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Reduction of Cost of Quality by Using Robust Design: A Case Study in Automobile Industry

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Abstract: **The aim of a parameter design experiment is to identify and design the settings of the process parameters that optimize the chosen quality characteristic and are least sensitive to noise (uncontrollable) factors. Cost of Quality is evaluated in terms of dimensional tolerances. Robust design is implemented in a gear hobbing process. The optimum setting of parameter is to be obtained in presence of uncontrollable noise factors. The target value for Root Diameter of a spur gear used in shaft in an automobile is 28.00 mm. The dimensional tolerance for of a spur gear 27.90-28.10 mm. It was found that these was arbitrarily accepted as the tolerance limit and any component with in these tolerance limit would be accepted as good quality. This concept is a traditional design concept where every part with in a range is accepted as of good quality. Taguchi parameter design tries to find an optimum value so that component meets the desired specification or in other words meets the target value. Experimental analysis is performed at different levels of control factors and noise factors. Optimum value of control factors is found by studying Signal to Noise ratio (nominal the best). Again the tolerance range for Root Diameter were calculated and it was effectively found that the tolerance range was found as 29. 95-28.05 mm. The tolerance was reduced from 0.2 mm to 0.1 mm which led to overall reduction in cost of quality of a spur gear.**

Keywords: **robust design, cost of quality, parameter design, control factors, noise factors, signal to noise ratio, taguchi quality loss function and tolerance limit.**

1. INTRODUCTION

Robust design is used to improve the quality of a product by minimizing the effects of variation without eliminating the causes (since they are too difficult or too expensive to control). CoQ is usually understood as the sum of conformance plus non-conformance costs, where cost of conformance is the price paid for prevention of poor quality (for example, inspection and quality appraisal) and cost of non-conformance is the cost of poor quality caused by product and service failure (for example, rework and returns). His method is an off-line quality control method that is instituted at both the product and process design stage to improve product manufacturability and reliability by making products insensitive to environmental conditions and component variations. The end result is a robust design, a design that has minimum sensitivity to variations in uncontrollable factors.

Gears used in automobile have very less tolerance value because any minute changes in dimension will lead to damage in the whole system of an automobile. Hobbing process is used for cutting gear teeth which needs to be insensitive to external noise factors to obtain a robust dimensional specification. But due to presence of various factors, it is impossible to maintain a good dimensional tolerance which in turn effects the overall quality of a component.

1.1 IDENTIFICATION OF COST OF QUALITY:

Inspection or measurement is classified as Cost of Conformance (CoC). The price of conformance is the cost involved in making certain that things are done right the first time, which includes actual prevention and appraisal costs.

1.1 IDENTIFICATION OF PROBLEMS:

Root Diameter is the diameter of the Root Circle that passes through the bottom of the tooth spaces. The dimensional specification of spur gear are shown in figure below.

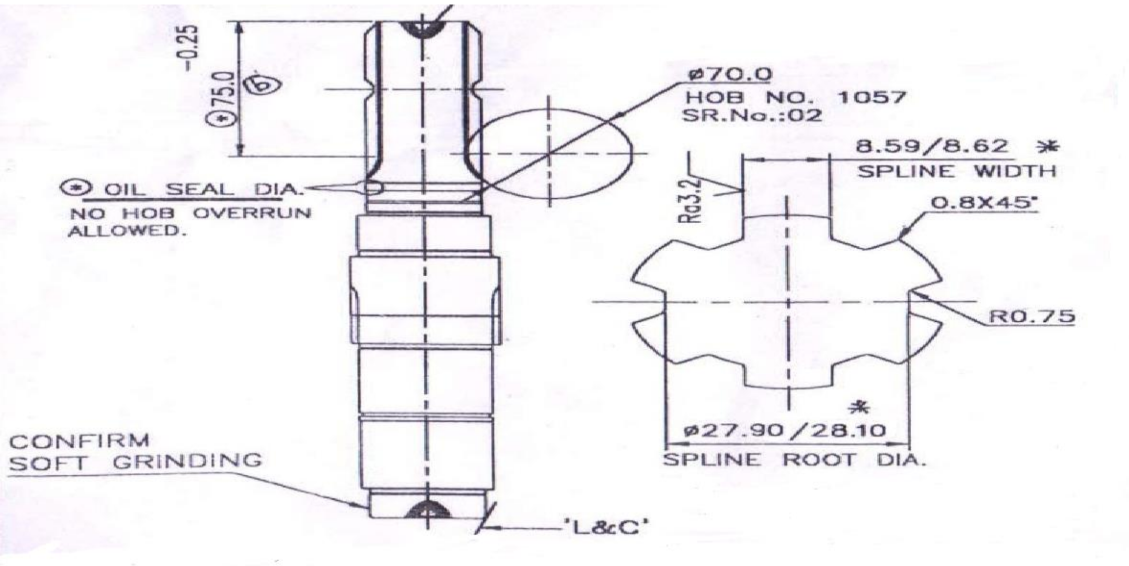

Figure 1: Orthographic view of Spur gear

The initial cutting parameters for spur gear are Hob speed (rpm), In feed (mm) and Axial Feed (mm/rev) as listed in the table below.

TABLE I: Cutting parameters for gear

Parameters	**Values**
Hob Speed	250 Rpm
In Feed	0.5 mm
Axial Feed	2.00 mm/rev

The inspection performed on teeth after cutting should be with in following specification as listed in the table below.

TABLE II: Dimensional tolerance after Inspection

Dimension	**Output Response (Tolerance)**
Outer Diameter	34.70- 34.77 mm
Root diameter	27.90 - 28.10 mm
Spline Width	8.59 - 8.62 mm
Spline Width Taper	0.02 mm max.
P.C.D. Run out	0.04 mm
Lead Error	0.015 mm
Lead Error	0.05 mm max.

We observed that the initial root diameter of spur gear was within the tolerance **27.90-28.10 mm** has the highest effect on Cost of Quality in terms of tolerance deign. Due to this high tolerance limit of root diameter of gear up to 0.1 mm many gears were having life less than one year. High tolerance leads to high rejection rate at working level. All the gears with in the tolerance limit were initially accepted as rejections were not identified during 1st inspection. Whenever the product deviated from the target value of dimension 27.95mm, the quality of the gear was indirectly detoriated.

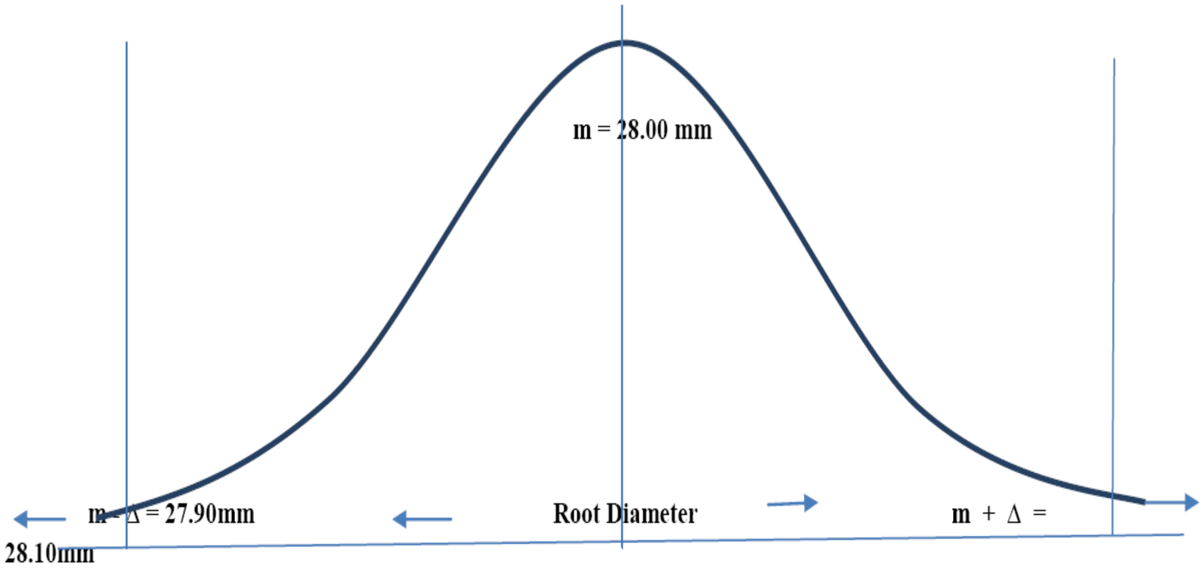

Figure 2: Quality Loss Function for Root Diameter Variation in Spur gear

2. RESEARCH METHODOLOGY

In this methodology, any deviation from target is considered as loss. The primary goal is to minimize the loss due to variation. System Design and Parameter design are the two main phases in robust design of a component.

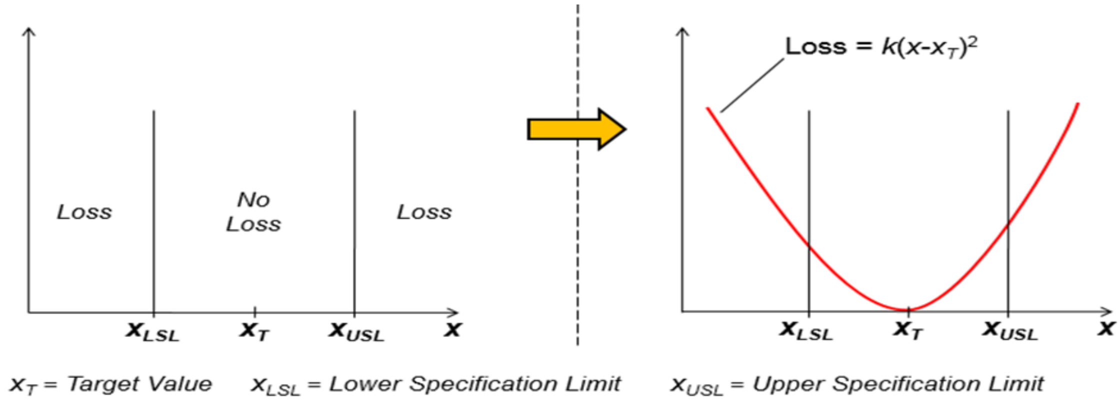

Figure 3: Traditional Design Vs Robust Design

2.1 SYSTEM DESIGN:

System design is the process of defining the architecture, components, modules, interfaces, and data for a system to satisfy specified requirement. It is the initial stage of product development. It comprises of following analysis:

I. REQUIREMENT ANALYSIS:

TABLE III: Requirement Analysis

Specification	Material / Type
Spur gear	Mild Steel
Cutting tool	Hob cutter (Carbide tool)
Coolant	Oil based / Water based

II. SYSTEM ANALYSIS:

Hobbing machine and **jigs and fixture** that define the system comes under system analysis Hobbing machine uses two skew spindles, one mounted with a blank work piece and the other with the hob. The angle between the hob's spindle and the work piece's spindle varies, depending on the type of product being produced. It is the most widely used gear cutting process for creating spur and helical gears and more gears are cut by hobbing than any other process since it is relatively quick and inexpensive. A type of skiving that is analogous to the hobbing of external gears can be applied to the cutting of internal gears, which are skived with a rotary cutter.

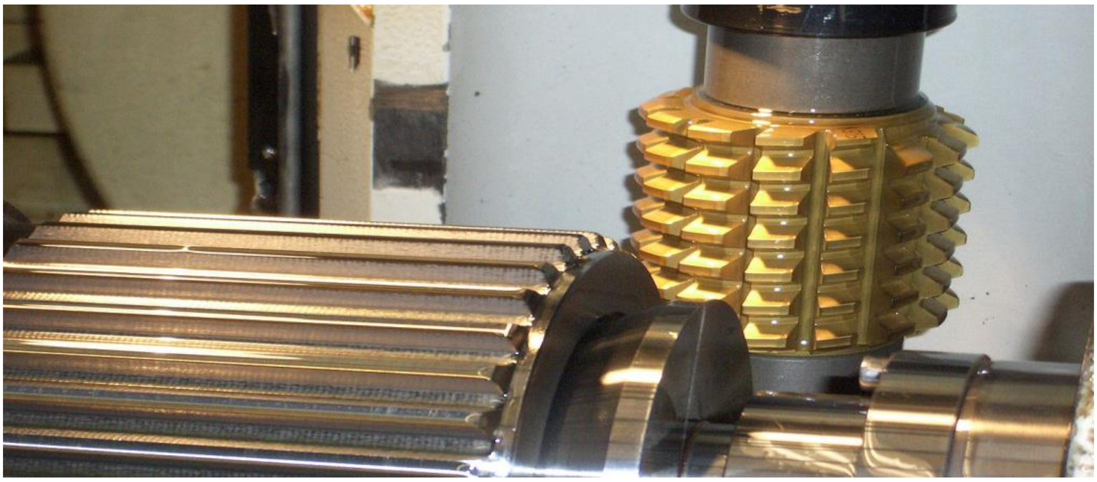

Figure 4: A gear hob in a hobbing machine with a finished gear

Hobbing machines are characterized by the largest module or pitch diameter it can generate. For example, a 10 in (250 mm) capacity machine can generate gears with a 10 in pitch diameter and usually a maximum of a 10 in face width.

III. INSPECTION ANALYSIS:

TABLE IV: Inspection Analysis

Dimension	Instruments
Root Diameter	Micrometer (0-25) 0.01 L/C
PCD (Pitch Circle Diameter)	Dial gauge (0-10) 0.01 L/C
Spline width	Micrometer (25-50) 0.01 L/C
Spline gauge	Spline ring gauge (GO gauge)

2.2 PARAMETER DESIGN:

After the system architecture has been chosen, the next step is parameter design. The objective here is to select the optimum levels for the controllable system parameters such that the product is functional, exhibits a high level of performance under a wide range of conditions, and is robust against noise factors that cause variability. Noise factors are those that cannot be controlled or are too expensive to control. Control factors are those parameters that can be set and maintained (design features). Studying the design parameters one at a time or by trial and error until a first feasible design is found is a common approach to design optimization. It consists of five major steps.

I. QUALITY CHARACTERISTICS IS DEFINED:

It is defined as output response to be determined from the experimental design. Tolerance limit for Root Diameter of Spur gear is a quality characteristic to be determined

II. CONTROL FACTORS AND THEIR LEVELS ARE SET:

TABLE V: Control factors and their levels

Control Factors	Level		
	1	2	3
Speed (rpm)	250	275	300
In Feed (mm)	0.4	0.5	0.6
Axial Feed (mm/rev)	1.9	2.0	2.1

III. NOISE FACTORS ARE DETERMINED:

(a) Vibration in hobbing machine –

Improper fitting of foundation bolt, loose bearing in machine, fixture foundation, wobbling in cutting tool, improper mounting of gear blank

(b) Coolant used –

- *Water based Coolant* – These are used when gears are exposed for longer time or even when kept in storage due to rust formation. It is also used at shipping or package stage due to corrosion. It is less heat absorbent.
- *Oil based Coolant* – It has more heat dissipation, better lubrication, high cutting speeds can be obtained, rust protection even in packaging and transportation stages, very less chances of corrosion and economical in overall cycle operation.

(c) Grain structure of material –

The grain structure of gear blank to be processed should be stream lined with the nature of cut. This help in cutting of gear splines properly. Many a times such a structure is not presented which leads to various error in gear cutting profile. Also the cooling rate while cutting and heat dissipation depends upon the grain structure which affects the overall design and leads to various errors.

IV. TEST CONDITIONS ARE DETERMINED:

It has three Control factors with three levels each, hence an orthogonal array L9 matrix experiment is set up.

V. MATRIX EXPERIMENTS ARE PREFORMED AND OUTPUT RESPONSE IS MEASURED:

Output response is measured in terms of root diameter (mm) of spur gear.

TABLE VI: Matrix Experiment

Experiment Run	**Speed (rpm)**	**In feed (mm)**	**Axial feed (mm/rev)**	**Root Diameter (mm)**			**Output Mean (mm)**
	Control Factor 1	Control Factor 2	Control Factor 3	Y1	Y2	Y3	
1	250	0.4	1.9	27.93	27.95	27.96	27.94
2	250	0.5	2.0	27.92	27.94	27.97	27.94
3	250	0.6	2.1	27.92	27.96	27.99	27.95
4	275	0.4	2.0	28.05	28.07	28.09	28.07
5	275	0.5	2.1	27.99	27.99	28.00	27.99
6	275	0.6	1.9	27.94	27.93	27.90	27.92
7	300	0.4	2.1	27.98	28.01	28.04	28.01
8	300	0.5	1.9	27.91	27.94	27.92	27.92
9	300	0.6	2.0	28.04	28.06	28.09	28.06

3. RESULTS AND DISCUSSIONS

After finding all the observation as given in Table 6, S/N ratio and Means are calculated and various graph for analysis is drawn by using Minitab 17 software. The S/N ratio for root diameter of spur gear is calculated on Minitab 17 Software using Taguchi Method.

3.1 MAIN EFFECT PLOT FOR MEAN, STANDARD DEVIATION AND S/N RATIO:

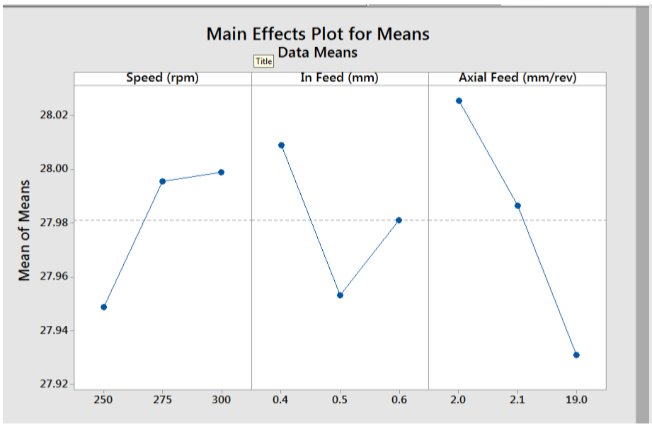

Figure 5: Main effect plot for means

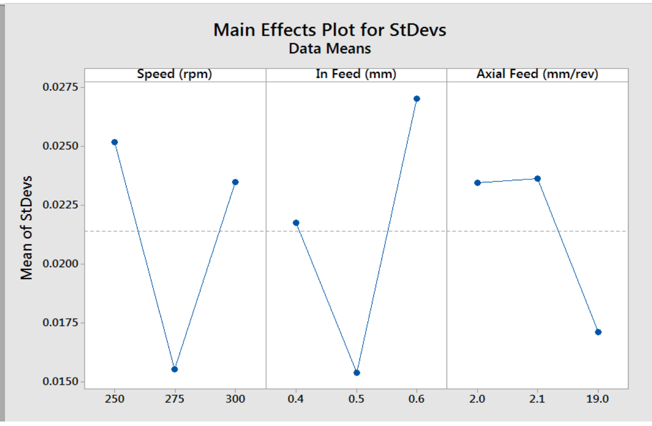

Figure 6: Main effect plot for StDevs

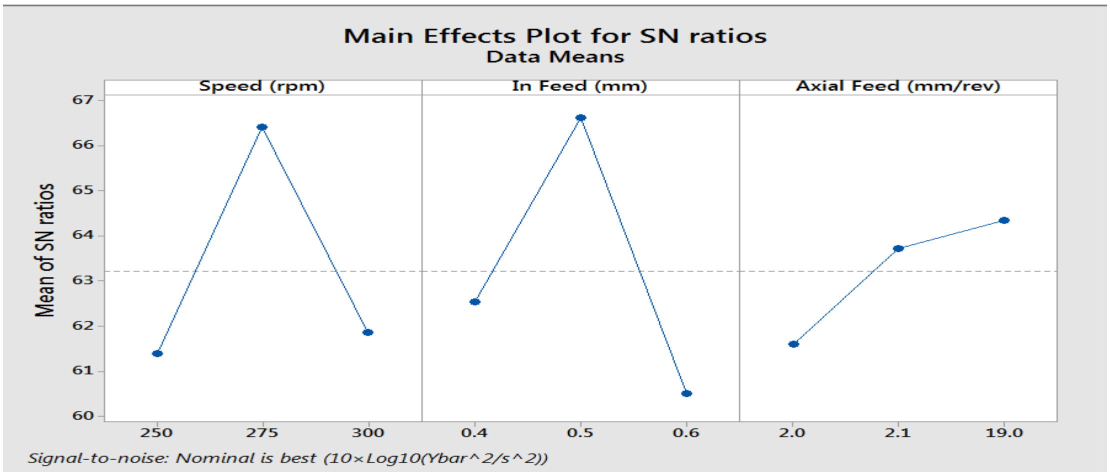

Figure 7: Main Effect Plot For SN Ratio

3.2 CALCULATION AND ANALYSIS:

In case of dimension, SN ratio is selected as nominal the best type (mid value of level of control factor)

I. SN RATIO FOR SPEED:

SN ratio for level 1 is SNL_1 = (65.2468 + 60.9092 + 58.0189)/3 = 61.39

SN ratio for level 1 is SNL_2 = (62.9442 + 73.7123 + 62.551)/3 = 67.07

SN ratio for level 1 is SNL_3= (59.4038 + 65.2396 +60.9465)/3 = **61.8633**

TABLE VII: SN ratio for Speed (rpm)

Speed (rpm) of Hob	Level	SN Ratio
250	1	61.39
275	2	67.07
300	**3**	**61.86**

We observe that the nominal value is for Level 3 i.e. **Hob Speed of 300 rpm** is one of the optimum parameter.

II. SN RATIO FOR IN FEED:

TABLE VIII: SN ratio for In feed (mm)

In feed (mm)	Level	SN Ratio
0.4	**1**	**62.53**
0.5	2	66.62
0.6	3	60.50

We observe that the nominal value is for Level 1 i.e. **In feed of 0.4 mm** is one of the optimum parameter.

III. SN RATIO FOR AXIAL FEED:

TABLE IX: SN ratio for Axial feed (mm/rev)

Axial feed (mm/rev)	Level	SN Ratio
1.9	1	61.59
2.0	**2**	**63.71**
2.1	3	64.34

We observe that the nominal value is for Level 2 i.e. **Axial feed of 2.1 mm/rev** is one of the optimum parameter

3.3 PERFORMANCE AT OPTIMUM LEVEL:

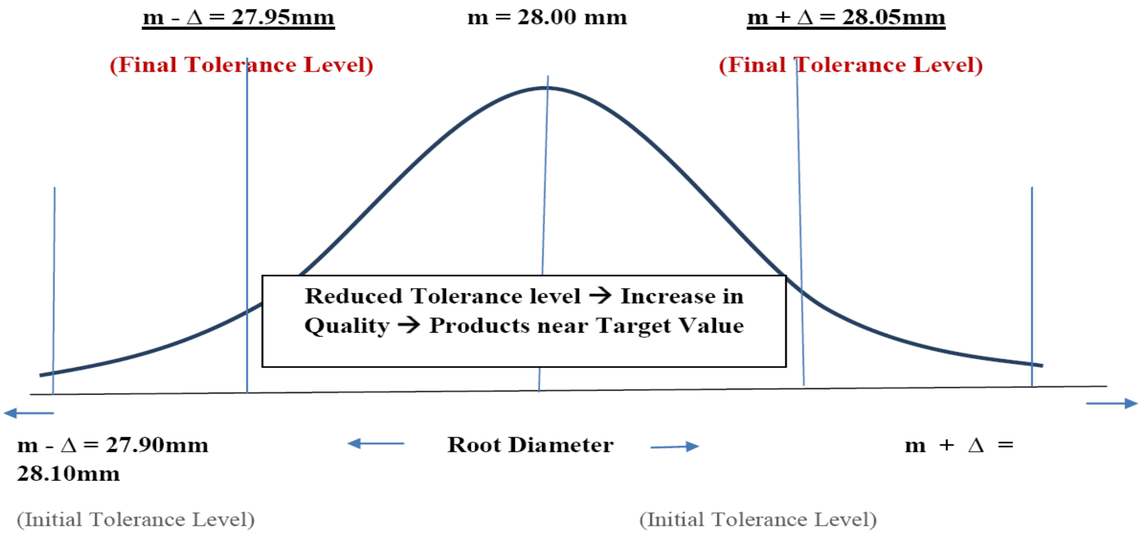

Figure 8: Root Diameter Variation for Spur gear at Optimum level

Experiments were carried out at optimum level for a batch of 20 gears and their root diameter tolerance came within **27.95 – 28.05 mm**. It meant that the tolerance was reduced from **0.2 mm** to **0.1 mm**. It exactly fits the taguchi design as Taguchi relates quality at target value in robust design approach. It meant that the design was made more robust as it is near to the target value. Any deviation from the target is termed as quality loss which is reduced in this case. Our primary goal is to reduce the tolerance deviation so that the life of gear is increased thereby the wear and tear due to meshing with other will also get minimized.

4. CONCLUSION

To achieve optimum tolerance design for Root Diameter for spur gear we conclude the following values from experimental result: Hob speed at 275 rpm, In feed of 0.4 mm, Axial feed of 2.0 mm/rev. Optimum parameter to achieve best dimensional tolerance there reducing the cost of poor so as to minimize the deviation from the target value. The root diameter came with in the tolerance of **27.95 – 28.05 mm**. There was a **reduced tolerance level of 0.1mm** when experiments were carried out at optimum level of control factors. The dimensional tolerance were near the target value with increase in quality of a component. The wear and backlash were also reduced thereby robust design was achieved successfully

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