DETERMINE THE PROCESS PARAMETERS OF MACHINING OF GEAR ON ELECTRICAL DISCHARGE MACHINING

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ABSTRACT

Micro-wire EDM is an emerging technology in the field of Micro-machining to fabricate very complex micro products. This is used in the fields of dies, molds; precision manufacturing and contour cutting etc. any complex shape can be generated with high grade of accuracy and surface finish using CNC WEDM. The output of the process is affected by large no of input variables. Hence a suitable selection of input variables for the wire electrical discharge machining (WEDM) process depends heavily on the operator's technology & experience. In the present investigation an optimization of micro wire EDM has been carried out using Taguchi method. Using taguchi's parameter design, significant machining parameters affecting the performance measures are identified as pulse off time, pulse on time, and current and optimal parameter setting is proposed. The effect of each control factor on the performance measure i.e. surface roughness, addendum circle, root circle, nose radius is studied individually using the plots of signal to noise ratio and analysis of variance. This work presents an experimental study in which wire EDM operations are performed on material SS-304 Steel plate. The effect of three machining parameters namely pulse on time, pulse off time and current are investigated. Trial run was conducted to establish the range of selected parameters. Subsequently pulse on time at three level , pulse off time at three levels and current at three levels are considered and 9 experiments as per the experimental plan of Taguchi's experimental design i.e. L9 OA are conducted . Five response variable namely Surface roughness, addendum circle, root circle, angle between top land and tooth face, and angle between bottom land and flank are measured. Signal to noise ratio for each response variable are computed. Subsequently, analysis of variance is used to obtain the percentage contribution of the parameters. The analysis of mean is performed to obtain optimum level of the machining parameters for multi performance characteristics. Analysis of variance is used to determine which machining parameters is significantly affected the multi performance characteristics and also to obtain the percentage contribution of each machining parameters towards the objective.

Keyword - *Wire EDM Machine, Taguchi's parameter design, Orthogonal Array, A study on Machining Parameter Optimization*

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1. INTRODUCTION

Electrical discharge machining (EDM) is one of the must extensively used nonconventional, thermo-electric metal removal process which encodes material from the work place by a series of discrete spark between a work and a tool electrode immersed in a liquid dielectric medium. Electrical energy is used directly to cut the material in final shape. Melting and vaporization takes place by theses electrical discharges. The minute a mounts of the work material is then ejected and flushed away by the dielectric medium. The sparks occur at high frequency which continuously and effectively removes the work prices material by melting and evaporation. To initiate the machine process electrode and work piece are separated by a small gap known as 'spark gap' which results into a pulsed discharge causing the removal of material. The dielectric acts as a deionizing medium between two electrodes and its flow helps in vacating the resoliclified debris to assure optimal conditions for spark generation.

In micro-wire EDM operation the work piece metal is cut with a special metal wire electrode that is programmed to travel along a definite path. Spark discharges and generated between a small wire electrode and a work piece to produce complex two dimensional and three-dimensional shapes according to a NC path. A very thin wire in the range of 0.18 mm in diameter as an electrode is used in the wire-cut EDM. It machines a work piece with electrical discharge like a bands haw by moving either the work piece or the wire. The mechanism of metal removal is same as in connectional EDM. The most prominent feature of a moving wire is that a complicated cutout can be early machined without using a forming electrode. The CNC system of wire EDM has the duty to provide the function of geometry trajectory, sequential control, pulse generator control, wire feed and wire tension control and machining process control. The wire transport system of a wire EDM guarantees a smooth wire transport and constant tension of wire. The machine consists of a work piece contour movement control unit, work piece mounting table and wire driven part which ensures accurate movement of the wire oat constant tension. The purpose of WEDM is to achieve better stability and higher productivity, higher machining rate with accuracy. A large number of variables are involved in the process; also the nature of the process is stochastic. Hence even a highly skilled operator is unable to perform the optimal performance.

1.1 Important Features of Micro-wire EDM

1. Electrode wear is negligible.
2. Forming electrode to produce shape is not required.
3. Machined surface are very smooth.
4. Dimensional and Geometrical Tolerances are very tight.
5. Straight hole production is possible with higher precision.
6. Relative tolerance between punch and die is much higher and die life is extended.
7. The machine can be operated unattended for long time at high rate.
8. No special skills are required to run the machine.
9. Any electrically conductive material can be machined irrespective of its hardness.
10. This process allows the shaping and machining of complex structure with high machining accuracy in the order of micron. The surface roughness achievable is Rz = 0 μm.

1.2 Process Parameters of Micro-wire EDM Process

S.No.	Parameters	Range
1	Frequency	0-200KHz
2	Pulse width	1-10 μs
3	Gap% of Voltage	60-100%
4	Gain	0-100
5	Pulse peak currant	40A
6	Output Voltage	60-250V
7	Dwell time	0.205
8	Polarity	+/-
9	Hole diameter	0.05-1mm
10	Spindle speed	100-1000 ___

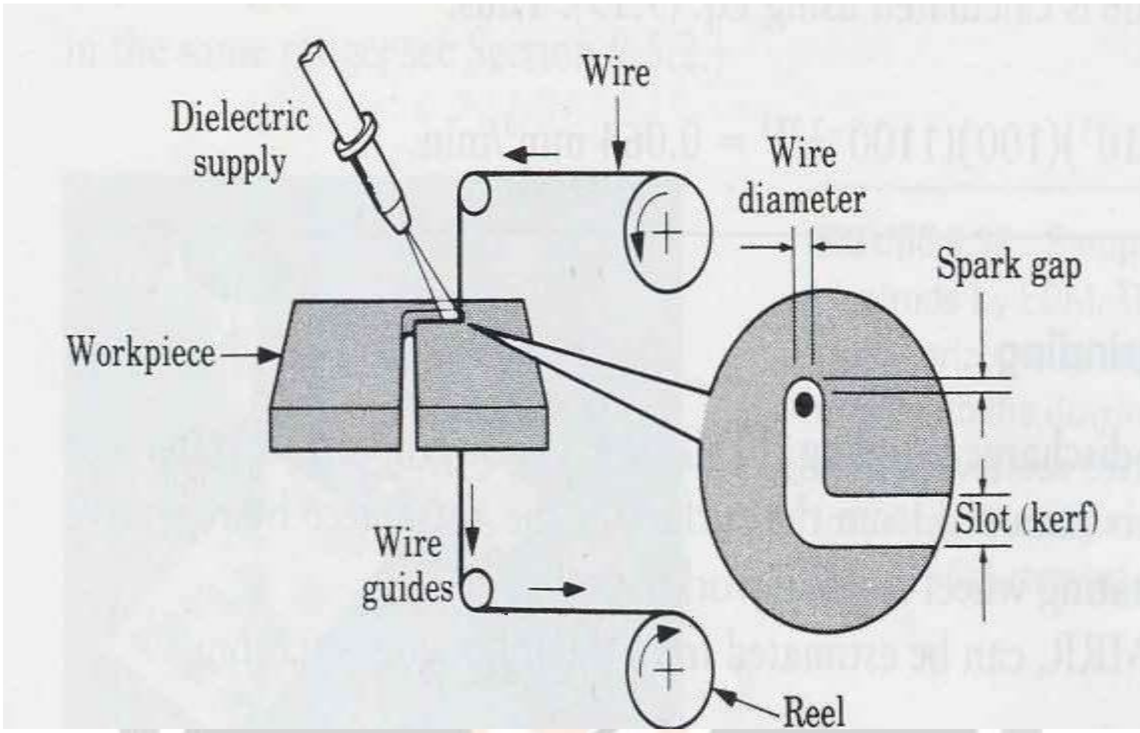
Table-1.1 Process Parameter

Machine Parameters:

1. Pulse on time.
2. Pulse off time.
3. Current.

Wire Parameters:

1. Material of wire.
2. Diameter of wire.
3. Wire speed.
4. Wire tension.



2. Monitoring and control of micro-wire EDM:

In this paper presented by Mu-Tian Yan description about the development of a new monitoring and control system has been given. it contains a new pulse discriminating and control system has been given. it contains a new pulse discriminating and control system which identifies four major gap states categorized as –

1. Open circuit
2. Normal spark
3. Arc discharge
4. Short circuit

Observing the characteristics of gap voltage waveform investigations were made to study the influence of machining feed rate, pulse interval and thickness of the work piece on the variation of proportion of normal discharge, arc discharge and short circuit (also known as normal ratio arc ratio and short ratio respectively). observations reflects that high machining feed rate or increase of work piece height results in increase of short ratio .Also it is observed that long pulse interval causes an increase in the short ratio under a constant feed rate .A control strategy is devised to achieve the stability of the machining operation. It is done by regulating the pulse interval of each spark in real time based on identified gap states.

2.1 Material Selection and Its Properties

To perform this experiment material selected is Stainless Steel SS-304. Chemical composition of this stainless steel is given in table 3.1. Physical properties of this alloy are as follows: Density is 8.03 g/cm3, Poisson's ratio is 0.275, Elastic modulus is 193 GPa, tensile strength is 621 MPa, yield strength is 290 MPa and thermal conductivity is 100 C.

Elements	Mn	Si	Ni	C	Cr	S
Percentage	2.000	0.75	12.00	0.08	20.00	0.530

Table 1.2 Chemical composition of Stainless Steel SS-304

The selected Stainless Steel SS-304 is available in the form of flat rectangular bar of cross sectional area 63mm X 6mm and length of 610mm is purchased from local market.

Figure 1.2 Stainless Steel SS-304 flat

2.2Wire EDM Machine

The wire EDM in figure 3.2 represents current technology. The system consists of a CNC control, power supply with anti-electrolysis circuitry, automatic wire threading, hand held pendant, programmable Z-axis, water chiller and filtration system.

2.3Experimental Methodology:

STEER CORPORATION DK7712 NC WEDM machine was used to perform the experiments.
Molybdenum wire with 0.18mm diameter was used in the experiment. The work piece material ,SS-304 hot die steel with 100mm×100mm×5mm was used. During the experiment external gear having diameter of 10 mm was cut. Molybdenum wire with 0.18 diameters was used in the experiment.

2.4 Experimental Setup for Testing

In this set up main focus is on testing Gear manufacturing of stainless steel (SS-304). In our project Surface roughness testing machine that was prepared after gear manufacturing is visually inspected for any kind of defect and its mechanical property i.e. surface roughness is also verified. Set up required for testing are as follows:-

2.4.1WIRE EDM Machine

Wire EDM's are manufactured in various sizes and styles of flush or submerged type machines to fit the needs of the consumer. Large scale EDM's can handle work pieces weighing over ten thousand pounds and can cut over twenty inches thick. Automatic Wire Threaders (AWT) is usually standard equipment on most models. In addition to the X-Y table travels, wire EDM's have U / V travels for providing the movement to cut tapers. Most machines can cut tapers of 20-30 degrees depending on work piece thickness.

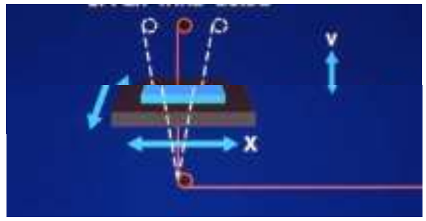


Figure 1.4 Wire EDM Machine

2.4.2 Testing specimen

The specimen is made of stainless steel ss-304 plate. The gear manufacturing was obtained by machining of stainless steel SS-304 with the help of wire EDM machine and molybdenum wire use as a tool. The gear is inspected by surface roughness tester machine and stereo zoom microscope, for measuring Ra (surface roughness) and gear profile. Figure 3.6 shows the specimen

Fig1.5:- Surface Roughness Test Specimen

3. The steps suggested by Taguchi

Determine the quality characteristic to be optimized: The first step in the Taguchi method is to determine the quality characteristic to be optimized. The quality characteristic is a parameter whose variation has a critical effect on product quality.

Identify the noise factors and test conditions: The next step is to identify the noise factors that can have a negative impact on system performance and quality.

Identify the control parameters and their alternative levels: The third step is to identify the control parameters thought to have significant effects n the quality characteristic. Control (test) parameters are those design factors that can be set and maintained. The levels (test values) for each test parameter must be chosen at this point.

Design the matrix experiment and define the data analysis procedure: The next step is to design the matrix experiment and define the data analysis procedure. First, the appropriate orthogonal arrays for the noise and control parameters to fit a specific study are selected.

Conduct the matrix experiment: The next step is to conduct the matrix experiment and record the results.

Analyze the data and determine the optimum levels for control factors: After the experiments have been conducted, the optimal test parameter configuration within the experiment design must be determined. To analyze the results, the Taguchi method uses a statistical Journal of Engineering Research and Studies E-ISSN0976-7916 JERS/Vol.III/ Issue I/January-March, 2012/70-74 measure of performance called signal to noise (S/N) ratio.

Predict the performance at these levels: The final step is an experimental confirmation run using the predicted optimum levels for the control parameters being studied.

4. ANALYTICAL PROCEDURE

4.1 Design of experiments

It is based on Taguchi's concept which have been in developed into an engineering method of quality improvement referred to as quality engineering in Japan and as robust design in the west, which is discipline engineering process that seeks to find best trade off a product design. Concepts technique used in robust design Taguchi's concept such as "quality", S/N Ratio, Orthogonal arrays Degree of freedom and analysis of variance " may be synthesis in engineering studies. The quality lose function is considered as an innovative means for determining the economic advantage of improving system safety or operational safety .orthogonal arrays are used to study many parameters simultaneously with a minimum of time and resources to produce an overall pictures for more detailed safety based design an operational decision making. The Signal to noise ratio is employed to measure quality.

4.2 Machining factors

The machining factors and their levels used in present study as shown in table 3.3.

Table 1.3: Machining factors and their levels

Factors	Level-1	Level-2	Level-3
Pulse on time	15	20	25
Pulse off time	4	5	6
Current	3	4	5

4.3 Orthogonal arrays

Taguchi's has developed a system of tabulated designs (arrays) that allow for the maximum number of main effects to be estimated in an unbiased (orthogonal) manner, with a minimum number of runs in the experiment. Orthogonal arrays [6] are used to systematically vary and test the different levels of each of the control factors. Commonly used Oas includes the L4, L9, L12, L18, and L27. The columns in the OA indicate the factor and its corresponding levels, and each row in the OA constitutes an experimental run which is performed at the given factor settings. Typically either 2 or 3 levels are chosen for each factor. Selecting the number of levels and quantities properly constitutes the bulk of the effort in planning robust design experiments.

Exp no.	A	B	C
1	1	1	1

2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

TABLE 1.4: Orthogonal Array L9

4.4 Signal to noise ratio and ANOVA approach

The S/N ratio developed by Dr. Taguchi [6] is a performance measure to choose control levels that best cope with noise. The S/N ratio takes both the mean and the variability into account. In its simplest form, the S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The S/N equation depends on the criterion for the quality characteristic to be optimized. While there are many different possible S/N ratios, three of them are considered standard and are generally applicable in the situations below:

- Biggest-is-best quality characteristic (strength, yield),
- Smallest-is-best quality characteristic (contamination),
- Nominal-is-best quality characteristic (dimension).
-

In addition to the Signal to Noise Ratio (S/N ratio), the obtained results have been tested using statistical Analysis of Variance (ANOVA) with Pareto chart to indicate the impact of process parameters on surface roughness. The reason of combining Pareto chart with Analysis of Variance was to detect causes applying the principle that 80 percent of the problems usually stem from 20 percent of the causes. Pareto ANOVA technique of analysis has been used in this experimentation to analyze data for process optimization in past research also. Pareto ANOVA is a simplified ANOVA method, which uses Pareto principle. It is a quick and easy method to analyze result of parameters design. It does not require an ANOVA table and therefore, does not use F-test. The calculations of these tables are done by the use of standard orthogonal arrays. The preferred parameter settings are then determined through analysis of the “signal-to-noise” (SN) ratio where factor levels that maximize the appropriate SN ratio are optimal. There are three standard types of SN ratios depending on the desired performance response.

1.Smaller the better (for making the system response as small as possible)

$$SNs = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^{\,2}\right) \quad \text{………….. 3.1}$$

2. Nominal the best (for reducing variability around a target):

$$SN_T = 10 \log \left(\frac{\overline{y}^2}{S^2} \right) \quad \ldots\ldots\ldots\ldots\ldots \; 3.2$$

3. Larger the better (for making the system response as large as possible):

…………………….3.3

These SN ratios are derived from the quadratic loss function and are expressed in a decibel scale. Once all of the SN ratios have been computed for each run of an experiment, Taguchi advocates a graphical approach to analyze the data. In the graphical approach, the SN ratios are plotted for each factor against each of its levels. Finally, confirmation tests should be run at the "optimal" product settings to verify that the predicted performance is actually realized. 2. 5 Steps applied in Taguchi methods Taguchi proposed a standard procedure for applying his method for optimizing any process.

5. Orthogonal Array& array Selector

Dr. Taguchi's Signal-to-Noise ratios, which are log functions is based on orthogonal Array experiments which gives much reduced variance for the experiment with optimum settings of control parameters. Orthogonal Array provide a set of well balanced minimum experiments and desired output which serve as objective functions for optimization and helps in data analysis and prediction of optimum results.

Orthogonal Arrays significantly reduces the number of experimental configurations to be studied Montgomery, (1991). The effect of many different parameters on the performance characteristic in a process can be examined by using the orthogonal array experimental design proposed by Taguchi. Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. Determining what levels of a variable to test requires an in depth understanding of the process, including the low, medium, and high value of the parameter. If the difference between the low and high value of a parameter is large, the values being tested can be further apart or more values can be tested.

If the range of a parameter is small, then less value can be tested or the values tested can be closer together

Number of Levels	Number of Parameters (P)														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32						
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50				

Number of Levels	Number of Parameters (P)														
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L36	L36	L36	L36	L36	L36	L36								
4															
5															

Table 1.6 Array Selectors

In Taguchi method to increase the experimental efficiency, the L9 mixed orthogonal table designed by Ross in 1988 is used for design of experiment (table 1.3). In this table P1, P2, P3 and P4 represents parameters and 1, 2 and 3 represents low, medium and high level respectively. Process parameters that can be select in this experiment are cutting tools of different materials, depth of cut, cutting speed, feed-rate, working temperature etc.

Experiment	P1	P2	P3	P4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 1.7 Design of experiment table.

5.1 Signal to Noise ratio

S/N ratio is a measure of robustness used to identify control factors that reduce variability in a product or process by minimizing the effects of uncontrollable factors (noise factors). Control factors are those design and process parameters that can be controlled. Noise factors cannot be controlled during production or product use, but can be controlled during experimentation. Signal factor is a factor, with a range of settings that is controlled by the user of the product to make use of its intended function. Signal factors are used in dynamic experiments, in which the response is measured at each level of the signal. Higher values of the signal-to-noise ratio (S/N) identify control factor settings that minimize the effects of the noise factors.

The Response table contains a row for the average signal to noise ratio for each factor level, Delta, and Rank. The table contains a column for each factor. Delta is the difference between the maximum and minimum average signal to noise ratios for the factor. The Rank is the rank of each Delta, where Rank 1 is the largest Delta.

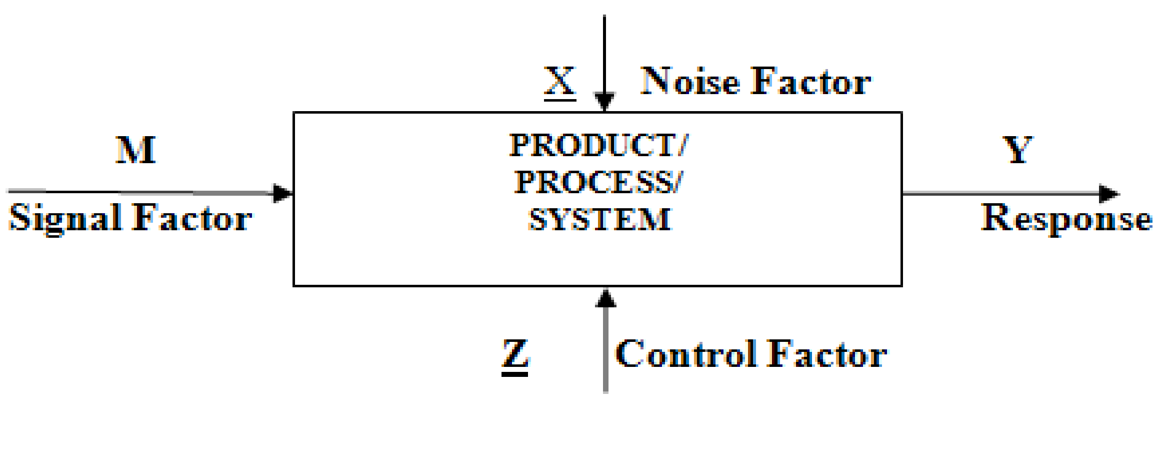


Fig 1.8 Diagram of Product/Process/System

Figure 1.2 Parameter diagrams of Product / Process / System

Taguchi specified three situations, on this basis expression for signal to noise ratio is to be selected. The situations are given as follows:

Larger the better (for example, agricultural yield)

$S/N = -10 \log \{1/n\Sigma(1/Y2)\}$

Smaller the better (for example, carbon dioxide emissions)

$S/N = -10 \log (\sigma 2)$

On-target, minimum-variation (for example, a mating part in an assembly)

$$S/N = 10 \times \log((\bar{Y}^2) \div \sigma^2)$$

5.2Objectives of the Research Work

The prime objectives of the present research work were:

1. To explore the capability of WEDM for manufacturing high quality miniature Gears.
2. To analyze the effect of WEDM parameters on micro-geometry and surface Roughness of miniature gears.
3. To optimize the WEDM parameters to minimize the surface roughness.
4. To establish WEDM as a superior alternative process for manufacturing the high Quality miniature gears.

6. CONCLUSIONS

This work presents an experimental study in which wire EDM operations are performed on material SS-304 Steel plate. The effect of three machining parameters namely pulse on time ,pulse off time and current are investigated. Trial run was conducted to establish the range of selected parameters. Subsequently pulse on time at three level , pulse off time at three levels and current at three levels are considered and 9 experiments as per the experimental plan of Taguchi's experimental design i.e. L9 OA are conducted . Five response variable namely Surface roughness, addendum circle, root circle, angle between top land and tooth face, and angle between bottom land and flank are measured. Signal to noise ratio for each response variables are computed. Subsequently, analysis of variance is used to obtain the percentage contribution of the parameters. The analysis of mean is performed to obtain optimum level of the machining parameters for multi performance characteristics. Analysis of variance is used to determine which machining parameters is significantly affected the multi performance characteristics and also to obtain the percentage contribution of each machining parameters towards the objective. The results of the present study the following conclusion are drawn:

- The optimum combination of machining parameters and their level in surface roughness areA3,B3,C1
- The optimum combination of machining parameters and their levels for decreasing the deviation in addendum circle are A3,B2,C2
- The optimum combination of machining parameters and their levels for decreasing the deviation in root circle are A2,B1,C2
- The optimum combination of machining parameter for angle between top land and tooth face are A2,B1,C3.
- The optimum combination of machining parameter for angle between top land and tooth face are A2,B3,C1.
- Pulse on time, pulse off time ,and current are significantly affect the surface roughness, addendum circle, root circle, angle between top land and tooth face, angle between bottom land and flank.
- The percentage contribution of surface roughness are current (41.95%), pulse off time (29.12%), pulse on time (27.36%).
- Pulse on time is least significant factor for surface roughness.
- The percentage contribution of addendum circle are current (33.82%), pulse on time (33.25%), pulse off time (32.69%).
- Pulse off time is least significant factor for addendum circle.
- The percentage contribution of root circle are pulse off time (59.55%),pulse on time (26.31%), current(13.33%).
- Current is least significant factor for root circle.
- The percentage contribution of angle between top land and tooth face are current (41.23%), pulse off time (38.21%), pulse on time (32.56%).
- Pulse on time is least significant factor for angle between top land and tooth face.
- The percentage contribution of angle between bottom land and flank are current (38.31%), pulse on time (26.43%), pulse off time (23.64%).
- Pulse off time is least significant factor for angle between bottom land and flank.

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