Investigation of Involute Profile Error on Spur Gear Processed using Wire EDM

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Abstract. Demand on high accuracy product are getting raised recently. Wire Electrical Discharge Machining (EDM) is one of non-conventionalmachining who can produce high accuracy product with two axis. By using sparks from electrical energy to erode material in conductive fluid, called electrode fluid. A spur gear with JIS B 1701:1973 standard has specific criteria, including dimension and mechanical tolerance. DIN 1.2378 is a medium carbon steel which is common to use as a gear in automotive industry. This martial is like the ordinary one, but with an extra nickel. The aim of this research is to observe how far effect Wire EDM parameter process such as pulse on time, open voltage, pulse current and wire tension affected on involute profile error of spur gear shape with Taguchi matrix orthogonal L18 methods as experimental design. From research we concluded that the most involute profile error is a minus profile, it means involute curve on actual gear smaller than ideal involute curve. The smallest dimensional distortion involute profile error is 79μm and the highest 125μm. Process parameter pulse on time, open voltage, and pulse current has directly proportional to involute profile error, while wire tension has inversely proportional to involute profile error.

Keyword : Mechanical Tolerance, Non conventional machining , Pulse on Time, Spur gear, Wire EDM

1. Introduction

Wire EDM processing material using a series of continuous spark from electrical discharge [1], discharge erode material with frequency between 330 kHz to 10 MHz. that energy transfer into dielectric fluid [2]. That spark come up between anode and cathode and transfer thermal energy with range temperature from 8000°C to 20.000°C [3], this enough to melting and erode material. There are no contact between them, and in make work piece processed with wire EDM has low stress on work pieced 185 Pa [4]. Commonly dielectric fluid are distilled, de-ionised and CH-Based water [5].

Wire EDM can process some material conductive materials like super alloy steel [6], Nimonic [7] even Titanium [8] and Zirconium [9]. Recently EDM also able to processing non-conductive materials, like ceramic with auxiliary conductive layer [10]. Blessed with that advantage, make wire EDM applied widely in some industry who require complex geometry and high accuracy component, including automotive industry [11]. In that industries gear for transmission is a critical aspect, they have tight mechanical tolerance.

Spur gear configured with parallel shaft and suitable for transmission system with high radial force because no axial force consequence. Gear work with embedded from one gear to another one successively. For gear travelling smoothly, without dearly fraction, created tooth profile a manner shape that’s called involute. When gear go rounds, on profile will show a point of contact who
travelled following a straight line that called line of action, that’s line of contact from both diameter. By this line force forwarded from pinion to wheel on length of contact, that’s called pressure angle. If a spur gear didn’t meet their lowest deviation criteria, it has a consequent such as energy will not transfer fully in involute are between pinion and wheel [12]. When a spur gear dimension more than maximum deviation it might appearing backlash and chatter [13].

2. Literature Review
A research observed about influence of wire EDM parameter process to surface roughness on spur gear who has processed using Wire EDM. Material using EMS 45 steel and 0.25 mm brass wire. Surface roughness as a dependent variable, then independent variable is current and wire speed. Range of pulse current is 3, 5 and 7 Ampere and wire speed is 8, 10 and 12 mm/s. Performed surface roughness from 2.855 μm to 2.653 μm. Independent variable inversely proportional to surface roughness [14]. Another variate wire tension from 5, 8 11, 15, 19, to 22 N as independent variable. Dependent variable is surface roughness, kerf width, material removal rate and recast layer. Material AISI 308 stainless steel and 0.18 mm Molybdenum wire cutting. From this research wire tension affected surface roughness recast layer has inversely proportional. The lowest surface roughness is 3.03 μm, and the highest surface roughness are 7.02 μm. The lowest recast layer is 225.9 VHN, and the highest surface roughness are 220.9 VHN. While wire tension and material removal rate has direct proportional, the lowest material removal rate is 3.22 mm³/s, and the highest surface roughness are 3.67 mm³/s. There are no significant effect on wire tension to kerf width [15]. A research observe about wire EDM pulse on time, pulse off time, servo voltage, wire tension to cutting speed and surface roughness using Multi Objective Optimisation on the basis of Ratio Analysis (MOORA) shown that the optimal wire EDM parameters to get high cutting speed and low surface roughness at pulse on time 115 μs, pulse off time 45 μs, servo voltage 40V and wire tension 7 Kgf [16]. Forcasting about wire EDM using grey ANFIS, show that flushing, table feed, pulse on time pulse off time, current, voltage, wire tension, wire speed has influence on mechanical tolerance like circularity, cylindricity, perpendicularity and parallelism [17]. Pulse on time, pulse off time, peak current, and gap voltage on material removal rate and surface roughness in Titanium Alloy Ti6Al4V, found microcrack, creater, and globule on specimen [18]. Pulse on time is most significant to material removal rate, surface roughness, kerf width and dimensional deviation than other parameter [19]. An increasing of pulse on time frequency and current density lead to high deposit materials on electrode [20]. Material removal rate and surface roughness using En-19a Material, observed parameter is servo voltage, pulse on time, pulse off time. The significant level from each parameters is pulse on time 74.2%, pulse off time 1.01% and servo voltage 15.9% to surface roughness [21]. Investigation on gear profile accuracy produced using EDM sinking shown that in last quarter teeth is most founded dimensional distorsion including tooth thickness, oscillation of the total normal length, radial runout, deviation of left profiles, accumulated pitch error of left profiles, pitch deviation of right profiles, accumulated pitch error of right profiles [22]. A research comparing geometrical accuracy and surface finish between wire-EDM and CNC milling machine using material aluminum alloy AA6063. The geometrical accuracy measurement was performed wire-EDM has more accurate than CNC milling [23].

3. Methods
This research work piece is a spur gear like the previous one [14], on that research there is no detail about standard applied. In this research spur gear flown JIS B1701-1973 standard, with full-Depth 20° involute system. Dimension from work piece shown on Figure 1. On this research DIN 1.2378 using as material, that material processing with machine Wire EDM CHMER 32G. DIN 1.2378 material chemical composition shown on table 1. Wire electrode using 0.25mm zinc coated brass wire. Parameter selection base on [14] and [15], but with different value due on capacity process from different machine. Parameter combination shown on Table 2.
From table 1 this research has 18 combination. Varitate variable process pulse on time 3 level that is three μs, 5 μs and 7 μs. Open voltage have three level 75 V, 85 V, and 95 V. Pulse current have 3 level 3A, 5 A and 7 A. wire tension 4 gf and 8 gf. Figure 1 shown data from involute error taken, it taken on six point marked with blue triangle. First cutting marked with red triangle. Data collection has 1 dedendum space from first cutting point because in the first cutting wire EDM parameter was not settle. Image from specimen taken using camera with 10x macro lens.

4. Result
Data involute profile error distortion during observation shown on table 3.
From Table 3 we can see with additional on pulse current will raised error from involute profile error. Like previous [14] but affected on surface roughness. This caused pulse on time value, frequency discharge to erode material will increased, it make more material molten and erode during machining, it confirmed with previous research [23]. High pulse on time might appearing double sparkling phenomena, this make material erode increasing. This affected on involute profile error, sehingga actual dimension drom spur gear smaller than ideal one. A raised of open voltage and pulse current value has an impact to involute profile error. Discharge energy who penetrate and erode material getting higher, it followed by involute profile error get raised on table 3. Wire tension is a factor control wire strahoght during machining process on wire EDM. High wire tension, make wire stay straight snd pendicular, but if too high migh come wire rupture. If wire tension too low, wire will dragging behind holder [24]. 

![Figure 2. Illustration of wire 4gf and 8gf tension](image2.png)
On this research a higher value from wire tension lead to lower involute profile error. It came from wire drag, while cutting condition on wire drag behind holder come cycle effect phenomena and lead to wire on imbalance condition during cutting process. This affected on involute errore, because wire travel not on the line shoul be. The lowest dimensional distorsion shown on figure 3 and 4.

Figure 3 show lowest dimensional performed by combination pulse on time 3\(\mu\)s open voltage 75V pulse current 3A and wire tension 8g. Figure 4 show highest dimensional performed by combination pulse on time 7\(\mu\)s open voltage 95V pulse current 7A and wire tension 4g. On high combination of pulse on time open voltage and pulse current with low wire tension, discharge energy penetrate work piece more higher with high frecuency. Followed with wire not on stable condion make involute profile error high. If we cutting with this on condition on straight line, error might decreased.

5. Conclusion
Variable process pulse on time, open voltage, and pulse current have directly proportional to involute profile error. Wire tension has inversely proportional to involute profile error. Profile Error Involute on this research is minus profile. Actual spur gear is smaller than ideal one. For future research observerd about optimization parameter on involute profile error of spur gear performed by wire EDM.

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