Techno-Economic Aspects in Micromachining of H11 Hot Die Steel Mould using EDM - A Case Study

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ABSTRACT
To achieve competitive edge in manufacturing in this era of stiff competition, most manufacturing companies are focusing on selection of shaping a component by considering various technical and economical factors like type of material, shape, process, process parameters and cost of processing. Companies are using Techno-Economic analysis to estimate optimal technology and economic processes to carry out their tasks in economical and efficient way. Product miniaturization has opened up a whole new vista of possibilities in the manufacturing industry. Various micromachining processes like CNC, EDM, LBM, and ECM are being used to produce micro grooves/holes; each process having its relative merits and demerits in terms of metal removal rate, wear rate, rejection, cost of process and wastage of material as stated by different researchers. The present work has been carried out to identify various Techno-Economic aspects in micromachining of H11 Hot Die Steel Mould using EDM in small scale industry. The experimental work has been carried out by using Taguchi Design L-18 Orthogonal Array and verified by ANOVA. The optimized EDM process parameters for MRR and ROC to cut micro grooves/holes have been worked out. It is estimated that with the induction of this micromachining process with optimized process parameters, the company has enhanced its productivity and profitability compared to previous processing by CNC machines.

Keywords
EDM, MRR, radial Over Cut, machining of H11 Hot Die Steel, mould and Die.

1. INTRODUCTION
Miniaturization is very promising for medical and biotechnology applications requiring micro-systems to interact with molecules, proteins, cells and tissues. For instance, with the miniature devices, cancer agents like PSA, CA can be detected at early stages and miniaturizing such devices will reduce the cost of cancer monitoring and save many lives. Miniature equipments like probes, stents and fibre optic cameras used in surgeries to avoid tissue damage during surgeries, implants etc. and their market is growing rapidly. With miniaturization, products with more functionality are achieved like a cell phone not only provides mobile communication, but also has internet, GPS, camera, audio/video player, video games etc. Digital data storage (hard-disc drives) gets smaller and store more data. Micromachining is capable of fabricating three dimensional micro features on a variety of engineering materials like ceramics, metals, composites, polymers etc. Egashira et al. **(2010)** carried out EDM process of submicron holes using two types of electrodes: tungsten electrodes (1μm or less) made by combining wire electro discharge grinding and ECM, along with silicon electrodes (< 0.15μm) originally intended as probes for scanning probe microscopes. Holes drilling was done using a relaxation-type pulse generator at open-circuit voltage of 20V or lesser with only machine's stray capacitance. Better holes of < 1μm diameter and > 1μm depth were drilled successfully using tungsten tools. **Iosub et al. (2010)** revealed influence of EDM parameters on MRR, TWR and surface quality of SiC/Al (aluminium matrix composite) reinforced with 7% SiC and 3.5% graphite. 27 brass tools of 3.97 mm diameter; with different Pulse-ON, Pulse-OFF and peak currents were used to machine the hybrid composite using mathematical model developed by full factorial design and regression analysis. Good surface quality of the composite was obtained easily by controlling EDM parameters. Biermann and Heilmann (2011**)** demonstrated that by downsizing of components and industrial relevance of bored holes with small diameters and high length-to-diameter ratios, combination of laser pre-drilling and single-lip deep hole drilling could shorten process chain in machining components having non-planar surfaces, and also could reduce tool wear in machining case-hardened materials. In this research, the combination of these two processes was realized and found out for first time. Garn et al. (2011) investigated vibration effect on micro-EDM. Micro-EDM boring was divided into 3 parts namely, start-up, major boring and work piece breakthrough of tool. Investigations revealed a delayed start-up of process on work surface for micro-EDM; but, this effect could be reduced by introducing vibration on work piece and its cause was analyzed by single discharge analysis which also provided as a means for investigating the effect of vibration frequency. Zhang et al. (2011) demonstrated for online fabrication of micro tool, a micromachining system based on electrochemical dissolution of material, which consisted of mechanical movement of equipment, ultra short pulse power supply, circulation system of electrolyte, and hall current sensor for detecting process status. In micro-ECM, micro tool and micro-structures of work could be sequentially machined by changing machining conditions. Applying tungsten tool with 8 μm diameter and ultra short voltage pulses, micro-cross with a 30 μm width groove, which had sharp edge, was obtained. Jiang et al. (2012) evacuated debris which were formed during the erosion process which limited achievable aspect ratio. To address the problem of debris accumulation, a pulse generator, which was capable of shutting off harmful pulses and to applying high discharge energy pulses, had been developed. A series of experiments were conducted; experimental results revealed improved small-hole drilling efficiency and increased aspect ratio. Karthikeyan et al. (2012) revealed behavior of micro Electric Discharge Milling as per shape, form and surface quality of channel; also rotation of tool, traverse were significant where it influenced flow of molten metal, flushing and redeposition of debris. Tool rotation effect not only disturbed plasma but also influenced the final shape and form of the channel. Using SEM of micro channel at different instants and conditions of machining, physical nature of process understood and results presented.

2. EXPERIMENTATIONS

Experimental work has been performed on Sparkonix EDM, Model S-35, in supervision of EDM operator, at M/s S.G Engineering Works, Chandigarh.

For experimental investigation in micro-EDM, the following Techniques/equipments are used:

S No Particulars (Techniques/equipments used)

1. Parametric optimization (Taguchi Method, ANOVA)
2. Experimental Investigation (EDM Equipment)
3. Work Material (H11 Hot Die steel)
4. Cylindrical Tool Electrode (Copper with 500µm diameter)

Spark Gap Voltage, Peak Current, Pulse-ON and Pulse-OFF are the parameters considered for analyzing the EDM performance criteria i.e. Metal Removal Rate and accuracy (minimum radial overcut) of micro hole.

Fig. 1: Sparkonix EDM equipment, Model S-35 used for Experimentations

Table 1: Specifications of Equipment

Machine Unit Particulars	Specifications
Work Table	400mm x 300mm
X Travel	250mm
Y Travel	150mm
Z Travel	300mm
Electrode Pipe Dia range	0.3mm to 3.0mm
Max. Job Height	150mm
Max. Drilling Depth	100mm
Maximum Work Piece Weight	400Kg
Maximum Electrode Weight	35Kg
Dielectric Capacity	260Litres

For micromachining of H-11 hot die steel by EDM, cylindrical shaped Copper tool electrode (Fig. 2) is used.

Fig. 2: Copper Tool Electrode

Table 2: Tool Electrode Specifications

Particulars	Specifications
Material Used	Copper
Electrical resistivity	0.0167 $\Omega mm^2/m$
Purity	99.8%
Melting point	1083°C
Density	8.9 kg/dm^3
Height	13.7mm
Diameter	500µm

Two response variables MRR and ROC (accuracy) are considered for present study. Each time material is being removed from work; there is generation of micro hole, due to thermal damage. MRR is found out with the help of hole volume which is calculated by using average hole diameters from SEMs. Stop watch is used for measuring the machining time. ROC is determined by difference between diameter of micro tool and micro hole.

MRR (mm^3/min) = $\pi/4 \times (D_{avg})^2 \times h$ / Machining Time (minutes)

ROC (µm) = D_{avg}- d_{avg} / 2;

Where, **h** = work piece height; $\mathbf{D_{avg}}$ = average dia. of machined hole and $\mathbf{d_{avg}}$= average dia. of micro tool.

Experiments on micromachining of H-11 hot die steel are conducted on EDM equipment (Sparkonix Model S-35) using copper tool electrode of 500µm diameter. The tool alignment is done with the help of dial indicator to avoid any error due to tool displacement during machining. Tip of indicator is touched at various points on cylindrical tool circumference, while tool is rotated which helps in aligning the tool vertically straight. The tool is kept perpendicular to work surface, for proper machining.

3. RESULTS AND DISCUSSION

Observations are made during conduction of 18 experiments on EDM according to L18 orthogonal array, with different set of input parameters. Machining time taken in minutes for each experiment is observed with a stop watch.

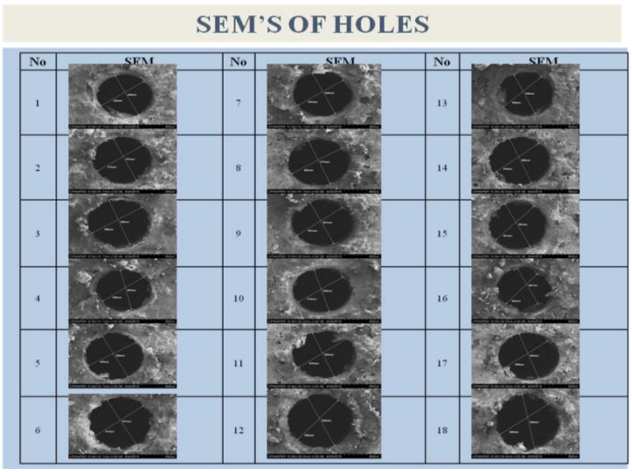

Fig. 3: SEM's of Holes made by EDM Micromachining of H11 Hot Die Steel

Higher MRR (2.14) and S/N Ratio (6.6083) are observed at 40V SGV, 2A Current, 6µs T_{ON} and 2µs T_{OFF}. It is prepared with Minitab with following rule to select Optimum Parameters from graph: S/N Ratio as well as Mean: Always **Highest** Point in all graphs.

Fig. 4 shows S/N ratio for MRR increases sharply for increase in T_{ON}. So for MRR, optimum values are SGV=40V, SC=2A, T_{ON}=6µs and T_{OFF}=2µs.

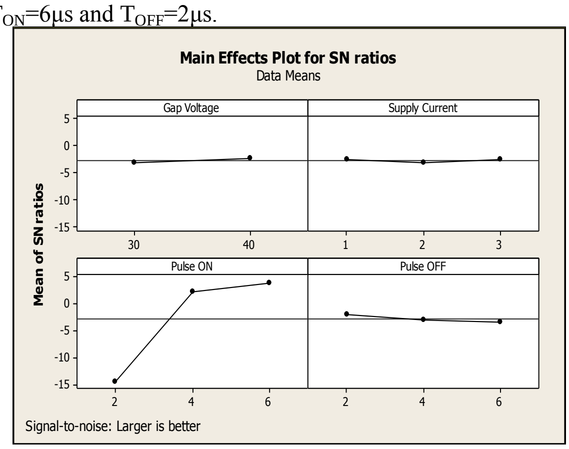

Fig. 4: Main Effect Plot for S/N Ratio (MRR)

Fig. 5 shows the main effect plot of mean; here MRR is almost constant from 1A to 3A SC. MRR increases from 2µs to 6µs T_{ON}, showing more time arc remains more material is removed. MRR also increases by increas0ing SGV and by decreasing T_{OFF}. These two graphs show that T_{ON} and T_{OFF} are the most predominant factors for MRR.

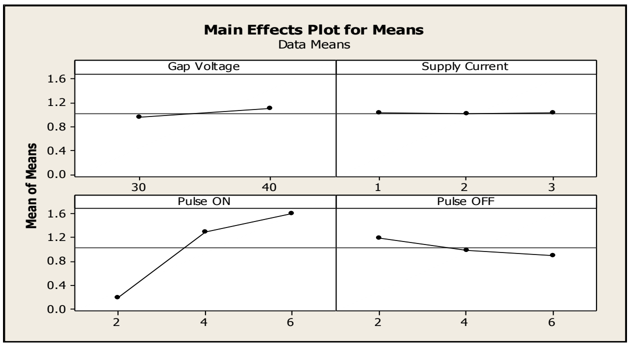

Fig. 5: Main Effect Plot for Mean (MRR)

Fig. 6 shows interaction plot graph for Means of different input parameters for MRR. This graph has been used to explain effects of two input parameters at a time on the MRR.

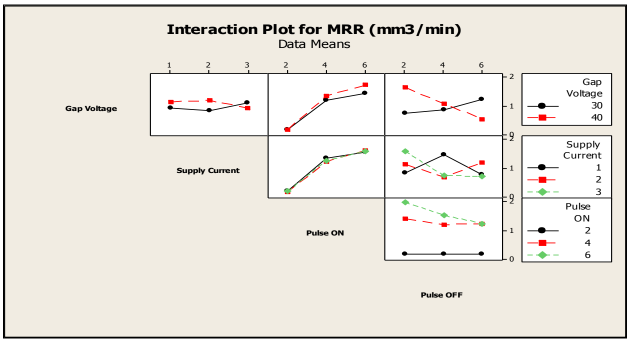

Fig. 6: Interaction Graph for MRR

Now results obtained for ROC are analyzed, after conduction of all 18 experiments, values of ROC, S/N Ratios and Means are calculated for different set of input parameters. Result analysis includes tables and graphs for S/N ratio and means, interaction graphs for different input parameters and ANOVA. Minimum ROC (2.75) and S/N Ratio (-8.7867) are observed at 30V Voltage, 2A Current, 2µs T_{ON} and 2µs T_{OFF}.

It was prepared with Minitab with following rule to select Optimum Parameters from graph: S/N Ratio: **Highest** Point in all graphs; Mean: **Lowest** point in all graphs. S/N ratio for ROC is plotted to select optimum parameter. It is seen this value decreases sharply for increase in T_{ON}. So optimum values are SGV=30V, SC=2A, T_{ON}=2µs and T_{OFF}=2µs.

Fig. 7 is S/N ratio for Radial overcut for different levels of input parameters. It is seen the value decreases with T_{ON}. S/N ratio decreases for 30V to 40V SGV. So, optimum values are SGV=30V, SC=2A, T_{ON}=2µs and T_{OFF}=2 µs.

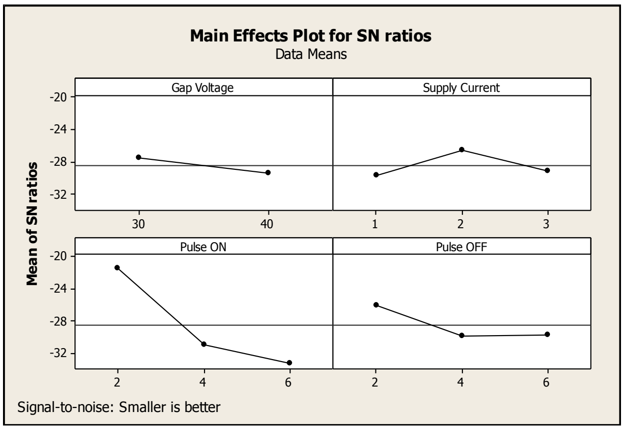

Fig. 7: Main Effect Plot for S/N Ratio (ROC)

Fig. 8 is main effect plot for mean. ROC decreases for 1A to 2A SC, and further increases for 2A to 3A. ROC decreases for 6µs to 2µs T_{ON} showing less time the arc remains less ROC produced leading to accuracy and productivity. ROC decreases by decreasing SGV and T_{OFF}. So from these graphs, it is seen T_{ON} & T_{OFF} are the most predominant factors.

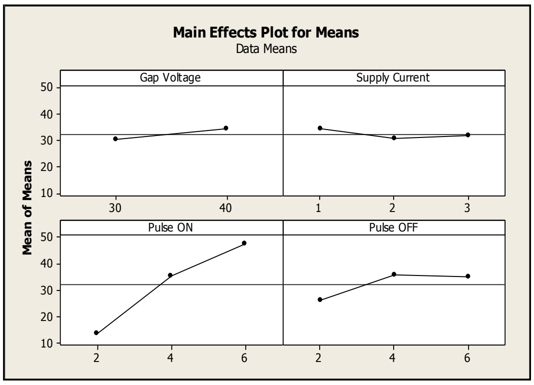

Fig. 8: Main Effect Plot for Mean (ROC)

Fig. 9 shows the interaction plot graph for Means of different input parameters for **ROC**. This graph explains effects of two input parameters at a time over ROC.

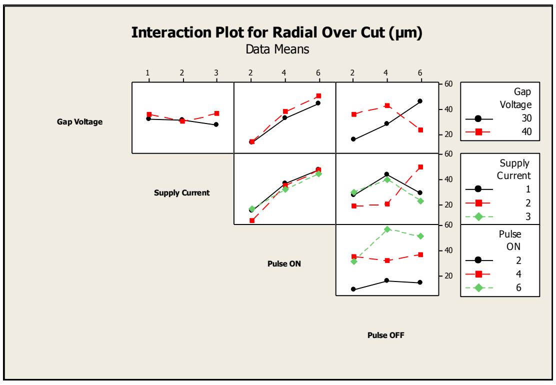

Fig. 9: Interaction Graph for ROC

4. CONCLUSIONS

Following conclusions have been drawn:

- MRR is increased with T_{ON} and SGV; also ROC increases with T_{ON} and SGV.
- Most dominant factors affecting MRR and ROC are T_{ON} and T_{OFF} as analyzed by Taguchi method.
- Optimum Micromachining conditions for MRR are $T_{ON=}$6 µs, T_{OFF}=2 µs, SC=3A and SGV=40 V.
- Optimum Micromachining conditions for ROC are T_{ON}=2 µs, T_{OFF}=2 µs, SC=2A and SGV=30 V.
- Total operating cost excluding initial set up cost for CNC is approx. Rs.18, 45,500/- and for EDM it is approx. Rs. 1,03,550; and there is saving of Rs.17, 41,950/- to the company;
- Also if we exclude other fixed costs like transformer cost, AC cost and CAD/CAM software cost, then also total operating cost excluding other fixed costs for CNC is approx. Rs.1, 45,500 and for EDM it is approx. Rs. 1, 03,550; and there is still saving of Rs. 41,950/- to the company; that means CNC is costs than EDM in any case.

Thus it is suggested to use micro EDM, for better machined circular micro hole as compared to the micro hole produced by CNC, leading to better economical conditions for industry with suggested optimized parameters.

5. REFERENCES

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