International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Determination of Optimum Working Parameters for Multiple Response Characteristics of Worm Gear Box

Hardik G.Chothani, Kalpesh D Maniya

Abstract: ***The reason for this task is to optimize the multiple response of single start worm gear using three working parameters to improve its performance. As the input torque and lubricant heating time are the most effective responses of worm gear box to reduce the no-load dependent losses, they are taken as the response parameters in this research. Taguchi Grey Relational Analysis (GRA) is the method used to determine the influence of type of lubricant, volume of lubricant and speed of worm gear on multiple responses (input torque & lubricant heating time) of worm gear. The specific test rig is developed based on direct torque measurement technique to measure the input torque and lubricant heating time of worm gear box. Experimental results have shown that the input torque and lubricant heating time can be improved effectively through Taguchi-Grey Relational Analysis. The result is validated using the Confirmation Test. ANOVA determines the important of parameters. It has been found that the type of lubricant and speed of worm gear are influential parameters for worm gear performance. By selecting these parameters, efficiency of the worm gearbox can be increased.***

Keywords: Worm gear, No-Load Dependent losses, Taguchi Grey relational method, ANOVA

I. INTRODUCTION

The worm gearbox is widely used for high reduction ratios and self locking characteristics [1]. Worm gears offer a number of advantages in comparison to other types of transmission, which allows for a wide scope of applications in the fields of power and movement transmission. [2].

In spite of their good features, in comparison with all other gears, worm gear have relatively high power loss, very high heat generation inside gearbox during operation, due to these characteristics, efficiency of worm gearbox is very low [3].

Manuscript published on 30 September 2019
* Correspondence Author
Mr.Hardik G. Chothani*, Research Scholar,Mechanical Engineering Gujarat Technological University, Ahmedabad, India. Email: chothanihardik@yahoo.com
Dr.Kalpesh D. Maniya, Mechanical Engineering Department, C.K.Pithawala College of Engineering & Technology, Surat, India. Email: maniyakalpesh77@yahoo.com

Power losses in gearbox can be isolated into load-dependent power losses (LPS) and non-load dependent losses (NPS). LPS are mainly friction power losses of gear teeth and bearing and NPS are the churning power losses, windage power losses and shaft seals power losses [4].

Energy losses when gears are dragged in the lubricant called churning power losses and dragged in the air inside gearbox, called windage losses. These losses are affected by the oil level, viscosity of the lubricant, geometry of gear, clearance and rotational speed.[5-8]. No load dependent losses can be measured through input torque required by gear box. Input torque plays the important role to reduce the no load dependent losses so in this paper input torque is considered as the first response variable.

In worm gear box, sliding and rolling action takes place simultaneously. This sliding action generates the more friction and heat, Which increases the temperature of lubricant and reduces the efficiency of worm gear box [9]. The lubricant in a worm gear box removes the heat of the gearbox also. Depending Thermal stability of worm gears plays an essential role in their proper operation and compliance with the anticipated operating functions and it mostly depends on a lubricant. The oil sump temperature exerts the greatest impact over the formation of an oil film in the contact zone. An increase in the oil sump temperature results in a decrease of oil viscosity [2]. So in this paper lubricant heating time for raising 10 º C temperatures of oil sump is considered as a second response variable.

There are several parameters influencing the input torque and lubricant heating time of the worm gearbox such as type of lubricant, material of gear, geometry of gear, speed of worm, lubricant viscosity, lubricant volume, axial distance and others. From these, type of lubricant, volume of lubricant and speed of worm are taken into consideration for the optimization of multiple responses of worm gear box.

Many methods are available for the optimization. However, to overcome the deficiency of regression analysis, Grey Relational Analysis (GRA) has been used to solve the problem [10-11]. M.Slavica et al. have optimized the parameters of planetary gearbox using Taguchi-Grey Relational Analysis and they considered as influential factors, gear material, module and gear width for their analysis. [12]. Lubricant viscosity, speed of worm and current intensity were used to optimize the efficiency and output power of worm gear [13].

Many authors worked on this technique to optimize the multi response characteristics. [10, 11, 14-16].

II. METHODOLOGY

A. Experimental work

The working model of experimental set up is available in Fig. 1.The worm gear box is driven by an electric motor connected to it through an adaptable coupling via torque sensor. Torque sensor (0.01 accuracy and 50 N.m capacity) is used to measure the input torque and convert it into digital signal. Two foot-mounted bearings are used to avoid the vibration and misalignment of shaft.

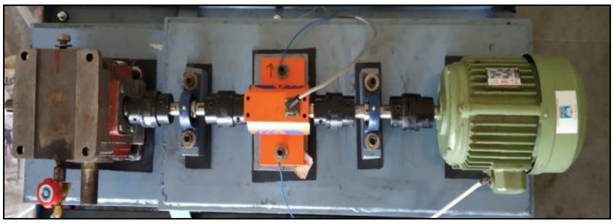

Fig. 1. Worm gearbox test rig

Fig. 2. Temperature sensor & its arrangement

Fig. 3. Worm and worm gear

For measuring the pressure of air inside the gearbox, a pressure gauge is mounted on the top of the housing. An oil level indicator is used to measure various levels of oil. A temperature sensor is used to determine the temperature of lubricant as shown in Fig. 2. To rotate the motor at various speeds, Variable Frequency Drive (VFD) is used. A one-way air valve is used to diminish the effect of windage power losses. A worm gear box of the standard size is selected for this experiment. The experiment is performed on a single start worm gearbox having inside volume for lubricant 180mm x 180mm x 280mm. The other specifications of worm gear and lubricant properties are given in Table I & Table II respectively. Fig. 3 shows the single started worm and worm-wheel.

Table-I: Geometry of worm gear

Gear	Worm Wheel	Worm Shaft
Number of teeth	30	Single start
Material	CuSn12	16MnCr5
Module (mm)	3	
Pressure angle	20	
Centre distance (mm)	75	
Outer dia. (mm)	132	40
Reduction ratio	30:1	

Table-II: Properties of oil

Lubricant	Oil-A	Oil-B	Oil-C
Name of oil	Mineral oil-EP grade 140	Mineral Oil-SP grade 320	Synthetic oil –PAO grade 320
Kinamatic Viscosity (cSt) @ 40 °C	312	184	330
Kinamatic Viscosity (cSt) @ 100 °C	33	24.1	35.5
Viscosity Index	95	90	162
Density (Kg/m3)	880	870	790

B. Design of Experiment

Table III shows the three controllable variables regarded in this three level study. The feasible ranges for these factors have been-selected by trial experiments on the same test rig. The experimental design of Taguchi (L9) is built using the Minitab ® 18 as shown in Table IV

Table-III: Experimental parameters with their levels

Control factors	Unit	Level 1	Level 2	Level 3
(A)Type of oil	-	Oil A	Oil B	Oil C
(B) Speed of worm (rpm)	[rpm]	1000	1200	1400
(C) Oil Volume	[lit]	1.5	2.1	2.7

The direct torque measurement technique was used to measure the input torque of the single start worm gear box at 40 °C temperature of lubricant. Simultaneously, the time was measured to raise the temperature from 30 °C to 40 °C. The lubricant heating time for 10 °C rise in temperature was considered. The experiment results are analyzed in Table IV.

Table-IV: Experimental design using L9 orthogonal array

Experiment No	Type of oil (A)	Speed of worm (B)	Oil volume (C)	Input torque (N.m)	Lubricant Heating time (min.)
1	A	1000	1.5	2.29	13.46
2	A	1200	2.1	2.67	9.05
3	A	1400	2.7	3.32	8.16
4	B	1000	2.1	2.09	14.14
5	B	1200	2.7	2.45	13.04
6	B	1400	1.5	2.31	10.51
7	C	1000	2.7	2.5	16.57
8	C	1200	1.5	2.12	11.15
9	C	1400	2.1	2.5	8.55

C. Gray Relational Analysis (GRA)

Grey Relational Analysis prescribes the level of information between level of nothing & everything[17]. Optimum process parameters can be selected for multiple responses by using Grey Relational Analysis. Detail steps of Grey Relational Analysis are given in Fig. 4 [16].

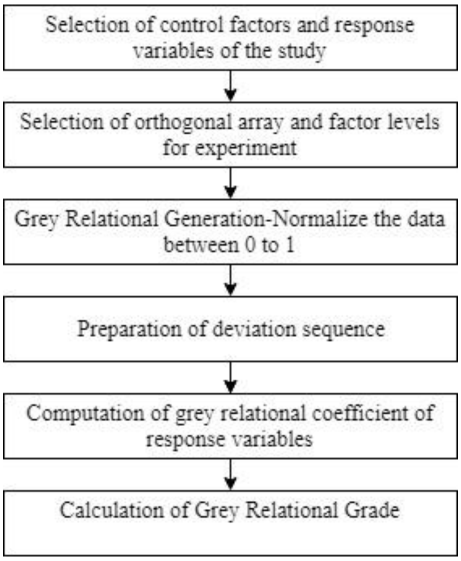

Fig. 4. Flow chart for GRA [16]

D. Data Pre-processing

In GRA, multiple responses in the range between zero and one are first normalized, which is also known as the Grey Relational Generation [10-14].

Responses need to be normalized before they are analyzed with GRA[18]. The sequence can be normalized as in (1) for the smaller the better.

$$Z_{ij} = \frac{x_{ij} - Min\{x_{ij}\}}{Max\{x_{ij}\} - Min\{x_{ij}\}} \quad \text{for } i=1,2..m \ \& \ j=1,2..n \quad (1)$$

However, the sequence can be normalized as in (2) for the higher the better

$$Z_{ij} = \frac{Max\{y_{ij}\} - x_{ij}}{Max\{x_{ij}\} - Min\{x_{ij}\}} \quad \text{for } i=1,2..m \ \& \ j=1,2..n \quad (2)$$

Where,

Z_{ij} is grey relational generation value,

min x_{ij} and max x_{ij} are the smallest and largest values of the x_{ij}

x_{ij} is the j^{th} response characteristic in the i^{th} experiment.

E. Grey Relational Coefficient and Grey Relational Grade (GRG)

With the help of this normalized data, the grey relational coefficient is calculated to express the relationship between the desired and actual experimental data. Then, the Grey Relational Grade is computed by averaging the respective grey relational coefficient for each process response. The overall evaluation of the multiple process responses is based on the grey relational grade. Optimization of a parameter is the level with the highest grey relational grade (larger is better)[10-14,16].

Equation (3) used to determine the grey relational coefficients for the individual output from the normalized value and ξ = 0.5 considered as coefficient constant.

$$\left(z_{0j}, z_{ij}\right) = \frac{\Delta\min + \xi\Delta\max}{\Delta_{0j} + \xi\Delta\max} \quad \text{for } i=1,2..m \ \& \ j=1,2.n \quad (3)$$

Where,

(Z_{0j}, Z_{ij}) grey relational co-efficient,

$\Delta_{0j} = |x_{0j} - x_{ij}|$,

Δ min = min of Δ_{ij} ,

Δ max = max of Δ_{ij} ,

ξ is the coefficient constant and its value € [0,1].

The GRG can be determined from Grey Relational Coefficient using (4) for the combined multi-objectives and it is ranked in the order [10-14, 16].

$$\delta_i = \frac{1}{n}\sum_{j=1}^{n} y_{ij} \qquad \text{for } i=1,2\ldots\ldots m \qquad (4)$$

Where,

δ_i is the GRG for the i^{th} experiment

n is the response characteristics numbers.

The grey relational grade δ represents the level of correlation between the reference sequence and the comparability sequence [19].

F. Analysis of Variance (ANOVA)

ANOVA's aim is to explore the parameters that influence t he output responses.This is achieved by sorting out total variability of GRG.

It is evaluated by each parameters and error by the amount of square deviations from the complete mean of GRG into contributions.

The percent of the process parameters to the complete amount of squared deviations is used to assess the significant of the parameter modification in output responses. Furthermore, The process parameters are also determined by F-test that have important impact on the output responses[20].

III. RESULT AND DISCUSSION

The input torque of single start worm gear and lubricant heating time for increasing 10 °C (from 30 °C to 40 °C) are given in Table IV. For the input torque response, the smaller the best and for the lubricant heating time, the higher the best characteristics are taken into consideration. Table V is the normalized outcomes obtained by equations (1) and (2) for all responses. Deviation sequence is performed after the normalization.

Table-V: Data pre-processing of each performance characteristic

Exp.No	Input torque (N.m)	Lubricant Heating time (min)
1	0.8374	0.6302
2	0.5285	0.1058
3	0.0000	0.0000
4	1.0000	0.7111
5	0.7073	0.5803
6	0.8211	0.2794
7	0.6667	1.0000
8	0.9756	0.3555
9	0.6667	0.0464

The grey relational co-efficient results for the experimental layout are calculated as per (3) and grey relational grade (GRG) are calculated as per (4). A higher GRG shows that the result is very nearer to the ideal normalized value. The values of grey relational co-efficient and GRG are given in Table VI. Ranking order is given according to higher GRG.

Table-VI: Grey Relational Coefficient & GRG

Exp. No	Grey koef. (Input torque)	Grey koef. (Lubricant Heating time)	Grey Relation Grade (GRG)	Rank
1	0.75	0.57	0.665	4
2	0.51	0.36	0.437	8
3	0.33	0.33	0.333	9
4	1.00	0.63	0.817	1
5	0.63	0.54	0.587	5
6	0.74	0.41	0.573	6
7	0.60	1.00	0.800	2
8	0.95	0.44	0.695	3
9	0.60	0.34	0.472	7

Optimization of single GRG is achieved by converting Optimization of the different multiple responses. The total mean of the GRG and mean of GRG for each working parameters are given in Table VII. Fig. 5 shows the Grey Relational Grade graph, where the line between the graphs indicates the total mean values of the GRG. Fig. 5 also shows the optimum parameters for multiple responses are A2B1C1.

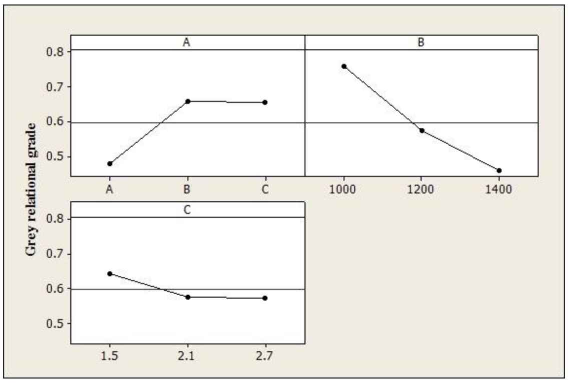

Fig.5 Grey relational grade graph

Table-VII Responses for GRG

Level	A	B	C
I	0.4782	0.7605*	0.6443*
II	0.6591*	0.573	0.5752
III	0.6557	0.4595	0.5735
Delta	0.1808	0.3011	0.0708
Rank	2	1	3

Total mean GRG=0.5976

An asterisk (*) in Table VII indicates the best suited level value for considered multiple response of worm gear box. According to the GRG values given in Table VII, the optimal operating parameters are lubricant type B (level 2), 1000 rpm worm speed (level 1), 1.5 liter oil volume (level 1) for both the input torque and lubricant heating time. In short optimum parameters are A2B1C1 for considered response of single start worm gear box.

Table-VIII: ANOVA for GRG

Source	DOF	SS	Mean square	F-value	P-value	% of Contri.
A	2	0.0642	0.0321	24.70	0.0039*	29.82
B	2	0.1387	0.0693	53.35	0.018*	64.42
C	2	0.0098	0.0049	3.77	0.210	4.55
Error	2	0.0026	0.0013			1.20
Total	8	0.2153				

(*) p value less than 0.05

Result of ANOVA is given in Table VI. Table VIII shows that the speed of worm has the highest influence (64.42%) on the GRG followed by the type of lubricant (29.82) and volume of lubricant (4.55).Type of lubricant and speed of worm have a importance impact on the multiple responses as their p-values are less than 0.05 (95% confidence level) and volume of lubricant is not significant.

A. Confirmation test

Confirmation test is carried out to check the precision. It also helps to determine the improvement in responses. According to GRA optimum level of working parameters are A2B1C1, confirmation test was performed with same set of parameters. Improvement in the performance of worm gear box for multiple considered responses is revealed in Table IX.

Retrieval Number: C4656098319/19©BEIESP
DOI:10.35940/ijrte.C4656.098319
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The optimal GRG ($\eta_{opt.}$) is predicted using (5) as described below:

$$\eta_{opt} = \eta_m \sum_{i=1}^{q} \left(\bar{\eta}_i - \eta_m \right) \quad (5)$$

Where,
η_m - Average GRG,
η_i - Optimum level of GRG
q - Number of parameters that impact on responses.

Table IX demonstrates the test outcomes using the processing parameters for the input torque and lubricant heating time. The predicted value of GRG was calculated using (5) and for same optimum parameters A2B1C1 experiment was conducted and obtained its GRG. The initial level GRG was 0.665 and for A2B1C1 sequence GRG is 0.899 so the improvement in the GRG is 0.232.The confirmation tests shows a nice agreement between the performance expected and actual of worm gear box for considered responses.

Table-IX: Confirmation test

Description	Initial condition	Optimal factors	
		Predi.	*Exp.*
Level	A1B1C1	A2B1C1	A2B1C1
Input torque	2.29		2.01
Lubricant heating time	13.46		15.51
GRG	0.665	0.8159	0.899
Improvement in grade	-		0.232

IV. Conclusion

In this research work, the most suited working parameters were determined for the multiple responses (input torque and lubricant heating time) of worm gearbox by using the Taguchi-GRA.

The test was designed based on Taguchi's design of experiments with the L9 orthogonal array to minimize the number of experiments with the help of Minitab 18. Multiple responses were converted into optimization of a single response with the help of Grey Relational Analysis and its adequacy has been confirmed by both logically as well as experimentally by conducting confirmatory experiments.

According to GRA, optimum level of input parameters for multiple responses of input torque and lubricant heating time are type of oil-B (SP grade 320), worm speed-1000 rpm and volume of oil-1.5 (A2B1C1).

ANOVA is used to identify the important working parameter of worm gearbox for input torque and lubricant heating time. ANOVA indicated that Worm speed is the most important factor influencing worm gearbox's various performance characteristics because its p-value is less than 0.05.It shows that efficiency of worm gearbox can be increased by varying speed of worm. Other parameters are not influenced to efficiency as worm speed.

The improved in GRG is found to be 0.232 which signifies the improvement in both responses simultaneously with the values of input parameters as variables at type of oil-B (SP grade 320), worm speed-1000 and volume of oil-1.5 liter. The percentage error between predicted GRG and experimental GRG is found to be within 10 %. According to confirmation test this result can be increased by changing the speed of worm. Therefore grey relational analysis can be applicable for the optimization of process parameters and help to improve process efficiency.

REFERENCES

1. M. Turci, E. Ferramola, F. Bisanti, and G. Giacomozzi, "Worm Gear Efficiency Estimation and Optimization", Gear Technology, vol. 92, pp. 46–53, 2016.
2. D. Miltenović and A. Miltenović, "Permissible Temperatures and Thermal Stability of Worm Gears", International Journal of Engineering, vol. 3, pp. 61–66, 2017.
3. M. Tomislav, O. Milan, and K. Milan, "Influence of Low Temperatures on No-Load Power Losses in Worm Gears", Strojarstvo, vol. 51, no. 2, pp. 139–142, 2009.
4. B. Magyar and B. Sauer, Calculation of the "Efficiency of Worm Gear Drives, in International Gear Conference" , 26th–28th August, 2014, Lyon, pp. 15–23, doi: 10.1533/9781782421955.15.
5. J. Polly, D. Talbot, A. Kahraman, A. Singh, and H. Xu, "An Experimental Investigation of Churning Power Losses of a Gearbox", Journal of Tribology, vol. 140, no. 6, pp. 1–8, 2018, doi: 10.1115/1.4038412.
6. C. Changenet, G. Leprince, F. Ville, and P. Velex, "A Note on Flow Regimes and Churning Loss Modeling, Journal of Mechanical Design", vol. 133, no. December 2011, pp. 1–5, 2011, doi: 10.1115/1.4005330.
7. Y. Jiang, X. Hu, Y. Dai, C. Luo, and L. Feng, " Churning Power Losses of a Gearbox with Spiral Bevel Geared Transmission", Tribology International, vol. 129, no. 1, pp. 398–406, 2018, doi:10.1016/j.triboint.2018.08.041.
8. G. Leprince, C. Changenet, F. Ville, P. Velex, C. Dufau, and F. Jarnias, "Influence of Aerated Lubricants on Gear Churning Losses – An Engineering Model", Tribology Transactions, vol. 54, no. 6, pp. 929–938, 2011, doi: 10.1080/10402004.2011.597542.
9. M. Lewis, Worm-Gear Reducers Reach New Heights, in Machine Design, Emerson Power Transmission, pp. 1–5, 2004.
10. C. Lin and Z. Shan, "Use of the Taguchi Method and Grey Relational Analysis to Optimize Turning Operations with Multiple Performance Characteristics", Materials and Manufacturing Processes, vol. 19, no. 2, pp. 209–220, 2004, doi: 10.1081/amp-120029852.
11. H. Hasani, S. A. Tabatabaei, and G. Amiri, "Grey Relational Analysis to Determine the Optimum Process Parameters for Open-End Spinning Yarns", Journal of Engineered Fibers and Fabrics, vol. 7, no. 2, pp. 81–86, 2012, doi: 10.1177/155892501200700212.
12. B. Stojanovic, S. Miladinovic, S. Velickovic, and R. Nikolic, "Optimization of Parameters of a Planetary Gearbox Using the Taguchi-Grey Relational Analysis, Communications", vol. 20, no. 3, pp. 30–35, 2018.
13. M. Slavica, R. Sasa, V. Sandra, and A. Raed, "Optimization of Efficiency of Worm Gear Reducer by using Taguchi-Grey", Applied engineering letters, vol. 2, no. 2, pp. 69–75, 2017.
14. M. N. Pervez, F. Shafiq, Z. Sarwar, M. M. Jilani, and Y. Cai, "Multi-Response Optimization of Resin Finishing by using a Taguchi-based Grey Relational Analysis", Materials, vol. 11, no. 3, 2018, doi: 10.3390/ma11030426
15. S. M. Baligidad, U. Chandrasekhar, K. Elangovan, and S. Shankar, "Taguchi's Approach: Design Optimization of Process Parameters in selective Inhibition Sintering", Materials Today: Proceedings, vol. 5, no. 2, pp. 4778–4786,2018, doi:10.1016/j.matpr.2017.12.051.
16. Y. Kuo, T. Yang, and G. W. Huang, "The use of Grey Relational Analysis in solving Multiple Attribute Decision-Making Problems", Computers and Industrial Engineering, vol. 55, no. 1, pp. 80–93, 2008, doi: 10.1016/j.cie.2007.12.002.
17. L. B. Abhang and M. Hameedullah, "Determination of Optimum Parameters for Multi-Performance Characteristics in Turning by using Grey Relational Analysis", International Journal of Advanced Manufacturing Technology, vol. 28, no. 4, pp. 450–455, 2006, doi: 10.1007/s00170-011-3857-6.
18. J.M.Pujara, "An investigation of Material Removal Rate and Kerf on WEDM through Grey Relational Analysis", Journal of mechanical engineering & science, vol. 12, no. 2, pp. 3633–3644, 2018, doi: 10.15282/jmes.12.2.2018.10.0322.
19. C. P. Fung, "Manufacturing Process Optimization for Wear Property of Fiber-Reinforced Polybutylene Terephthalate Composites with Grey Relational Analysis", Wear, vol. 254, no. 3–4, pp. 298–306, 2003.
20. R. Sallehuddin, S. M. Hj Shamsuddin, and S. Z. Mohd Hashim, "Grey Relational Analysis and its Application on Multivariate Time Series", in IEEE 2008 Eighth International Conference on Intelligent Systems Design and Applications (ISDA), 2008, doi: 10.1109/isda.2008.181.