Study Of Gear Teeth Distortions Due To Heat Treatment

V. Khade, M.S.Ramgir

Abstract: The work aims to study the distortion occurred due to heat treatment on the Gear teeth. The paper studies, various causes of distortion, control techniques to eliminate distortion, which includes changes in design, selection of material, heat treatment process, mainly due to quenching that includes cooling rates, quenching mediums, fixtures. An experimental study and results conducted for the effects of the distortion on the Gear teeth and to reduce the distortion with certain changes design modification, resulting in shape & size changes, phase changes, changes in hardness, microstructure, and residual stresses. It is observed that adequate velocity of quench oil around the component to be heat treated ensures uniform & desired cooling rate as per heat treatment cycle. Modification in design of baffles achieved the adequate velocity and minimization of distortion. Also, Fixtures for holding finished parts or assemblies during heat treatment may be either support or restraint type to control dimensional relations during aging.

Index Terms: Gear Teeth, Distortion, Quenching, Heat Treatment, Defects

1 Introduction

THE distortion of the gears made out of casehardened steel is one of the biggest flaws in the carburizing-hardening process[1]. Distortion includes both the notion of "Variations of dimensions" as well as the notion of "curving." The variation of dimensions caused by structural tensions is unavoidable, while curving is an avoidable distortion of the gear caused by inaccurate heal, the faulty heating and cooling, inappropriate placement of the gears, uneven carburization, structural defects, etc. The variation of dimensions is determined by several elements. One of the most important determining factors is the connection between the depth of the case and the thickness of the gear tooth[3]. Quenching characteristics are influenced significantly by the degree of agitation, for normal speed quench oil under varying degrees of propeller agitation. It can be seen that increasing the degree of agitation reduces the stability of the vapor phase and increases the maximum rate of cooling. The performance obtained from a quenchant in practice, therefore, depends upon actual conditions in the quench tank [6]. Non uniform agitation/quenching or non uniform circulation of quenchant around a part results in an assortment of cooling rates that creates shape distortion. Uneven hardening, with the formation of soft spots, increases warpage. Similarly, an increase in case depth, particularly uneven case depths in case-hardening steels, increases warpage on quenching [9]. The probable causes of distortion during carburizing heat treatment using Sealed Oil Quench Furnace, Quench Oil circulation is considered the scope of study in this report.

- *V.Khade is currently pursuing masters degree program in Mechanical DesignEngineering in Rajarshi Shahu College of Engineering, Tathwade Pune-411033.*
  E-mail: vinay.khade1985@gmail.com
- *Prof. M.S. Ramgir is Professor of masters degree program in Mechanical DesignEngineering in Rajarshi Shahu College of Engineering, Tathwade Pune-411033. E-mail: milindramgir@yahoo.co.in*

2.1 Review Stage

The experiment is carried out on the Cam-shaft Gear; these gears were loaded on the base tray and fixture.

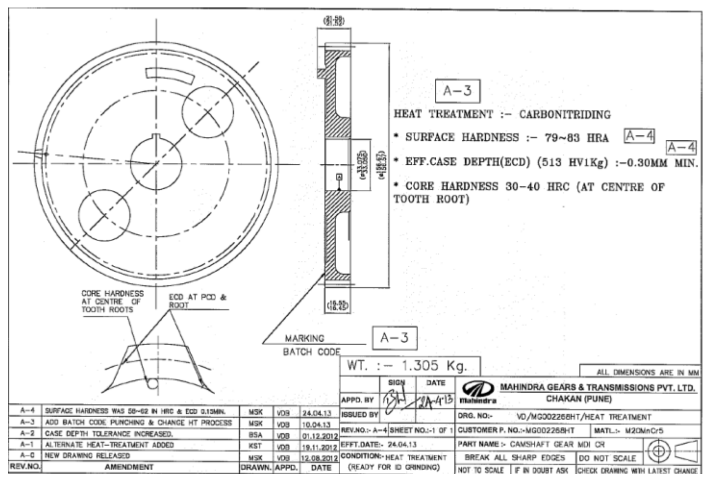

***Fig no. 1** Cam Shaft Gear*

Total charge weight 1000kg is loaded in the Furnace heating chamber. The complete procedure is automated. Charge is heated to 8700 C in the heating chamber in the sealed and controlled atmosphere as per the cycle setting. SQF has total 6 nos. burners for the comprising of gases Endo gas 8-10 Nm3/hr, Processed LPG 170 Nm3/hr and Ammonia 100Nlph. RTD's installed used to monitor the temperature of the furnace. On completion of heating cycle the charge is automatically removed from the heating chamber and brought in the front chamber where it is quenched in the oil bath within 18 seconds, Hot quench oil, Hi-quench MT650, at oil temperature 1100 C. On completion of quenching the charge is removed from the furnace and washed in the washing machine with Ferro clean solution of 2-4% for 30 mins at temperature of 700 C.

Fig no. 2 *Sealed Quench Furnace*

Then, in the washing machine, with the tank capacity of 7000 lits, the specimen forwarded for cleaning with Ferro-clean solution of 2-4% at 70 deg C for 30 mins, followed into the Tempering machine with capacity of 1000 kg, LPG Gas fired, charge is reheated at 160 deg C for 120 mins. A 9 points study conducted on the charge to measure and find out the amount of distortion occurred after the quenching process.

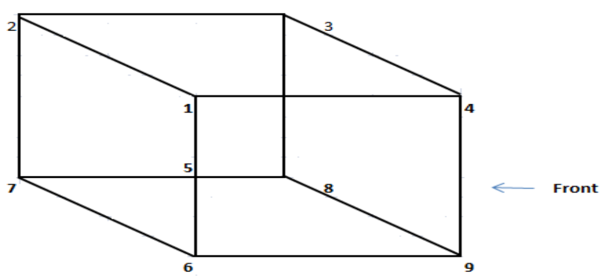

Fig no. 3 9 *Points Arrangement*

Heat Treatment Cycle			
Process	Temp.	Time	C.P.
PreHeating	400°c	60 Min.	
Carburising/ Carbonitriding	870°c	50 Min.	0.95%
Diffusion	870°c	20 Min.	0.85%
Gas Cooling	-	-	-
Hardening	830°c	30 Min.	0.75%
Oil	110°c	30 Min.	550 RPM
Temp.	160°	120 Min.	

Table no. 1 Heat treatment Cycle

Fig no. 4 *Arrangements of Gears in the Fixture*

2.2 Test Conducted on the Specimen

Various dimensional test conducted on the manufactured gear were tooth thickness measurement, span of the gear, diameters of the gear. Our focus of study was on DOP- Diameter of the pin, the outside diameter of the gear, in which the dimensional deviation was observed.

2.3 Hardness Test

The hardness of the specimen measured on the Rockwell hardness tester.

3 Results & Discussions

According to the data collected and 9 point study report on the arrangement of gears on the fixture, the zones 1, 2 & 4 were prone to maximum distortion and deterioration. The table below gives a detail report of the distortion. This shows that sufficient quantity of oil with sufficient velocity and for the enough period of time does not flow through these zones. These can be achieved with the change in the design of the oil flow in the quench tank, or the amount of agitation to be increased in the tank. Increase in agitation RPM noted splashing of oil into the heating chamber. So, RPM is maintained as 550.

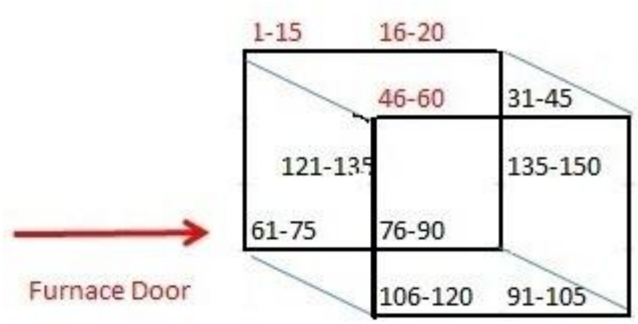

Fig no. 5 *Result for Zonal Deterioration*

Serial, No of Parts	Zone	AHT	BHT	Deterioration
1-15	Zone 1	1.33	2.05	0.72
16-30	Zone 2	0.88	1.88	1
31-45	Zone 3	1.16	1.28	0.12
46-60	Zone 4	1.34	2.07	0.73
61-75	Zone 5	0.97	1.22	0.25
76-90	Zone 6	0.74	1.11	0.37
91-105	Zone 7	1.11	1.47	0.36
106-120	Zone 8	1.49	1.89	0.4
121-135	Zone 9	2.02	1.62	-0.4
135-150	Zone 10	1.12	1.28	0.16

Table no.2 Result Chart for Zonal Deterioration

4 Designs & Calculations

4.1 Design of Quenching Tank:

Volume of Quench Oil = 1:10 times the weight of Charge.
Weight of Charge = 1000 kgs.
Weight of Quench Oil = 10 x 1000 = 10,000kg
= 10,000 lits = 10 m^3.
Working height of SQF from ground level = 1000mm.
Width of Quench tank = 3700 mm.
Length of Quench tank = 2000 mm.
Height of Quench tank = 1800 mm.
Volume of tank = 1800 x 3700 x 2000
= 1.332 x 10^10 mm^3 = 13.32 x 10^9 mm^3= 13.32 m^3.
Height of Oil in tank = 1500 mm.
Oil Volume = 3700 x 2000 x 1500
= 11.1 x 10^9 mm^3 = 11.1 m^3.

4.2 Design of Agitator:

4.2.1 Design of Agitator Shaft:

Internal Pressure of Quenching tank = 0.2 MPa
Diameter of Agitator (Impeller) = 300 mm.
Width of Blade = 70 mm.
Agitator Blades = 2 nos.
Thickness of Blade = 6 mm.
Speed = 550 rpm.
Liquid in Quenching tank = MT 650
Viscosity = 35 cP
Overhang of the Agitator shaft from bottom bearing & agitator = 450 mm.
Shaft Material: Cold rolled steel IS -2062A
Permissible shear stress in shaft = 55 MPa.
Elastic limit in tension = 246 MPa.
Baffles in tank = 2 nos.
Modulus of Elasticity = 2.1 x 10^5 MPa.

4.2.2 Shaft Design:

For the design, available motor of power 7.5 Kw, power to the input of shaft.
Torque require to the Agitator = Tc = P / 2ΠN
= 7500 / (2Π x 550/60) = 130.21 Nm.
Maximum Torque during start up = Tm = 1.5 x Tc
= 1.5 x 130.21 = 195.32 Nm
= 195.32 x 10^3 Nmm.
Permissible shear stress = 55 MPa = 55 N/mm^2
Polar Modulus of Shaft = Zp
= 195.32 x 10^3 / 55 = 3551.27 mm^3.
Also, Zp = (Π / 16) d^3
3551.27 = (Π / 16) d^3
Substituting,
Those values we get d = 26.24 mm, say d = 30 mm.

Let us now check for the stress in the shaft.
The force = Fm = Tm / 0.75 Rb = 195.32 x 10^3 / (0.75 x 150)
= 1736.17 N.
The maximum bending moment M at the bearing point from the shaft overhangs
M = 1736.17 x 450 = 695 x 10^3 Nmm = 695 Nm.
The equ ivalent bending moment = Me,
Me = (1 / 2) {M + √ (M^2 + Tm^2)}
= (1 / 2) {695 + √ (695^2 + 195.32^2)}
= 708 Nm = 708 x 10^3 Nmm.
Therefore, we have
f = 708 x 10^3 / {(Π / 32) d^3}
= 267 N/mm^2.
This value is greater than permissible elastic limit 246 N/mm^2.
Therefore, we use shaft diameter 35 mm,
Now, calculating combined loading stress, f, for shaft diameter 35 mm,
f = 708 x 10^3 / {(Π / 32) d^3}
f = 708 x 10^3 / {(Π / 32) 35^3}
We get, the stress f = 168.2 N/mm^2.

Since, calculated stress on shaft is less than permissible value 246 N/mm^2., selected shaft diameter as 35 mm.

4.2.3 The Blade:

It is essential to see whether the impeller blades bear the stress.
The bending moment, BMmax = Fm (0.75 Rb - Rh),
Also, f = BMmax / Z, where Z = 1 / 6 bt x bw^2
The diameter of hub is twice the diameter of shaft,
Rh = 70 / 2 = 35 mm, Rb = 300 / 2 = 150 mm.
BMmax = Fm (0.75 Rb - Rh) = 1736.17 (0.75 x 150 - 35)
= 5580.54 Nmm.
Therefore, f = 5580.54 / (1 / 6 x 6 x 70^2)
= 1.14 N / mm^2, which is acceptable.

4.3 Design of Elevator Guide Channel:

Diameter of channel = 360 mm.
Blade angle, θ = 15
Area of the Channel,
Ae = (Π / 4) de^2
= (Π / 4) x 360^2 = 101.17 x 10^3 mm^2 = 0.1017 m^2 Tangential velocity at the inlet of Agitator, Ua = r ω^2
Where, ω = 2 Π N / 60 = 2 Π x 550 / 60 = 8639.37 mm/s = 8.639 m/s.
We know that, tan θ = Va / Ua, (where, Flow Velocity, Va)
tan 15 = Va / 8.639
Therefore, Va = 2.314 m/s.
Discharge in the elevator guide channel,
Qe = Va x Π x Db x Wb
= 2.314 x Π x 0.3 x 0.07 = 0.1527 m^3/s
Since, 2 nos, agitator, Total Discharge,
Qe = 2 x 0.1527= 0.305 m^3/s.

4.4 Design of Oil Channel:

Here we consider 3 cases while designing the flow through oil channel

4.4.1 Qe = Qo

Cross-sectional area of the Oil Channel,

$Ao = 0.45 \times 0.455 = 0.204\ m^2$.

Oil flow through channel,

$Qo = Ao \times Vo$

As discharge remains constant through Continuity equation,

$Qe = Qo = 0.305\ m^3/s$.

Therefore, velocity,

$Vo = Qo / Ao = 0.305 / 0.204 = 1.4915\ m/s$.

Here, the velocity reduces, further, the oil advances through the Guide vane section

4.4.2 Qe > Qo

Cross-sectional area of the Oil Channel,

$Ao = 0.35 \times 0.35 = 0.1225\ m^2$.

Oil flow through channel,

$Qo = Ao \times Vo$

Assuming the velocity of oil constant

Therefore, Discharge of Oil flow,

$Qo = 0.1225 \times 1.4915 = 0.1827\ m^3/s$.

Here, the discharge got reduced by 40% which caused the distortions in the gears, observed the trials.

4.4.3 Qe < Qo

Cross-sectional area of the Oil Channel,

$Ao = 0.5 \times 0.5 = 0.25\ m^2$.

Oil flow through channel,

$Qo = Ao \times Vo$

Assuming the velocity of oil constant

Therefore, Discharge of Oil flow,

$Qo = 0.25 \times 1.4915 = 0.3728\ m^3/s$.

Here, the discharge got increased by 23% which also caused the distortions in the gears, observed the trials. It is assumed that flow of oil and lower velocity of oil 1.4915 m/s is the probable cause of distortions in the gears.

Thus, to improve the velocity the flow of oil is maintained, 0.305 m³/s. accordingly, guide vane section design modified to achieve higher velocity of oil.

4.5 Design through the Guide vane section:

Cross-sectional area of oil channel in guide vane section,

$Ag = 1 / 2 \times b \times h$

$Ag = 1 / 2 \times 0.108 \times 0.399 = 0.0215\ m^2$

Total area for Oil to flow into the at guide vane section

$= Ao – Ag$

$= 0.2047 – 0.0216 = 0.1831\ m^2$.

Discharge of Oil through the Guide vane section,

When $Qg = Qe = 0.305\ m^3/s$.

$Qg = Ag \times Vg$

$0.305 = 0.1831 \times Vg$

Therefore, $Vg = 1.665\ m/s$.

Discharge of Oil through the Guide vane section,

When, $Qg = Qe = 0.1827\ m^3/s$.

$Qg = Ag \times Vg$

$0.1827 = 0.1831 \times Vg$

Therefore, $Vg = 0.9972\ m/s$.

Discharge of Oil through the Guide vane section,

When, $Qg = Qe = 0.3728\ m^3/s$.

$Qg = Ag \times Vg$

$0.3728 = 0.1831 \times Vg$

Therefore, $Vg = 2.036\ m/s$.

4.6 Design Conclusion:

Increase in velocity is observed with oil channel area (0.45 x 0.455= 0.204 m²) & Velocity as Vg =1.665 m³/s which resulted into decrease in distortions in Gears.

Oil Channel Dimensions mm	Oil Channel Area m²	Oil Flow m³/s	Oil Velocity m/s	Oil Velocity Guide section m/s	Agitator Rpm
0.45 x 0.455	0.204	0.305	1.4915	1.665	550
0.35 x 0.35	0.1225	0.1827	1.4915	0.9972	550
0.5 x 0.5	0.25	0.3728	1.4915	2.036	550

Table no. 3 Design results

Serial No of Parts	Zone	AHT	BHT	Deterioration
1-15	Zone 1	1.03	1.35	0.32
16-30	Zone 2	0.99	1.28	0-29
31-45	Zone 3	1.2	1.48	0.28
46-60	Zone 4	1.14	1.27	0.13
61-75	Zone 5	0.9	1.11	0.21
76-90	Zone 6	0.88	1.01	0.13
91-105	Zone 7	1.21	1.27	0.06
106-120	Zone 8	1.09	1.19	0.1
121-135	Zone 9	1.02	1.42	0.4
135-150	Zone 10	1.12	1.08	-0.04

Table no.4 Result Chart for Zonal Deterioration after modification of Guide vanes

After changes in design of the oil channel certain changes occurred which increased the flow of oil which in-turn reduced the distortion in the manufactured jobs. The zones which where prone to distortion, got reduced the deviation. Again the same study was conducted to show the results in the change.

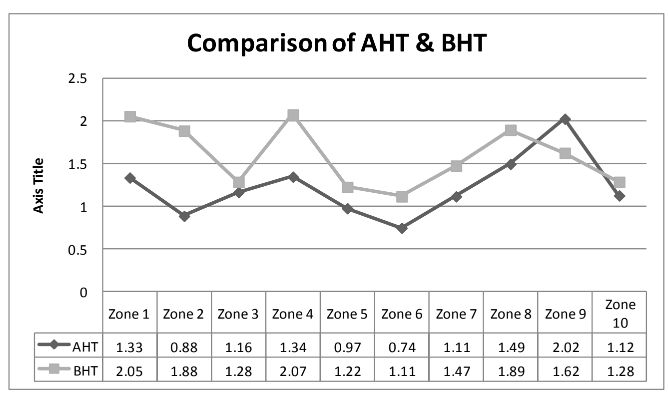

Fig no. 6 *Comparison trend of *AHT & BHT before modification*

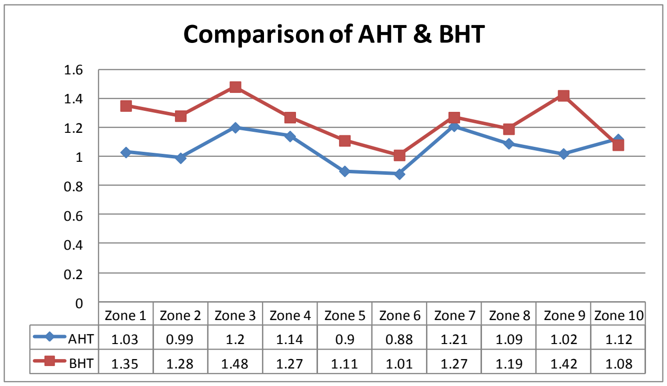

Fig no. 7 *Comparison trend of AHT & BHT after modification of guide vane area*

4.7 Hardness

With the results obtained from hardness test that the changes in hardness were within the permissible limits as designed. The effective case depth required was 0.3mm, we achieved 0.45mm. Also the hardness required was 79-83 HRa, achieved was 81 HRa average.

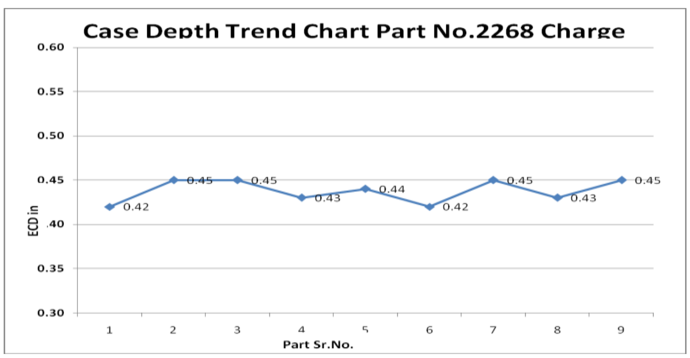

Fig no. 8 *Effective Case Depth Variations*

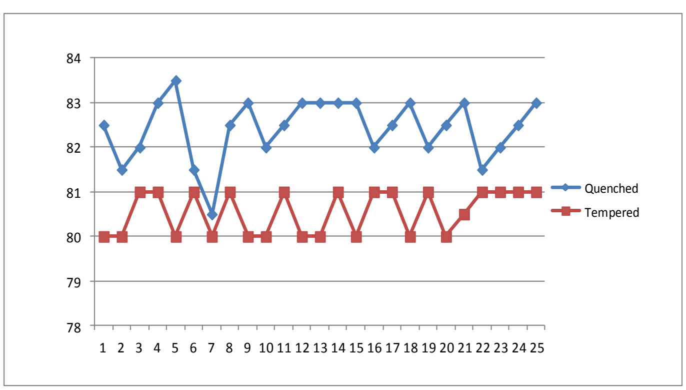

Fig no. 9 *Comparison trend of AHT & BHT before modification*

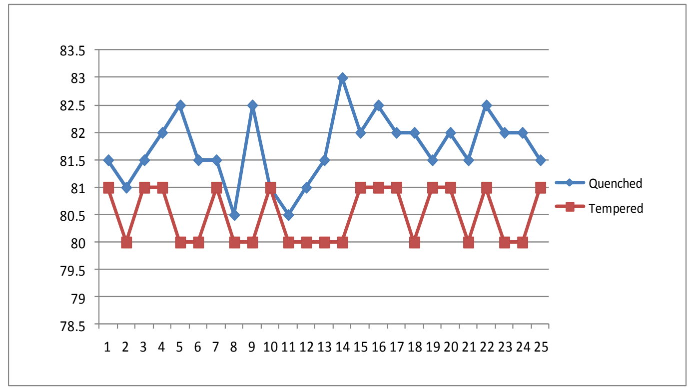

Fig no. 10 *Comparison trend of AHT & BHT after modification of guide vane area*

5 Conclusion

5.1 Correct Quenching oil temperature and Flow rate selection:

Proper selection of quenchant with desirable quenching properties, uniform temperature of oil and adequate agitation during hardening results in minimum distortion.

5.2 Modification of Fixture design or arrangement of the components in the fixture:

Inadequate support during the heat-treatment cycle, poorly designed quenching fixtures, or incorrect loading of the parts may cause distortion. Fixtures for holding finished parts or assemblies during heat treatment may be either support or restraint type to control dimensional relations during aging.

5.3 Modification design of baffles to control flow velocity:

Adequate velocity of quench oil around the component to be heat treated ensures uniform & desired cooling rate as per heat treatment cycle. Modification design of baffles achieved the adequate velocity and minimization of distortion. Optimum velocity of 1.665 m/s with 550 rpm recorded minimum distortion of gear after heat treatment process.

Acknowledgment

The authors would like to thank M/s. Mahindra Gears Ltd., & Mr. Pravin Deshpande, General Manager, Production & Quality, for giving us an opportunity to conduct the experimental work at their Chakan plant, We also show our deep gratitude to Mr. Sachin Thorat, Sr. Manager, Quality Assurance, Metallurgy & Testing, HOD, Mahindra Gears for guiding, leading and providing us the information and knowledge, throughout the work for getting out the results. We also take this opportunity to express a deep sense of gratitude to Dr. Abhay Pawar, HOD, Department of Mechanical Engineering & JSPM's Rajarshi Shahu College of Engineering for cordial support, valuable facilities and guidance, which helped us in completing this task through various stages.

.

References

[1] Anil Kumar Sinha, "Defects and Distortion in Heat-Treated Parts," Bohn Piston Division.

[2] Zhichao Li and B. Lynn Ferguson, "Controlling Gear

Distortion and Residual Stresses During Induction Hardening”.

[3] B.L. Ferguson *, Z. Li, A.M. Freborg, “Modeling heat treatment of steel parts".

[4] K. Loeser, V. Heuer and D. R. Faron,, " Distortion Control by Innovative Heat Treating; Technologies in the Automotive Industry".

[5] R.A. Hardin1and C. Beckermann2 " Simulation of Heat Treatment Distortion," 1Research Engineer, 2Professor, Department of Mechanical and Industrial Engineering; the University of Iowa, Iowa City IA 52242

[6] R. Husson a,b, C. Baudouin a, R. Bigota, E. Surab, “Experimental identification of the process influences on gear distortion during heat treatment,” Proc Arts et M´etiers ParisTech Metz, Laboratoire de Conception Fabrication Commande (EA 4495); b. Renault, Powertrain Process Engineering Division(11)

[7] O.P. Khanna, “Material Science and Metallurgy,” Khanna Publications.

[8] C Gadagkar1, Dr. D. N. Shivappa2, Pradeepa Shivaswamy3, “Identification of Gear Distortion in Manufacturing and Finding Solution using Reactive Improvement Methodology,” 1P.G Student, 2Professor, Department of Mechanical Engineering, Sir M Visvesvaraya Institute of Technology, Bangalore, Karnataka Pin Code: 562 157 3Head Automotive Projects, Voith Eng. Pvt Ltd, Bangalore, Pin Code: 560046

[9] Marcell Suliteanu, “Minimizing Gear Distortion DurIng Heat Treating,” heat treating consultant from Minnetonka, MN.