Enhancement of Material Removal Rate in EDM

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Abstract--- Electrical Discharge Machining (EDM) is one of the earliest non-traditional machining process. EDM process is based on thermoelectric energy between the workpiece and electrode. Material removal rate (MRR) is an important performance measure in EDM process as it is very slow then other traditional machining processes.

Since long many EDM research have been explored a number of ways to improve and optimize the MRR including some unique experimental concepts. Despite a range of different approaches , all the research work in this area shares the same objective of achieving more efficient material removal coupled with a reduction in tool wear and improved surface quality.

The paper reports research on EDM relating to improvement in MRR along with some insight into mechanism of material removal. In this research attention is focussed on the analysis of MRR by increasing the amount of heat content externally using some explosives like Carbon and Sulphur. DOE approach is adopted to justify the exact response of the Heat Input(Q) with two other parameters like Current(I_p) and Air-Pressure (P_a) as Input parameters. MRR is taken as a response parameter. The Experiment is done by L9 array and result are calculated and analysed to know the effect of parameters.

Keywords:
MRR Measurement by Applying DOE,Taguchi Method and ANOVA Analysis

I. NOMENCLATURE

DOE: Design of Experiments
ANOVA:Analysis of Variance
EDM: Electro Discharge Machining

II. INTRODUCTION

EDM is a non-traditional manufacturing process based on removing material from a part by means of a series of recurring electrical discharges (created by electric pulse generators at short intervals) between a tool called electrode and the part in the presence of a dielectric fluid. In EDM electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. EDM is mainly used to machine difficult to machine materials and high strength temperature resistant alloys.

EDM can be used to machine difficult geometries in small batches or even on job-shop basis. EDM performance are mainly dependent on eight main factors are polarity, open-circuit or no-load voltage, discharge current, pulse duration, electrode material, pulse interval, gap control and circulation rate. The first four of this are called planning parameters that are dependent on the type of machining operation and whether the cut is roughing or finishing operation. The last four are adjusted to give the best operating conditions for the machine used and the results required. The pulse interval, gap control and circulation rate are the operating parameters, which are automatically monitored and corrected in modern machines. Several researchers carried out various investigations for improving the process performance. Material Removal Rate (MRR) and Surface Roughness (SR) are most important response parameters in EDM.

III. WORKING PRINCIPAL OF ELECTRO DISCHARGE MACHINING(EDM)

The working principle of EDM is shown in Fig.01 . This technique has been developed in the late 1940s. The electrode moves toward the workpiece reducing the spark gap so that the applied voltage is high enough to ionize the dielectric fluid. Short duration discharges are generated in a liquid dielectric gap, which separates electrode and workpiece. The material is removed from tool and workpiece with the erosive effect of the electrical discharges. The dielectric fluid serves the purpose to concentrate the discharge energy into a channel of very small cross sectional areas. It also cools the two electrodes, and flushes away the products of machining from the gap. The electrical resistance of the dielectric influences the discharge energy and the time of spark initiation. Low resistance results in early discharge. If resistance is large, the capacitor will attain a higher charge value before initiation of discharge.

A servo system is employed which compares the gap voltage with a reference value and to ensure that the electrode moves at a proper rate to maintain the right spark gap, and also to retract the electrode if short-circuiting occurs. When the measured average gap voltage is higher than that of the servo reference voltage, preset by the operator, the feed speed increases. On the contrary, the feed speed decreases or the electrode is retracted when the average gap voltage is lower than the reference voltage, which is the case for smaller gap widths resulting in a smaller ignition delay. Thus short circuits caused by debris particles and humps of discharge a crater are avoided. Also quick changes in the working surface area, when tool shapes are complicated, does not result in hazardous machining. In some cases, the average ignition delay time is used in place of the average gap voltage to monitor the gap width. The RC circuit employed in EDM did not give good material removal rate, and higher material removal rate was possible only by sacrificing surface finish. A major portion of the time of machining was spent on charging the capacitors.

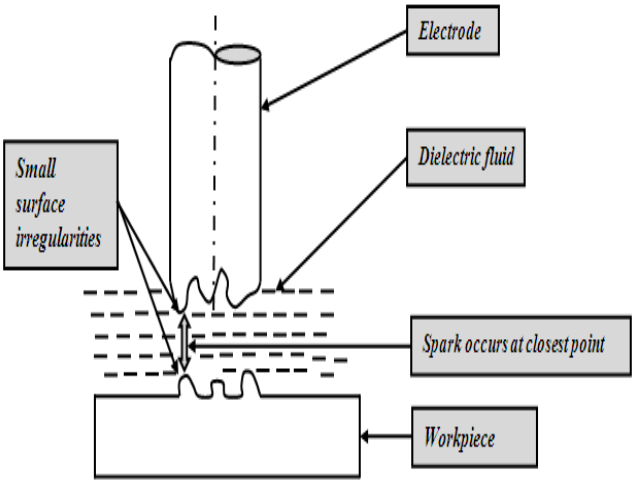


Fig. 01: Principle of Electro Discharge Machining

EDM has been replacing drilling, milling, grinding and other traditional machining operations and is now a well established machining option in many manufacturing industries throughout the world. And is capable of machining geometrically complex or hard material components, that are precise and difficult-to machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mold making industries, aerospace, aeronautics and nuclear industries. Electric Discharge Machining has also made its presence felt in the new fields such as sports, medical and surgical, instruments, optical, including automotive R&D.

IV. EDM PROCESS CAN BE CATEGORIZED INTO TWO GROUPS

A. EDM Process Parameters

B. EDM Performance Measures

A. EDM Process Parameters are as under

1) Material Removal rate:

Maximum of MRR is an important indicator of the efficiency and cost effectiveness of the EDM process, however increasing MRR is not always desirable for all applications since this may scarify the surface integrity of the workpiece. A rough surface finish is the outcome of fast removal rates.

Several researches have explained the material removal mechanism (MRM) in terms of the migration of material elements between the workpiece and electrode. Soni and Chakraverti showed an appreciable amount of elements diffusing from the electrode to the workpiece and vice versa. These elements are transported in solid, liquid or gaseous state and alloyed with the contacting surface by undergoing a solid, molten or gaseous-phase reaction.The types of eroded electrode and workpiece elements together with the disintegrated products of dielectric fluid significantly affect the MRM relating to the three phases of sparking, namely breakdown, discharge and erosion . In addition, reversing the polarity of sparking alters the material removal phenomenon with an appreciable amount of electrode material depositing on the workpiece surface.

2) Tool Wear Rate:

The tool wear process (TWP) is quite similar to the MRM as the tool and workpiece are considered as a set of electrodes in EDM. Mohri et al.claimed that tool wear is affected by the precipitation of carbon from the hydrocarbon dielectric onto the electrode surface during sparking. They also argued that the rapid wear on the electrode edge was due to the failure of carbon to precipitate at difficult-to-reach regions of the electrode.

From this simple understanding of TWP, some useful applications exploiting both the advantages and disadvantages of electrode wear have been developed. Marafona and Wykes introduced a wear inhibitor carbon layer on the electrode surface by adjusting the settings of the process parameters prior to normal EDM conditions. Although the thickness of the carbon inhibitor layer made a significant improvement on the TWR, it has little effect on the MRR. On the other hand, for applications requiring material accretion, a large pulse current is encouraged to increase electrode wear implanting electrode material onto the workpiece.

3) Surface Quality:

The electrical discharge machined (EDMed) surface is made up of three distinctive layers consisting of white layer/recast layer, heat affected zone (HAZ) and unaffected parent metal . Lim et al. provided a review on the metallurgy of EDMed surface, which is dependent on the solidification behaviour of molten metal after the discharge cessation and subsequent phase transformation. The thickness of the recast layer formed on the workpiece surface and the level of thermal damage suffered by the electrode can be determined by analysing the growth of the plasma channel during sparking. Since the white layer is the topmost layer exposed.

B. Process Parameters:

(1) Pulse-On Time

(2) Pulse Off Time

(3) Peak Current

(4) Arc Gap

(5)Duty Cycle

1) Pulse-On Time:

Pulse on time is the time Period during which machining takes place. Material Removal Rate (MRR) is directly proportional to amount of energy applied during pulse on Time. When pulse with small on time are used, Material removal by electron bombardment is predominant due to higher response rate of less massive electrons. However, when the longer pulses are used, energy sharing by positive ions is predominant and MRR decreases. When the electrode polarities are reversed, longer pulse are found to produce higher MRR.

2) Pulse-Off Time:

Pulse off time is the time during which re-ionization of dielectric takes place. More pulse off time means greater machine time. A non-zero pulse off time is a necessary requirement for EDM operation. Discharge between the electrodes leads to the ionization of the spark gap. Before another spark can take place, the medium must de-ionize and regain its dielectric strength. This takes some finite time and power must be switched off during this time. Too low

values of pulse off time may lead to short-circuits and arcing. A large value on another hand increases the overall machining time since no machining can take place during the off-time. The surface roughness is found to depend strongly on the spark frequency. When high frequency sparks are used lower values of surface roughness average (R_a) are observed, because the energy available in given amount of time is shared by large no. of sparks leading to shallower discharge craters. Each cycle has an on-time and off-time that is expressed in units of micro seconds.

3) Peak Current:

It is most important parameter in EDM process and it is amount of power used in discharge machining. Peak current is measured in units of amperage. During each pulse-on time, the current increases until it reaches a preset level, which is expressed as the peak current. An increase in current, result in increased in MRR as well as increased in surface roughness (SR) and tool wear rate (TWR). In die-sinking and wire EDM applications, the maximum amount of amperage is governed by the surface of cut.

4) Arc Gap:

It is the distance between the electrode and the work piece during the process of EDM. It may be called as the spark gap.

5) Duty Cyle:

It is the percentage of on-time relative to total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time plus off-time). The result is multiplied by 100 for the percentage of efficiency or the so called duty cycle.

V. METHODS OF IMPRIVING MRR

In this paper various methods are presented to enhance the Material Removal Rate (MRR) significantly.

A. By Electrode Design:

Several electrode geometries have also been tried to find improvement in material removal rate. Researchers have found that hollow tube electrodes and electrodes with eccentric drilling results in better material removal rate. This improvement takes place due to improved flushing condition arrangement for such designs. Research on 3D form tool with different geometries revealed that best tool shape for higher MRR and lower TWR is circular in shape, followed by triangular, rectangular, and square cross sections. Limitation of frame type and plate type tool is that these tools are applicable only for basic (spheres, conics and simple 2 D sweeps) and intermediate (complex 2D sweeps, ruled surfaces, and fillets) shapes.

B. By Controlling Process Parameters:

The material removal rate can be controlled and improved by controlling process parameters. The first parameter affecting the MRR is discharge voltage. This parameter is basically related to spark gap and dielectric strength. Before the current flows, the voltage increases causing ionization path in dielectric fluid. This voltage is called open gap voltage. Once current starts flowing, the voltage drops and stabilizes the working gap level. Thus higher voltage setting results in higher spark gap. Due to higher spark gap, flushing conditions improves resulting in higher MRR and rough surface. Electric field strength increases by increasing open circuit voltage resulting in higher MRR.

Longer pulse duration results in higher material removal resulting in broader and deeper crater formation. However, too much pulse duration is counter productive and once optimal value for a particular workpiece- electrode combination is exceeded, material removal rate starts decreasing. Pulse interval influences the speed and stability of the cut. In theory, the shorter interval results in faster machining operation. But if the interval is too short, the ejected workpiece material will not be swept away by the flow and the fluid will not be deionized resulting in unstable next spark.

C. By EDM Variations:

A hybrid machining process (HMP) involving high-speed machining (HSM) was proposed by researchers. An increase in material removal rate was reported but success of such machining was found to be dependent to a large extent on the availability and performance of a single cutting dielectric fluid. Xu et al. introduced a new kind of electrical discharge machining technology named tool electrode ultrasonic vibration assisted electrical discharge machining in gas medium. Experimental results showed that material removal rate could be increased greatly by introducing ultrasonic vibration. The comparison of MRR in traditional EDM in gas and ultrasonic vibration assisted gas medium EDM for machining cemented carbides workpiece was reported. MRR was found considerably higher for a particular discharge pulse-on time for ultrasonic vibration assisted machining.

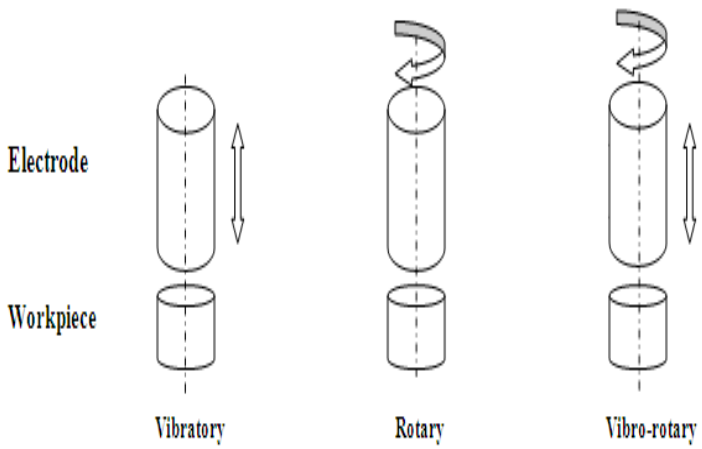


Fig:02: Vibro Rotary Electrode

D. ByPowder Mixed Dielectric Fluid:

Powder mixed electric discharge machining (PMEDM) is one of the new innovations for the enhancement of capabilities of electric discharge machining process. In this process, a suitable material in fine powder is properly mixed into the dielectric fluid. The added powder improves the breakdown characteristics of the dielectric fluid. The

insulating strength of the dielectric fluid decreases and as a result, the spark gap distance between the electrode and workpiece increases. Enlarged spark gap distance makes the flushing of debris uniform. This results in much stable process thereby improving material removal rate and surface finish. Fig. 03 show the principle of powder mixed EDM.

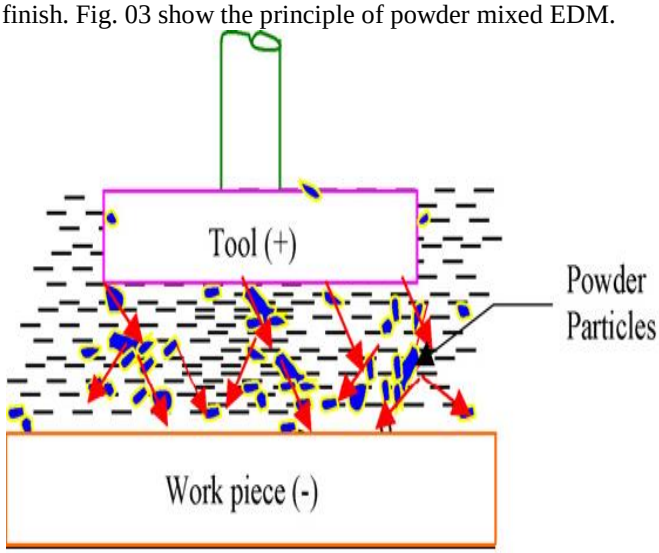


Fig:03: Principle of Powder-Mixed

VI. DESIGN OF EXPERIMENTS AND RESULTS:

In this Research paper new approach is adopted to improve the Material Removal rate(MRR). accrding to this approach various Explosives like carbon,Sulphure and mixture of carbon and Sulphur is used. Here it is taken as 50& by volume.

The basic purpose of using explosives is to increase the heat input during the process in EDM. In this approach explosives are fired when spark is generated during the process and it leads to the addition of heat content and improves the MRR significantly.so Heat Input is taken as a one of the parameter in conducting the experiment.and it is taken in different three values by changing the volume of explosives in drilled electrode as shown in table:03.

Fig:04: Drilled Electrode of Different Diameter

Below equatuion holds the generation of heat addition depending on the volume and its calorific value.

$$Q\ (KJ) = M_c CV_c + M_s CV_s$$

Where,

M_c= mass of Carbon (gm)

CV_c= CalorificValue of Carbon (KJ/Kg)

M_s= Mass of Sulphur (gm)

CV_s = Calorific value of Sulphur(KJ/Kg)

Fig:05: Weighing of Explosives on Weighing Machine

In this paper to conduct the research DOE is considered.

Three Parameters with Three Level is Choose to carry out the experiment. Experiment is done considering L9 Array.

Input Parameters:

(1) Input Current(I_p)

(2) Air Pressure(P_a)

(3) Heat Input(Q)

Response Parameter:

(1) MRR

Sr.No.	Machining Parameters	Values
01	Open Circuit Voltage	100 V
02	Tool Polarity	Staright
03	Electrode Lift Time	0.2 Sec.
04	Depth of Cut	0.4 mm
05	Type of Dielectric	Air
06	Workpiece material	Mild steel
07	Electrode Material	Copper

Table:01: Fixed Input Parametrs

VII. MEASUREMENT TECHNIQUES FOR MRR

MRR for each experimental run is to be calculated by weight difference of specimen before and after machining.

MRR= Initial Weight(W_i) – Final Weight(W_f)/ Machining Time(T)

Where,

W_i= Initial Weight of Specimen(gm)

W_f = Final Weight of Specimen(gm)

T= Machining Time (Min)

VIII. EXPERIMENTATION AND DATA COLLECTION:

Experiments are performed in three sets and values of MRR are taken for further analysis By weighing the difference in initial and final weight of the specimen.

Then analysis is done to determine which one of the parameteris most effective out of three by using MINITAB sofwares .

Parameters / No. of Exp.	Input Current Level 1	Air Pressure Level 2	Heat Input Level 3
01	28	3	21.64
02	28	4	27.27
03	28	5	45.44
04	31	3	27.27
05	31	4	45.44
06	31	5	21.64
07	43	3	45.44
08	43	4	21.64
09	43	5	27.27

Table:02 : L9 Orthogonal Array

Exp. No.	Initial weight (gm)	Final weight (gm)	Machining Time (Sec)	MRR (gm/min)	MRR (mm^3/min)
01	36.36	36.03	310	0.063	8.085
02	37.13	36.81	285	0.071	9.060
03	36.99	36.66	275	0.072	9.11
04	36.68	36.34	265	0.079	10.03
05	36.86	36.53	255	0.077	9.83
06	36.18	35.84	272	0.075	9.49
07	36.86	36.53	240	0.087	11.07
08	37.07	36.74	253	0.081	10.20
09	36.13	35.79	242	0.084	10.67

Table:03: Observation Table

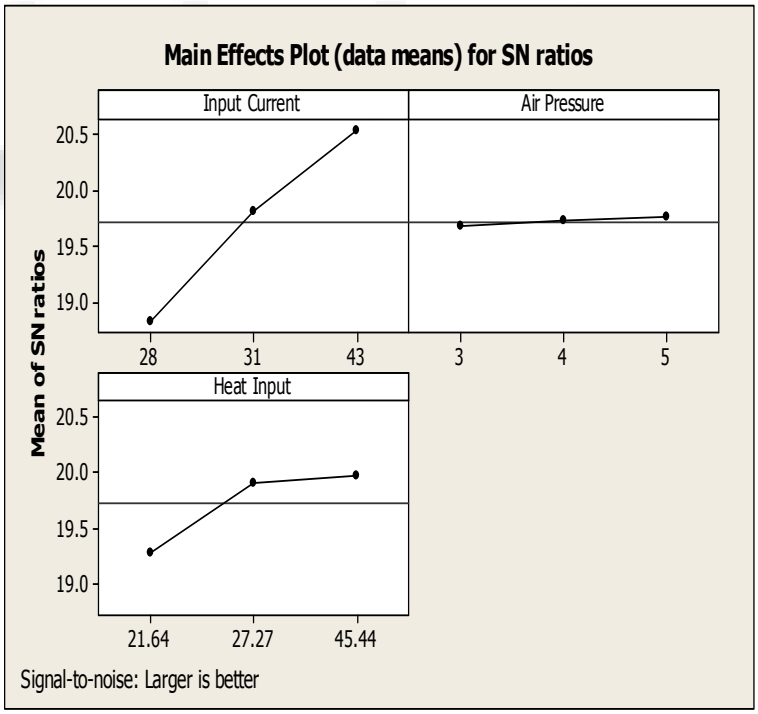
IX. TAGUCHI ANALYSIS FOR MRR:

From the observation Table 04, S/N ratio values of each run of MRR are used to calculate mean of S/N ratios at three levels of all factors and are given in Table 05. It gives us rank of all factors in this study considering the mean of S/N ratios for MRR at different levels.

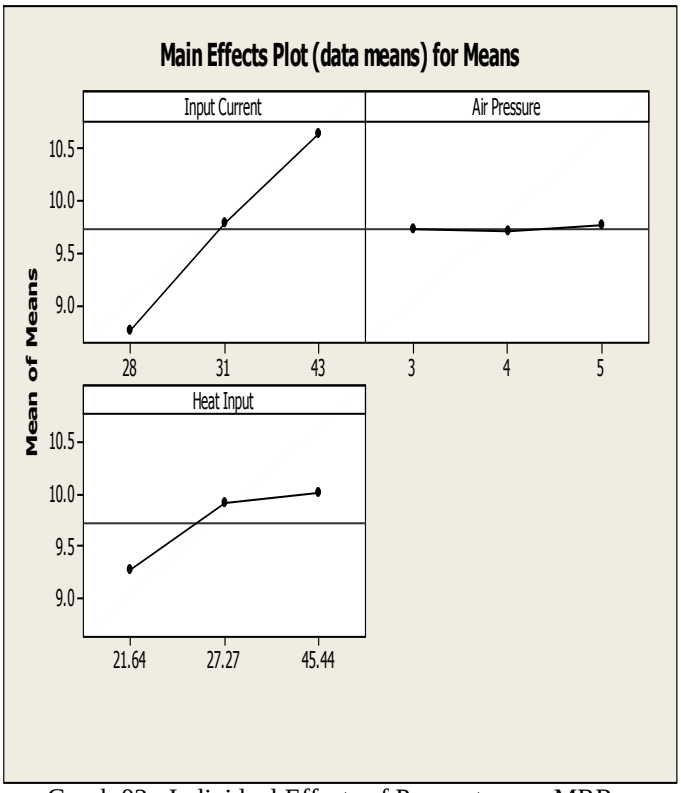
LEVELS ⇨ / FACTORS ⇩	LEVEL 1	LEVEL 2	LEVEL 3	RANK
Input current(I_P)	18	19.5	20.5	1
Air pressure(P_A)	19.7	19.8	19.9	3
Heat input(Q)	19.3	19.7	20	2

Table:04: Means of Signal to Noise Ratio for MRR

As MRR is Higher the Better type quality characteristic, therefore, greater S/N values are considered to be optimal. The graph:01 shows the individual effect of the control factors on MRR.



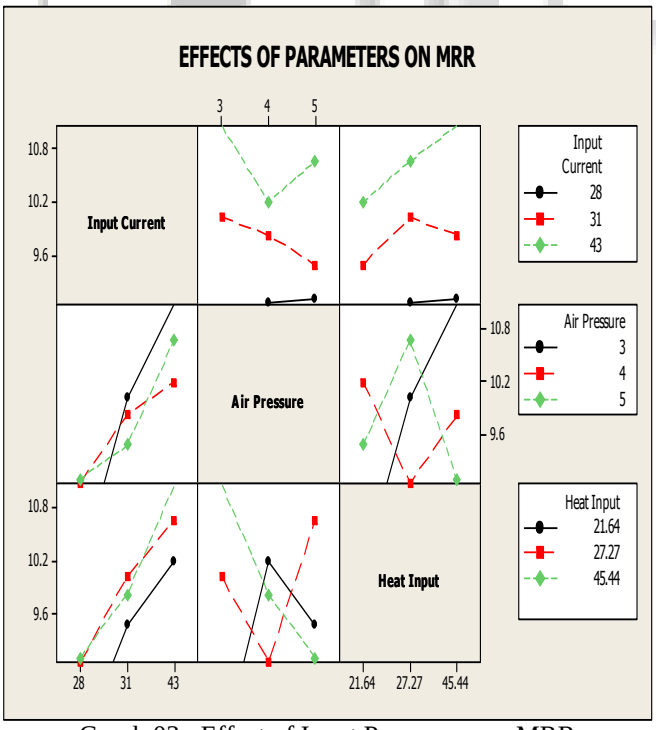
Graph:01: Effects of Various Factors on MRR



Graph:02: Individual Effects of Parameters on MRR

X. ANALYSIS FOR MRR BY ANOVA:

ANOVA determines which parameters significantly affect the MRR. It is observed that Input Current, Air Pressure, Heat Input are most significant in controlling MRR. From graph 03. optimum combination of factors for MRR is shown.



Graph:03: Effect of Input Parameyrs on MRR

CONCLUSIONS:

Within the range of selected parameters for the present work, following conclusions are drawn

- Input Current, Air pressure and Heat Input significantly affect the MRR
- Input current is the Main effective factor which affects the MRR significantly
- Heat Input comes second to affect on MRR improvement
- Air pressure ranks on third effective parameter which improves the MRR

Finally, it has been concluded that the addition of heat input with increase of current & air pressure improves the MRR significantly by this experiment.

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