

# Effect of the process parameters on dimensional deviation of Titanium alloy miniature gear manufactured by Wire Electric Discharge Machining

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**Abstract-** Manufacturing of Titanium alloy miniature gear is one of the biggest challenge in recent past. Wire electric discharge machining is widely used to cut hard material. Selection of the wire electric discharge machining process parameters to obtain the minimum dimensional deviation such as Dimensional deviation in outer diameter, dimensional deviation in inner diameter and dimensional deviation in land is very crucial. In this work, suitable process parameters such as Current, Pulse on time, Pulse off time, Wire tension and Dielectric fluid, have been identified to achieve low deviation in dimensions of miniature gear. Different dielectric fluids have been prepared using the mixture of ethylene glycol, alumina nano powder and oxygen in demineralized water. The dimensional deviations are measured using profile projector and suitable parameters ranges are identified. Titanium alloy based miniature gear will be useful in industries.

**Keywords:** Miniature gear, Dimensional deviation, Titanium alloy, WEDM, current

## I. Introduction

Machining of Titanium alloy is a challenging task. Wire electric discharge machining (WEDM) is an advance machine to cut the hard materials such as

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titanium alloy, nimonic alloy, and other super alloy. Different process parameters ranges have been identified to achieve better dimensional accuracy of Titanium alloy miniature gear manufactured by WEDM. The Titanium alloy miniature gears are known for high strength applications. They are widely used in dental instruments, ink jet nozzles, micropumps, micromotors, watches, drones etc.

Wide research has been done in the field of micro-machining but very limited research is present in the field of miniature gear fabrication. In a recent study, a miniature gear of polycrystalline diamond was manufactured and roughing and dressing of the profile was also done by WEDM. The supply of discharge energy is tremendous in case of conventional WEDM as compare to micro-WEDM which results high thermal damages. High discharge energy generates craters on the polycrystalline diamond surface and results thick damaged layer and poor surface finishing [1]. The dimensions deviations are the biggest problem in miniature gears manufactured by WEDM. The macro geometry dimensional parameters are outside diameter, span and tooth thickness. The micro geometry dimensional parameters are pitch run-out, lead profile, and surface roughness [2-4]. The reason of the dimensional deviation using WEDM is the formation of craters because of presence of high discharge energy and the shifting of wire from desire path i.e. known as wire lag [4, 5]. Profile or dimensional errors are developed due to the WEDM process parameters. Profile and pitch error can be reduced at low voltage. At high PON time and voltage, there is supply of high force and spark energy which further results high MRR with the high surface roughness [5-9]. At high voltage and PON time, the time for transferring discharge energy on the surface of miniature gear increases and time for flushing dielectric fluid decreases which develops irregular and deep craters on miniature gear tooth profile and increases the dimensional errors such as profile and pitch error [6-8, 10-12].

The main purpose of this research work is to identify the range of process parameters during the Titanium alloy miniature gear manufacturing using WEDM machining to achieve high dimensional accuracy of the miniature gear. The composition

of titanium alloy is given in table I. 31 miniature gears have been prepared and dimensional deviation in outer diameter (DOD), dimensional deviation in inner diameter (DID) and dimensional deviation in land (DLAND) are considered as performance characteristic for the experiments. Different dielectric fluids are prepared after mixing alumina nanopowder, ethylene glycol (EG) and oxygen in demineralized (DM) base water.

Table I. Chemical composition of Titanium alloy

Constituents	Al	C	Fe	Ni	Cu	V	Mn	Ti
Composition (%)	0.005	<0.03	0.036	0.005	0.007	0.025	0.004	Remainning

## II. Experimental setup and procedure

These experiments are conducted on DK7712 CNC WEDM machine of Steer Corporation. The main process parameters during manufacturing of miniature gear are current, pulse on time (PON), pulse off time (POFF), wire tension and dielectric fluid. Alumina nanopowder, ethylene glycol (EG) and oxygen have been mixed in demineralized water (DM) to prepare different dielectric fluids such as ethylene glycol mixed demineralized water, alumina powder mixed demineralized water, ethylene glycol and alumina powder mixed demineralized water, ethylene glycol and oxygen mixed demineralized water, oxygen mixed demineralized water, alumina powder and oxygen mixed demineralized water, and finally alumina powder, ethylene glycol and oxygen mixed demineralized water. The effects of these parameters on the deviation in dimensions are investigated. The outer diameter, inner diameter and land of the gear are measured using profile projector as shown in fig.1 and their dimensional deviation are calculated using the below given formulae.

$$\text{Dimensional deviation (\%)} = \left( \frac{\text{Observed dimension} - \text{Theoretical dimension}}{\text{Theoretical dimension}} \right) \times 100 \quad (1)$$



Figure 1: Optical Profile projector

## III. Results and Discussions

The effects of the process parameters are investigated on dimensional deviation and their reasons have been discussed.

### A. Effect of current on dimensional deviation

The current is varying from 1-6A and other parameters are kept constant. The PON time and POFF time are constant at the value of 20 μs and 3 μs respectively. The actual geometry of the miniature gear is shown in fig 2. Its outer diameter, inner diameter and land values are 7mm, 5mm and 0.5mm respectively. The dimensional deviations such as DOD, DID and DLAND are measured in profile projector and data are presented in table II. The variations in the dimensional deviation at different values of current are also shown in fig 3.

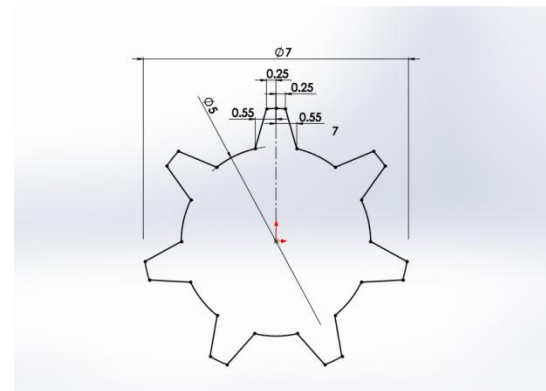


Fig2. Geometry of Miniature gear

Table II: Dimensional deviation with varying current

Current (1-6 A)	DOD (mm)	DID(mm)	DLAND(mm)
1 A	0.244	0.23	0.088
2 A	0.188	0.179	0.189
3 A	0.194	0.18	0.165
4 A	0.24	0.179	0.142

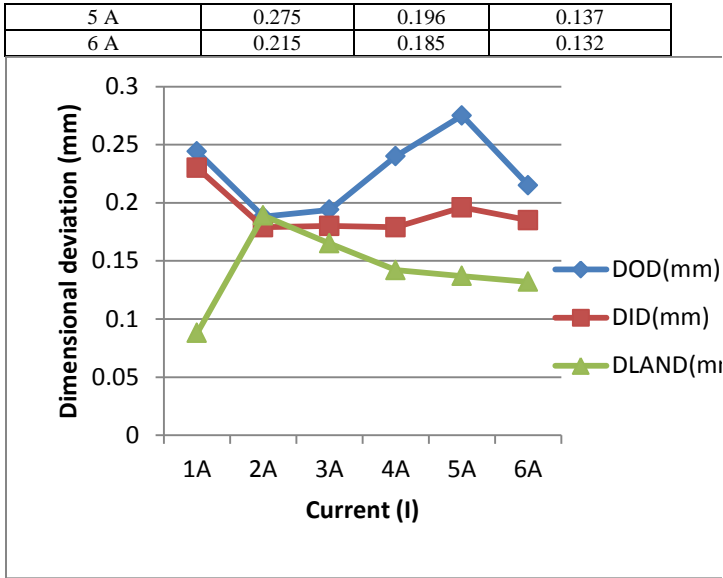


Fig. 3: Variation of dimensional deviation with current

The dimensional deviation is high at low as well as at high value of current because at low value of current there is no proper supply of discharge energy which reduces the cutting efficiency. At high current, the supply of discharge energy is tremendously high and produces large craters which lead to create large deviations in the dimensions. Better dimensional accuracy is achieved at the middle range of current.

### B. Effect of POFF time on dimensional deviation

The POFF time is varying from 1-6  $\mu\text{s}$  and other parameters are constant. The constant value of PON time and current is 20  $\mu\text{s}$  and 3 A respectively. The dimensional deviation data for varying POFF time is shown in the table III. The fig. is also represented the effect of varying POFF time on deviation.

Table III: Dimensional deviation with varying POFF time

POFF time (1-6 $\mu\text{s}$ )	DOD (mm)	DID	DLAND
1 $\mu\text{s}$	0.234	0.196	0.151
2 $\mu\text{s}$	0.202	0.198	0.062
3 $\mu\text{s}$	0.23	0.174	0.121
4 $\mu\text{s}$	0.214	0.164	0.145
5 $\mu\text{s}$	0.203	0.183	0.158
6 $\mu\text{s}$	0.205	0.152	0.103

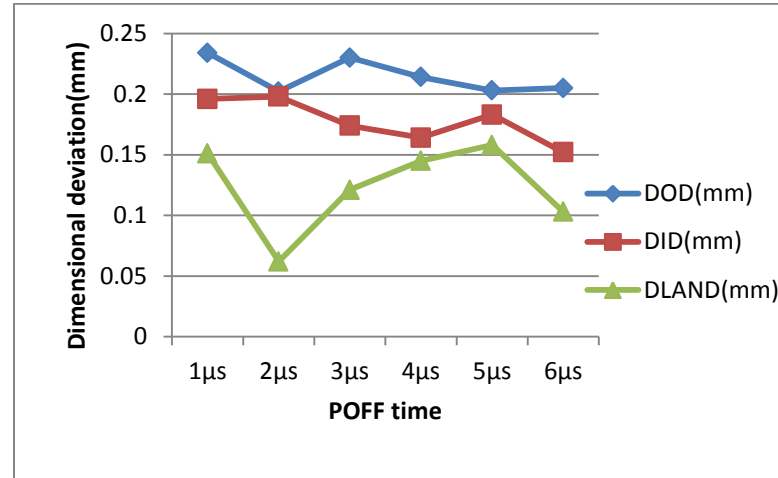


Figure 4: Variation of dimensional deviation with POFF time

According to the fig. 4, at low value of POFF time, discharge energy supply is huge and time to remove debris from machining surface is very less which tends to result high dimensional deviation. At high value of POFF time, the supply of discharge energy stops for long time and it provides sufficient time to eliminate debris from the machining surface through the flushing of dielectric fluid and further results low deviation in dimensions. .

### C. Effect of PON time on dimensional deviation

The PON time is varying from 10-30  $\mu\text{s}$  and other parameters are constant. The POFF time is kept at 3  $\mu\text{s}$  and current is kept at 3 A. The experimental data of dimensional deviations are represented in table IV. The fig 5 is showing the effect of varying PON time on dimensional deviation.

Table IV: Dimensional deviation with varying PON time

PON time (10-30 $\mu\text{s}$ )	DOD (mm)	DID	DLAND
10 $\mu\text{s}$	0.181	0.184	0.151
15 $\mu\text{s}$	0.2	0.204	0.158
20 $\mu\text{s}$	0.21	0.205	0.189
25 $\mu\text{s}$	0.242	0.213	0.13
30 $\mu\text{s}$	0.214	0.239	0.154

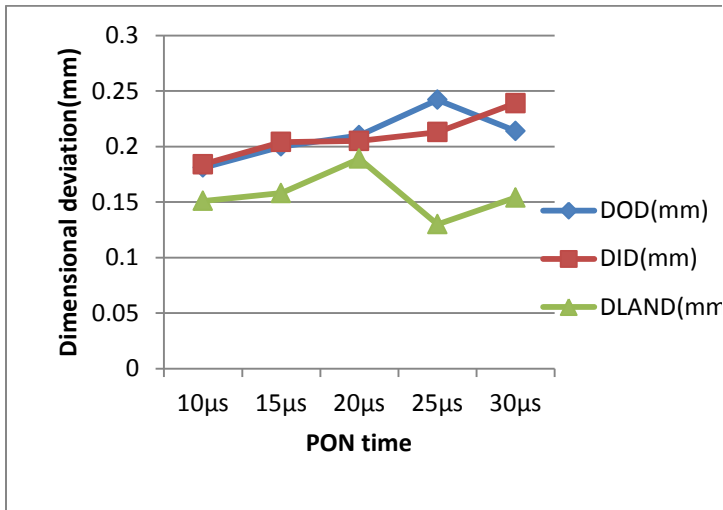


Figure 5: Variation of dimensional deviation with PON time

From the fig 5, it can be clearly noticed that at low value of PON time, the dimensional deviation is low because at low PON time, again the supply of discharge energy reduces which further tends to improve the dimensional accuracy. Better dimensional deviation is achieved at low PON time. On the other side as PON time increases, the discharge energy supply also increases which creates high impact on machining surface and causes high deviation in dimensions.

#### D. Effect of Wire Tension time on dimensional deviation

The wire tension is varied from 1- 25 N and others parameters are constant. The current, PON time, POFF time are kept at 3 A, 20 μs and 3 μs respectively. The data of dimensional deviation on varying wire tension is shown in table V. The effect of wire tension on the dimensional deviation is shown in fig 6.

Table V: Dimensional deviation with varying Wire tension

Wire Tension	DOD (mm)	DID	DLAND
1 N	0.237	0.277	0.114
5 N	0.27	0.2	0.126
10 N	0.249	0.235	0.126
15 N	0.239	0.24	0.151
20 N	0.27	0.207	0.163
25 N	0.25	0.215	0.04

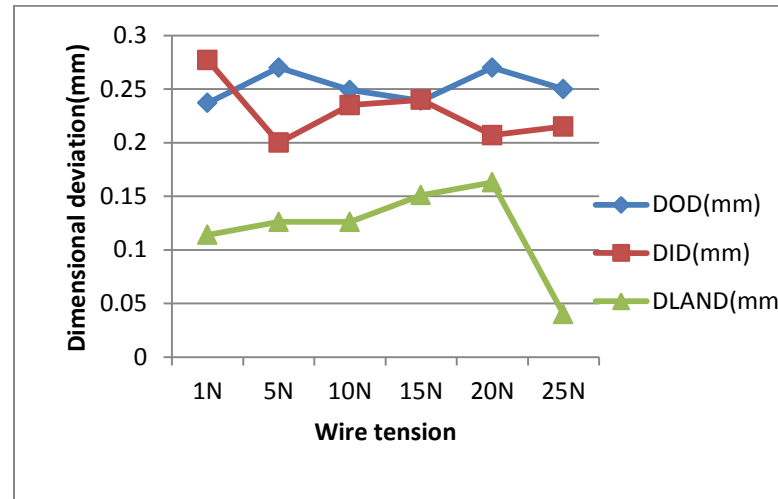


Figure 6: Variation of dimensional deviation with wire tension

As wire tension increases, dimensional deviation is reducing because wire is at tight and straight position at high tension which decreases the vibrations in wire and improves the dimensional accuracy.

#### E. Effect of Dielectric fluids on dimensional deviation

Different dielectric fluids are prepared to investigate the effect of varying dielectric fluids on dimensional deviations. The other parameters like current, PON time, POFF time and wire tension are constant with values of 3A, 20 μs, 3 μs and 15N respectively. Demineralized water is the base dielectric. Alumina nanopowder, Ethylene glycol and oxygen are mixed in to the base dielectric fluid as shown in the table VI. Fig. 7 represents the effect of dielectric fluids on dimensional deviations.

Table VI: Dimensional deviation with different dielectric fluids

Dielectric fluid with desired proportion	DOD (mm)	DID	DLAND
Demineralized water (DM)	0.233	0.204	0.115
DM (60%) + Ethylene glycol (EG) (40%)	0.15	0.19	0.093
DM + Alumina powder (20gm)	0.163	0.133	0.078
DM (60%) + EG (40%) + Alumina powder (20gm)	0.177	0.15	0.113
DM (60%) + EG (40%) + Oxygen	0.189	0.117	0.07
DM + Oxygen	0.171	0.117	0.082
DM + Alumina (20gm) + Oxygen	0.177	0.195	0.167
DM (60%) + Alumina (20gm) + EG (40%) + Oxygen	0.196	0.22	0.13

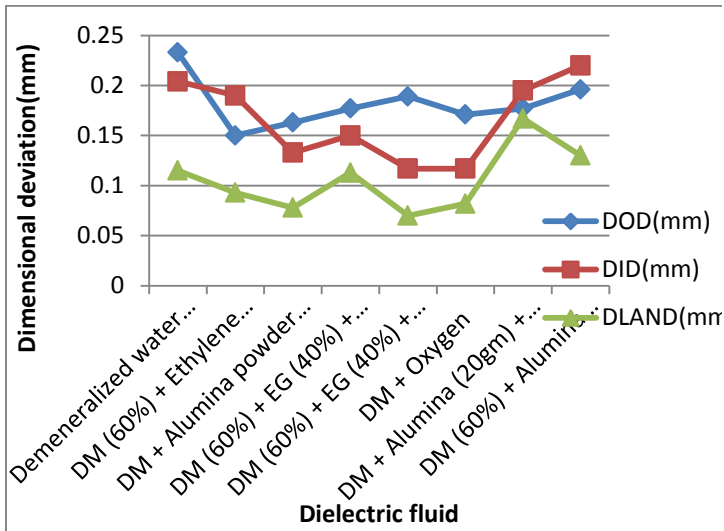


Figure 7: Variation of dimensional deviation with different dielectrics

Dimensional deviations are low while alumina powder mixed demineralized water, ethylene glycol and oxygen mixed demineralized water and oxygen mixed demineralized water are used as dielectric fluids because dielectric strengths of ethylene glycol, alumina powder and oxygen are 35 KV/mm, 15 KV/mm and 0.92 KV/mm respectively which reduce the dielectric strength of base dielectric fluid after mixing with it and further reduce the supply of discharge energy. On the other side demineralized water causes high dimensional deviation because demineralized water is having high dielectric strength of 65 KV/mm which causes large supply of discharge energy.

## IV. Conclusion

In the present study, Titanium alloy miniature gears are manufactured using WEDM and the effects of the process parameters are identified on the dimensional deviation. Selection of the WEDM process parameters are done to achieve minimum dimensional deviation in outer diameter, inner diameter and land. Suitable process parameters are selected such as current, pulse on time, pulse off time, wire tension and dielectric fluids. New dielectric fluids are prepared by mixing alumina nanopowder, ethylene glycol and oxygen in demineralized base water. Following are the findings:

1. The dimensional deviation is high at low value of current because of improper supply of discharge energy. At high value of current again the deviations are high because of high supply of discharge energy which creates larger craters.
2. At low POFF time, time to flush debris from machining surface is not sufficient which results high dimensional deviation. At high POFF time, time to remove debris from the machining surface is sufficient through the flushing of dielectric fluid and it results low deviation in dimensions.
3. At low PON time, the supply of spark energy reduces which further improves the dimensional accuracy. On

the other side as PON time increases, supply of spark energy increases which develops high impact on the machining surface and results high dimensional deviation.

4. Dimensional deviation is reduced at high wire tension because wire is at straight position which decreases the vibrations of the wire and reduces the dimensional deviations.
5. Dimensional deviations are low while alumina powder mixed demineralized water, ethylene glycol and oxygen mixed demineralized water, and oxygen mixed demineralized water are used as dielectric fluids because these mixtures reduces the dielectric strength of the fluids due to their low dielectric strength as compare to dielectric strength of base liquid demineralized water.

## References

- [1] M-T. Yan, G-R. Fang, Y-T. Liu, J-R. Li, (2013) Fabrication of polycrystalline diamond wheels by micro wire-EDM using a novel pulse generator, *Procedia CIRP* 6 203 – 208
- [2] Townsend, D.P., (2011), *Dudley's gear handbook*, Tata McGraw-Hill Publishing Company, New Delhi.
- [3] Davim, P.J., (2010). *Surface Integrity in Machining*, Springer, London, pp. 1-66.
- [4] Benedict, G.F., (1987). *Nontraditional manufacturing processes*, Marcel Dekker, Inc., New York, pp. 207-254.
- [5] Puri, A.B., Bhattacharyya, B., (2003), "An analysis and optimization of the geometrical inaccuracy due to wire lag phenomenon in WEDM", *International Journal of Machine Tools & Manufacture*, 43, pp. 151-159
- [6] Gupta, Kapil & Jain, Neelesh Kumar (2013) *Manufacturing of High Quality Miniature Gears by Wire Electric Discharge Machining*, Chapter 40 in *DAAAM International Scientific Book 2013*, pp. 679-696.
- [7] K. Gupta, N. K. Jain, (2014), *Analysis and optimization of micro-geometry of miniature spur gear manufactured by wire electric discharge machining*, *precision engineering*, 38, 728-737
- [8] Mohammad Yeakub Ali1, A. N. Mustafizul Karim, Erry Yulian T. Adesta, Ahmad Faris Ismail, 'Aisy Anuarin Abdullah and Mohd Nazrol Idris, (2010) *Comparative Study of Conventional and Micro WEDM based on Machining of Meso/Micro Sized Spur Gear*, *International Journal Of Precision Engineering And Manufacturing* Vol. 11, 5, 779-784
- [9] Mohammad Yeakub Ali and Ammar Sami Mohammad, (2008) *Experimental Study of Conventional Wire Electrical Discharge Machining*

- for Microfabrication, *Materials and Manufacturing Processes*, 23, 641–645,
- [10] K. Gupta, S.K. Chaube, N.K. Jain, (2014), exploring WEDM for manufacturing high quality mesogear, *Procedia material science* 5, 1755-1760.
- [11] Kapil Gupta, N.K. Jain, (2013) Deviations In Geometry Of Miniature Gears Fabricated By Wire electrical Discharge Machining, Proceedings of the ASME 2013 International Mechanical Engineering Congress and Exposition IMECE2013 November 15-21, San Diego, California, USA
- [12] K Gupta, NK Jain, (2013) On Micro-Geometry of Miniature Gears Manufactured by Wire Electrical Discharge Machining, *Materials and Manufacturing Processes*, 28, 1153–1159,