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# Plastic Moulded Gear Blank Dimensional Conformance Using Grey Relational Analysis

KEYWORDS: Dimensional conformance, Taguchi technique, Orthogonal Array, Grey Relational Analysis

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**ABSTRACT**
*Moulded plastic gearing is rapidly becoming a real contender in moderate power gearing applications. Maintaining the accurate dimensions of the gear (e.g. diameter and thickness) is the stringent requirement from the designer and becomes the challenge for manufacturer. In this paper, major focus is given on the optimizing the process parameters of injection moulding so that the robust system can be defined which can give the dimensional control on gear diameter and thickness. The process parameters chosen are Injection Pressure, Holding Pressure, Cooling Time, Hold on Time, Temperature and Injection Speed. For reliable experimentation, three levels are taken for each factor. Taguchi technique has been used to decide the number of experiments to be carried out and as per that L27 Orthogonal Array (OA) has been used. After conducting experiments using L27 OA, the results obtained are used to optimize the process parameters using Grey Relational Analysis (GRA) approach.*

**INTRODUCTION:**
Along with the rapid progress of production techniques for high-tech products, better quality of products is required for the survival in the current market. Besides providing various functions, the trend of the design for plastic products is light, thin, short, and small. Therefore, the setting of process parameters for plastic products has a remarkable influence on their quality. Injection molding is one of the most important techniques for polymer processing (to manufacture plastic products) because of its high speed for molding and its capability of manufacturing complex geometric shapes of products. Besides, injection molding is capable of mass production, so it is widely used for many products, especially for electronic products, such as computers and communication products. Injection molding is usually adopted to produce thin parts or thin covers for these products.

Plastic injection molding uses plastic in the form of pellets or granules as a raw material. It is then heated until a melt is obtained. Then the melt is injected into a mould where it is allowed to solidify to obtain the desired shape. The mould is then opened and the part is ejected. The process parameters such as cycle time, fill time, cooling time, injection time, injection speed, injection pressure, holding pressure, melting temperature, mould temperature and so on need to be optimized in order to produce finished plastic parts with good quality. Various studies have been conducted to improve and optimize the process, so as to obtain high quality parts produced on a wide range of commercial plastic injection molding machines.

For any experiments, deciding the number of experiments to be carried out is the key issue and Taguchi method helps to select minimum number of experiments.

**2. Taguchi Method:**
The control factors that may contribute to reduced variation and improved quality can be identified by the amount of variation present and by the shift of mean response when there are repetitive data. The SN ratio transforms several repetitions into one value which reflects the amount of variation present and the mean response. There are several SN ratios available depending on the type of characteristic: continuous or discrete; nominal-is-best, smaller-the-better or larger-the-better. In this section we will only discuss the case when the characteristic is continuous. The discrete case will be explained later.

(i) Nominal is Best Characteristics (ii) Smaller the Better Characteristics (iii) Larger the Better Characteristics.

**Orthogonal Arrays (OA) Selection:**
An orthogonal array is a fractional factorial matrix which assures a balanced comparison of levels of any factor or interaction of factors. It is a matrix of numbers arranged in rows and columns where each row represents the level of the factors in each run, and each column represents a specific factor that can be changed from each run. The array is called orthogonal because all columns all columns can be evaluated independently of one another.

For achieving dimensional conformance of gear blank, based on the literature review and peer discussion, following factors and their levels has been selected.

**Table 1. Factor and its Level**

| Factor | | | | Level | | |
|---|---|---|---|---|---|---|
| | **Description** | **Symbol** | **Unit** | **1** | **2** | **3** |
| A | Injection Pressure | $P_I$ | bar | 55 | 60 | 65 |
| B | Holding Pressure | $P_H$ | Bar | 25 | 30 | 35 |
| C | Cooling Time | $t_C$ | sec | 25 | 30 | 35 |
| D | Hold on Time | $t_H$ | sec | 2 | 3 | 4 |
| E | Temperature | T | $^0$C | 190 | 200 | 210 |
| F | Injection Speed | $V_I$ | mm/sec | 35 | 40 | 45 |

For six factors and three levels the L27 Orthogonal Array has been selected and is given in Table 2.

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**Table 2: $L_{27}$ Orthogonal Array and Results**

| Test No. | Factors | | | | | | Response | |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | Thickness | Diameter |
| 1 | 55 | 25 | 25 | 2 | 190 | 190 | 3.25 | 97.5 |
| 2 | 55 | 25 | 25 | 2 | 200 | 200 | 3.23 | 98.59 |
| 3 | 55 | 25 | 25 | 2 | 210 | 210 | 3.25 | 98.6 |
| 4 | 55 | 30 | 30 | 3 | 190 | 190 | 3.22 | 98.83 |
| 5 | 55 | 30 | 30 | 3 | 200 | 200 | 3.26 | 98.87 |
| 6 | 55 | 30 | 30 | 3 | 210 | 210 | 3.23 | 98.67 |
| 7 | 55 | 35 | 35 | 4 | 190 | 190 | 3.23 | 98.91 |
| 8 | 55 | 35 | 35 | 4 | 200 | 200 | 3.25 | 98.62 |
| 9 | 55 | 35 | 35 | 4 | 210 | 210 | 3.25 | 98.7 |
| 10 | 60 | 25 | 30 | 4 | 190 | 190 | 3.27 | 98.85 |
| 11 | 60 | 25 | 30 | 4 | 200 | 200 | 3.22 | 98.87 |
| 12 | 60 | 25 | 30 | 4 | 210 | 210 | 3.25 | 98.7 |
| 13 | 60 | 30 | 35 | 2 | 190 | 190 | 3.26 | 98.71 |
| 14 | 60 | 30 | 35 | 2 | 200 | 200 | 3.22 | 98.64 |
| 15 | 60 | 30 | 35 | 2 | 210 | 210 | 3.23 | 98.64 |
| 16 | 60 | 35 | 25 | 3 | 190 | 190 | 3.28 | 98.77 |
| 17 | 60 | 35 | 25 | 3 | 200 | 200 | 3.24 | 98.79 |
| 18 | 60 | 35 | 25 | 3 | 210 | 210 | 3.22 | 98.53 |
| 19 | 65 | 25 | 35 | 3 | 190 | 190 | 3.24 | 98.79 |
| 20 | 65 | 25 | 35 | 3 | 200 | 200 | 3.22 | 98.71 |
| 21 | 65 | 25 | 35 | 3 | 210 | 210 | 3.22 | 98.78 |
| 22 | 65 | 30 | 25 | 4 | 190 | 190 | 3.23 | 98.76 |
| 23 | 65 | 30 | 25 | 4 | 200 | 200 | 3.25 | 98.9 |
| 24 | 65 | 30 | 25 | 4 | 210 | 210 | 3.22 | 98.88 |
| 25 | 65 | 35 | 30 | 2 | 190 | 190 | 3.22 | 98.66 |
| 26 | 65 | 35 | 30 | 2 | 200 | 200 | 3.26 | 98.62 |
| 27 | 65 | 35 | 30 | 2 | 210 | 210 | 3.28 | 98.55 |

**3. EXPERIMENTAL SETUP: The experiment is carried out on L&T Microprocessor Controlled injection molding machine whose specifications are given below**


**Figure 1. L & T Plastic Injection Moulding Machine**

| | |
|---|---|
| Machine Code | CBD/PP/MC/014 |
| Machine Manufacturer | M/s L&T DEMAG Plastics Machinery Ltd |
| Clamping Force | 85 T |
| Shot Capacity | 96 grams |
| Screw Diameter | 30 mm |
| Injection Pressure | 2755 bar |
| Injection Rate | 67 gm/sec |
| Screw Stroke | 178 mm |
| Maximum Nozzle Depth | 45 mm |
| Mould Opening/Closing Stroke | 350 mm |
| Mould Height (Min/Max) | 200 mm / 500 mm |
| Machine Day Light | 850 mm |
| Platen Size | 508 mm × 508 mm |
| Distance Between The Tie Bars | 420 mm × 420 mm |
| Ejector Stroke (max) | 120 mm |
| Screw L/D Ratio | 20:01 |

**Test Specimen:**
High Density Polyethylene (HDPE) is a thermoplastic material which is supplied by the manufacturer in a 'ready to use' palletised form.

**Figure 2.HDPE Granules**

**Figure 3. Test specimens**

**4 GREY RELATIONAL ANALYSIS (GRA):**
In grey relational analysis, black represents having no information and white represents having all information. A grey system has a level of information between black and white. This analysis can be used to represent the grade of correlation between two sequences so that the distance of two factors can be measured discretely. In the case when experiments are ambiguous or when the experimental method cannot be carried out exactly, grey analysis helps to compensate for the shortcoming in statistical regression. Grey relation analysis is an effective means of analyzing the relationship between sequences with less data and can analyze many factors that can overcome the disadvantages of statistical method. Grey relational analysis is widely used for measuring the degree of relationship between sequences by grey relational grade. Grey relational analysis is applied by several researchers to optimize control parameters having multi-responses through grey relational grade.

Data pre-processing is the first stage in grey analysis since the range and unit in one data sequence may differ from the others. Data pre-processing is a means of transferring the original sequence to a comparable sequence. Depending on the characteristics of a data sequence, there are various methodologies of data pre-processing available for this analysis.

Experimental data yij is normalized as Zij ($0 \le Zij \le 1$) for the $i^{th}$ performance characteristics in the $j^{th}$ experiment can be expressed as:

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For S/N ratio with Larger-the-better condition

$$Z_{ij} = \frac{y_{ij} - min(y_{ij}, i = 1,2..n)}{max(y_{ij}, i = 1,2..n) - min(y_{ij}, i = 1,2..n)}$$

For S/N ratio with Smaller-the-better condition

$$Z_{ij} = \frac{max(y_{ij}, i = 1,2..n) - y_{ij}}{max(y_{ij}, i = 1,2..n) - min(y_{ij}, i = 1,2..n)}$$

For S/N ratio with Nominal-the-better condition

$$Z_{ij} = \frac{(y_{ij} - Target) - min(|y_{ij} - Target|, i = 1,2..n)}{max(|y_{ij} - Target|, i = 1,2..n) - min(|y_{ij} - Target|, i = 1,2..n)}$$

According to Deng, larger normalized results correspond to better performance and the best normalized result should be equal to one. Then, the grey relational coefficients are calculated to express the relationship between the ideal (best) and the actual experimental results.

The Grey relational Co-efficient $\gamma_{ij}$ can be expressed as:

$$\gamma_{ij} = \frac{\Delta min + \xi \Delta max}{\Delta_{oi}(k) + \xi \Delta max}$$

Where,

a. j=,2…m, 1,2…n; k=1n is the number of experimental data items and m is the number of responses.

b. $y_o(k)$ is the reference sequence ($y_o(k)=1$, k=1,2…m); $y_i(k)$ is the specific comparison sequence.

c. $\Delta_{oj} = \|y_{ok} - y_{jk}\|$=The absolute value of the difference between $y_o(k)$ and $y_i(k)$

d. $\Delta_{min} = \underset{\forall j \epsilon i \ \forall k}{minmin} \|y_{ok} - y_{jk}\|$ is the smallest value of $y_j(k)$

e. $\Delta_{max} = \underset{\forall j \epsilon i \ \forall k}{maxmax} \|y_{ok} - y_{jk}\|$ is the largest value of $y_j(k)$

f. $\xi$ is the distinguishing coefficient which is defined in the range $0 \le \xi \le 1$ (the value may adjusted based on the practical needs of the system, it will be 0.5 generally)

The Grey relational grade $\bar{\gamma}_j$ is expressed as:

$$\bar{\gamma}_j = \frac{1}{k} \sum_{i=1}^{m} \gamma_{ij}$$

From the above discussion, the use of the quantity model of grey relational analysis establishes the analytic processing step that includes the following steps:

**Step 1.** Normalizes the experimental results of each performance characteristic.

**Step 2.** Calculate the grey relational coefficient.

**Step 3.** Calculates the grey relational grade by the mean value of grey relational coefficient.

**Step 4.** Performs the response table and response graph for each level of the machining parameters.

**Step 5.** Recognizes the noticeable and unnoticeable variable factors and selects the optimal levels of machining parameter.

**Step 6.** Confirms the test and verifies the optimal levels of machining parameter.

**Table 3: Grey Relational Grade and Rank**

| Level | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | 0.745608 | 0.742238 | 0.744462 | 0.763926 | 0.735408 | 0.741592 |
| 2 | 0.720547 | 0.714914 | 0.719006 | 0.713688 | 0.719688 | 0.723049 |
| 3 | 0.718376 | 0.727378 | 0.721062 | 0.706917 | 0.729434 | 0.719889 |
| Δ | 0.027232 | 0.027325 | 0.025456 | 0.057009 | 0.01572 | 0.021704 |
| Rank | 3 | 2 | 4 | 1 | 6 | 5 |

**Confirmation Tests:**

Confirmation or Verification tests were carried out to check the variability between the theoretical results obtained through Grey Relational analysis and the actual tests. This will help to understand the robustness of the designed system


**Figure 4. Confirmation Test Specimens**

**Table 4. Confirmation Test Results**

| Sr. No. | Confirmation Test No. | Diameter | | % Deviation | Thickness | | % Deviation |
|---|---|---|---|---|---|---|---|
| | | Theoretical | Actual | | Theoretical | Actual | |
| 1 | C01 | 98.0996 | 98.02 | 0.08 | 3.2029 | 3.05 | 4.77 |
| 2 | C02 | 98.0996 | 98.10 | 0.0004 | 3.2029 | 3.13 | 2.27 |

**5.CONCLUSION**

The research activity carried out founds successful for achieving the dimensional conformance (i.e. maintaining desired values of diameter and thickness of gear blank within close tolerance). It is seen that the Taguchi method is best suitable for deciding the number of experiments to be carried out and Grey Relational Analysis (GRA) can be used for solving multi-response optimization problems. Injection Pressure ($A_1$ = 55 bar), Holding Pressure ($B_1$ = 25 bar), Cooling time ($C_1$ = 25 sec), Hold on Time ($D_1$ = 2sec), Temperature ($E_1$ = 190 $^0$C) and Injection Speed ($F_1$ = 35 mm/sec) is the optimum process parameter combination giving the dimensional values, diameter = 98.02 mm and thickness = 3.05 mm, which are very close to desired one.

(1) Hold on Time (2) Holding Pressure (3) Injection Pressure (4) Cooling time (5) Injection Speed (6) Temperature.

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