GREY RELATIONAL ANALYSIS TO DETERMINE THE OPTIMUM PROCESS PARAMETERS FOR WORM GEAR REDUCER

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ABSTRACT **-**This article focuses on an approach based on the grey relational analysis for optimizing the process parameters for worm gear reducer with multiple performance characteristics. A grey relational grade obtained from the grey relational analysis is used to optimize the process parameters. Optimal process parameters can be determined by the Taguchi method using the grey relational grade as the performance index. Churning power loss and efficiency of gear were selected as quality characteristics. Using these characteristics, the process parameters, including worm shaft speed, immersion depth of oil inside the gearbox and Temperature of oil in housing are optimized. The raw materials used in this investigation were CuSn12 for worm gear and 16MnCr5 for worm shaft. The Experimental results show parameter immersion depth (oil depth) has the most significant effect on the multiple performance characteristics.

Keywords **-Worm gear, Grey relational analysis, Churning power loss, Efficiency of worm gear**

1. INTRODUCTION

Worm and wheel gears are widely used for nonparallel, nonintersecting, right angle gear drive system applications where a high transmission gearing ratio is required. The worm gearbox is widely used for high reduction ratios, because it can pro- vide both “small cost” and “small size” by allowing a single reduction unit to be used for many application.[1] In comparison to other type of gears, the worm gear has a lower value of the efficiency. The reason for the difference between the invested and the useful power is the power losses occurring in the gear reducer.[2] Power losses in gearbox can be isolated into load dependent losses and non-load dependent losses. Load dependent losses comprise of gear contact loss and bearing grinding loss.[3] Then again, non-load dependent losses comprise of oil seal loss, gear churning and windage loss and bearing churning and windage loss. The magnitude of the gear churning power losses of worm gears and their causes were examined in this paper and also analyzed the effect of churning power loss on efficiency of gear.

A common way to lubricate worm gearboxes is dip lubrication. The gears are partially immersed in the oil sump at the bottom of the gearbox housing, and as they rotate during operation they lubricate the whole gearbox by dragging and splashing the lubricant around, including onto the gear mesh. Dragging in the lubricant is called churning.[4]–[7] The results of several investigations on other gear [8], [9] have revealed that parameters such as speed, immersion depth of oil inside the gearbox and Temperature of oil in housing affect churning power loss and also efficiency Thus, the optimum machine parameters will be important to achieve the best desired properties.

Previously, the Taguchi Method was used to analyze optimal process parameters of a single quality characteristic. This method focused on optimizing a single quality response. However, products in some processes have more than one quality response which should be considered. The Taguchi method primarily uses engineering judgment to decide optimal factor levels for multi-responses, which increases uncertainty during the decision-making process. This problem can be solved by the grey system theory introduced by Deng. By comparing the computed grey relational grades, the arrays of respective quality characteristics are obtained in accordance with response grades to select an optimal set of process parameters.[10]

In this paper, using the grey relational method,different process parameters of the worm shaft speed, immersion depth of oil inside the gearbox and Temperature of oil in housing were optimized to achieve the best multiple quality characteristics.

2. EXPERIMENTAL WORK

The schematic representation of the test rig used in this study is presented in figure 1 An electric engine works the worm gear by means of an adaptable coupling through torque sensor. Amid this work, the speed was connected to the worm gear box up to a greatest estimation of 1500 rpm. The torque was calculated with oil and without oil experiment by torque sensor through direct torque measurement technique. Thermocouples were put at better place to quantify the temperature of housing, bearing and oil as appeared. Output power was calculated by rope brake dynamometer. The above parameters are sufficient to get churning power loss and efficiency of worm gear. For this experiment standard size of worm gear box was selected having 3” center distance and 30:1 reduction ration.Geametry and lubrication details are given in table 1 and table 2 respectively.

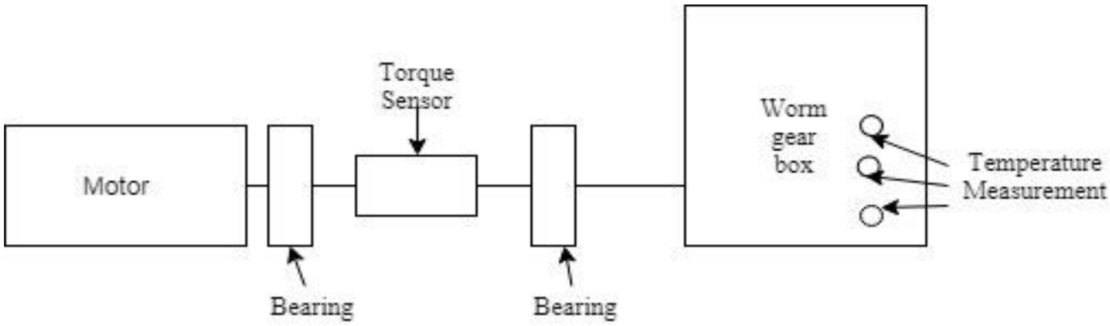

Fig 1 layout of churning power loss of worm gear test rig

Table 1. Geometry of worm gear

Parameter	Unit	Worm gear	Worm shaft
Number of teeth		30	Single started
Module	mm	3	
Pressure angle	º	20	
Center distance	mm	75	
Operative diameter	mm	122	30

Table 2. Property of Oil

Sr.No	Type of oil	Kinamatic Viscosity @ 40 ºC	Kinamatic Viscosity @ 100 ºC	Viscosity Index	Density(Kg/m3)
1	SP grade 320	320	40	95	900

Based on the requirement that the degree of freedom of the orthogonal field is greater than or equal to the sum of the efficiency and churning power loss, the standard orthogonal matrix L9 is selected. The considered factors are: the input number of revolutions, immersion depth of oil inside the gearbox and Temperature of oil in housing, and all factors are the third level. Table 3 shows the control factors with their considered levels.

Table 3. Levels of control factors

Control factors	Unit	Level 1	Level 2	Level 3
(A) Speed of worm (rpm)	rpm	1300	1400	1500
(B) Immersion depth	mm	95	140	175
(C)Temperature	oC	40	45	50

Experiment design and the result of experiment is shown in table 4 and table5.Table 5 shows the churning power loss and efficiency of worm gear reducer at different level.

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Table 4. Experimental layout using an L9 orthogonal array.

Experiment No	Worm gear box factors and level		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 5. Experimental result for churning power loss and effieciency

Experiment No	Churning power loss(W)	Efficiency
1	32.62	0.32
2	50.84	0.34
3	62.69	0.31
4	19.36	0.33
5	33.84	0.43
6	87.37	0.35
7	14.79	0.36
8	69.28	0.42
9	86.03	0.31

3. GRAY RELATIONAL ANALYSIS

The grey relational analysis is the multi response optimization process applied to find the optimum combination of the process parameters and also to examine the influence of each input parameter on the response characteristics. This processneeds asample that consists of a limited size with discrete chronological data in order to facilitate reliable modelling and estimation of thesystem behavior. The following steps can be employed for the GRA:

3.1. Data processing and normalizing

Since, the output characteristics such as churning power loss and efficiency are needed to be maximized and minimized, the higher the better and the smaller the better characteristic is chosen. It is necessary to normalize the output responses before analyzing them with the grey relational theory.[11] Normalization for the experimental results of each response is done and also rated between 0 and 1. The normalization for the output characteristics is calculated by using Eq. (1) and Eq. (2). Eq. (1) is for higher the better attributes or criterion and Eq. (2) is used for smaller the better attributes or criterion. Churning power loss comes under smaller is better and efficiency comes under larger us better.

$$Z_{ij} = \frac{y_{ij} - Min\{y_{ij}, i = 1, 2, ..., n\}}{Max\{y_{ij}, i = 1, 2, ..., n\} - Min\{y_{ij}, i = 1, 2, ..., n\}} \quad (1)$$

$$Z_{ij} = \frac{Max\{y_{ij}, i = 1, 2, ..., n\} - y_{ij}}{Max\{y_{ij}, i = 1, 2, ..., n\} - Min\{y_{ij}, i = 1, 2, ..., n\}} \quad (2)$$

Where $y_{ij}$is the jth performance characteristic in the ith experiment,and min $y_{ij}$and max $y_{ij}$are the minimum and maximum values ofthe jthperformance characteristic for the alternative ithexperiment. Table 6 shows the sequences after the grey relational generation.

Table 6. Data preprocessing of each performance characteristic.

Exp.No	A	B	C	Churning power loss	Efficiency
1	1300	95	40	0.754248202	0.028117592
2	1300	140	45	0.503259758	0.247288294
3	1300	175	50	0.34003913	0.015477228
4	1400	95	45	0.93702464	0.123380356
5	1400	140	50	0.737439146	1
6	1400	175	40	0	0.301921177
7	1500	95	50	1	0.384908492
8	1500	140	40	0.24923435	0.917243633
9	1500	175	45	0.018467793	0

3.2. Grey relational coefficient and grade

The grey relational coefficients for the individual output can be determined from the normalized values by using Eq. (3) and the coefficient constant is assumed to be $\xi = 0.5$.

$$\left(y_0(k), y_i(k)\right) = \frac{\Delta \min + \xi \Delta \max}{\Delta_{0j} + \xi \Delta \max} \quad (3)$$

Where

(i) j = 1,2,…,n; k = 1,2,…, m, n is the number of experimental data items and m is the number of responses
(ii) y0(k) is the reference sequence (y0(k) = 1, k = 1,2,….,m); yi(k) is the specific comparison sequence
(iii) Δ0j = ǁy0(k) – yj(k)ǁ The absolute value of the difference between y0(k) and yj(k)
(iv) Δ min = min min ǁy0(k) – yi(k)ǁ is the smallest value of yj(k)
(v) Δ max = max max ǁy0(k) – yi(k)ǁ is the largest value of yj(k)
(vi) ξ is the coefficient constant, which is defined in the range 0≤ξ≤1.

The grey relational grade (GRG) for the combined multi-objectives can be determined from grey relational coefficient of the responses and it is being ranked in the order. The evaluation of the performance characteristics is based on grade and it is calculated using Eq. (4). The grey relational coefficient and grade values are presented in Table 7. [10], [12], [13]

$$\delta_j = \frac{1}{k}\sum_{i=1}^{m} y_{ij} \quad (6)$$

Where δ_j is the grey relational grade for the *jth* experiment and *k* is the number of performance characteristics.

Table 7 Grey relational coefficient & Grey relation grade (GRG)

Exp.No	Grey koef.(Churning power loss)	Grey koef.(Efficiency)	Grey Relation Grade (GRG)	Rank
1	0.67	0.34	0.51	5
2	0.50	0.40	0.45	6
3	0.43	0.34	0.38	7
4	0.89	0.36	0.63	4
5	0.66	1.00	0.83	1
6	0.33	0.42	0.38	8
7	1.00	0.45	0.72	2
8	0.40	0.86	0.63	3
9	0.34	0.33	0.34	9

The mean of the grey relational grade for each level of parameters, and the total mean of the grey relational grade is summarized in Table 8. Figure 2 shows the grey relational grade graph, where the dashed line indicates the total mean of the grey relational grade.

Table 8. Responses for Grey relation grade

Level	A	B	C
1	0.4171	0.6200	0.5045
2	0.6108	0.6055	0.4411
3	0.5642	0.3665	0.6465
Delta	0.1937	0.2535	0.2053
Rank	3	1	2

Total mean grey relational grade=0.5306

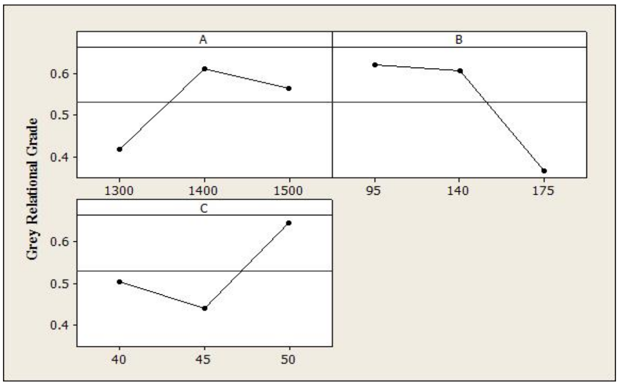

Figure 2 Grey relational grade graph.

3.3 Analysis of Grey Relational Grade and Selection of Optimal Level of Parameters

The purpose of the ANOVA is to investigate which factors significantly affect the performance

Characteristic. This is accomplished by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from the total mean of the grey relational grade, into contributions by each machining parameter and the error.The percentage contribution by each factor to the total sum of the squared deviations SST can be used to evaluate the importance of the cutting parameter change on the performance characteristic. In addition, the F test can also be used to determine which factor has a significant effect on the performance characteristic.

Analysis of variance (ANOVA) has been performed using statistical software, MINITAB 16 on grey relational grade values to evaluate the influence of process parameters on multi-machining characteristics. ANOVA for grade values (Table 9) shows that three parameters worm speed (A), pulse-on time (C) and dielectric flow rate (F) significantly affect the multi-machining characteristics (p-value ≤0.05) under 95% confidence levels.

Table 9. ANOVA for grey relational grade

Source	DOF	SS	Mean square	F-value	P-value	Percentage contribution (%)
A	2	0.061	0.030	7.14	0.123	23.64
B	2	0.121	0.06	14.15	0.05*	46.89
C	2	0.066	0.033	7.72	0.115	25.58
Error	2	0.008	0.0042			
Total	8	0.258				

DOF: degree of freedom; * Significant parameters

3.4 Optimal Grey Relational Grade Value:

In order to predict the optimal values of the grey relational grade which is an index of multi-machining characteristics, only significant parameters are included which has been found utilising analysis of variance (ANOVA). The optimal grey relational grade (ηopt.) is predicted using equation (7) as described below:

$$\eta_{opt.} = \eta_m + \sum_{i=1}^{q} (\eta_i - \eta_m) \qquad (7)$$

Where: η_m is the average grey relational grade; η_i is the average grey relational grade at the optimum level; and q is the number of parameters that significantly affects the machining characteristics.

3.5 Confirmatory Experiments.

Based on Eq. (7), the estimated grey relational grade using the optimal cutting parameters can then be obtained. Table 10 shows the results of the confirmation experiment using optimal cutting parameters. As shown in Table 10, efficiency increased from 0.32 to 0.35, churning power loss is greatly reduced from 32.62 to 10.34 W. Through this study, it is clearly shown that the multiple performance characteristics of worm gear are greatly improved.

Table 10. Predicted and experimental values

	Initial condition	Optimal factors	
		Prediction	Experiment
Level	A1B1C1	A2B1C3	A2B1C3
Churning power loss(w)	32.62		10.34
Efficiency	0.32		0.35
Grey Relational Grade	0.51	0.8159	0.75

CONCLUSION

A grey relational analysis was used to optimize the process parameters of worm gear reducer with multiple performance characteristics (Churning power loss and Efficiency). The experimental results show immersion depth has the most significant effect on the multiple performance characteristics. Temperature of oil in housing is second and is followed by input worm shaft speed.

Basically, larger the grey relational grade, better the corresponding multiple performance characteristics. The computed grey relational grade corresponding to the optimal setting is 0.75, which is greater than the highest grade values among the 9 experiments. Therefore, using present approach machining characteristics has been improved successfully.

The result of the confirmation tests yielded an improvement of 0.24 in grey relational grade, after validation.

Therefore, the integration of grey relational analysis and the Taguchi Method can be applicable for the optimization of process parameters and help to improve process efficiency.

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