Distortion Reduction Strategies for PCD Runout of Cam Shaft Gear

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Abstract: The purpose of heat treatment will be to modify the structure of material and relieve the stresses set up in the material. Rejection of Gears is susceptible, after heat treatment process, due to excess distortion. This leads to risk of getting PCD Runout fired owing to its chronicle failure. Analysis of this variation needs data collection methodology and systematic study of process capability to achieve low losses. Cam Shaft Gear is a vital component in Engine Assembly of automobile and is responsible for fuel injection and power generation in vehicle. In this paper, an attempt is made to formulate research framework to achieve process capability of Cam shaft Gear distortion issues in form of PCD runout, after heat treatment process, by enhancing defect free strategies for reduction of PCD runout. The results showed, enhanced process capability after modification in bar design and correcting quenching fluid velocity.

Keywords:*Camshaft Gear, PCD Runout, Distortion, Process Capability*

1 Introduction

Gear generating involves gear cutting through the relative motion of a rotating cutting tool and the generating, or rotational, motion of the work piece. The two primary generating processes are hobbing and shaping. Hobbing uses helically fluted cutting tool (HOB) and fed axially to a rotating workpiece, across the gear blank. Hobbing can be performed on single gear blank, but effectively allows stacking of multiple workpieces, increasing production rate. Based on hardness of gears, manufacturing of gears can be classified into hard stage and soft stage as shown in Fig. 1.

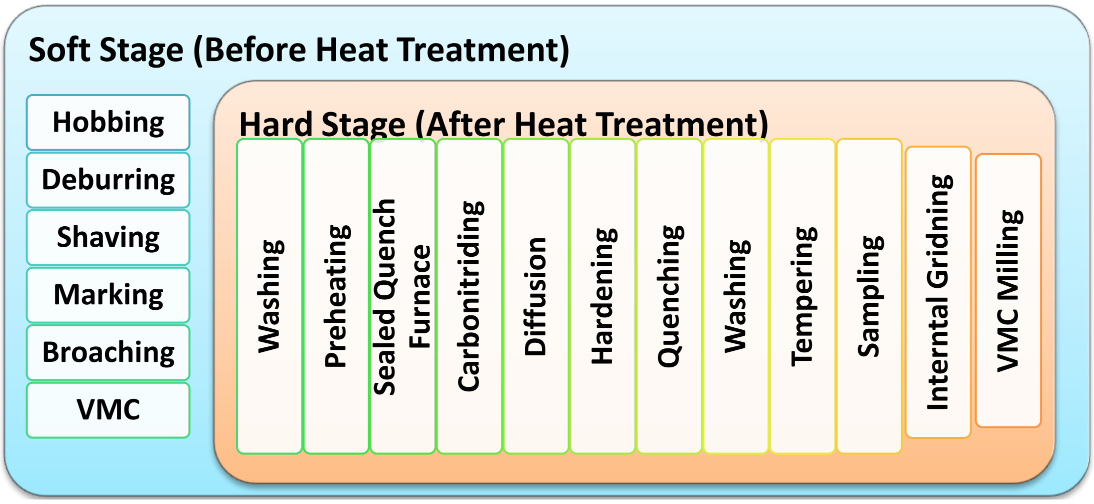

Fig. 1. Process Flow for Cam Shaft Gear Manufacturing

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Soft Stages of Gear before heat treatment includes manufacturing and finishing steps. After treatment of gearsincludes stage wise heat treatment based advancements such as carbonising, diffusion and hardening. This step aims at smoothing function of gears with reliability during operations.

1.1 Description of Existing Manufacturing Setup

Heat Treatment is looked as an operation or combination of operations involving the controlled heating and cooling of metal in the solid state for the purpose of obtaining specific properties. The purpose of heat treatment will be to modify the structure of material and relieve the stresses set up in the material. For this purpose, Sealed Quench Furnaces (SQF) is used with oil quenching media. The gears are loaded on the base tray and fixture, with a total charge capacity weight 1000 kg is loaded in the furnace heating chamber with an automated procedure. Charge is heated to 9000Cin the heating chamber in the sealed and controlled atmosphere as per the cycle setting. 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. After completion of quenching the charge is removed from the furnace and washed in the washing machine. Quenching of steel involves the rapid cooling of austenite to transform it into the hard structure-martensite.

1.1.1 Part Description

Cam shaft gear of having outer diameter 156.7 mm and inner diameter 33.05 mm with chamfer length 1.4, depth 9.90, GD & T //0.02, total thickness 21.70 and free from dent, burr, damage and dust is used for manufacturing.

Fig2. Camshaft Gear with a Keyway at centre

Fig 3. Back Side of Gear

Its other specifications are noted in table 1

Table 1 Technical Characteristics of Camshaft Gear

Technical Characteristics	
Metallurgical Composition	Steel Grade – 20MnCr5, Carbon Steel
Chemical Composition	C-0.18, Mn-1.14, Cr-1.05, Ni-0.028, MO-0.003, P-0.012, S-0.029, Si-0.18, Al-0.034
Standard	DIN 17210:1969
Usage	Power Transmission Medium
Machining	Helical Gear Cut on its OD with Internal Spline to avoid misalignment with power input shaft
No. of Teeths	66, Right handed helical gear
Helix Angle	23o33''
Used in	Engine Gear and fitted in Camshaft during its assembly, thereby known as Camshaft Gear
Heat Treatment Required	Normalized and Shot Blasted

Technical Characteristics	
Micro Structure	Uniform Normalized of ferrite and pearlite
Surface Hardness	81-83 HRA
Finish Weight	0.324 kg
Operational Description	It has two pocket holes that help in bolting during assembly. It has a rectangular shaped lug provided on its back side. The fitted assembly of gear on camshaft in closed housing is provided with sensor. During the operation when gear comes funder sensor, fuel injection occurs; Fuel injection to the engine is totally dependent on the relative position of lug and sensor, resulting in a cyclic process.

The heat treatment requirements of Camshaft Gear are noted in Table 2

Table 2 Heat Treatment Details of Camshaft Gear

Process	**Temperature (0C)**	**Time (Minutes)**	**Carbon Potential %**
Preheating	480	60	-
Carbonitriding	870	50	0.95
Diffusion	870	10	0.85
Hardening	830	30	0.75
Oil	130	-	550
Tempering	160	150	
Oil make – HiQuench MT 650			

1.1.2 Expected Outcome of Gears Quality

The gears produced should be free from distortion. Distortion is an irreversible and unpredicted changes in shape and size, phase changes, changes in hardness, microstructure and residual stresses of the component during processing from heat treatment and from temperature variations and loading in service. Section 2 reports literature survey result with this approach.

2 Literature Survey

Number of researchers made attempts to form research framework to address the problem of Quality of Gears. Few relevant studies on addressing distortion problems are as per following.

Suleyman Saritas and et al (2002) concluded that Pores in sintered P/M steels influence their thermal response and thereby hardenability.

BL Ferguson and et al (2005) found that hardening process leads to geometric distortion and recommends optimized method to derive the phase transformation kinetics parameters from dilatometry experiments. They further recommend specific model preparation to predict distortion and residual stresses by experimental method.

Christian Bahnsen and et al (2005) carried out distortion study for 20MnCr5 component and concluded that internal stresses act as major contributor.

Anil Kumar Sinha, Bohn Piston Division (2014) carried out distortion study and concluded that faulty heat treatment practices, deficiency in the grade of steels used, part defect, improper grinding and poor part design are contributory factors.

Jeevan P. George, et al (2014) carried out research work on gear treatment process by simple fixture and recommends better cooling mechanism, reduction of gear weight and improved fixture to hold gears during the treatment. However, fixture itself acts as another interface for cooling mechanism to be addressed leading to more complex formation of research framework.

V. Khade, et al (2015) carried out research work case hardened steel gears and found that distortion is characterized by uneven hardening, formation of soft spots, increase in warpage during quenching and increase in case depth. They concluded use of sealed oil in quench furnace is the predominant cause of distortion.

From this review, it is evident that specific component should be experimentally analyzed and statistically minimize effects of distortion in specific environment. It is therefore, relevant that distortion studies depicting PCD runout should be carried out.

3 Problem Identification

The Camshaft gear part produced is susceptible for distortion depicting in PCD runout. It is found that this problem is mainly occurring in a certain lot. As one part is costing about 400/-, it is critical to find the systems of associated errors and eliminate it.

Fig. 4. shows monthwise rejection of parts due to PCD runout.

Fig. 4. Monthwise rejection due to PCD

The corresponding cost of Poor Quality is demonstrated in Table 3

Table 3 Cost of Poor Quality

Sr. No.	Description	Poor Quality Parameter
1.	Number of parts rejected for December	55
2.	Number of pieces scrapped last month	55
3.	Number of pieces scrapped last month	0
4.	Scrap Cost Per Piece	398/- Approx
5.	Rework Cost Per Piece	0
6.	Total Scrap Cost	21980/-
7.	Total Rework Cost	0
8.	Total Rejection Cost	21980/-
9.	Extrapolated Total Rejection Cost in a year	262680/-

3.1 Experimental Study

A study is conducted on the charge to measure and find out amount of distortion occurred after the quenching process.

Cause and Effect Diagram

The cause and effect diagram is plotted to analyze the effect of PCD Runout Problem in form of distortion

3.1.1 Formulation of Hypothesis in valid/invalid formation from Cause and Effect Diagram

The hypothesis Identification based on Cause and Effect Diagram is done as indicated herewith.

Hypothesis 1 – DOP

Hypothesis 2 – Fixture not ok

Hypothesis 3-Flatness not Ok

Hypothesis 4- Heat Treatment Cycle not OK

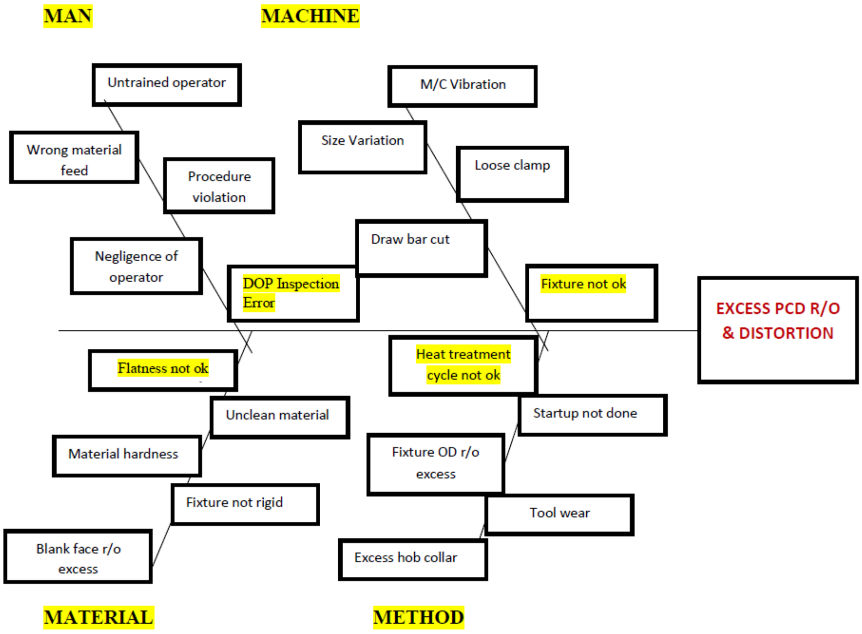


Fig. 5. Cause and Effect Diagram of PCD Runout

Table 4 Hypothesis Conclusion

Sr. No.	Probable Cause	Test Observations	Conclusion
1.	DOP Inspection Error	MSA and Gauge R & R if acceptable	Hypothesis is invalid
2.	Fixture not ok	Continuous 50 parts checked and PCD run out is ok	Hypothesis is invalid
3.	Flatness not ok	Out of 18 parts 6 good parts and 6 bad parts are considered and relation of RCD Runout with flatness is carried out	Hypothesis is invalid
4.	Heat Treatment Cycle not ok	18 piece study and 150 piece study done with Before Heat Treatment, parts found ok and sent for heat treatment and were inspected and 65% parts were not found ok	Hypothesis is valid

Table 5 Gauge R & R Data

PART NAME	camshaft engine gear	PART NO.	MG002268	UPPER TOL .LIMIT	90
GAUGE / EQUIPMENT NAME	rolling tester	GAUGE / EQUIP.NO.		LOWER TOL. LIMIT	0
GAUGE / EQUIP. LEAST COUNT	0.01	CHARACTERISTIC	DOP(FINAL)	TOLERANCE	90

DATA COLLECTION													
APPRAISER	NO. OF TRIALS/PARTS		1	2	3	4	5	6	7	8	9	10	AVERAG
	ashwin	1	70.000	72.000	75.000	71.000	74.000	71.000	70.000	72.000	75.000	72.000	72.2
		2	68.000	72.000	73.000	75.000	75.000	70.000	74.000	75.000	80.000	71.000	73.3
		3	70.000	70.000	72.000	74.000	71.000	72.000	73.000	76.000	78.000	74.000	73
		AVG.(k1)	69.3333	71.3333	73.3333	73.3333	73.3333	71	72.3333	74.3333	77.6667	72.3333	72.833333
		RANGE (k1)	2.00000	2.00000	3.00000	4.00000	4.00000	2.00000	4.00000	4.00000	5.00000	3.00000	3.30000
	NO. OF TRIALS/PARTS		1	2	3	4	5	6	7	8	9	10	AVERAG
	pawan	1	65.000	68.000	73.000	72.000	74.000	68.000	73.000	70.000	78.000	68.000	70.9
		2	70.000	69.000	73.000	77.000	72.000	75.000	74.000	74.000	81.000	70.000	73.5
		3	68.000	73.000	76.000	68.000	75.000	74.000	72.000	70.000	80.000	71.000	72.7
		AVG.(k2)	67.6667	70	74	72.3333	73.6667	72.3333	73	71.3333	79.6667	69.6667	72.366666
		RANGE (k2)	5.00000	5.00000	3.00000	9.00000	3.00000	7.00000	2.00000	4.00000	3.00000	3.00000	4.40000
	NO. OF TRIALS/PARTS		1	2	3	4	5	6	7	8	9	10	AVERAG
	roshan	1	65.000	71.000	75.000	74.000	75.000	71.000	70.000	74.000	76.000	70.000	72.333333
		2	68.000	75.000	74.000	72.000	72.000	73.000	72.000	73.000	79.000	74.000	73.777777
		3	67.000	72.000	71.000	70.000	76.000	75.000	69.000	73.000	77.000	71.000	72.1
		AVG.(k3)	66.6667	72.6667	73.3333	72	74.3333	73	70.3333	73.3333	77.3333	71.6667	72.466666
		RANGE (k3)	3.00000	4.00000	4.00000	4.00000	4.00000	4.00000	3.00000	1.00000	3.00000	4.00000	3.40000

Table 6 Summary Results of Gauge R & R Studies

RESULTS / EVALUATION	
REPEATABILITY (EQUIPMENT VARIATION) $EV = 2 \times K1$	11.28500
REPRODUCABILITY (APPRAISER VARIATION) $AV = \square \{(8DIFF \times K2)^2 - (EV^2 / nr)\}$	-2.98504
REPEATABILITY & REPRODUCABILITY (R & R) $R \& R = \square (EV^2 + AV^2)$	11.67312
PART VARIATION (PV) $PV = Rp \times K3$	16.74000
TOTAL VARIATION (TV) $TV = \square (R \& R^2 + PV^2)$	20.40807
% EQUIPMENT VARIATION (EV) $\% EV = 100 \times \{EV \div TT\}$	12.54%
% APPRAISER VARIATION (AV) $\% AV = 100 \times \{AV \div TT\}$	-3.32%
% REPEATABILITY & REPRODUCABILITY $\% R \& R = 100 \times \{R \& R \div TT\}$	12.97%
% PART VARIATION (PV) $\% PV = 100 \times \{PV \div TT)$	18.60%

The noted part variation if 18.60% and Repeatability and Reproducibility is 12.97%. The total variation from R & R is conditionally accepted if it is below 20% which indicates that the measurement system is capable and can be used as decision making process.

The variation in flatness with respect to PCD runout is observed for total 10 parts (C10).From fig 6, it is evident that flatness variation is not affecting PCD Runout and their after distortion of workpiece. 18 jobs are inspected for PCD runout before modification at existing systems. The outlier test is conducted for these 18 jobs within value of 0.04 mm for PCD run out at soft stage and 0.09 mm for PCD runout at hard stage.The result is indicated in Fig 7.

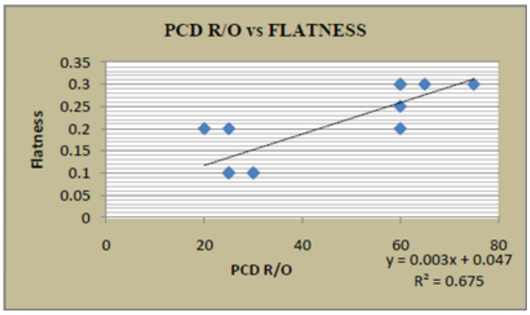
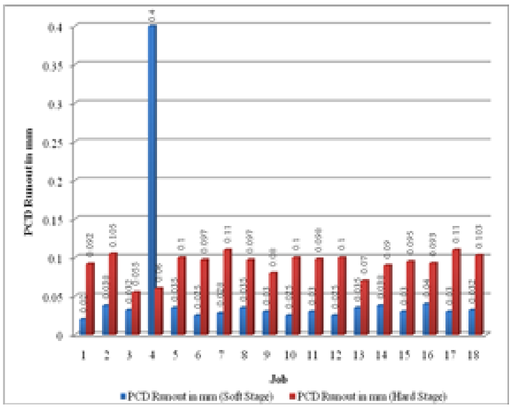


Fig. 6. Relation of PCD runout with Flatness



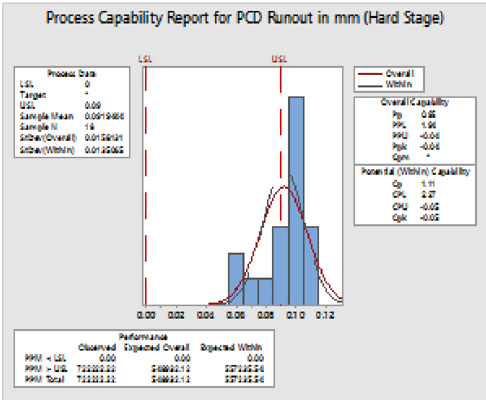


Fig. 7. PCD Runout for 18 Jobs **Fig. 8.** Process Capability of Existing System

Fig.7 indicates higher PCD runouts in soft stage rather than hard stage. The hard stage process capability report for PCD runout is occurring due to defects induced in soft stage.

The process Capability study indicates that parts are out of upper specification limit. The Cpk and Ppk values are negative (-0.05 and -0.04) indicating that the process mean falls outside specification limits as the process is producing a large proportion of defective output.

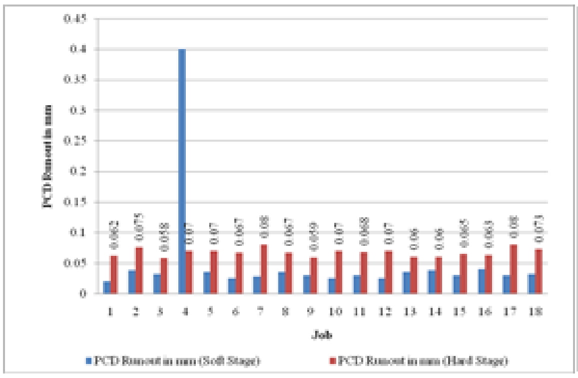
4 Modifications in Process to improve process capability

For the heat treatment process, gears are loaded on a round bar in a quenching stand with a batch of 480 parts. The single round bar was used in tank to pass through the centre hole of gear which often leads to uneven vibrations causing distortion.

Fig. 9. (a) Round Bar **Fig. 9. (b)** Star Bar **Fig. 9. (c)** Gear Loading Stand

To overcome this distortion problem 2 star bars are loaded along alternative holes instead of round bar at centre hole as shown in fig 9. The star bar provides stability to the gear, thereby reducing vibrations and distortions.
In quenching process, oil is preferred than air. The flow of oil therefore is a vital parameter as it affects phase transformation. Increase in fluid velocity will enable the cooling rate at the center of the component exceeds the critical cooling rate. Therefore, a high speed accelerate quenching oil is recommended for usage with 1.665 m/s velocity, rather than 1.491 m/s which was already used, due to higher availability of speed step in quenching pump.

The PCD runout is once again checked after modification as demonstrated in fig 10.



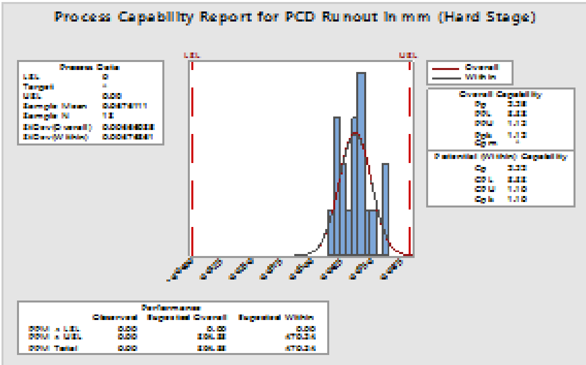


Fig. 10. PCD Runout after modification **Fig. 11.** Process Capability after modification

The Cpk and Ppk values are in positive (+) indicates that the process mean falls within the specification limits as the process is not producing any defective input. Therefore, it can be concluded that the process spread is within the specification spread.

5 Conclusions

1. The experimental framework presented in this paper helps to set the maximum and minimum limit for quenching speed based on process capability improvement by modifications from round bar to star bar. Other conclusions are as per following
2. The flatness variation is not affecting PCD runout and distortion of workpiece.
3. The distortion of gears in form of PCD runout are caused by heat treatment process and it can be reduced by
4. Modification of Round Bar design into Star Bar Arrangement
5. Inadequate support during the heat-treatment cycle, poorly designed bars and quenching fixtures 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.
6. Correct Quenching oil temperature and flow rate selection
7. Poor selection of quenchant with desirable properties, high speed fluid velocity, uniform temperature of oil and adequate agitation during hardening results in minimum distortion. Change in Fluid velocity from 1.491 m/s to 1.665 m/s, gradual reduction in PCD run out was observed.

References

[1] V. Khade, M. S. Ramgir, Study of Gear Teeth Distortions Due to Heat Treatment, International Journal of Scientific and Technology Research, Volume 4, Issue 02, February 2015, 74-79

[2] Jeeven P. George, Justin Koshy, Biju cherian abrasham, Distortion Reduction in Gear Heat Treatment Process by a Simple Fixture, International Journal of Emerging Technology and Advanced Engineering, Volume 4, Issue 11, November 2014, 306-312

[3] Suleyman Saritas, Roger D. Doherty and Alan Lawley, Effect of Porosity on the hardenability of P/M Steels, Research Gate, January 2002

[4] Anil Kumar Sinha, Bhon Piston Division, Defects and Distortion in Heat-Treated Parts, ASM Handbook, Volume 4, Heat Treating, ASM Handbook Committee,601-619

[5] Christian Bahnsen, Brigitte Clausen, Franz Hoffmann, Hans-Werner Zoch, Influence of Carburising on Distortion Behaviour, 1st International Proceedings on Distortion Engineering 2005, 228-234,

[6] B.L. Ferguson, Z. Li, A.M. Freborg, Modelling heat treatment of steel parts, Computational Materials Science, Volume 34, Issue 3, November 2005, 274-281