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Machinablity Evaluation and Parameter Optimization of PMEDM Process of OHNS-O2

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Abstract – Electrical discharge machining (EDM) is a non-conventional machining process used to manufacture intricate profiles, complex shapes, process hard materials that are extremely difficult to machine by conventional machining processes. This thermo electric machining technique is continuously emerging from a mere tool and dies making process to a micro scale machining applications. In recent years, researches have emphasized on process performance like material removal rate (MRR), tool wear rate (TWR), surface roughness (SR). Powder mixed electrical discharge machining (PMEDM) has emerged as one of the advanced techniques in the direction of the enhancement of the capabilities of EDM. The use of powder mixed electrical discharge machining helps overcome this drawback and increases the efficiency of the machining process. A suitable selection of tool can reduce the cost of machining. In the present experimental work, a study has been made to optimize the process parameters of powder mixed electrical discharge machining (PMEDM). This study focused on the machining of OHNS using graphite powder. The experiments were carried out as per L9 orthogonal array with DOE principle. Each experiment was performed under different conditions such as Ampere rating, pulse on time and pulse off time. The optimal factor for Surface Roughness was obtained, when Pulse on time is 8µs, Pulse Off time 6 µs and Amps-12 and Machining timing was Pulse on time is 10µs, Pulse Off time 8 µs and Amps-10 and MRR was obtained Pulse on time is 10µs, Pulse Off time 4 µs and Amps-14. Particularly surface roughness depending on the pulse on time.

Index Terms – PMEDM, surface roughness (Ra); material removal rate (MRR); current (I); voltage (V); pulse on(Ton).

1. INTRODUCTION

In PMEDM, the addition of suitable powder particles to the dielectric leads to superior surface finish combined with better machining rates compared to those for conventional EDM (without powder). A typical dielectric circulation system used in PMEDM. This kind of specially designed system is mounted in the working tank of an EDM setup. A stirrer or a micro-pump is provided to avoid the settling of powder particles at the bottom of dielectric reservoir. It also helps to prevent the stagnation of the powder particles on the workpiece surface. A set of permanent magnets is provided to separate the debris from the powder particles through the filtering system. This separation is possible only when the workpiece is magnetic in nature and the powder material is not. Current understanding of the PMEDM is presented here as the process is yet to be fully established. In PMEDM, fine powder particles are suspended in the dielectric oil. An electric field is created in the inter-electrode gap (IEG) when sufficient voltage (about 80 to 320V) is applied between them. Ionization of dielectric takes place as in the case of conventional EDM. Under the applied electric field, positive and negative charges accumulate at the top and bottom of the powder particles respectively (Workpiece positive and tool negative case). The capacitive effect of the electrodes leads to the formation of chains of powder particles. First discharge breakdown occurs where the electric field density is the highest (between 'a' and 'b' in Fig. 1.6). This breakdown may be between two powder particles or a powder particle and an electrode (Tool or workpiece). Redistribution of electric charges takes place after the first discharge and electric charges gather at point 'c' and 'd'. Further discharge happens between these powder particles and the other particles where electric field density is highest.

1.1 Applications of PMEDM

EDM has been used in manufacturing of aerospace components such as fuel system, engine, impeller and landing gear components where high temperature and high-stress conditions prevail. However, the safety and life of the components were questionable due to poor surface integrity. Application of PMEDM process in place of conventional EDM adequately addressed the problem arising due to poor surface integrity.

Some of the specific applications of PMEDM in automobile industry include the manufacturing of engine blocks, cylinder liners, piston heads and carburetors. With the increased precision, accuracy and the capability to be used under micro machining domain, PMEDM is also used to produce medical implants and surgical equipment. Some of the specific devices include surgical blades, dental instruments, orthopedic, spinal, ear, nose, and throat implants. Surface modification in the form of electro discharge coating is also realized by PMEDM technique. Therefore, light metallic alloys can be surface treated for wear resistance applications typically in automobile and aerospace industries.

2. LITERATURE REVIEW

The invention of powder-mixed EDM (PMEDM) process took place around late seventies and the first publication came in 1980. In PMEDM, the addition of suitable powder particles to the dielectric leads to a superior surface finish, and better machining rate compared to those for conventional EDM (without powder-mixed dielectric). A novel EDM two-tank system was first developed and marketed by Mitsubishi . One of the tanks consisted of standard dielectric oil and the second one contained powder-mixed dielectric. After completion of initial machining operation in the first tank, the tool head moved to the second tank to perform the finish machining. However, the extensive application of PMEDM in the industry requires a thorough understanding of its mechanism and the influence of different powder characteristics on performance measures. The emphasis in the current section is given on influence of powder characteristics and machining parameters on various responses. Some of the major application areas, variants of the basic PMEDM process and potential future direction of research are also discussed.

Vijaykumar .S[1] presented a comprehensive analytical modelling of PMEDM process of Beryllium copper alloy with experimental validation. An axis symmetric three-dimensional model has been developed and simulated using ANSYS 15.0 software for obtaining the temperature distribution on the surface of workpiece during a single discharge machining process. And the temperature profile was utilized to estimate the material removal rate. Experiments were performed to validate the numerical results. The average percentage error of 7.8% was obtained between numerical and experimental results. Thus, a good agreement between the experimental and numerical results shows that the software model can efficiently simulate and predict the real time results.

Chethan Roya[2] et.al were optimized the process parameters of powder mixed electrical discharge machining (PMEDM). Response surface methodology has been used to plan and analyze the experiments. Analysis were done to investigate the effects of the process parameters viz. pulse current (I), pulse on-time (Ton) and concentration of the Al powder in kerosene dielectric (C) and its effects on material removal rate (MRR), tool wear rate (TWR) and surface roughness (Ra). Process parameters were optimized for high MRR, low TWR and low Ra using desirability function approach of MINITAB software. Due to frequent short circuiting, addition of Al powder to the dielectric fluid reduces the MRR whereas TWR decreases for low peak current of 2 A with the increase in the concentration of powder. Addition of Al powder further improves the surface roughness to a value of 3.31 μm.

Ryota Toshimitsua [3] et.al observed very small surface roughness can be readily obtained by controlling the electrical discharge conditions, or by using metal powder mixed working fluids. In addition, it was reported that EDM ed surface using metal powder mixed fluids sometimes has high surface functions, such as high hardness, high corrosion resistance and so on. Therefore, the high functional EDM finished surface is well expected to be applied as a final metal mold surface. Through this study, formation of chromium containing layer on the EDMed surface was tried by using chromium powder mixed fluid.

Jagdeep Singh [4] et.al were developed a method that optimize the multi-performance characteristics (MPCs), i.e. micro-hardness (_-H) and surface roughness (SR) for the powder mixed electrical discharge machining (PMEDM) of Tungsten Carbide (WC-Co) alloy. Initially, authors successfully achieved the optimal parameter selection for PM-EDM of WC alloy by using grey relational analysis . Therefore, authors established the grey-fuzzy and grey-ANFIS approach to handle that uncertainty and discreteness present in the data, this study also shows the comparison between these methods. Theoretical prediction of grey-fuzzy approach shows that the proposed approaches can prove useful for optimizing MPCs. It is observed that experiment no. 24 withpulse-on time, 100 _s (A3); pulse-off, 50 _s (B2); current, 9˚A (C3) and powder, C (D1) factor combination provides best MPC'S amongst 27 experiments. This study shows that the use of graphite powder is found to be more suitable for improvement in surface characteristics of WC-Co. Results shows that pulse-on time is the dominating factor comparative to others factors which affect the study.

S. Tripathy[5] et.al were evaluated the effectiveness of optimizing multiple performance characteristics for PMEDM of H-11 die steel using copper electrode. The effect of process variables such as powder concentration (Cp), peak current (Ip), pulse on time (Ton), duty cycle (DC) and gap voltage (Vg) on response parameters such as Material Removal Rate (MRR), Tool Wear Rate (TWR), Electrode Wear Ratio (EWR) and Surface Roughness (SR) have been investigated using chromium powder mixed to the dielectric fluid. Analysis of variance (ANOVA) and F-test were performed to determine the significant parameters at a 95% confidence interval. Predicted results have been verified by confirmatory tests which show an improvement of 0.161689 and 0.2593 in the preference values using TOPSIS and GRA respectively. The recommended settings of process parameters was found to be Cp = 6 g/l, Ip =6Amp, Ton = 100 µs, DC = 90% and Vg = 50 V from TOPSIS and Cp = 6 g/l, Ip = 3Amp, Ton = 150 µs, DC = 70% and Vg = 30 V from GRA.

3. INDLUENCE OF POWDER

3.1 Influence of Powder Characteristics

Jahan et al. presented a comprehensive analytical modelling of PMEDM process. Fig. 3.1 shows the schematic representation of different forces acting on a powder particle present in the inter-electrode gap.

In Fl, Fc, Fd, Fe and 'f' are lift, columbic, drag, electric, friction (direction only) forces respectively. W denotes the self-weight of the particle. The derived formula for breakdown energy of powder-mixed dialectic is provided in Eq. (2.1).

$$E_{br}^2 = E_i^2 - 2\sigma T \frac{1}{\varepsilon_1}\left(\frac{\varepsilon_p + 2\varepsilon_1}{\varepsilon_p - \varepsilon_1}\right)\left[\frac{1}{r^3}\left(\ln\frac{N_f}{N_i}\right)\right] \quad (2.1)$$

where i E = Initial voltage for concentration i N , br E = Breakdown voltage for final concentration f N , □□= Boltzmann constant, T = Temperature, 1 □□= Permittivity of dielectric, p □□= Permittivity of powder particle and r = Radius of powder particle.

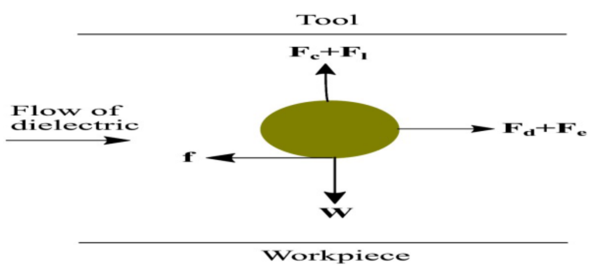


Fig. 3.1 Different forces acting on a powder particle

From Eq. (2.1) it is evident that br E depends on particle radius and change in concentration 'N', permittivity of the particles and dielectric. For no addition of powder particles or unchanged concentration (f N = i N), the value of br E = i E , which means no change in breakdown strength. The derived expression for spark gap during PMEDM is given in Eq. (2.2).

$$d_2 = \alpha d_1\left(1 + \frac{r + h_p}{g_d}\right) \quad (2.2)$$

where α = Field enhancement factor for small protrusion, d g = Distance between bottom of the particle and micro-peak, p h = Height of the protrusion. d1= Spark gap without powder suspension. From Eq. (2.2), it is clear that spark gap during PMEDM (d2) is higher thanthat of conventional EDM process (d1).Density, size, electrical and thermal conductivities are some of the critical characteristics of the powder particles that significantly affect PMEDM process. Increase in electrical conductivity of the dielectric, and resulting extension of discharge gap in PMEDM, as discussed earlier, enhance spark frequency and facilitate easy removal of debris from the machining zone.

4. HARDENING

4.1 METAL HARDENING

The use of this treatment will result in an improvement of the mechanical properties, as well as an increase in the level of hardness, producing a tougher, more durable item. Alloys are heated above the critical transformation temperature for the material, then cooled rapidly enough to cause the soft initial material to transform to a much harder, stronger structure. Alloys may be air cooled, or cooled by quenching in oil, water, or another liquid, depending upon the amount of alloying elements in the material. Hardened materials are usually tempered or stress relieved to improve their dimensional stability and toughness.Steel parts often require a heat treatment to obtain improved mechanical properties, such as increasing increase hardness or strength. The hardening process consists of heating the components above the critical (normalizing) temperature, holding at this temperature for one hour per inch of thickness cooling at a rate fast enough to allow the material to transform to a much harder, stronger structure, and then tempering. Steel is essentially an alloy of iron and carbon; other steel alloys have other metal elements in solution. Heating the material above the critical temperature causes carbon and the other elements to go into solid solution.

Quenching "freezes" the microstructure, inducing stresses. Parts are subsequently tempered to transform the microstructure, achieve the appropriate hardness and eliminate the stresses.

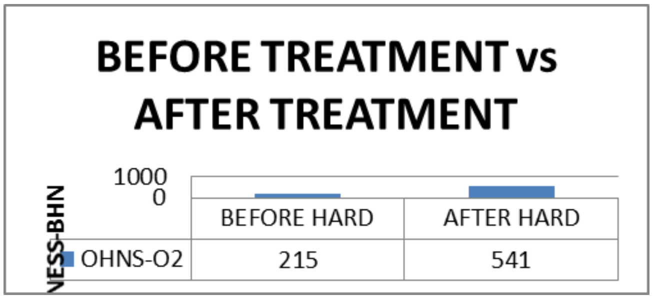
BEFORE HEAT TREATMENT–BHN

SL.NO	TRIAL-1	TRIAL-2	AVG
HRB	94.0	96.0	95
BHN	205	216	215

AFTER HEAT TREATMENT- HRC

SL.NO	TRIAL 1	TRIAL-2	AVG
HRC	53.9	54.2	54
BHN	535	547	541

4.2 HARDNESS COMPARISION BEFORE AND AFTER TREATMENT



After heat treatment hardness value enormously changed

5. MATERIALS AND METHODS

5.1. EXPERIMENTAL SETUP

Electrodes were machined to a cylindrical shape of 20 mm diameter and 25mm length. Cylindrical piece of 32 mm diameter and thickness 12 mm of Ohns-O2 has to be planned.

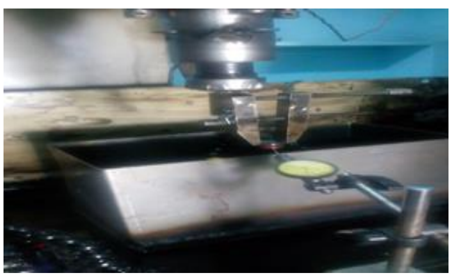


Figure 5.1: PMEDM Experimental Setup

5.2. ELECTRODE MATERIALS

Electrode material has a significant influence on important output parameters, such as, material removal rate, surface roughness and dimensional accuracy. Copper and brass are two commonly used EDM electrode materials in the industry because these materials have high melting temperature and excellent electrical and thermal conductivity. Copper can be easily machined to any shape, suffers less wear, has good thermal conductivity, and is economical. Brass is inexpensive and very easy to machine, but it has high electrode wear. It is often used for tubular electrodes in specialized small hole EDM drilling machines where high wear is acceptable. Electrodes made from special powders by using powder metallurgy technology have been used to modify EDM surfaces in recent years and excellent wear and corrosion resistance has been achieved under specific machining conditions

5.3 WORK MATERIAL DETAILS

Work material – OHNS-O2

Work material size–32mm dia 12mm thickness

5.3.1 CHEMICAL PROPERTIES

Table 5.1: Chemical properties

Sl.No	Element	Composition In Weight %I	
		Min	Max
1	Carbon, C	0.85	0.95
2	Manganese,Mn	1.8	2.2
3	Silicon, Si	0.15	0.40
4	Tungsten		0.1
5	Chromium,Cr	0.2	0.5
6	Vanadium,V	0.05	0.2

5.4.MACHINING PARAMETERS (GENERAL)

Table 5.2: Experimental details

PARAMETER	DESCRIPTION
Work piece	OHNS-O2
Tool	Copper
Powder	Graphite
Flushing pressure	0.5 kg/cm2
Polarity	+Ve
Gap voltage	45 V
Powder concentration	5g/L
Peak current	10,12,14 Amps
Pulse on time	8,10,12 µs
Pulse offTime	4, 6,8, µs
Machining depth	1.2 mm

5.5 DESIGN OF EXPERIMENT

Table 5.3: Process parameters and their levels

s.no	Pulse on time	Pulse off time	Gap current
1	8	4	10
2	10	6	12
3	12	8	14

5.6 AN ORTHOGONAL ARRAY L_9 FORMATION

Table 5.4: L9 Array formation

T.no	DESIG	T On	T Off	Amps
1	$A_1B_1C_1$	8	4	10
2	$A_1B_2C_2$	8	6	12
3	$A_1B_3C_3$	8	8	14
4	$A_2B_1C_2$	10	4	12
5	$A_2B_2C_3$	10	6	14
6	$A_2B_3C_1$	10	8	10
7	$A_3B_1C_3$	12	4	14
8	$A_3B_2C_1$	12	6	10
9	$A_3B_3C_2$	12	8	12

Based on the Taguchi design all hardened OHNS-O2 specimen were machined with 5 milligram graphite mixed with dielectric fluid.

5.7 EXPERIMENTAL DATA

Table: 5.5 Experimental Data of the PMEDM process

S	Desig	T On	T Off	Amps	RA µm	MT min	MRR gm/min
1	$A_1B_1C_1$	8	4	10	5.027	42	0.003
2	$A_1B_2C_2$	8	6	12	5.360	36	0.002
3	$A_1B_3C_3$	8	8	14	4.703	31	0.006
4	$A_2B_1C_2$	10	4	12	5.516	29	0.005
5	$A_2B_2C_3$	10	6	14	7.024	25	0.002
6	$A_2B_3C_1$	10	8	10	6.028	38	0.003
7	$A_3B_1C_3$	12	4	14	4.389	19	0.008
8	$A_3B_2C_1$	12	6	10	3.196	31	0.004
9	$A_3B_3C_2$	12	8	12	2.005	24	0.005

5.8 SURFACE ROUGHNESSES (ANALYSIS OF RESULT)

Table: 5.6 Surface Roughness and S/N Ratios

S	Design	T On	T Off	Amps	RA	SNRA1
1	$A_1B_1C_1$	8	4	10	5.027	-14.0262
2	$A_1B_2C_2$	8	6	12	5.360	-14.5833
3	$A_1B_3C_3$	8	8	14	4.703	-13.4475
4	$A_2B_1C_2$	10	4	12	5.516	-14.8325
5	$A_2B_2C_3$	10	6	14	7.024	-16.9317
6	$A_2B_3C_1$	10	8	10	6.028	-15.6035
7	$A_3B_1C_3$	12	4	14	4.389	-12.8473
8	$A_3B_2C_1$	12	6	10	3.196	-10.0921
9	$A_3B_3C_2$	12	8	12	2.005	-6.0423

5.8.1 ROUGHNESS RESPONSE FOR EACH LEVEL OF THE PROCESS PARAMETER

Table: 5.7 Response Table Ratios-Smaller is better

LEVEL	T ON	T OFF	AMPS
1	-14.019	-13.902	-13.241
2	-15.789	-13.869	-11.819
3	-9.661	-11.698	-14.409
DELTA	6.129	2.204	2.589
RANK	1	3	2

Table: 5.8 Analysis of Variance for Surface Roughness

Source	Df	SS	MS	F	P	contri
T On	2	13.6612	6.8306	13.73	0.068	76
T Off	2	1.4812	0.7406	1.49	0.402	8
Amps	2	1.7578	0.8789	1.77	0.361	10
Error	2	0.9946	0.4973			6
Total	8	17.8949				100

Regression Equation:RA = 4.805 + 0.225 TON_8 + 1.384 TON_10 - 1.609 TON_12 + 0.172 TOFF_4 + 0.388 TOFF_6- 0.560 TOFF_8 - 0.055 AMPS_10 - 0.512 AMPS_12 + 0.567 AMPS_14

5.9 MACHINING TIME (ANALYSIS OF RESULT)

Table: 5.9Machining Time And S/N Ratios Values for MT

S	Desig	T On	T Off	Amps	MT	SNRA1
1	$A_1B_1C_1$	8	4	10	42	-32.4650
2	$A_1B_2C_2$	8	6	12	36	-31.1261
3	$A_1B_3C_3$	8	8	14	31	-29.8272
4	$A_2B_1C_2$	10	4	12	29	-29.2480
5	$A_2B_2C_3$	10	6	14	25	-27.9588
6	$A_2B_3C_1$	10	8	10	38	-31.5957
7	$A_3B_1C_3$	12	4	14	19	-25.5751
8	$A_3B_2C_1$	12	6	10	31	-29.8272
9	$A_3B_3C_2$	12	8	12	24	-27.6042

5.9.2 MACHINING TIME FOR EACH LEVEL OF THE PROCESS PARAMETER

Table: 5.10 Response Table-MT-Smaller is better

LEVEL	T ON	T OFF	AMPS
1	-31.14	-29.10	-31.30
2	-29.60	-29.64	-29.33
3	-27.67	-29.68	-27.79
DELTA	3.47	0.58	3.51
RANK	2	3	1

Table :5.11 Analysis of Variance of MACHINING TIME

Source	DF	SS	MS	F	P	% of contr
T On	2	204.222	102.111	229.75	0.004	47
T Off	2	1.556	0.778	1.75	0.364	1
Amps	2	219.556	109.778	247.00	0.004	51
Error	2	0.889	0.444			1
Total	8	426.222				100

Regression Equation:MT = 30.556 + 5.778 T ON_8 + 0.111 T ON_10- 5.889 T ON_12 -0.556 T OFF_4 + 0.111 T OFF_6+ 0.444 T OFF_8+ 6.444 AMPS10 0.889 AMPS_12 - 5.556 AMPS_14

5.10 MRR (ANALYSIS OF RESULT)

Table : 5.12 S/N Ratios Values for The MRR

NO	Desig	T On	T Off	Amps	MRR [gm/min]	SNRA1
1	$A_1B_1C_1$	8	4	10	0.003	-50.4576
2	$A_1B_2C_2$	8	6	12	0.002	-53.9794
3	$A_1B_3C_3$	8	8	14	0.006	-44.4370
4	$A_2B_1C_2$	10	4	12	0.005	-46.0206
5	$A_2B_2C_3$	10	6	14	0.002	-53.9794
6	$A_2B_3C_1$	10	8	10	0.003	-50.4576
7	$A_3B_1C_3$	12	4	14	0.008	-41.9382
8	$A_3B_2C_1$	12	6	10	0.004	-47.9588
9	$A_3B_3C_2$	12	8	12	0.005	-46.0206

MRR FORMULA: Before weight-After weight/Time taken X Density

NO	B.W	A.W	NO	B.W	A.W
1	85.41	84.13	6	85.33	84.23
2	85.39	84.54	7	85.16	83.75
3	85.63	83.92	8	85.41	84.12
4	85.29	83.80	9	85.21	84.02
5	85.23	84.59	-	-	-

5.10.1 MRR FOR EACH LEVEL OF THE PROCESS PARAMETER

Table:5.13 Response Table for MRR-Larger is better

Level	T ON	T/OFF	AMPS
1	-49.62	-46.14	-49.62
2	-50.15	-51.97	-48.67
3	-45.31	-46.97	-46.78
Delta	4.85	5.83	2.84
Rank	2	1	3

Table: 5.14 Analysis of Variance-MRR

Source	Df	Seq SS	Adj MS	F	P	% Of Contri
T On	2	0.000010	0.000005	2.26	0.306	31
T/Off	2	0.000012	0.000006	2.74	0.268	37
Amps	2	0.000006	0.000003	1.47	0.404	20
Error	2	0.000004	0.000002			12
Total	8	0.000032				100

Regression Equation:MRR = 0.004222 - 0.000556 T ON_8- 0.000889 T ON_10+ 0.001444

T ON_12+ 0.001111 T OFF_4- 0.001556 T OFF_6

+ 0.000444 T OFF_8- 0.000889 AMPS_10- 0.000

222 AMPS_12+ 0.001111 AMPS_14

6. CONCLUSION AND RESULT

The aim of the research work was to investigate the machinability of OHNS-O2 through powder mixed EDM. Experimentally analyzed using three process parameters were varied viz. Pulse on time, Pulse off time and ampere rating constant with dielectric pressure and constant graphite powder mixed with fluid to study the influence on the responses MRR, Machining timing and Ra. Machining Timing &MRR were merge on the same parameter. Based on the experimental results the following conclusions are drawn:

6.1.1OPTIMAL CONTROL FACTOR

1. Surface Roughness-A1 (Pulse on time-8µs),B3(Pulse off time 8 µs)C2(Amps-12)

2. Machining Timing- A2 (Pulse on time -10) B3 (Pulse off time -8 µs)C1 (Amps-10)

3. Material Removal Rate- A2 (Pulse on time -10µs) B1 (Pulse off time -4 µs)C3(Amps-14)

Minimum Surface finish and machining timing were held at through lower level pulse on time and medium rating of amps.MRR were held at through lower level pulse off time and Maximum rating of amps.

6.1.2 PERCENTAGE CONTRIBUTION OF PROCESS PARAMETER

1. Surface Roughness- Pulse on time 76%

2. Machining Timing -Amps 51%

3. Material Removal – Pulse off time 37%

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