WARPAGE CONTROL IN WASHERS OF THRUST BEARING USING TAGUCHI ROBUST DESIGN METHODOLOGY

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Abstract: Designing high quality products and processes at a low cost is an economic and technical challenge to an engineer a systematic and efficient way to meet this challenge is the parameter design method of design optimization for the performance, quality and cost. The parameter design method uses a mathematical tool called orthogonal array and a measure of quality called signal-to-noise (S/N ratio). In this project **Warpage control in washers of thrust bearing using Taguchi robust design Methodology** an attempt has been made to control the using parameter design.

Parameter design is an approach for design of experiments (DOE) which enables one to identify the nature and effect of parameter(s) by conducting minimum number of experiments using orthogonal arrays, allows the effect of process parameters to be determined efficiently, effect of various process parameters are determined by ANOVA analysis. The estimation of the process parameter's effect is then used to optimize process parameter.

I. INTRODUCTION

Warpage Definition: Twist, out of shape, distortion under pressure or from heat is known as Warpage.

Development of Changes in Dimensions and Shape

Two main causes for changes in dimensions and shape are known:

- Non-thermal volume changes (for example, as a result of structural transformation)
- Deformation (plastic and elastic)

Such changes may be caused by various processes in a work piece (Fig. 1) Non-thermal volume changes are caused by phase changes, which may be transformation or precipitation processes.

Deformation processes may either be plastic or elastic. In the absence of external forces and moments, elastic deformation is always caused by residual stress. In this connection, the mutual interaction between these parameters is especially important.

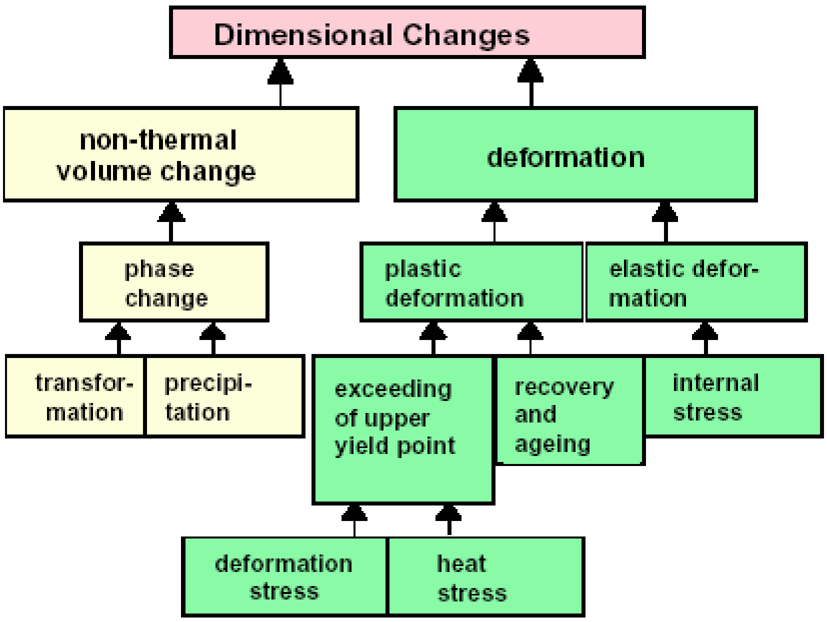


Fig. 1 Causes of changes in dimensions and shape

For example, machining to correct a deviation from the specified shape will lead to residual stress which may cause elastic deformation of the component. If residual stress is released in a thermal process, the elastic deformation of the component which has taken place up to that point will result in a further change in shape. Plastic deformation may be caused by relaxation or ageing processes or generally by local comparison stress in excess of the yield strength of the material. This comparison stress value, which can be calculated from the stress situation, normally with reference to several axes, is generally the result of superposed thermal and transformation stresses. These mechanisms may be initiated by a number of different processes in the workpiece.

Need for Warpage Control

- Due to increase in warpage the surface of washer will be uneven and Friction between Needle rollers and the washer will increase and affect smooth functioning of Bearings.
- When the ring of rolling elements begins to rotate it is automatically centered in relation to shaft axis, because of warpage on thrust plates the misalignment will occur.
- Due to warpage the dynamic capacity and Nominal life (number of hours at constant speed the bearing will maintain before showing the first signs of material fatigue) will reduce.
- Controlling warpage will reduce cycle time in grinding and Lapping process which are done to minimize the surface distortion.

Benefits of Warpage control

- Lesser rejection
- Process cost reduction
- Cycle time reduction
- Better Surface finish

III. OBJECTIVE OF STUDY

NRB Bearings manufactures variety of bearings; Needle Thrust Bearing is one among them. The company has been encountering the warpage as one of the major problems in bearing components. Especially on the thrust washer (CP-1732). Warpage or distortion in the washer CP-1732 of needle thrust bearing is a major concern for NRB Bearings.

The warpage is induced in during the operation of Blanking and Punching and further drastically increases in Heat treatment process. Heat treatment consists of two cycles, hardening and tempering. The increase in Warpage occurs in hardening cycle and decreases to certain extent in tempering cycle. (fig.2) the objective of study is to control and minimize the increase in warpage during the heat treatment process.

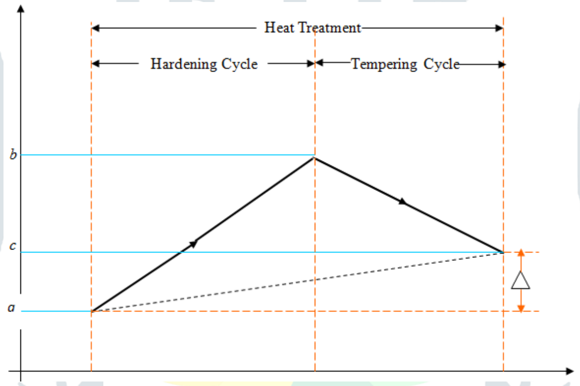


Fig2 Warpage graph in Heat treatment

To achieve this objective,

% Increase in warpage $\Delta = \left(\frac{c-a}{a}\right)\times 100$

Where,

a: is warpage before Heat treatment (microns)
b: is warpage after Hardening cycle (microns)
c: is warpage after Tempering cycle (microns)

Four factors namely Endogas, tempering temperature, tempering time, soaking time are selected as the parameters to be optimized. Parameter Design based on Taguchi Experimental Design is used to optimize the process parameters.

IV. EXPERIMENTAL DETAILS

The Taguchi optimization of heat treatment process requires experiments to be conducted as per an orthogonal array. The selection of appropriate orthogonal array depends on the number of factors and the number of distinct levels defined for each of the factors [1].
The major parameters affecting warpage in heat treatment are, Endo gas, Hardening temperature, Quenching temperature, Soaking time, Job configuration in furnace, Component geometry, Composition of material, Tempering temperature, Tempering time, Furnace condition.

In the present investigation, three levels are defined for the four selected process parameters namely Endo gas, Tempering temperature , Tempering time , Soaking time as summarized in Table 5.1. Hence f=4 and L=3.
This gives minimum number of experiments to be conducted as

$$e = f(L-1)+1 \quad (1.1)$$

$$e = 4(3-1)+1 = 9$$

Table 1.1 Factors and their Level

Sl. No.	Code	Factors (units)	Levels		
			1	2	3
1	A	Endo gas Nm/hr 6 to 6.6	6	6.3	6.6
2	B	Tempering temperature 170^o to 180^o C	170	175	180
3	C	Tempering time 120 to 150 minutes	120	135	150
4	D	Soaking time 20 to 30 minutes	20	25	30

Table 1.2 L_9 Orthogonal array

Trial no.	Levels of input parameters			
	A	*B*	*C*	*D*
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

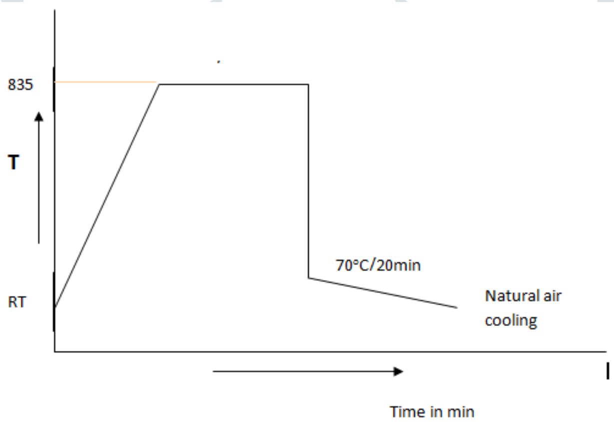
Hence, L_9 orthogonal array is selected as presented in Table 1.2. In the present study, nine numbers of heating treatment trials as per L9 orthogonal array were carried out on thrust washer CP 1732.

V.CONDUCTING THE EXPERIMENTS AS PER L_9 ORTHOGONAL ARRAY

Experiments were conducted on Wessman-Ipsem Furnace. The thrust washer CP 1732 received after completing Blanking and Piercing operation done at Bliss Mechanical press is fed in to Polishing barrel for deburring operation to free the washer from burr, Rust and Scratch marks.

This processed washer is then loaded to Wessman-Ipsem Furnace in trays. The sample for the experiments is kept in the tray connected by a loose string with a special Ink marking. Like this nine samples were taken according to L9 array. The heat treatment cycle of thrust washer CP 1732 consists of two cycles namely hardening cycle and tempering cycle as shown in Fig. 3

1. Hardening Cycle



2. Tempering Cycle

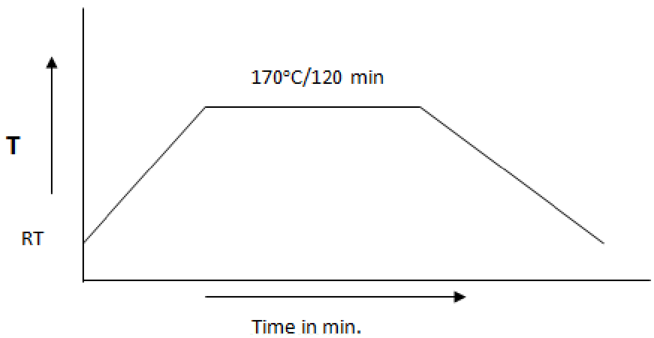


Fig.3 Heat treatment cycles of thrust washer CP 1732

Table 1.3 Experimental plan and measured warpage in Microns

Expt. No.	a	A(Nm/hr)	B (ºC)	C (min)	D (min)	c
1	10	6	170	120	20	20
2	20	6	175	135	25	28
3	11	6	180	150	30	20
4	13	6.3	170	135	30	23
5	22	6.3	175	150	20	24
6	18	6.3	180	120	25	26
7	21	6.6	170	150	25	26
8	25	6.6	175	120	30	37
9	15	6.6	180	135	20	16

Table 1.4 computed values of % increase in warpage (Δ) and S/N Ratio (η)

Expt. No.	$\Delta = \left(\frac{c-a}{a}\right) \times 100$	η (dB)
1	100%	-40
2	40%	-32
3	81.81%	-38
4	76.92%	-37.7
5	9.09%	-19.17
6	44.44%	-32.955
7	23.81%	-27.53
8	48%	-33.62
9	6.66%	-16.477

Where, a – Warpage before heat treatment (microns) c – Warpage after heat treatment (microns)

The warpage measured for each trial of L9 array is utilized to determine the optimal warpage control parameters using Taguchi technique. The computed values of % increase in warpage and signal to noise ratio for each response are summarized in Table 1.4 and the calculation is shown in Annexure A.

The result of ANOM is summarized in Table1.5 and is represented in the response graph as shown in Fig.4

Table 1.5 Results of ANOM

Factors	Levels (dB)			Optimum value	Optimum level
	L_1	L_2	L_3		
A	-36.667	-29.94	-25.875	-25.875	3
B	-35.076	-28.26	-29.14	-28.26	2
C	-35.525	-28.725	-28.233	-28.233	3
D	-25.215	-30.828	-36.44	-25.215	1
Optimum mean = -39.993					

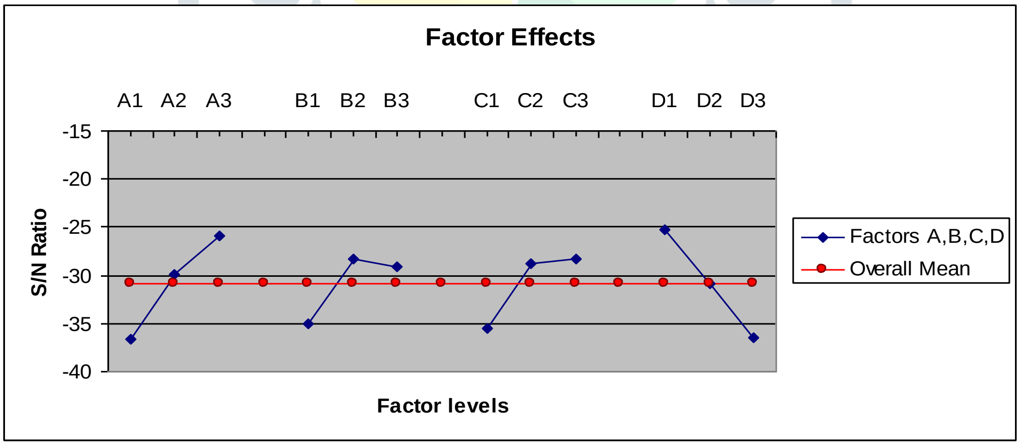


Fig. 4 Response graph

VI. DETERMINATION OF OPTIMUM FACTOR LEVEL COMBINATION

Factor levels corresponding to the highest S/N Ratios are to be selected by Robust design approach. In Trade off it has not always been done so. Sometimes the levels are selected based on the primary response. Sometimes the levels are selected based on the percentage contribution of the factors. Sometimes the levels are selected based on the relative importance of the performance characteristics. Sometimes the levels are selected -based on the manufacturing convenience. The basis for such Trade off is the knowledge, experience and ingenuity of the designer.

ANOVA was performed on the S/N ratios to obtain the contribution of each factor. The responses for each level of each factor were added to identify the level giving the best response value. Table 1.6 is the summary of percentage contribution of all factors for different response. The level indicated in table for each factor is the optimum level. Calculation is shown in Annexure C.

A_3, level 3 of factor A (Endo gas) is optimum for warpage control. Therefore Level 3 of factor A is selected.
B_2, level 2 of factor B (tempering temp.) is optimum for warpage control. Therefore Level 2 of factor B is selected.
C_3, level 3 of factor C (tempering time) is optimum for warpage control. Therefore Level 3 of factor C is selected.

D_1, level 1 of factor D (soaking time) is optimum for warpage control. Therefore Level 1 of factor D is selected. The optimum factor level of combination obtained is A3, B2, C3, and D1.

From the results of ANOVA as shown in Table 1.6, it is observed that soaking time and endo gas have major contributions in controlling the warpage. On the other hand, tempering time has moderate effect and the tempering temperature has least effect on warpage.

Table 1.6 Summary of ANOVA

Factors	Degrees of Freedom	Sum of Squares	Mean Squares	% Contribution
A	2	178.2	89.1	32.45
B	2	82.16	41.08	14.95
C	2	99.64	49.82	18.14
D	2	189.2	94.6	34.42
Total	8	549	68.625	100

Since the ANOVA has resulted in zero degree of freedom for error term, it is necessary to pool the factor having less influence for correct interpretation of results. After selecting the optimal level of process parameters, the final step is to predict and verify the adequacy of the model.
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Experiments were conducted with optimal levels of factors obtained by Taguchi optimization. The measured values of warpage under the optimal process conditions were used to determine the observed values of signal to noise ratio (ηobs).

Table 1.7Results of Conformation experiment

Trial no.	*a*	*c*	$\Delta = \left(\frac{c-a}{a}\right)\times 100$	η_{obs}
1	20	21	5.0 %	-13.979
2	16	17	6.25 %	-15.917
Avg. Signal to noise ratio observed (η_{obs}),*dB*				-14.948

In order to judge the closeness of observed value of signal to noise ratio with that of the predicted value, the variance of prediction error (□ 2pred) is determined and the corresponding two-standard deviation confidence limits for the prediction error of the signal to noise ratio is calculated. From the results of conformity tests, summarized in Table1.7, It can be observed that the calculated value of prediction error is within the confidence limit, which indicates that the additive model of warpage control is adequate.

Table 1.8Confirmatory Test Results

Levels *(A, B, C, D)*	**3-2-3-1**
Signal to noise ratio observed (η_{obs}), *dB*	-14.948
Predicted Signal to noise ratio (η_{pred}), *dB*	-19.987
Prediction error, *dB*	5.039
Confidence limit *(2σ), dB*	± 14.48

CONCLUSION

The following conclusions were drawn from the present investigation

- Warpage control is achieved with optimal level settings of process parameters.
- All factors considered contribute to the performance characteristics.
- The percentage contribution of error is within 15%, which indicates that, no important factors are left out from analysis.
- Robust Design can be used as effective tool for Total Quality Management with less experimentation.
- The parameter design based on Taguchi methodology used to optimize the process parameters has given optimal levels for control factor settings.
- The objective of the research
- i.e. to control the warpage during heat treatment process is achieved with less than 10% increase in warpage. The results are acceptable in controlling the warpage
- The result of verification experiments has shown the quality of additive model is adequate and percentage of improvement is satisfactory.

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