

# Review of Research Work on Performance Measures in Die Sinking EDM

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## Abstract

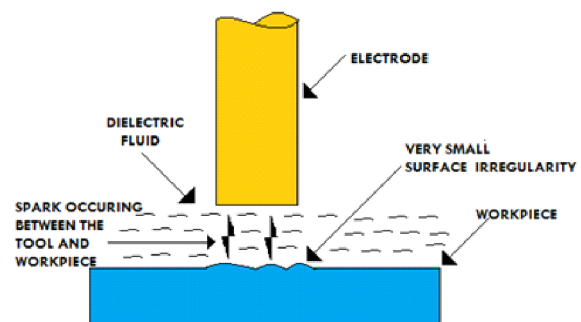
*Electro Discharge Machine (EDM) is one of the non-conventional machines utilized to cut hard material and complex contours that are difficult to achieve by other conventional techniques. The material is removed by spark generated between the tool and work gap, which melts and vaporizes the material and is then flushed along the flow of dielectric. It has been extensively used in various industries, for improved efficiency and productivity. The present research tends to review the diverse work executed by researchers on various performance measures of EDM. The utmost considered performance measures are material removal rate, tool wear rate, surface roughness, radial overcut, residual stress, white layer thickness and black layer that are reviewed in this paper. The paper also elaborates future trends for research on EDM.*

## 1. INTRODUCTION

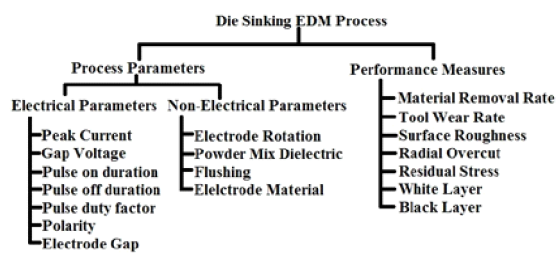
Electro-discharge Machining or generally known as EDM is a non-conventional approach of material removal process that is extensively used to produce dies, moulds, etc in automotive and aerospace industries. This machining process is applicable for very hard materials that are difficult to cut by other conventional machining processes. It is utilized to cut complex contours and delicate cavities which are impossible to attain by other methods. A thorough review process has been conducted in order to understand the importance of research work on performance measures held related to EDM.

The review presented here is based on the research work performed on various performance measures in die sinking EDM viz. material

removal rate (MRR), tool wear rate (TWR), surface roughness, radial overcut, residual stress, white layer formation on workpiece and black layer formation on tool. The review will present the current trend and the activities carried out in order to influence the performance measures of EDM. Based on the literature survey, the research gaps are identified and the objectives of research are found.



**Fig.1:** Spark occurrence at closest point of the work and the tool



**Fig.2:** Process parameters and performance measures of die sinking EDM

## 2. PERFORMANCE MEASURES

### 2.1 Material Removal Rate (MRR)

In the literature survey, peak current ( $I_p$ ) is discovered to be the crucial parameter while considering the material removal rate of the metals and the MRR increases with rise in the level of peak current [3, 10, 11, 18, 25, 30, 34, 36, 43, 45, 57, 49, 52, 60-62, 64, 65]. More or less all the researchers have concentrated on peak current and have come to an inference that it has major influence on material removal rate. The peak current governs the intensity of sparks striking the workpiece and guides to utmost removal of work material. A maximal value of peak current will favor for achieving maximum material removal rate. More or less all the researchers have found that material removal rate follows an escalating trend with peak current.

The subsequent considered and influencing parameter found to govern the material removal rate of the work material is pulse on duration or pulse on time ( $T_{on}$ ). It has also alike trend as perceived for peak current and the material removal rate increase with rise in the level of pulse on time [3, 10, 11, 18, 25, 31, 34, 37, 43, 52, 61, 62].

Considering pulse off time ( $T_{off}$ ), it shows fluctuating effect on material removal rate [3,36]. Some researchers have also claimed that pulse off time have great dominance on material removal rate and it increases with rise in the level of pulse off time [13,52].

Another parameter that has gained notice during the past literature study is the voltage or gap voltage. Almost all the researchers have undertook voltage among their study parameters. The researcher proclaimed that voltage is the least determine parameter for material removal rate [10,64,65]. A couple of researchers also deduced that when the value of voltage is increased, the extent of material removal rate in decreased [18,34,64,65].

In recent time, pulse duty factor ( $\tau$ ) has also been undertaken to determine EDM parameter considered by the researchers. It is perceived during the survey that elevated pulse duty factor yields greater material removal rate [24, 31, 37, 43, 49]. For preferable material removal rate, a elevated value of pulse duty factor is recommended by the researchers.

While undergoing the survey, it was found that the material removal rate is also affected by the electrode material used to machine the workpiece [11,12,14,15,52]. The researchers have claimed that using a copper electrode imparts better material removal rate in contrast to other materials [11,31]. Copper tungsten was also observed to have influence on material removal rate and yields more MRR [6]. Shape of the electrode used to machine the work also dominates the MRR. Round shaped electrode was found to be imparting higher MRR followed by square shaped electrode [51]. The MRR was also found to increase with higher tool rotation during EDM process [58].

The discharge energy has also influenced the enhancement of the material removal rate and the MRR rises with it [5,64]. More the discharge energy, more is the intensity of spark and hence better MRR is achieved.

Some of the authors have also considered fluid pressure of the dielectric medium to be a process

parameter and concluded that keeping a lower level of it will result in higher material removal rate [13, 31, 58]. The flushing leads to removal of debris from the gap and medium for spark transmission. If optimum pressure is not maintained then the debris of the work material removed from the surface may get intact to the work material leading to interruption of sparks. When tap water was chosen over other dielectric fluids, an enhanced material removal rate were achieved [17,31]. Concentration of powder also influences the material removal rate that leads to its enhancement [47].

## 2.2 Tool Wear Rate (TWR)

One more common performance measure for focus in present researches on EDM is the Tool wear rate. The excess tool wear is considered to be a flaw of EDM process that has to be optimized to acquire perfect shape and long lasting use of tool.

The electrical parameters have crucial dominance on the tool wear rate [12] and their increase or decrease changes the tool wear drastically. The discharge energy of the spark considerably influences the tool wear with increase in the discharge energy and the tool wear rate rises [4,29,41,53].

Peak current has more pronounced effect on tool wear rate and the tool wear rate rises with elevation in the level of peak current [4,7,29,34,41,48,62]. Peak current exerts influence on the intensity of spark and at higher value of peak current, the spark intensity hikes. This will lead to more positive ions striking the surface of the tool and hence the tool wear rate shoots up with peak current.

Moreover, pulse on time has a similar impact on tool wear rate as that of the peak current. Researchers have discovered that larger pulse on

time (Ton) results in higher tool wear rate and smaller pulse on time results in lower tool wear rate [7,18,27,29,34,62]. Few researchers have also concluded that tool wear rate reduces with rise in the level of pulse on time [41,48]. This might depend on the material of tool and work used in the study.

A mix result was interpreted for gap voltage with respect to tool wear rate. Though being a insignificant parameter for tool wear rate [18] but the tool wear rate increases with increase in the voltage [16]. Factors like pulse duty factor, voltage, pulse off time were discovered insignificant towards tool wear rate [16,18,29,34,62].

Tool rotation was also considered by few researchers and it was found that increase in tool rotation will enhance the tool wear rate as the debris from the gap is instantly removed [63]. Considering all these, even then tool rotation is an insignificant parameter for tool wear rate [4,53]. Many of the researches have focused on tool material in their study and have concluded that the tool material also dominate the tool wear rate [12,29,52,60]. Majority of the researchers have used copper, brass, copper-tungsten, copper-chromium, graphite tool in their study. Copper based tools are found to have low tool wear rate.

## 2.3 Surface Roughness

Better surface characteristics are majorly needed in present time industries. Research has been carried out to find the influence of various EDM parameters on the quality of surface produced post machining. Due to advancement of technology and demand, it is required to produce a finished product in one go of machining. Since EDM is a non-conventional precise machining process, hence it is required to produce a surface that does not require further finishing after machining on EDM. Several researches have

performed to find optimum machining parameters to obtain best surface quality. All most all the researches were focused on surface quality of the machined work surface.

During the survey, it was found that peak current is one of the most remarkable EDM parameter that considerably influenced the quality of surface produced by machining. Surface roughness directly depends upon peak current [8, 11, 16, 18, 25, 28, 46, 54-56, 69]. Majority of the researchers have suggested a lower level of peak current in order to acquire better surface finish [8, 11, 16, 18, 25, 30, 31, 46, 48, 50, 52, 56, 57, 59, 66]. This might be due to the intensity of spark at higher level of current which will cause larger craters and hence produces a rough surface on machine work material.

Moving on to the second most commanding parameter spotted in various literature i.e. pulse on time or pulse on duration (Ton). It causes a uniform increase in surface roughness [5, 8, 16, 48, 50]. Surface roughness depends upon the on duration of the pulse. Various literatures have suggested that a lower pulse on time should be set to procure lower surface roughness [8, 16, 18, 25, 36, 44, 46, 48-50, 52, 57, 59, 62]. This is similar to the trend followed by peak current.

Researchers have also quoted that the surface roughness directly depends upon the discharge energy [5,24-26,54,66]. It plays a vital role in the quality of surface produced while machining on EDM. Discharge energy of spark depends upon various parameters on the process.

Few literatures also quoted that the electrode material is the most significant non-electrical parameter for surface roughness [11,14]. Tools such as copper, brass, copper-tungsten, aluminium, graphite, etc were used in the researches to find the best suited electrode. Some of the reviews

concluded that copper gives worst surface finish as compared to other electrode while machining stainless steel [11,31] while for tools steel, copper produces best surface finish [14]. Titanium based alloy & aluminium electrode prove to be better than graphite and copper [50]. Brass was also found to produce better surface finish [11]. Few researches also quoted that use of copper-tungsten electrode will deliver minimum surface roughness [31,44].

Moving on the polarity of the tool, a mix review is obtained on it. Few literatures were found that were supporting the negative polarity of the tool for better surface finish [57] while others were in favor of positive polarity [30]. Polarity will influence the intensity of electrons striking the surface of the work material during machining on EDM.

Few researches have been performed with rotating tools and it was concluded by the researchers that surface finish in rotating tool is better than the traditional tool [16,58]. Pulse duty factor [31,49,54] and gap voltage [57,66] were observed to be the least influencing parameters for surface roughness. However a lower level of these parameters is suggested for better surface finish. Similarly tool shape is also observed to be insignificant for surface roughness [51], however the round shape produces smoother surface as compared to other shapes of the tool.

Researchers have also concluded that the powder mixed dielectric fluid also have major dominance on surface roughness and dielectric mixed with powder improves the surface finish as compared to the plain dielectric [39,57,68].

Surface roughness is directly influenced by the hardness of the work materials [2]. Pulse off time was also observed by various researchers and was

found to be insignificant for surface roughness as compared to other electrical parameters [8,46,52].

#### **2.4 Radial Overcut (ROC)**

Many researches consider electrical parameters as major influencing parameters for ROC. Peak current is one those parameter that have major dominance on overcut of the machined hole [34-36,53,65] and it is suggested to keep a low value of  $I_p$  for lower ROC [35,36]. Voltage was also found to have mix influences. Some researches suggests it to be significant for overcut and a lower value is set to achieve lower overcut [35,36] while the other recognize it as a least influencing parameter [65]. Higher the discharge energy, larger is the radial overcut [36, 53].

Pulse duty factor ( $\tau$ ) is also considered to have influence on radial overcut [34] while pulse on and off durations are insignificant for it [35]. With rotation speed of the electrode, the radial overcut is also increased [53].

Radial overcut also depends upon the tool material [6,14]. In a research, a Cu-W tool offers lower ROC than copper electrode [6] while in other a copper tool offer a lower ROC than ZrB<sub>2</sub>-40 wt % Cu [14]. So tool material is an important aspect for ROC.

#### **2.5 Residual Stress**

Residual stresses are the internal stresses developed in the machined surface due to sudden cooling and phase change of the machined workpiece. Studies have been performed to analyze the development of residual stress either compressive or tensile. Majority of the researches have shown that only the thermal aspect is responsible for development of residual stress.

The tensile residual stress results from the rapid cooling and phase change occurring during the machining process [23, 32, 42, 63, 64]. The

development of residual stresses results in crack formation on the machined surface [19, 23, 32, 38, 42, 63, 64].

The review provide a mix views over the depth of these stresses developed. At one instance it is concluded that the residual stress increases rapidly with respect to depth and reaches a maximum value within the heat affected zone [20] while other conclude that it is generated near the surface and then fall rapidly with depth [21].

Fewer studies have shown the influence of electrical parameters on development of residual stress. Peak current was analyzed and found to have influence on residual stress and its value is increased with  $I_p$  [61,64]. Similarly pulse on time also directly influences the development of residual stress on the machined surface [61].

#### **2.6 White Layer Thickness**

In the review process, it was established that peak current and voltage have major dominance on white layer thickness over other electrical parameters. Higher current [9, 30, 33, 49, 50, 59] and higher voltage [9, 30, 33, 40, 50] results in thicker white layer. White layer thickness also depends upon the discharge energy of the spark. Increase in discharge energy increases the recast layer thickness [5, 9, 26, 38, 48].

Pulse on time also has pronounced influence on white layer formation [5, 9, 26]. It should be kept lower to obtain minimum white layer thickness [30, 48, 49, 50, 59]. With increased in pulse duty factor ( $\tau$ ), the white layer thickness increases [49, 50]. White layer formed is non-homogenous and hence it experience cracks [22, 32].

Powder mixed dielectric reduces the formation of white layer [30, 33, 68]. A low powder concentration is suitable for lower white layer

thickness [30, 33]. The material removal rate (MRR) is also found retarded by formation of white layer on machined surface [15]. Heat source parameter also have influence on formed recast layer [5, 26].

Recast layer thickness varies with respect to the drilling depth [19]. Researchers have also shown that negative polarity is suitable for lower white layer thickness [30]. Recast layer thickness reduces by rotary electrode as compared to stationary electrode [40]. The electrode material also has influence on white layer thickness [50].

### 2.7 Black Layer

During the process of sparking, a black layer or carbon layer is deposited on the tool surface that influences the effectiveness of the material removal process of EDM.

This black color developed on tool surface is due to the migration of carbon present in dielectric [70,73,76]. It changes the thermal conductivity of the tool [1]. This migration of elements from work and dielectric on the surface of tool transpire at extremely high temperature and this black layer fends off the tool wear [71].

The black layer does not constitute carbon alone, rather it also accommodates iron, chromium, vanadium and molybdenum [70,73]. The main inherent of the layer is carbon turn loose from the dielectric and the carbon layer with 15?20-?m extent linking rapidly to the top of tool at the initial phase. Furthermore, the order of carbon layer formation on the grounds of the temperature distribution theory of the electrode surfaces are discussed [72].

It is brittle in nature and affects the thermal conductivity of the tool [73]. The extent of black layer is conditional on the discharge energy [74]. Considering pulse duty factor, higher value assists black layer formation. No black layer was noticed at a lower magnitude of pulse duty factor [75].

This layer impedes the material removal from the workpiece [77]. The transmutation of the dielectric fluid lays the foundation of a thin film of carbon on the tool surface [78].

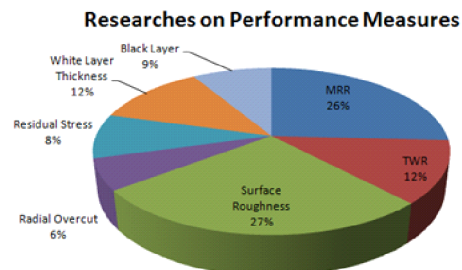


Fig.3: Researches on performance measures

## 3. DISCUSSION AND FUTURE TRENDS

After scrutinizing the diverse literature on performance measures of EDM, following conclusions have been derived:

Fig. 3 shows the percentage of researches conducted on various performance measures. It can be perceived that major work performed by researchers is on material removal rate and surface roughness. On the contrary, other considered performance measures are least studied.

- Few studies have been reported on radial overcut of machined hole. Major causes of radial overcut were not so effectively elaborated by the researchers.
- A very few literature were available on residual stress development in machined workpiece. However, no studies have been carried to express the influence of electrical parameters of EDM.
- There is no literature available on relation of residual stress with machined surface damage.
- Black layer formation on tool surface was studied by few researchers.
- Predominance of electrical parameters in observed in the literatures while the non-electrical parameters have not received much focus.

#### 4. SUMMARY

A review of the researches performed to assess the performance measure of EDM related to the electrical and non-electrical parameters have been presented through this paper. The review of past twenty years has been discussed. Each of the researchers have tried to enhance and optimize the performance measures of EDM with varying electrical and non-electrical parameters. Efforts were made by researchers to improve the performance of machining by combination of EDM parameters. Performance measures like MRR, TWR, surface roughness, radial overcut, residual stress, white layer thickness and black layer have been the cynosure of the researchers.

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