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MATERIAL REMOVING METHOD FOR ROTATIONAL PARTS WITH WIRE EDM MACHINE

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***Abstract:**
The wire electrical discharge machine (EDM) was developed for cutting intricate profile. In modern edge, Wire EDM can be applied for turning on macro to micro parts, higher length diameter ratio parts and difficult machining materials. The use of present commercialised wire EDM for turning application has comparatively less material removal rate, high surface roughness and also high power consumption due to the lack of synchronise rotary control method. A present commercialised wire EDM turning differs with the principle of normal Wire EDM. Through this research, wire EDM is developed and featured with micro multi spiral cutting and synchronisation between linear motion & rotation speed of work piece. In present work, attempt has been made to design indigenous control with synchronise rotary motion control method bynew controlled wire EDM pulse generator. Developed intelligent wire EDM focuses on synchronisation between two new parameters; first is ‘degree of motion of workpiece’ and the second is ‘Y-infeed after one revolution’ instead of ‘rotational speed of workpiece(r/min)’ and ‘linear feed speed(mm/min)’ with a vision to improve performance parameters of rotational parts. Result shows that there is 16.22% improvement in material removal rate (MRR) and reduction in 32.00% surface roughness (SR) as compare with commercially available wire EDM turning. This intelligent Wire EDM is possible to use in many industries for turning on difficult material without evade principle of normal Wire EDM.
*** Keywords:***Intelligent wire EDM turning, synchronise rotary motion control, cylindrical work piece, material removal rate, surface roughness*

Introduction

High precision and micro work are the majority industrial items like micro rotational parts as micro tiny platinum stents, micro mold making, micro Actuator, micro stamping dies, micro gear, micro probes, auto steel pipet, micro shaft etc are mostly used in aerospace, biomedical but also use in dental, endoscopic and other surgical instrument components and, even jewellery-making.[1] These components diameter are from 30 μm to 2 mm generally and length diameter ratio is very high, engraving and complex profile of shape. Hence, these are inconvenient to machining by traditional machining process such as milling, turning, roaming and grinding. As another solution, the electrical discharge machining (EDM) process, which advance type machining process have micron size electric voltage potential wire rotate continuously on cutting workpiece surface by intermediate dielectric fluid thin film. So, erode the unwanted material from workpiece surface by generated spark ionised column. Workpiece is totally free to contact force, toughness and vibration at time of machining.[2] This reason it is most popular for manufacturing of precision and micro work.

David H. et al. [3] first patented electrical energy used for machining by erosion form. Eiichi Takarada et. al.[4] and Mervyn Rudgley et.al.[5]also patented of logic for controlling the spark gap between electrode and a workpiece. Masuzawa et. al.[6] developed grinding EDM machining technology for small shaft. A. Pramanik et. al.[7]–[9] investigates mechanisms of material removal, surface generation and taper kerf formation on metal matrix composite and other imperative materials. The WEDG working principal is shown in the figure 1. Fleischer et. al.[10] developed 100 micron or less diameter tungsten carbide milling tool by WEDG. Yao sun et. al.[11] developed carbon steel micro-rods by multiple cutting strategy in low speed wire electrical discharge turning.Jingxiang hu. et.al.[12] find optimum method for control parameter with closed interface of WEDM on the ring with high precision. Gauitrau et. al.[1] writes 15 microns fine wire commercially used in military purpose.R. N. Huang et. al.[13] uses the PID controlled servo feeding system for beteer control of Micro WEDM.Virginia et. al.[14]use the white layers technique for turning by EDM for machining the tool where tool is worn.Yingmou Zhu et. al.[15]–[17] rapid contour approaching used to turning and achieve high MRR Good Surface roughness and good controlling of diameter size of parts.

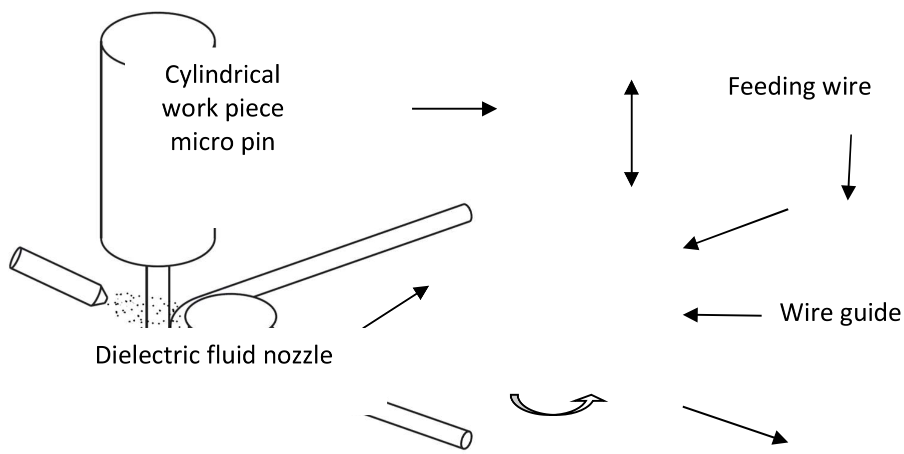

Figure 1. WEDG working principal [10]

Previous eminent researchers have used the same available WEDM with available Material Removing algorithms and tried to cut rotational part for further development. CWEDM rotates a cylindrical object against a wire with individual control same as conventional lathe machine. The workpiece is held and rotated on its axis while the machining is along the line of a desired cut by wire. In CWEDM, turning parameters like rotational speed of workpiece, depth of cut (X-infeed), cylindrical servo feed rate and cutting speed is specified through several parameters. These parameters are selected based upon the workpiece material, material size and shape, wire type, wire feed rate and more. Researchers improves response parameters i.e. Material removal rate(MRR), Surface roughness(SR), Wire wear(WW), Desired dimension accuracy(DD), Power consumption(PC) against variable parameters as shown in figure 2.

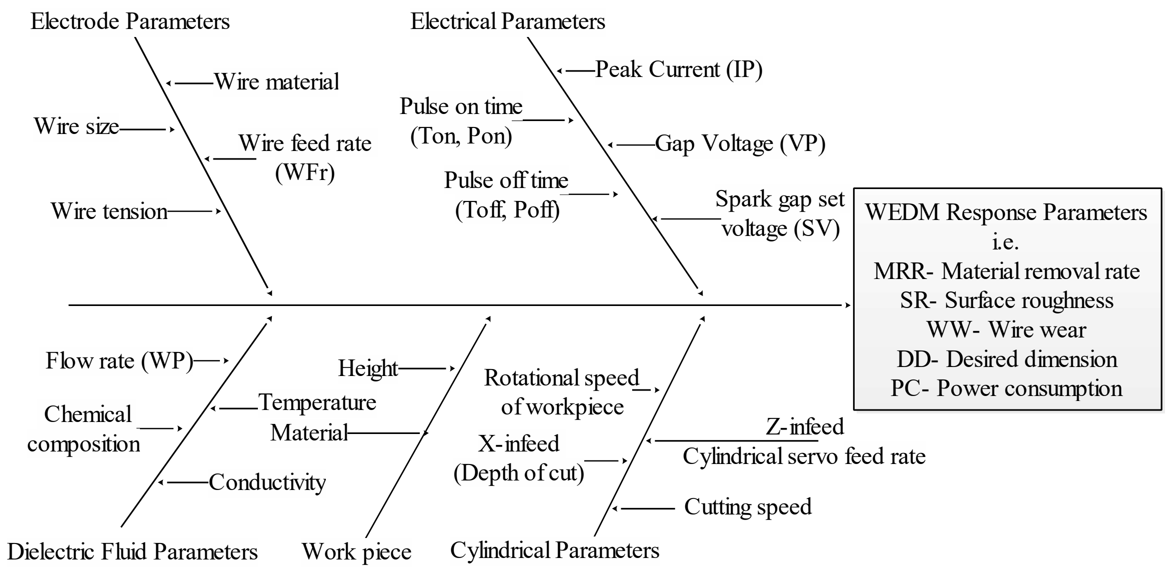

Figure 2. Different parameters in CWEDM

With less cylindrical servo feed rate or rotational speed of workpiece, more time required to cut material for desired length which decrease material removal rate and increase Power consumption, and with more cylindrical servo feed rate or rotational speed of workpiece, less time required to cut material for desired length which increase material removal rate but also increase the surface roughness. Hence, cylindrical cutting is micro multi spiral cutting and synchronisation needs between feed rate and rotation speed of workpiece(rpm)[18]–[22].

This research work includes development of new machine as well as new synchronise rotary motion control Method with focus on degree of motion of workpiece instead of rotational speed of workpiece and takes z-infeed after one revolution instead of feed rate for improvement of performance parameters for rotational parts.

Several researchers (Young song et. al. [23], Haddad M.J. et. al. [19]–[22]) have developed workpiece holding apparatus to generate turning effect on workpiece by attaching XY table of WEDM for cylindrical Machining on workpiece. In this research, software is developed with new Material Removing Method to reduce pick and valley effect increase material removal rate and reduce unnecessary power consumption during CWEDM.

Workpiece holding apparatus is key parts of CWEDM and facilitate with expected features like protection from die electric fluid, rotational accuracy, workpiece sizable limit and possible smallest rotation degree for precise work. Workpiece holding apparatus is design with those facilities as shown in figure 4.

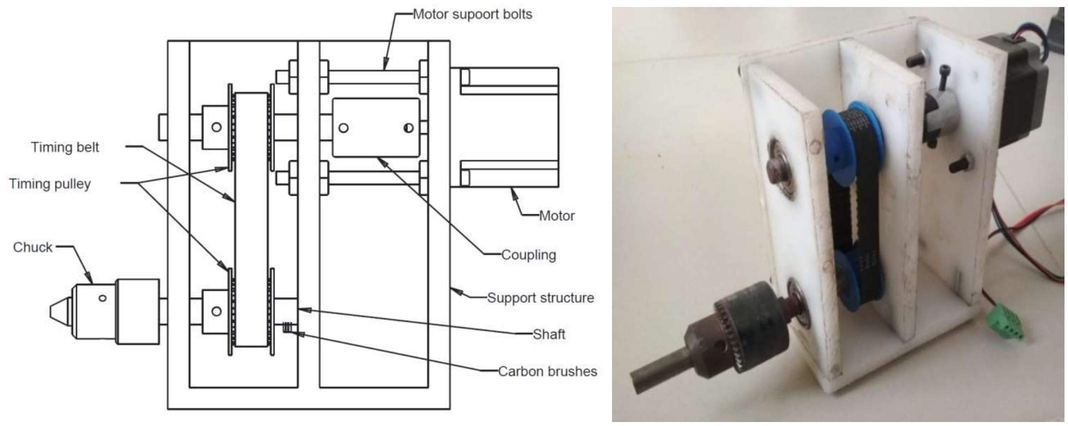

Figure 4. Workpiece holding apparatus schematic diagram with photograph

The workpiece is fitting in chuck in apparatus as shown in figure 3. One timing pulley is fit on chuck shaft supported two bearing with polyurethane (PU) material structure. A timing belt is used between timing pulley and stepper motor shaft to chuck motor timing pulley to deliver rotational force. Workpiece holding apparatus is connected with pulse generator through carbon brushes and connected to power supply (24 VDC) through stepper motor so the whole structure is made from PU material. Chuck run out error is most affected on material removal rate in cylindrical WEDM parts. Run out error in this research not exceed 10μm. Workpiece holding apparatus specification and components details as shown in table 2.

Table 2. Workpiece holding apparatus specification

Parameters	**Values**
Rotational speed	0.05 to 60 rpm
Diameter workpiece	0.05 to 10 mm
Stepper motor	stepper motor NEMA23 – 10 kg.cm torque
Timing belt	GT2- 5- 20mm width

New Material Removing Method based Software

Software divided in three parts; CNC program based on Feed strategy, Spark gap control software and Material Removing Method.

CNC program based on Feed strategy

Yingmou Zhu et. al.[15]–[17] proposed a feed strategy to remove unwanted material layer by layer for roughing and finishing process to achieve a fine surface quality. In this research, taking part of reference (20) for feed strategy, CNC program is generated from part drawing as shown in figure 5(a-b).

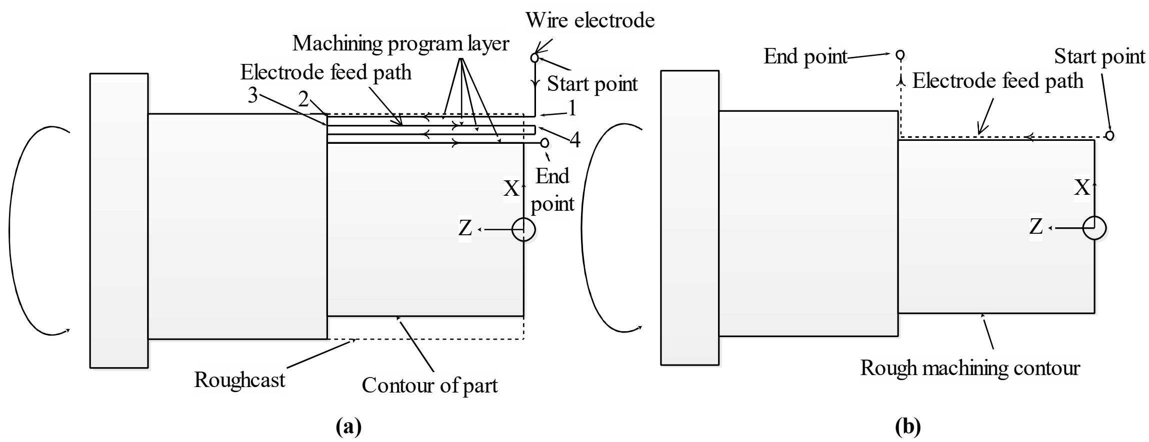

Figure 5: feed strategy: (a) Roughing operation, (b) Finishing operation

In CWEDM, only two axes viz. X and Z are used. X axis is along the radius of work part, whereas Z axis is along the length of the work part as shown in figure 5(a-b). According to CNC program wire electrode starts machining from point 1 to point 2 as shown in figure 5(a) and remove unwanted material layer by layer in XZ plane using spark gap control software and developed Material Removing Method.

Spark gap control software

Control of a spark gap is at least in part defined by the space between an erosion electrode wire and a target dimension as per feed strategy. If the spark gap is too large, the spark event may not occur. If the spark gap is too small, the spark event may be insufficient to remove desired amounts of material. If the erosion electrode wire contacts the workpiece, then no spark event may occur until a spark gap is restored. So, spark gap is required to maintain during machining which is measured by change of spark voltage.

A Voltage sensor configured to sense a Voltage in a spark gap; a programming is carried out through Visual basic 6.0 code to calculate a response command based on the Voltage sensed in the spark gap; and a motor control configured to cause a motor of the workpiece bad to selectively control the position of the erosion electrode according to the response command.

New Material Removing Method

This research work includes new Material Removing Method with focus on degree of motion of workpiece instead of rotational speed of workpiece and takes z-infeed after one revolution instead of feed rate to reduce pick and valley effect on surface, increase material removal rate and reduce unnecessary power consumption during WEDM.

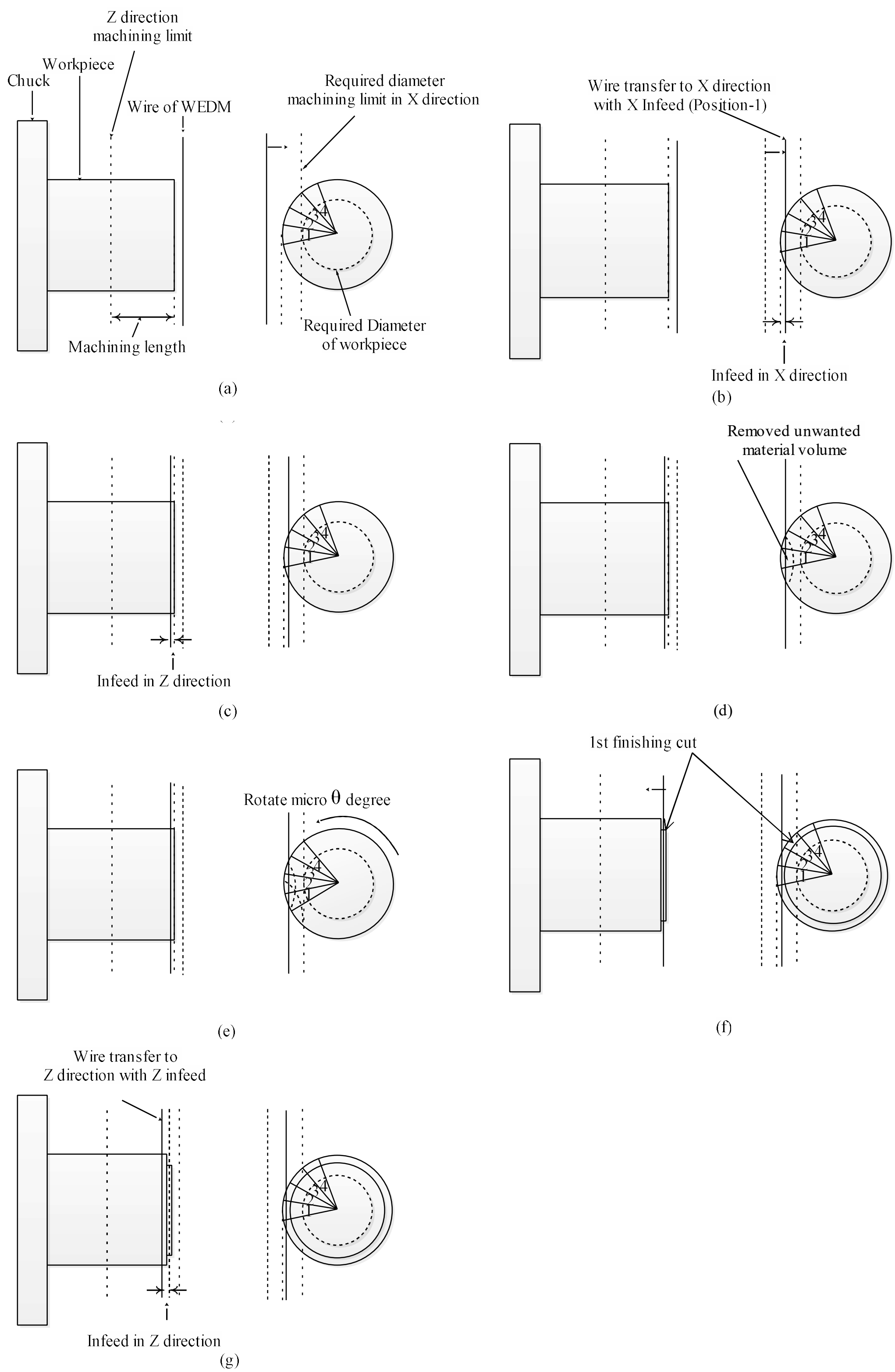

Figure 6: Machining steps as per Material Removing Method (a) to (g)

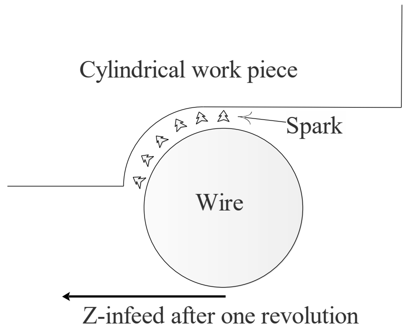

Figure 7: Spark condition situation

The program zero will be set at start point as shown figure 5(a) and 6(a). In the beginning machine moves, only along the X axis at position 1 with X-infeed (depth of cut) as per generated CNC program as shown in figure 5(a) and figure 6(a-b). Machine moves along the first cut with Z-infeed as shown in figure 6(c) Where unwanted workpiece material removed θ1 degree of workpiece as shown in figure 6(d) and figure 7. After the removing unwanted workpiece material θ1 degree, workpiece is rotate the θ degree at micro value as shown figure 6(e) for next θ2 degree part. θ degree calculated by knowledge based system instead of rotation speed of workpiece. The knowledge based system will be depends on parameters like material type, workpiece diameter, wire diameter, wire type etc. The new Material Removing Method will repeat the above step for complete one revolution and finish one perfect cut as shown in figure 6(f). Machine moves along the second cut with Z-infeed after one revolution instead of constant feed rate as shown in figure 6(g). Repeat above step until desired dimension achieved for both roughing process and finishing process as shown in figure 5. Here revolution per minute of chuck is not constant because it is depends on material removal which helps us to achieved good surface finishing, improving MRR and reduction in power consumption.

Developed Material Removing Method based Software is featured four features. One is to maintain spark gap per revolution as per Spark gap control software. Second is control the θ degree revolution of chuck. Third is control the X-infeed and Z-infeed layer by layer. Fourth is synchronization of features one, two and three till final part drawing program as per feed strategy. This Material Removing Methodis use for turning, facing, tapering as well as complex cylindrical parts.

Additionalinformation

The comparison experiments were aimed at considering effects of controllable parameters like degree of motion of workpiece and Y-infeed after one revolution on response parameters like material removal rate (MRR) and surface roughness (SR) after the implementation of the intelligent wire EDM turning with synchronise rotary motion control. Hence proper selection of controllable parameters will result in better response that gives higher material removal rate and less surface roughness.

Workpiece material

Wire EDM works with different metals like steel, titanium, aluminium, alloys, brass, and super alloys of all types. Wire EDM is usually used when low residual stresses are preferred, because it does not require high cutting forces for removal of material. GCr15 is a bearing steel. It can be applied in the toughened condition. GCr15 offers high corrosion resistance, wear strength and high hardness. GCr15 Material usually applied in section large forgings, such as locomotive traction gears, with supercharger drive gear, the rear axle, the connecting rod and the spring load greatly clip, oil drill pipe joints and fishing tools, etc. So, the experiments are conducted on GCr15 Material. The chemical composition was tested at Divine Laboratory at Ahmedabad for the selected work material. The data of chemical composition is presented as below in Table 3.

Table 3 Chemical composition: GCr15

Chemical	Obtained value (%)	Required value (%)
Carbon	0.98	0.95-1.10
Silicon	0.25	0.15-0.35
Manganese	0.30	0.20-0.40
Chromium	1.50	1.35-1.60
Molybdenum	0.09	Max 0.10
Phosphorus	0.021	Max 0.025
Sulfur	0.10	Max 0.10

Total 12*3=36 nos. of experiments has been carried out on round bar of 3mm diameter and 10mm length of GCr15 material as per shown in figure 8.

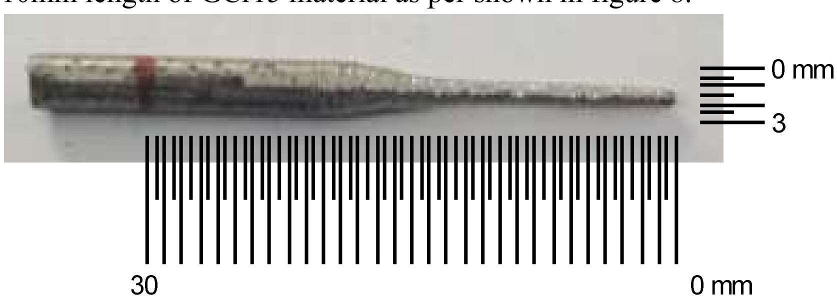

Figure 8. Workpiece machining

Response measurement

An experiment has been carried out and response parameters have been calculated. The MRR is represented as unwanted removed material from workpiece over a time to machining. This measured by derived to find MRR:

$$MRR = \frac{\pi}{4}(D^2 - d^2) \times \left(\frac{L_m}{T_m}\right) \tag{1}$$

Where, D is original diameter of workpiece, d is final diameter of workpiece, L_m is length of machining on workpiece and T_m is machining time.

The surface roughness value, also known as center line average (CLA) and arithmetic average (AA) is obtained by averaging the height of the surface above and below the center line. The surface roughness will be measured using a surface roughness HOMMEL TESTER T500 with least count 0.01 µm.

Controllable Parameters

An experiment has been carried out in previous control and new rotary motion control under the same constant parameters. Hence, constant parameters like the pulse on time were set as 30(μs), pulse off time was set as 10(μs), voltage was set 30(Volt) and X-Infeed was set 50(μm). In these two experiments, two parameters used as variable are the 'degree of motion of workpiece' and 'Y-infeed after one revolution' and the response of the experiment are MRR and SR.

Experimental results of the 'Rotation speed of workpiece'and 'linear feed speed' achieved by simple rotary control are presented in Table 4 with condition of 1mm/min linear feed speed and 90r/min rotational speed of workpiece respectively. Experimental results of 'degree of motion of workpiece' by new rotary motion control are presented in Table 5, where Y-infeed after one revolution' taken as 100 (μm). The 'Y-infeed after one revolution' experimental results by synchronise rotary motion control are presents in Table 4, where degree of motion of workpiece' taken as 3 degree.

Table 4 Experimental result by simple rotary control

Control type	Parameters and its value		MRR (mm3/min)	SR (μm)	Condition
Simple control (with feed rate)	Rotation speed of workpiece (r/min)	20	1.8	3.345	'Linear feed speed' taken as 1(mm/min)
		50	2.1	3.856	
		80	3.1	4.126	
		110	**3.2**	**5.225**	
	Linear Feed speed(mm/min)	0.1	2.2	3.206	'Rotational speed of workpiece' taken as 90 (r/min)
		0.4	2.3	3.612	
		0.8	3.1	4.236	
		1.2	**3.7**	**6.108**	
	Max. Average		**3.45**	**5.666**	-

Table 5 Experimental results by new synchronise rotary motion control

Control type	Parameters and its value		MRR (mm3/min)	SR (μm)	Condition
New rotary motion control	Degree of motion of workpiece(Degree)	1	2.1	3.322	'Y-infeed after one revolution' taken as 100 (μm)
		2	2.4	3.456	
		3	4	3.364	
		4	**4.3**	**3.562**	
	Y-infeed after one revolution (μm)	30	2.9	3.26	Degree of motion of workpiece' taken as 3 degree
		60	3.7	3.384	
		90	4.2	3.512	
		120	**4.3**	**4.145**	
	Max. Average		**4.3**	**3.853**	-

Analysis and results

Experimental result states that uniform surface roughness 3.322 to 3.562µm achieved in case of modified new rotary control where as simple control results show variation between 3.206 to 6.108 µm.Improvement in material removal rate(MRR) is 16.22% and reduction in surface roughness(SR) is 32.00% as compared to available wire EDM turning.

The 'degree of motion of workpiece' and 'Y-infeed after one revolution' improves the geometrical accuracy. The synchronised control system controls the spark gap and maintains it constant. Spark gap managed by spark gap voltage up to 30(µm) is used for precise discharge amount of energy. Figure 10 and figure 11 serve the point of graphical assessment and illustrate the plots of parameter effects on changes of MRR and SR. The most significant effect on MRR and SR is 'degree of motion of work piece'. MRR is directly proportion to the 'degree of motion of workpiece' and SR varies as per figure 9.

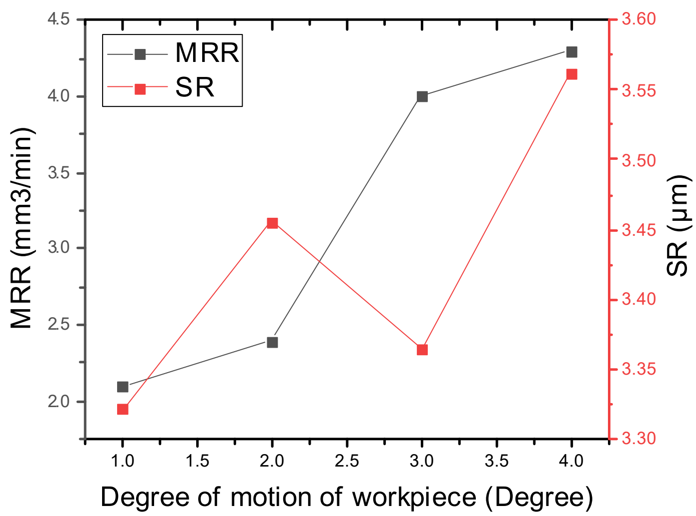

Figure 9. Influence of 'degree of motion of workpiece' on MRR and SR

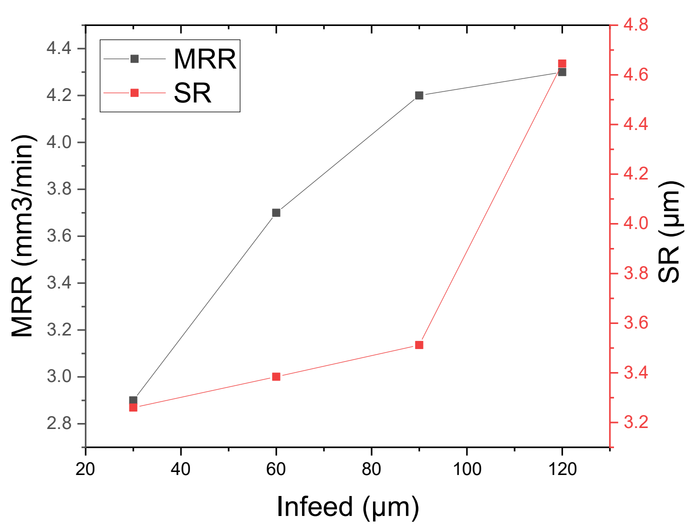

Figure 10. Influence of 'Y-infeed after one revolution' on MRR and SR

Furthermore, it can also be observed that the MRR and SR parameter against varies of 'Y-infeed after one revolution' parameter as figure 10. 'Y-infeed after one revolution' parameter has the most significant effect on MRR and SR. In addition, MRR changes direct proportion to the Y-infeed after one revolution whereas change of surface roughness is sudden.

Conclusion

The developed design of intelligent wire EDM turning machine is applied to manufacture precise complex shaped cylindrical parts in both macro and micro levels. By adapting newly develop material removing strategy in intelligent wire EDM turning system is enabled to have between 0.3° to 3° of 'degree of motion for workpiece' and 30-100 µm of 'Y-infeed after one revolution' instead of 'Rotation speed of workpiece' and 'Linear feed speed' parameters which is apart from the conventional wire EDM. After performing experiment with synchronise rotary motion control method improves material removal rate (MRR) at 16.22% and 32.00% reduction in surface roughness (SR) as compared to available wire EDM turning.

Conflict of interest

The authors declare that there are no conflicts of interest.

Acknowledgment

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