International Journal of Research in Engineering and Applied Sciences(IJREAS)
Available online at http://euroasiapub.org/journals.php
Vol. 7 Issue 5, May-2017, pp. 286~300
ISSN (O): 2249-3905, ISSN(P): 2349-6525 | Impact Factor: 7.196 | Thomson Reuters Researcher ID: L-5236-2015

EXPERIMENTALLY INVESTIGATION THE MATERIAL REMOVAL RATE IN POWDER MIXED ELECTRIC DISCHARGE MACHINING PROCESS ON HIGH SPEED STEEL

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ABSTRACT

Powder Mixed Electric Discharge Machining is capable of machining geometrically complex shapes and hard material components that are difficult to machine such as ceramics, carbides, heat treated tool steels, composites, super alloys, heat resistant steels etc. These hard material components are widely used in tool, die and mold making industries, automotive, aeronautics, nuclear industries and construction industries. For any manufacturing and fabrication process, particularly related to Electric Discharge Machining process the correct selection of machining parameters is one of the most important aspects to be considered.

This experimental work investigates the effect of dielectric fluid on the material removal rate. Further, the machining parameters like pulse on time, current and pulse off time are also investigated to improve the material removal rate. The experiment has been conducted on high speed steel work piece using square shaped copper electrode having cross-section 8mm×8mm. For this experimental work, kerosene oil and copper powder mixed kerosene oil are used as a dielectric medium. The layout of design of experiment is based on Taguchi L9 orthogonal array and the analysis of variance is used to analyze the results and to determine the most significance machining parameter.

Electric Discharge Machining

In this modern technological world, some challenges are encountered by manufacturing industries from difficult to machine material such as ceramics, composite, carbides and super alloys and stringent design requirements (intricate shape, high strength, high precision, good damping capacity, low thermal expansion, better surface quality etc) and cost of machining. The use of mechanical components having light weight and compact size is a trend in recent years, therefore modern industries has been an increase interest in advanced materials and non conventional machining processes. The use of non convectional energy resources like electrical, chemical, mechanical, ions and electrons is the new idea of manufacturing. The non convectional machining processes mean these processes do not use convectional tool for machining and use directly one form of energy. There is no physical contact between the tool and the work piece. For last few years advanced material with desired shape, size and required accuracy machine by the use of Electric Discharge Machining process. Modern Electric Discharge Machining process has been accepted worldwide as a standard machining process in manufacturing. During in late 1940s, Sir Joseph Priestley an English Scientist discovers the history of Electric Discharge Machining process. But it took a century for its practical use in manufacturing industries. In last sixty years, the popularity of Electric Discharge Machining process has grown by Leaps and Bound.

Electric Discharge Machining process is a non-convectional machining process in which electrically conductive material are machined through electrical sparks that occur between the work piece and tool in the presence of dielectric fluid. It employs the thermo electrical energy for machining extremely low machining ability materials, complicated shape of components regardless of hardness. Electric Discharge Machining process has its prime advantage of machining of any electrically conductive material irrespective their hardness by the application of thermal energy. In Electric Discharge Machining process there is no physical contact between tool and work piece. An inter electrode gap known as spark gap is maintained throughout the process by servo controlled mechanism. Electric Discharge Machining process is free from mechanical stresses, chatter and vibration problem during the machining as in case of conventional machining processes. Electric Discharge Machining process is a better machining option in the manufacturing industries.

Types of Electric Discharge Machining

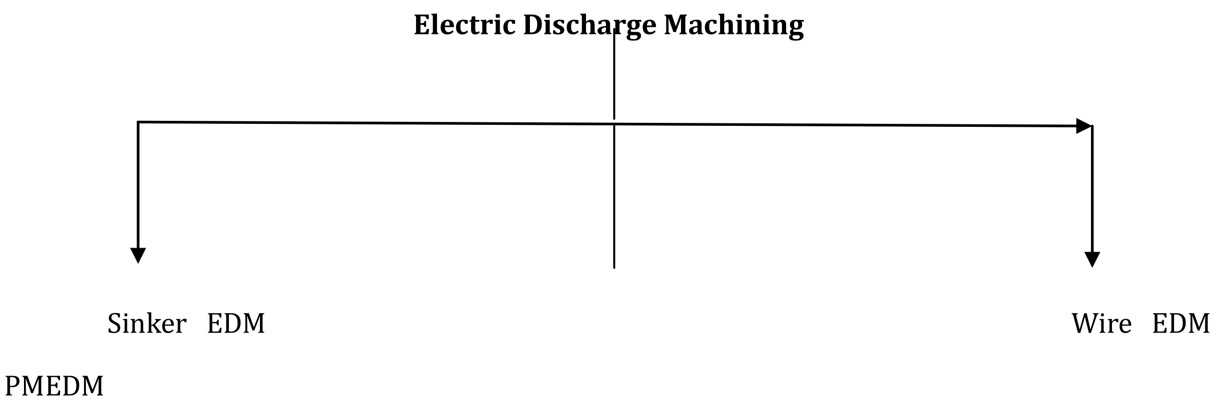

Fig: 1.1 Types of Electric Discharge Machining

Sinker EDM

Sinker EDM is generally used for geometries having intricate shape, where the EDM machine uses a machined tool to make the desired shape into work piece. Sinker EDM can drill a hole into the work piece without having a hole pre-drilled for the tool. Both the electrodes (tool and work piece) are separated by a small gap known as spark gap or arc gap. The spark gap generally varies between 0.01mm to 0.5mm and this spark gap is maintained by a servo control mechanism. Both the tool and work piece during machining process must be submerged in an electrically nonconductive dielectric medium. In Sinker EDM process, kerosene and EDM oil are often used as a dielectric medium because it provides less tool wear and better surface quality. Copper, brass, aluminium and graphite are commonly used as tool materials because of the high electrical conductivity and melting temperature and the ease of being fabricated into complicated shapes. In Sinker EDM process, the tool is manufactured into a desired shape and mounted on a ram that moves vertically up-down. The spark discharges can only occur under a particular spark gap size. A servo control mechanism is equipped to maintain the spark gap voltage and to power the ram moving vertically up or down to obtain a dischargeable spark gap and maintain continuous sparking.

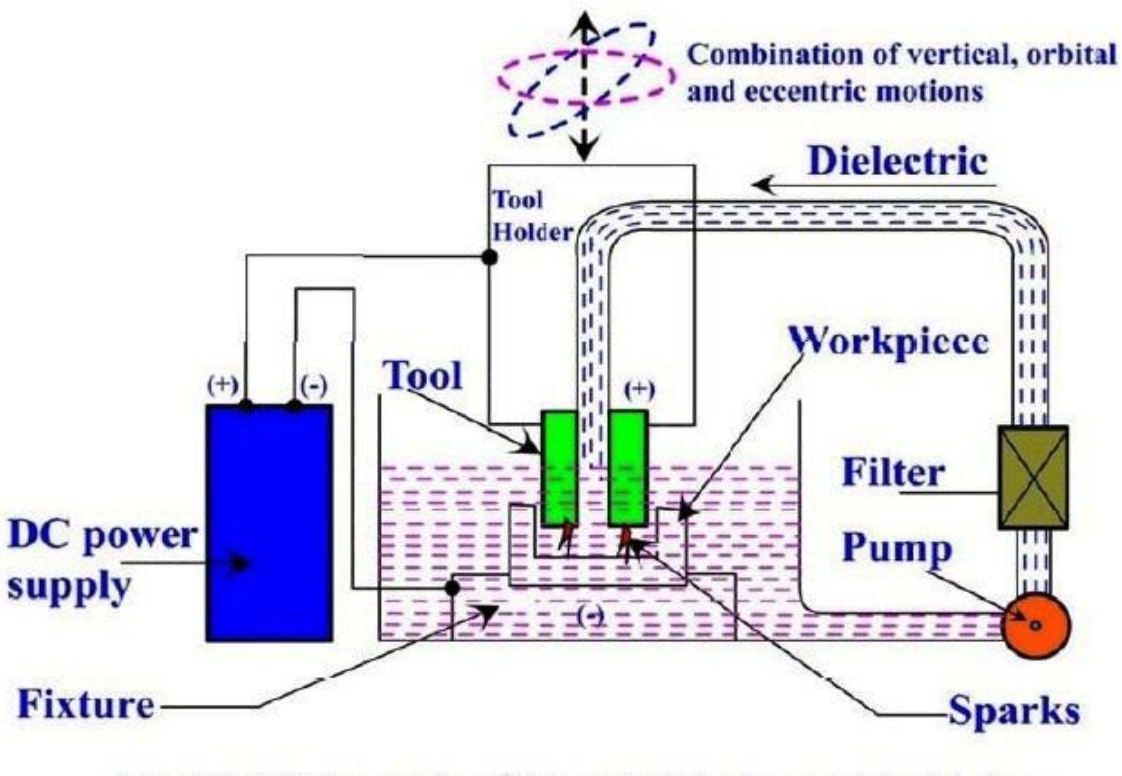

Fig: 1.2 Setup of Sinker EDM [4]

Wire EDM

Wire EDM is used for cut shapes through a part. In Wire EDM machining process, a predrilled hole must first be drilled in the work piece if a cutout needs to be created and then the wire can be fed through the hole to complete the machining process. In a Wire EDM process, the wire is held vertically by two wire guides located above and below the work piece. The wire is traveling longitudinally during machining process. The work piece is usually mounted on main table i.e. x-y table.

The trajectory of the relative movement between tool and work piece in the x-y coordinate system is controlled by a computer numerical control servo system according to a preprogrammed cutting passage. The computer numerical control servo system also controls the machining gap in real time, similar to the Sinker EDM process. De-ionized water is generally used as a dielectric fluid. The dielectric fluid is flushed from above and below the work piece into the machining area with two nozzles.

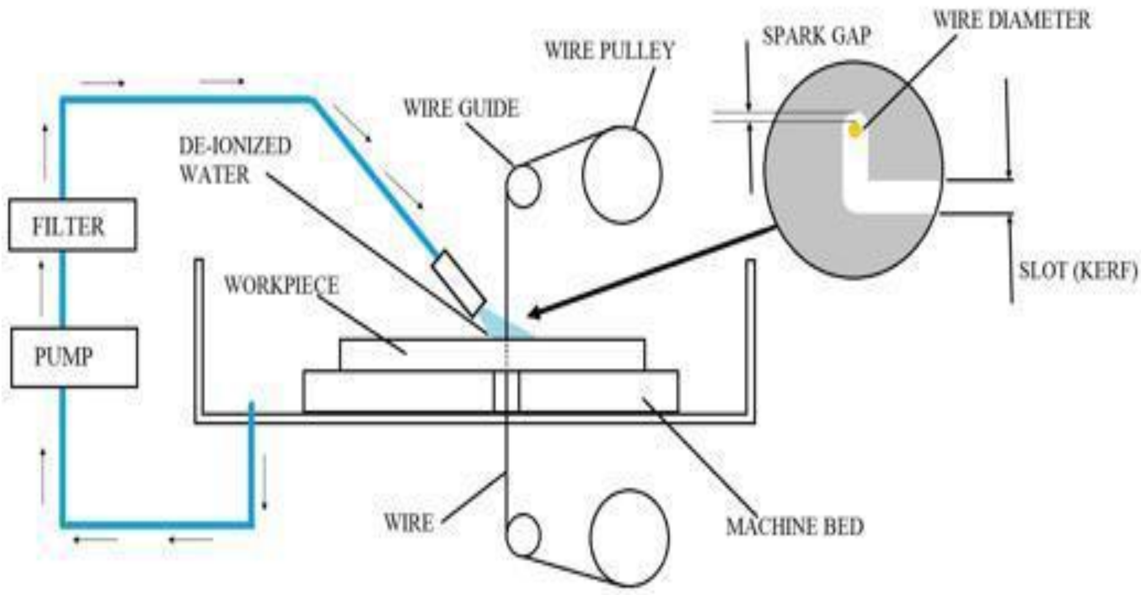

Fig: 1.3 Setup of Wire EDM [16]

PMEDM

The word PMEDM is stands for Powder mixed electric discharge machining. This method of machining is to be different to simple EDM. In PMEDM process metal powder is mixed with dielectric fluid for achieving good machining characteristics and better surface quality. Mainly copper, aluminium, magnesium, titanium, tungsten and graphite powder are used for the machining in PMEDM process.

Principle of PMEDM

The PMEDM process is based on the conversion of the electrical energy into heat energy by producing a series of continuous spark between the tool and work piece. Both the tool and work piece are electrical conductive and submerged in dielectric fluid separated by a small gap. In PMEDM process, the metal in powder form is mixed into the dielectric fluid. When a voltage is applied to the tool and work piece, an electric field is generated. The spark gap is filled up with additive particles of metal powder, and the distance between the tool and work piece increases from 30 μm to 50 μm to many times larger. The powder particles get energized and move in a zigzag way between the machining areas. Under the sparking area, the particles come close to each other and get together in clusters. After this the powder particles arrange themselves in the form of chains at different places under the machining area. This chain formation helps in bridging the gap between the tool and the work piece. Due to this bridging effect, the spark gap voltage and insulating strength of the dielectric fluid becomes less and an easy short circuit takes place between the tool and electrode, which causes erosion of material in the spark gap.

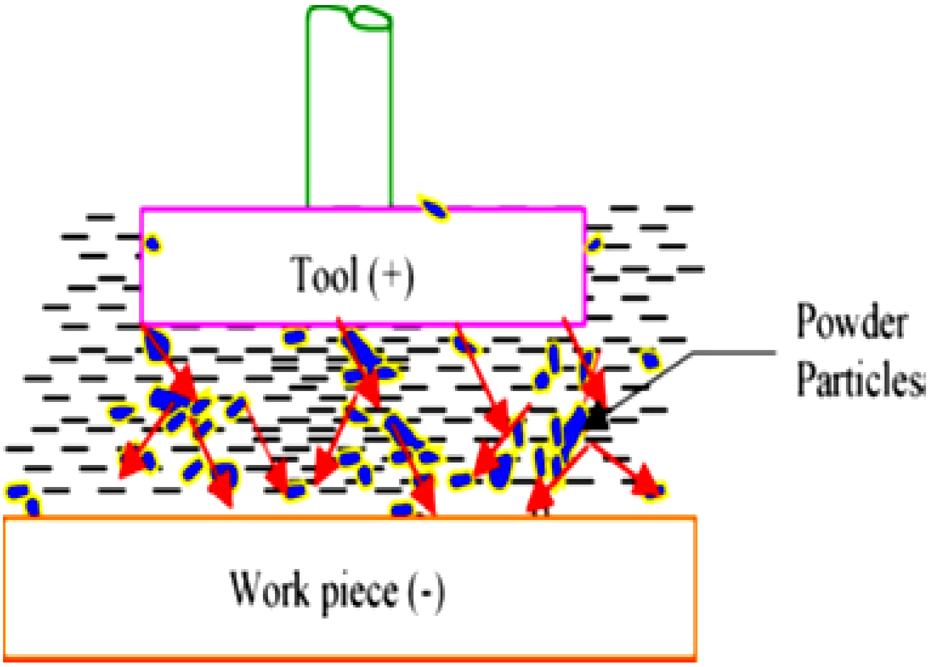

Fig: 1.4 Principle of PMEDM [3]

In PMEDM, the erosion process due to a single spark is generally passes through following five phases:

1. Pre-Breakdown Phase
2. Breakdown Phase
3. Discharge Phase
4. End Discharge Phase
5. Post Discharge Phase

1. Pre-Breakdown Phase: In this phase, the tool move close to the work piece and a small spark gap is maintained with the help of servo mechanism system. A high potential difference is applied between the tool and work piece and move towards the next phase (breakdown phase).

2. Breakdown Phase: The breakdown of dielectric medium is initiated by applying the voltage which crosses the boundary limit of strength of the dielectric medium used in the machining process. The breakdown point is normally present between the nearest surface of tool and work piece. Raise in intensity of current is occurred during the breakdown phase. A plasma channel is formed between the tool and work piece by the ionization of the dielectric medium, which further leads to discharge phase.

3. Discharge Phase: In discharge phase, incessantly attack of ions and electrons on the electrode is done by maintaining the flow of current at constant level which causes to a strong heating of work piece surface under sparking zone. By this action temperature is raised at a range of 8000 ºC to 12000 ºC, this begins to start a small molten metal pool at the surface of work piece. The radius of molten metal pool is increased with time as the plasma channel gets expend. The spark gap is an important parameter throughout the discharge phase.

4. End Discharge Phase: In this phase, cut-off of voltage is occurred therefore under the surrounding pressure in-force by the dielectric plasma channel get collapse.

5. Post Discharge Phase: In this phase, the plasma channel is ended and small metal is removed from the surface of work piece. Due to the cooling and collapsing of plasma channel, a thin layer known as white layer is deposited on the surface from charter on the surface of work piece

Machining Parameters of Sinker EDM

Machining parameters are variables within the process which affects the performance characteristics. If we want to an efficient machine performance we should have to identify the important machining parameters. These are generally controllable machining input variables that find the conditions in which machining operation is carried out. The various machining parameters of EDM are:

a. Pulse on Time
b. Pulse off Time
c. Duty Cycle

d. Discharge Current
e. Voltage
f. Spark Gap
g. Polarity
h. Dielectric Fluid
i. Flushing Pressure

a. **Pulse on Time (T_{ON}):** It is the time duration in microseconds under which actual machining is to be taken placed. It is the duration of time during which the current is allowed to flow through the circuit. In an Electric Discharge Machining process, the material removal is directly proportional to applied energy during the pulse on time, so longer is the pulse duration, crater produced by the current is wider and deeper. Both the discharge current and the ignition length are depends on gap size. With the discharge current, the amount of heat energy generated during single discharge is set by the pulse on time. When discharges with small pulse on times are used, the removal of material from the work piece surface is less or vice versa. Whereas the surface finish is inversely proportional to the pulse on time i.e. as the pulse on time increases, the surface finish decreases or vice versa.

b. **Pulse off Time (T_{OFF}):** It is the time duration in microseconds between the two consecutive sparks. The pulse off time allows solidifying the molten metal and washing out this solidified metal from the machining area by using accurate flushing method. The material removal rate is inversely proportional to the pulse off time i.e. as the pulse off time increases, the material removal rate decreases. On the other hand, the surface quality increases with increase in pulse off time.

c. **Duty Cycle (τ):** It is defined as the ratio of pulse on time to the total cycle time. It is measured in percentage. With higher percentage of duty cycle, the machine gives higher efficiency, if current is applied for the long duration of the pulse on time. The material removal rate is directly proportional to the duty factor. The mathematical expression for duty cycle are as:

$$\tau = \frac{\text{Ton}}{\text{Ton} + \text{Toff}} * 100 \quad \text{.....................} \ (1.1)$$

Where,

τ = Duty Cycle

T_{ON} = Pulse on time

T_{OFF} = Pulse off Time

d. **Discharge Current (I)**: Discharge current is the pre-set value of the current. It is the amount of electrical energy in ampere is supplied per cycle. In an electrical discharge the discharge current is directly related to the power intensity. This parameter determines the consumption of power during machining process, so it is an important machining parameter to be considered while machining. As the intensity of current of current is increase, the material removal rate also increases.

e. **Voltage (V):** It is the potential difference applied across the circuit. The electrical discharge influences by the spark energy is specified by the open circuit voltage. It is measured in volt. De-ionization of dielectric medium depends upon the strength of dielectric fluid used and the spark gap set voltage between tool and work piece.

f. **Spark Gap:** The spark gap also known as arc gap or inter electrode gap. It is the distance measured in mm between the tool and work piece. During an Electric Discharge Machining process, for the proper flushing and stability of spark it is the most important to set a constant spark gap. A servo controlled mechanism is used to maintain a constant spark gap. The value of spark gap generally varies from 0.01 mm to 0.5 mm.

g. **Polarity:** The potential of both the electrodes is specified through the polarity. It is either positive or negative for tool/work piece depends on application. In general the metal like titanium and carbide are cut with negative polarity of electrode.

h. **Dielectric Fluid:** In an Electric Discharge Machining process dielectric fluid is used as an electric insulator. Its function is to concentrate the electrical discharges to a narrow region, cooling the tool and work piece and flush away the debris from the machining area. Generally EDM oil, kerosene oil, de-ionized water, paraffin oil and transformer oil are used a dielectric fluid.

i. **Flushing Pressure (F_P):** In an Electric Discharge Machining process, for the supply of clean and filtered dielectric fluid into machining area, the flushing taken as an important consideration. If flushing is insufficient, it may cause to uncontrolled arcing and may create unwanted cavities which can also damage the work piece. In an Electric Discharge Machining process, generally pressure flushing, suction flushing and injection flushing are used to introduce the dielectric fluid through the spark gap.

Response Parameters

The response parameters are also known as performance parameters or output characteristics of machining process. In an Electric Discharge Machining process, the various response parameters are as:

a. Material Removal Rate
b. Tool Wear Rate
c. Heat Affected Zone
d. Over Cut
e. Surface Roughness

a. **Material Removal Rate (MRR):** It is the ratio amount of material removed from the surface of work piece to the machining time. It is measured in gram per minute. The material removal rate is large at anode with the shorter pulse duration, while material removal is larger at cathode with the large pulse duration. In an Electric Discharge Machining process, if the value of material removal rate is higher, it will take as better response characteristics.

$$MRR\ (g/min) = \frac{\text{Wwb} - \text{Wwa}}{\text{T}} \ldots \ldots\ldots\ldots\ldots\ldots (1.2)$$

Where,

Wwb = Weight of work piece before machining

Wwa = Weight of work piece after machining

T = Machining Time

b. Tool Wear Rate (TWR): It is associated with the wearing of tool during machining process. It is the ratio of the material removed from the tool to the total machining time. In an Electric Discharge Machining process, lower the value of tool wear rate better will be the response characteristics. Therefore, tool wear rate is the lower-the-better response characteristics. It is mathematically expressed as:

$$TWR\ (g/min) = \frac{\text{Wtb} - \text{Wta}}{\text{T}} \text{……………………} (1.3)$$

Where,

Wtb = Weight of tool before machining

Wta = Weight of work piece after machining

T = Machining Time

c. Heat Affected Zone (HAZ): Heat affected zone or heat affected area specified the area of the work piece that did not melt during electric discharges but has experienced a transformation or change of phase similar to heat treatment process under the high temperature of electric discharges.

d. Over Cut (OC): The over cut is the half of difference between the diameter of hole produced and electrode diameter. It is measured in mm. Smaller the value of over cut, better the response characteristics. Hence, over cut is the smaller the better performance parameter. It can be expressed mathematically as:

$$OC\ (mm) = \frac{\text{Dia .of hole produced} - \text{Dia .of Tool}}{2} \text{………} (1.4)$$

e. Surface Roughness (SR): It is the vertical deviations on the surface of work piece. It is generally measured in µm. The surface roughness is measured with the help of a profile-meter. R_a is the average value of surface roughness which mostly used as a surface roughness parameter. Smaller the value of surface roughness results in better response characteristics. Hence, surface roughness is the smaller the better performance parameter.

Benefits of Electric Discharge Machining Process

1. Since there is no physical contact between the tool and work piece, there is no mechanical deformation due to mechanical stresses during the machining process as occurred in conventional machining process.
2. The Electric Discharge Machining process is free from mechanical stresses and vibrations, because there is no direct contact between the tool and the work piece.
3. In an Electric Discharge Machining process, properties of work piece material like hardness, toughness and microstructure produce has no barrier to its application.
4. Slender and fragile work piece can also machine with this process.
5. Parts or components can produce with a high degree of accuracy and surface quality.
6. The surface produced through Electric Discharge Machining process consist multitude of small crater; which helps in retention of oil and better lubricating property.
7. Micro components and intricate shapes can also machine through this process with high degree of precession.

Limitations of Electric Discharge Machining Process

1. The main drawback of an Electric Discharge Machining process is that, it can machine only electrical conductive material.
2. Rate of material removal is low as compare to conventional machining processes.
3. Gap dimensions are difficult to predict.
4. The consumption of electrical energy is high.
5. Due to electrical discharges, thermal stresses are induced in the work piece.
6. Fabrication of tool is other problem.

Applications of Electric Discharge Machining Process

Electric Discharge Machining Process is widely used in modern industrial world. The various applications of this process are as:

1. Mostly mould and die industries are used this process to manufacture mould and dies.
2. It found application in medical industries in manufacturing of cannula tubes and dental accessories [16].
3. It used for cutting of internal threads and helical gears with high accuracy.
4. This process is used to manufacture turbine blades and to make cooling holes in turbine blades.
5. Extremely hard materials like composites, alloys and tool of carbide are machined easily with the help of this process.
6. Electric Discharge Machining process is used for wire drawing, forging, extrusion and thread cutting processes.

7. Electric Discharge Machining process is widely used for machining of exotic materials which are used in automotive and aerospace industries.

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