EDM applications. They also cite sustainability, dielectric formulation, and AI-based modeling as the directions in which future EDM research and innovation should be headed.

RESEARCH GAP

Despite notable advancements in EDM research, the integration of rotating workpiece systems with die-sinker EDM machines for cylindrical machining remains insufficiently explored—particularly in the context of H13 die tool steel, a material widely used in high-load tooling applications. While most existing studies have concentrated on Wire EDM (WEDM) or standard die-sinking EDM methods, the incorporation and analysis of mechanically driven rotating fixtures within die-sinker setups have received limited attention. Furthermore, although individual enhancements such as magnetic field assistance, powder-mixed dielectrics, and advanced electrode configurations have demonstrated performance improvements, their combined application within a rotational EDM environment has not been comprehensively investigated.
In addition, while statistical optimization techniques like Taguchi Design of Experiments (DOE) are commonly applied in EDM parameter studies, their use in the context of rotational die-sinker EDM systems is still underrepresented in the literature. Current research often overlooks experimentation involving H13 steel under rotating conditions, or fails to assess the complex interrelations between discharge parameters, spindle speed, and fixture design on overall machining outcomes. This study aims to address these research gaps by introducing a custom-designed rotating fixture for die-sinker EDM, optimizing key process parameters using Taguchi DOE, and developing predictive models for surface roughness (SR). The goal is to enhance the effectiveness and broaden the application of Electrical Discharge Turning (EDT) in high-precision cylindrical machining of hard tool steels.

OBJECTIVES

The objective of this research is to design a rotating workpiece attachment suitable for integration with a die-sinker EDM machine. This attachment will enable cylindrical machining of hard materials like H13 die tool steel. The study also aims to develop and test the fixture within an actual EDM setup. Using the Taguchi method, the effects of various machining parameters will be analyzed. The goal is to optimize material removal rate and surface roughness through systematic experimentation. The methodology adopted, as illustrated in Fig. 1, is structured to systematically achieve these objectives.

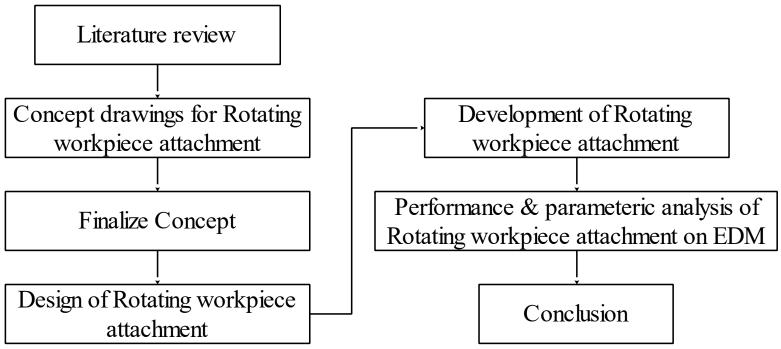

Fig.1. Methodology adopted

EXPERIMENTAL SETUP

Experiments were conducted on a TOOL CRAFT Spark Erosion EDM machine. The rotating fixture was custom-designed and attached to the work table. Control of rotation speed was achieved through a stepper motor. EDM machine specs included: 350x220 mm table size, 60L dielectric capacity, and 15–25 A current.

All the experiments will be conducted using an EDM machine made by TOOL CRAFT SPARK EROSION MACHINE. This machine's Z axis is powered by a servo motor, which is managed by the control panel. The gap voltage between the tool and the workpiece electrode is the basis for the servo control feedback.

The gap distance is determined by feeding the tool into the workpiece during machining in order to maintain the gap voltage all the time. The manual control of the X and Y axes is utilized. The EDM machine is shown in Fig.2., which includes a dielectric system, a pulse generator system, and a servo gap control system. Table 1. displays the configurations of the EDM machine made by TOOL CRAFT SPARK GENERATOR.

Fig.2. EDM Machine

Table 1. EDM Machine

Work Table	
Table Size	350X220 mm
Table Travel Longitudinal	220mm(X-axis),130mm(Y-axis)
Work Tank	
Tank Size	600X370X290 mm
Dielectric Fluid Level Over Table	200 mm
Work Piece	
Maximum Height	150 mm
Maximum Weight	100 kg
Servo Head	
Quill Stroke	200 mm
Electrode Pattern Size LXB	100X100 mm
Max Electrode Weight	20 kg
DIELECTRIC System	
Reservoir Capacity	60 litres
Filtration Level	10 microns
Pulse Generator	
Working Current	15 or 25 amps

MATERIAL SELECTION

The selection of workpiece material is a critical aspect of this experiment, as machining characteristics and EDM performance vary significantly across materials. In Electrical Discharge Machining (EDM), the choice of material greatly influences the efficiency, surface finish, and overall quality of the process. For this study, AISI H13 die steel was selected due to its exceptional properties and widespread application in tool and die industries. Classified under the AISI H-series as a chromium-based hot work tool steel, H13 is engineered to withstand extreme thermal and mechanical stresses during metal-shaping, shearing, and punching operations. Its air-

hardening capability and balanced alloy composition minimize distortion during heat treatment, making it ideal for high-precision applications. H13 has a very high level of toughness, fatigue resistance and thermal conductivity and is very convenient to use in hot and cold work tooling. Typical uses are ejector pins, inserts, core pins, casting die cavities, forging and extrusion dies, plastic mould cavities, shot sleeves and trimming dies. H13 has been very popular in thermoplastic and compression mold tooling due to its superior performance in high temperatures, as well as fast cooling capability, commonly resulting in a hardness of 50 52 HRC.
The AISI H13 die steel chosen to be used in this study is a hot work tool steel with great thermal resistance, toughness, and dimensional stability, which is based on chromium. Its chemical composition comprises major alloying components, which are chromium (4.75 5.50), molybdenum (1.10 1.75), and vanadium (0.30 0.60) that make it strong and wear resistant. Physically, it is 7.80 g/cm3 in density and 1427 o C in melting point. Mechanically, H13 has a high tensile strength (12001590 MPa) and high modulus of elasticity (215 GPa), which makes it the most suitable in high-stress tooling. Good conductivity (28.6 W/mK) and stable thermal expansion are thermal properties which make it perform better in high-temperature machining. The workpiece samples that had been chosen were then dimensioned accordingly to fit the rotating EDM system to perform cylindrical machining tests, as depicted in Fig.3.

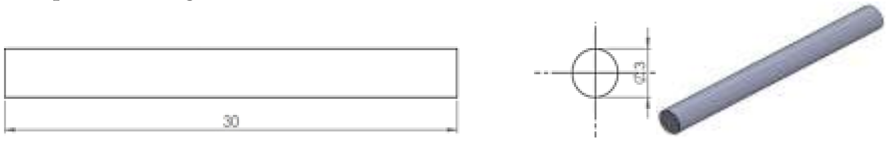

Fig.3. Workpiece specimens

DESIGN OF EXPERIMENT

Design of Experiment (DOE) is an orderly approach that is applied in the investigation, evaluation, and optimization of manufacturing and research processes. It also enables it to be able to study the relationships between several process variables and their influence on desired results in a systematic manner. DOE will be used in this research to determine the influence of various parameters of the EDM on the performance indicators, including Material Removal Rate (MRR) and Surface Roughness (SR). Out of the many DOE techniques, Factorial, Response Surface and Taguchi methods, the Taguchi is embraced due to simplicity, efficiency and robustness. This technique was invented by Dr. Genichi Taguchi in Japan and uses orthogonal arrays (OAs) and signal-to-noise (S/N) ratio to minimize experimental variance and to determine optimal conditions. The method reduces the number of attempts in the experiment and increases the accuracy of findings. The Taguchi method can also be used to identify the contribution and interaction of all process parameters and thus to control and optimize the process. The eight-step protocol, which covers the selection of the problem and level of factors, design of the array, carrying out of the experiment, and prediction of the performance, provides a holistic and replicable procedure.
Pulse on time (Pon) is the time each spark lasts and has a direct effect on the energy transferred and therefore the removal rate of the material. Pulse off time (Toff) is the interval between discharges, affecting debris removal and sparking efficiency. Gap voltage determines the spark gap and influences the discharge intensity, while servo feed controls the inter-electrode distance in real-time. Peak current, expressed in amperes, dictates the maximum power applied during each discharge. The primary response variables analyzed include surface roughness—resulting from residual molten material and discharge craters; material removal rate—calculated by the weight difference before and after machining divided by time; and electrode wear rate—defined by the volume loss of the tool relative to the workpiece. These variables serve as key indicators of process efficiency and quality in EDM machining.
The Taguchi method was adopted using an L9 orthogonal array. Four parameters were studied:
- Pulse on time (100, 200, 500 µs)
- Pulse off time (10, 20, 50 µs)
- Peak current (10.93, 17.18, 23.43 A)
- RPM (0.5, 0.75, 1)

Response variables:
- Surface Roughness (SR)

Table 2. DOE by Taguchi method

Sr no	Pulse on time(μs)	Pulse off time(μs)	Current(A)	RPM
1	100	10	10.93	0.5
2	200	20	23.43	0.5
3	500	50	17.18	0.5
4	100	20	17.18	0.75
5	200	50	10.93	0.75
6	500	10	23.43	0.75
7	100	50	23.43	1
8	200	10	17.18	1
9	500	20	10.93	1

By using a precision weight instrument, we assessed the material removal rate both before and after machining.

Response parameter

- Surface Roughness

Evaluation of Surface Roughness

Surface roughness testing is done in Divine Metallurgical Services Pvt. Ltd. Surface roughness test done at three different points of workpiece, this three points taken manually. All tests done on Surface Roughness Tester Mitutoyo (dmspl/07/16) as shown in Fig. 4.

Fig.4. Surface Roughness Tester Mitutoy

RESULTS AND DISCUSSION

Response table

Table 3. is show the response tables for SR along with the input parameters.

Table 3. Response table for Surface roughness

STD	RUN	Pon (μs)	Poff (μs)	IP (A)	RPM	SR1 (μm)	SR2 (μm)	SR3 (μm)	**SR (μm)**
1	9	100	10	10.93	0.5	7.769	7.645	7.527	**7.647**
5	1	200	20	23.43	0.5	9.654	9.466	9.568	**9.563**
9	7	500	50	17.18	0.5	10.726	10.542	10.357	**10.542**
2	8	100	20	17.18	0.75	9.328	9.126	8.701	**9.052**
6	3	200	50	10.93	0.75	9.385	9.211	8.943	**9.180**
7	5	500	10	23.43	0.75	11.484	11.352	11.088	**11.308**
3	6	100	50	23.43	1	10.834	10.745	10.557	**10.712**
4	4	200	10	17.18	1	9.825	9.946	10.066	**9.946**
8	2	500	20	10.93	1	10.561	10.78	10.667	**10.669**

Analysis of variance

The term "analysis of variance," or "ANOVA," refers to a series of statistical models that have been utilised to examine mean differences and the corresponding estimate techniques (such "variation" within and between groups). Ronald Fisher, a statistician, invented the ANOVA. The law of total variance, which divides the observed variance of a given variable into components attributed to various causes of variation, is the foundation of ANOVA. An ANOVA expands the use of the t-test beyond two means by offering a statistical test to determine if two or more population means are equal. Stated differently, when comparing two or more means, the ANOVA is employed.

Elements of ANOVA Table

- SOURCE: The ANOVA table is divided into variation sources that represent all treatments/factors and the Error(residual) and total variation.
- DF: Degrees of freedom of variation source
- SS: Sum of Squares for the source
- MS: Mean Squares for source
- F: F-Statistic associated with source (assess significance)
- p: p-value associated with F-statistic (assess significance)

Analysis of variance for Surface roughness

Table 8.4 displays the factors analysis of variances factors A-Pon, B-Poff, C-IP, and D- RPM show significant effects on the outcome, as their individual F values are non-zero with corresponding p-values indicating significance. which is clearly indicates Pon, Poff, IP, RPM are the most influencing factors for surface roughness as well as Pon x Poff, Pon x IP, Poff x Ip are significant and other factors are not significant. These interactions Pon x rpm, Poff x rpm, Ip x rpm have no sum of squares and zero degree of freedom suggesting that they are not influencing surface roughness.
All four parameters are significant effects on the outcome and most effected parameter is Pon (44.10%) and IP (34.98%). As shown in table 8.4 effect in percentage on RPM and Poff time (15.019%) and (5.89%) respectively. Which indicates RPM is also most effected parameter. Interaction parameters like Pon x Poff (0.0000001015%), Pon x IP (0.00000024%), Poff x Ip (0.0000007331940%) in which Pon x Ip show significant effects on the outcome.

Table 4 ANOVA for Surface roughness

Source	**Sum of Squares**	**df**	**Mean Square**	**Percentage (%)**
Model	5.260000122	8	1.26	-
A-Pon	2.32	1	2.32	44.1064
B-Poff	0.31	1	0.31	5.89
C-IP	1.84	1	1.84	34.98
D-RPM	0.79	1	0.79	15.0190
AB	0.00000005556	1	0.00000005556	0.000000105627
AC	0.00000001282	1	0.00000001282	0.0000002434
AD	0.000	0	0	0
BC	0.00000003861	1	0.00000003861	0.0000007331940
BD	0.000	0	0	0
CD	0.000	0	0	0
A^2	0.00000001464	1	0.00000001464	0.000000278326
Pure Error	0.000	0		
Cor Total	5.260000122	8		100

Equation in Terms of Coded Factors:

$$SR = +10.03 + 0.85 * A + 0.26 * B + 0.68 * C + 0.60 * D + 1.739E - 004 * A * B + 8.696E - 005 * A * C - 1.957E - 004 * B * C - 1.944E - 004 * A^2 \quad (3)$$

Increase in Pon time from 100 μs to 500 μs leads to an increase the SR from 9.052 to 11.308 μm. Increases in Pon from 100 to 500 μs there is continuous increase in SR shown in Fig. 5.

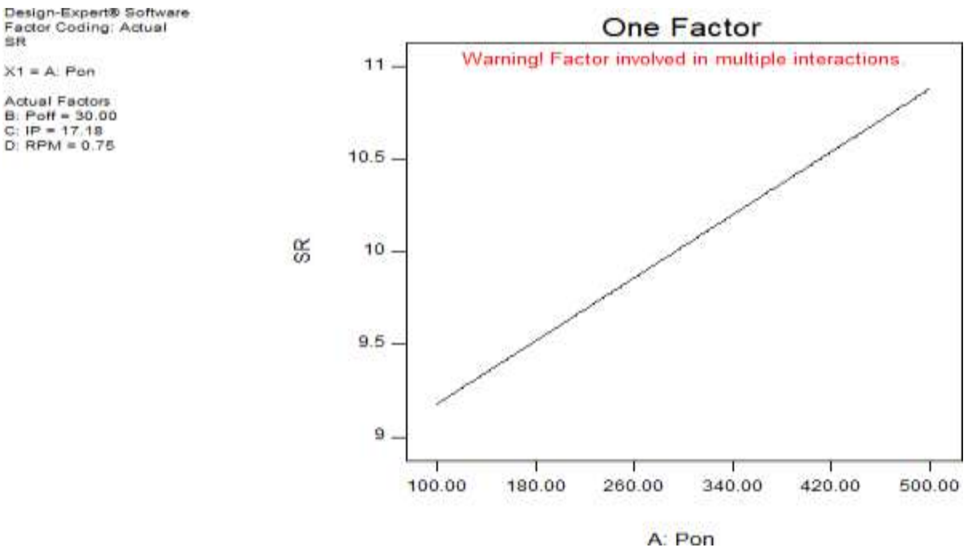

Fig. 5. Pon vs SR

Increase in Poff time from 10 µs to 50 µs leads to an increase the SR from 9.6-10.4 µm. As compared to Pon time surface roughness of Poff time not increases gradually as shown in Fig. 6.

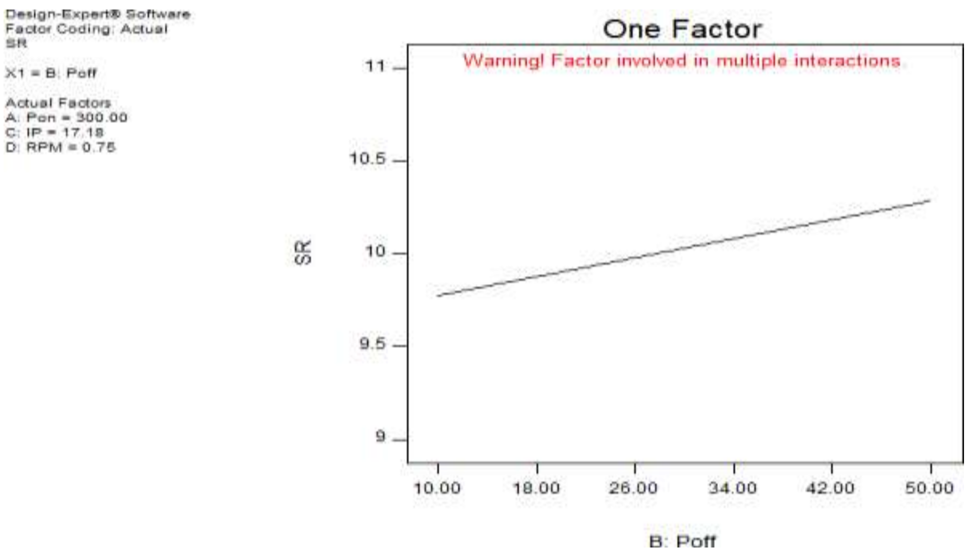

Fig. 6. Poff vs SR

Increase in Peak current from 10.93-23.43 ampere leads to increase the surface roughness from 9.052 to 10.712 µm.

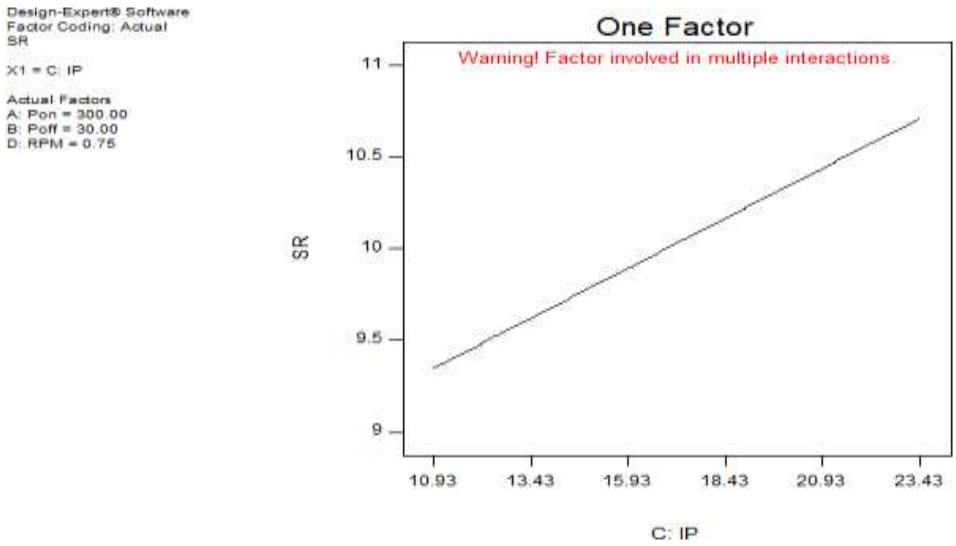

Fig.7. IP vs SR

Increase in RPM from 0.50-1 leads to increase the surface roughness from 9.4 to 10.6 µm.

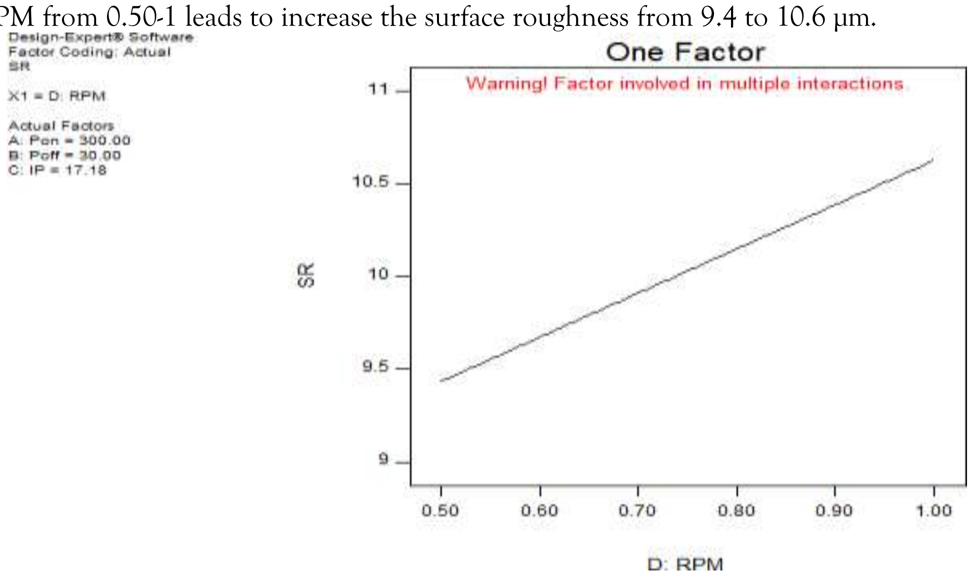

Fig.8. RPM vs SR

DIE-SINKER EDM TEST

The purpose of this test is to find difference between Die Sinker EDM machining outcomes to Die Sinker EDM machining with rotating workpiece attachment. In Die Sinker EDM test we took value as trivial value, mean value and maximum value from experiment conducted on rotating workpiece attachment to compare and find difference of Surface Roughness value. Table 5. show the result of SR value of Die Sinker EDM test.

Table 5. SR Value of Die Sinker EDM test experiment

PON (µs)	Poff (µs)	IP (A)	SR1	SR2	SR3	**SR (µm)**
100	10	10.93	7.196	7.276	7.365	**7.279**
500	50	17.18	9.626	9.743	9.518	**9.629**
100	50	23.43	10.395	10.298	10.159	**10.284**

COMPARISON OF THE TEST RESULTS

The comparison of the test results between the Die Sinker EDM and Die Sinker EDM with rotating workpiece attachment to evaluate difference outcomes value of MRR and Surface roughness. The difference margin (%) between Die Sinker EDM and Die Sinker EDM with rotating workpiece attachment calculated using equation below:

$$Difference\ margin\ (\%) = \frac{Die\ sinker\ EDM\ result\ -\ Die\ Sinker\ attachment\ result}{Die\ sinker\ EDM\ result} \quad (5)$$

Table 6. shows the difference between Die Sinker EDM test and Die Sinker attachment test for SR.

Table 6. Comparison test results for surface roughness

No.	Die Sinker test	Die Sinker with attachment test	Difference (%)
1	7.279	7.647	4.812
2	9.629	10.542	8.660
3	10.284	10.712	3.99

This result shows that Die Sinker EDM machining gives better SR for workpiece, but Die Sinker EDM machining with rotating workpiece attachment can perform turning operation on Die Sinker EDM to machine hard materials like H-13 die steel by which cylindrical part can be produced.

CONCLUSION

This experimental investigation successfully demonstrated the feasibility and advantages of using a rotating workpiece attachment with die-sinker EDM to perform Electrical Discharge Turning (EDT) on H13 die tool steel. Key findings include:

- The custom-designed rotating attachment effectively transformed the die-sinker EDM into a turning system capable of machining cylindrical geometries in hard materials.
- The application of Taguchi's method enabled efficient optimization of process parameters—pulse on time, pulse off time, peak current, and RPM—resulting in significantly enhanced machinability.
- Peak current emerged as the most influential parameter, contributing over 35% to surface roughness according to ANOVA analysis.
- The optimal combination of parameters yielded a minimum SR of 7.647 µm, demonstrating excellent machining performance.
- Mathematical models were developed for SR as functions of input parameters, providing predictive capabilities for future studies.

The study concludes that the integration of EDT with a rotating fixture is a promising solution for precision machining of cylindrical components in high-strength tool steels. Future work could focus on exploring additional optimization techniques like RSM or ANN and expanding the scope to include electrode wear rate and dimensional accuracy.

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