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To Arrive At Solution for Profile Distortion Problem Encountered During Heat Treatment Process of Gear Manufacturing Using Root Cause Analysis

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ABSTRACT: Gear Box, assemblies and hence quality of its components(referring to gears) play a vital role during transmission mechanism. Many issues have occurred and still do occur during the processing of gears especially in areas of Hobbing , Shaving, Heat Treatment processes, etc and best trials have been carried out so as to attain authentic solutions to the complexities occurred. Oerlikon Fairfield- a gear manufacturing MNC successfully uses Root Cause Analysis Techniques(PDCA cycle, Cause and Effect Diagram with Shainin Technique combination), DMAIC quality improvement Methodology in order to solve the problems encountered during part processing . The present paper deals with Profile fall/distortion problem occurring after heat treatment process during new development of helical gear. Modern gearboxes are characterized by high torque load demands, low running noise and compact design. In order to fulfill these requirements, profile specifications have to be tightly controlled. Current problem being one of major quality issues is resolved and controlled by using a combination of Cause and Effect Diagram with Shainin Technique and DMAIC-6 sigma break through methodology. Tool modifications being considered as final resort and hence implementation of modifications of shaving cutter during shaving stage (a pre heat treatment process) helped in achieving the required profile trace within the required post heat treatment process specifications.

KEYWORDS: Cause and Effect Diagram , Helical gear, Profile distortion/fall, Root Cause Analysis(RCA), Shaving Cutter modifications.

I. INTRODUCTION

Gears are transmitting elements using for transmitting power and motion. Basically gear manufacturing process consist the following steps Raw material (forgings procured),Blanking, Gear Cutting, Auxiliary operations, Gear Finishing, Heat Treatment, Post Heat treatment finishing. Heat-treating processes have been greatly used to enhance the mechanical properties of components made up of steel like bearings, gears, shafts, etc. But, heat treatment processes such as carburizing, quenching , tempering, etc usually cause uncontrolled distortion.

Distortion becomes a major concern during manufacturing of high quality gears. The causes of distortion found by researchers are mainly because of thermal stresses as well as phase transformations occurring during the heat treatment process. Gears experience distortion during the heat treatment process.

The present work is carried out at Oerlikon Fairfield where difficulty occurred while developing a new helical gear. Profile fall was evident post heat treatment process and this affected required gear accuracy. The difficulty is related to correction of profile distortion problem occurring post heat treatment. When gears are hardened, distortion problems lower the quality of the gears and this initiated for finding the root cause of distortion by using quality tools like Root Cause Analysis Techniques so as to eliminate distortion problem by finding the root cause. Generally Failure Mode Effective Analysis(FMEA), Cause and Effect Diagrams, Shainin Methodology, Plan do check act cycle (PDCA),DMAIC(define-measure, analyze -improve-control) methodology are effectively used in industries to attain solutions for problems encountered during part's processing.

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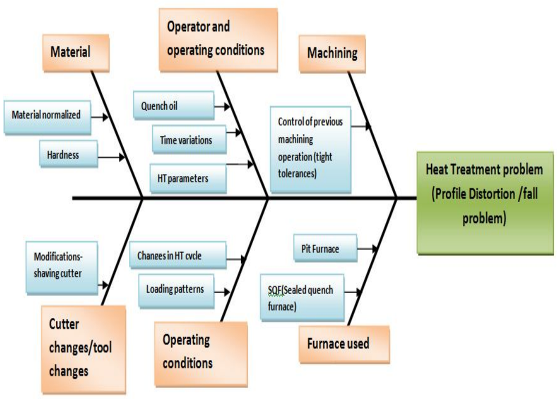
II. LITERATURE REVIEWS

Masoud Hekmatpanah [1] has studied on The Application of Cause and Effect Diagram in Sepahan Oil Company.The method has been used also to group categories that cause other types of problems which an organization confronts. This made Fishbone diagram become a very useful instrument in risk identification stage. Cause and Effect diagram was used to reduce scraps from 50000 to 5000 ppm. Daniel H. Herring [2] based on his studies says that each area in the gear tooth profile sees different service demands. Dimensional changes(growth, shrinkage, warpage) due to heat treatment cycle (heating and cooling) are a function of material selection, part geometry, manufacturing methods and equipment and heat treatment process and cycles. He concludes saying today, emphasis is placed on reducing the number of post heat treatment operations and hence heat treatment methods must be optimized.

Producing Profile and Lead modifications by Threaded Wheel and Profile Grinding by Dr. A. Türich [3] (the American Gear Manufacturers Association) says that Modern gearboxes are characterized by high torque load demands, low running noise and compact design. This paper focuses on how to produce profile and lead modifications by using the two most common grinding processes—threaded wheel and profile grinding. At INFAC [4] ,studies was conducted on Heat treatment and was reported that Heat treating is another important research subject a major statistically designed experiment determined the effect on part quality of the heating cycle, the carbon diffusion Cycle, the location of part within the carburizing furnace and of incoming residual stress in parts after carburizing. Results showed an unexpected trend towards the distortion in teeth and run out of parts with higher incoming stresses.

III. PROBLEM IDENTIFICATION, METHODOLOGIES AND EXPERIMENTATIONS

The present work focuses on profile fall/distortion of gear teeth encountered after Heat Treatment process. This problem is causing deviations from required gear accuracy and hence needs to be amended. It is very vital that the problem needs to be rectified in part's development phase itself so that the same problem does not recur while part is produced in lots i.e. during production phase.. The main objective is to arrive at authentic solution for the profile distortion problem encountered after Heat Treatment Process along with meeting quality, cost and delivery criterion.



CAUSE AND EFFECT DIAGRAM (Profile distortion problem)

B.Experimentations and checks carried out.

Checking the gear in soft stage(i.e during Shaving stage and Hard stage(Heat Treated Stage)

The graph of shaving stage was monitored and found that the profile was within the K sheet as required by the customer. The Diameter over Pin (DOP) was also checked during shaving stage and found that it was within the specifications .It is vital to consider DOP specifications during shaving stage so as to understand the growth and distortion occurring after Heat Treatment.

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DOP specifications required during shaving stage was 174.51-54mm and after inspection it was known that DOP was within the specifications ie 174.51-174.53mm . DOP Hence efforts are made to identify, understand, analyze, evaluate and study and recommend solutions for distortion problem(Heat treatment cycle variations, loading patterns, variation of Heat Treatment parameters, graphs, etc) .Hoshin planning is a step by step planning used to achieve the required results. In Hoshin Planning, PDCA cycle is mainly used .Root Cause Analysis Technique(Cause and Effect Diagram with Shainin Methodology is used in PDCA cycle's check phase) with DMAIC methodology are adopted in the present study to identify and solve profile distortion problem.

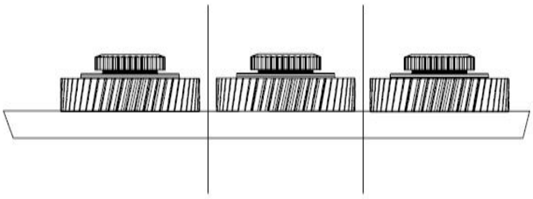
Cause and Effect Diagram for profile distortion problem

To identify the root causes, the Cause and Effect diagram is used to find the causes affecting profile distortion of the gear. Brain Storming sessions help in understanding the causes. Brain Storming sessions is also one of RCA tool. The groups of categories depicted in Fish Bone diagram help in understanding the probability of causes. From the diagram it is known that different causes that may be causing profile fall and each one of the probabilities have to be scrupulously checked so as to find the root cause. For this the problem of profile fall was evident after Heat Treatment Process.

specifications required after heat treatment was 174.54-174.62mm and after inspection it was known that DOP was within the specifications or slightly at higher end ie 174.60-174.63mm.DOP study is vital in analyzing profile distortion problem so as to understand the profile fall is from SAP(start of active profile) or only from PCD line(ie pitch circle diameter line) to EAP(end of active profile). From DOP checkings and graphs of gear teeth taken after Heat Treatment, it was understood that profile fall was occurring from PCD line to EAP and not from SAP trace.

Loading pattern changed

Initially 5 parts were considered for regular Heat Treatment process cycle carried out in sealed quench furnace(SQF) and Loading pattern used was Horizontal. Entire Heat Treatment process consists of washing, Preheating, Carburizing, Diffusion, Soaking/Holding Time, Quenching/Hardening, Tempering. Hence with the same Heat Treatment process cycle, loading pattern was changed from horizontal to vertical/bar loading in order to solve profile fall problem. But this change did not help much as profile distortion was still evident even with vertical/bar loading pattern. Hence this option was dropped.



HORIZONTAL LOADING

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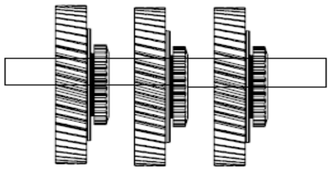

VERTICAL LOADING

Variations in HT(Heat Treatment) parameters
In order to eliminate the problems occurring , the following HT parameters were varied.
A) Carburizing . B) Diffusion. C)Holding Time

A)Carburizing Temperature is usually set or regularly set to 900-910 deg Celsius due to the variations occurring when carburizing temperature is increased or decreased.

Temperature variations	Problems
1) Temperature increased to 930 degrees And (time reduced-to maintain Case depth)	-more distortion and growth problems -DOP again increased(174.64-174.65mm)
2) Temperature reduced to 870 degrees And (time increased-to maintain case depth)	-DOP was maintained at higher specifications -No changes in distortion -major draw back was time consumption and hence the cost

Table 3.1a) Carburizing variations.

During carburization – CP%(carbon Potential is maintained to 0.9 to 1%).From previous results for other gears, CP% cannot be varied much during carburizing. If CP%- 0.6-0.7 – it leads to improper case hardness(with Retained Austenite and Carbides .If CP%- 1.2-1.3%- Reverse affects seen-part fails to absorb carbon- thus affecting martensite .

B) Diffusion
CP% usually maintained- 0.7% .
Diffusion done mainly-1)For proper carbon diffusion on the surface.2)To attain the desired case depth as case depth increases by 0.05 to 0.1mm during diffusion.(during carburizing-CD attained is around 0.7mm). Hence the final case

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depth achieved is up to 0.8mm.Trials were carried out by varying the CP% to check whether it affected the distortion problems.

CP% Variations	Problems
1) CP% increased to 0.8-0.9%	Case Microstructure was affected(RA-retained austenite and carbides evident in case)
2) CP% decreased to 0.5-0.6%	low case hardness attained(49 HRC)

Table 3.1 b) CP% variations

Hence proper CP% i.e. 0.7% was maintained during diffusion so as to attain desired microstructure and hardness.

C) Soaking Time/Holding Time

After the metal is heated to the proper temperature ,it is held at that temperature until the desired internal structural changes take place. This process is called SOAKING. The length of time held at the proper temperature is called the SOAKING PERIOD. Soaking temperature is the temperature just below the point at which the change takes place and then it is held at that temperature until the heat is equalized throughout the metal. Soaking Temperature is usually maintained at- 820-840 degree Celsius and normal soaking period is between (30-45mins) depending on part size, geometry, etc Variations were tried with soaking Time.

Soaking time Variations	Problems
1) Soaking time increased(> 45mins)	CP% dropped hence Case hardness was affected(48HRc) -Case depth increased(> than required ie > than 0.8mm)
2) Soaking time decreased(< 30mins)	No much variations or effects seen for this part -chances of warpage problems (by previous study)

Table.3.1c) Soaking Time variations

Hence variations carried out during Carburizing, Diffusion, Soaking – HT(Heat Treatment) parameters did not help in eliminating profile distortion problem.Hence Standard Heat Treatment Cycle was maintained as shown below.

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Table.3.1d) Standardized table

Process	Temp.	Time	C.P.
Carburizing	900±10°C	3:30Hrs.	1.00%
Diffusion	900±10°C	1:00Hr.	0.75%
Hardening	820±10°C	30 min. Soaking	0.75%
Hot Oil Quenching	100-110°C(Actu--al 105°C)	15 min. in oil tank	--

Variations in quench oils used

Initially cold quench oil(60-90 degrees Celsius) was used and the agitation set was fast for 20minutes.Cold oil was replaced by Hot oil(100-150 degree Celsius) and the agitation was set slow for same amount of time. Oil viscosity changes due to hot oil and slow agitation of quench oil gave some improvements in dimensional accuracies, but major improvements still to be corrected i.e. In spite of these variations the profile distortion problem was still seen.

Variations tried by varying Heat Treatment cycle

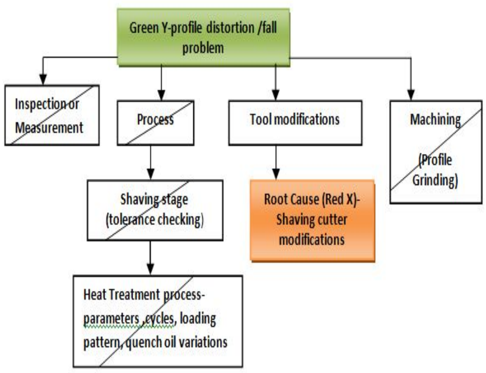
Normal or Regular Heat Treatment cycle was altered to Step Fitting Heat Treatment Cycle. During this cycle, parts are held during certain temperatures(eg at 750 degrees Celsius , 820 degree Celsius for certain period of time) so as to attain localized heat, grain growth, distortion control, etc. But this cycle did not help in solving profile distortion problem.

Profile grinding in order to correct profile distortions

This option was not considered as it was not approved from customer's end. Hence had to be dropped out.

Cutter tool i.e. shaving cutter modification

Shaving cutter modification , and hence modifications done in shaving stage was tried and successful results were attained.



RCA-SHAININ METHODOLOGY

IV. RESULTS AND DISCUSSIONS

Final resort in solving the problem of profile distortion was by modifying the shaving cutter so that the gear's profile would be controlled during shaving stage itself. Distortion was always evident after heat treatment due to which profile fall was occurring. Profile fall was 20-25 microns outside the customer's K sheet design.

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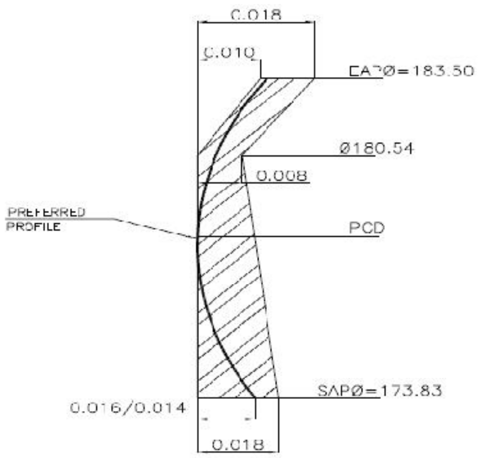
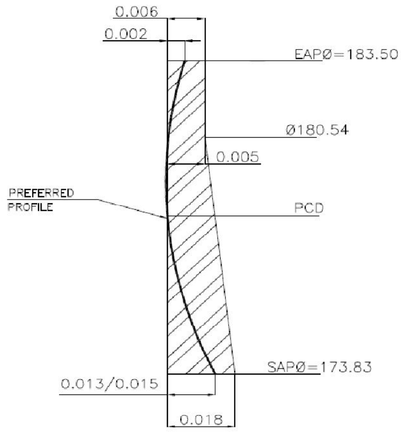
K sheet of shaving cutter changed from (Negative values to positive values) so as to eliminate profile fall which was occurring after Heat Treatment.

The profile fall of shaved part always portrays the negative values. Hence correction was worked out on reducing the negative values during 1st modification of shaving cutter. Improved results were seen after 1st modification but further improvement was required and because of this requirement, the shaving cutter was modified for the 2nd time where negative values were changed to positive values. When external gears are shaved , the engaging tooth profiles of shaving cutter teeth and gear teeth are of convex surfaces. This understanding is vital so as to comprehend the shaving cutter modifications.

The cutter modifications with parts shaving stage graphs and Heat Treated parts graphs are shown for better understanding and analysis.



2)



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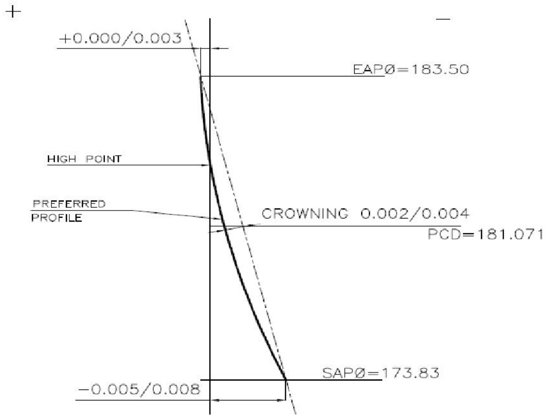
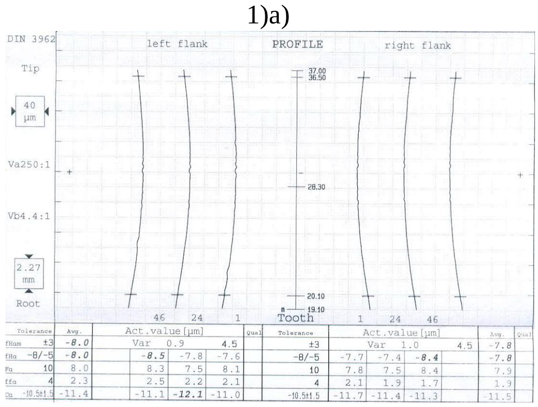


1)Initial shaving cutter-K sheet length from centre line is -0.018mm and cutter profile trace is -0.010mm(negative values)
2)After 1st modification of shaving cutter teeth profile shows -0.018mm changed to -0.006mm and- 0.010mm to -0.002mm.(negative values, but improved)
3) After 2nd modification of shaving cutter teeth profile shows cutter profile trace changed to +0.002mm to +.003mm.(positive values)

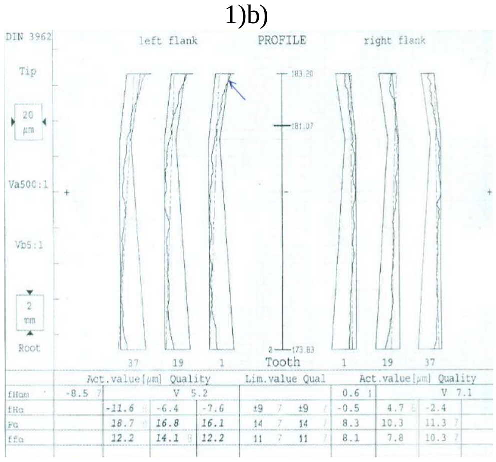
Changes in Shaving cutter's modification graphs along with gear's shaving graphs shown

1)a)



Initial shaving cutter 's graph.

1)b)



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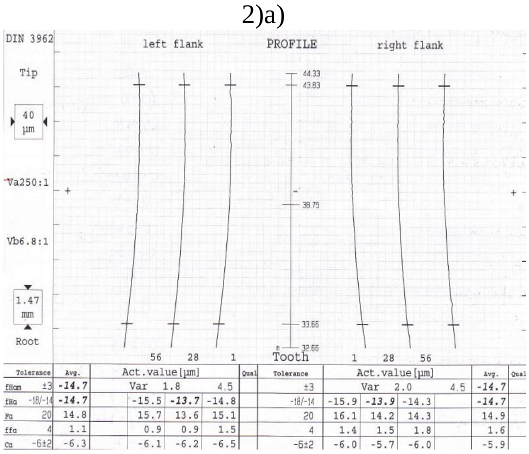
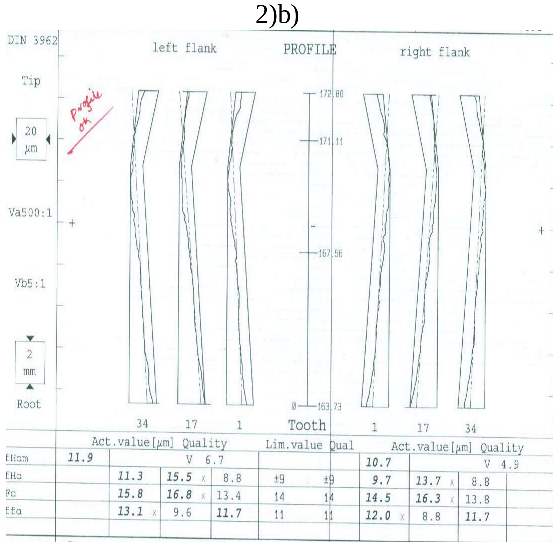
Part's shaving graph when initial shaving cutter was used.

2)a)



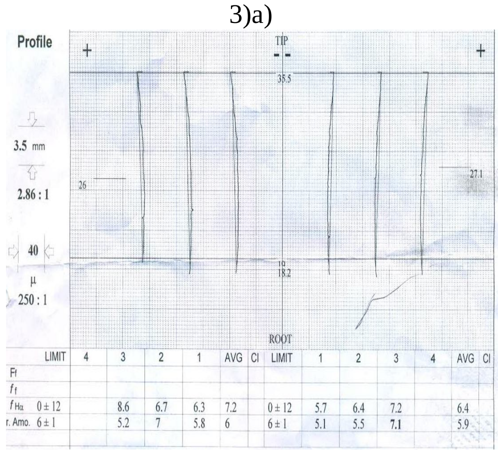
shaving cutter's graph after 1st modification.

2)b)



Part's Shaving graph attained for 1st modification of shaving cutter and improved shaving graph is evident.

3)a)



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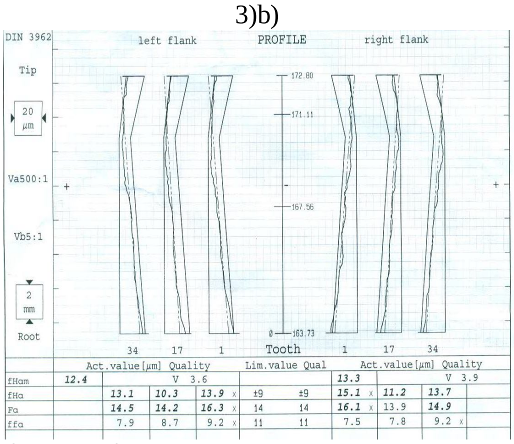
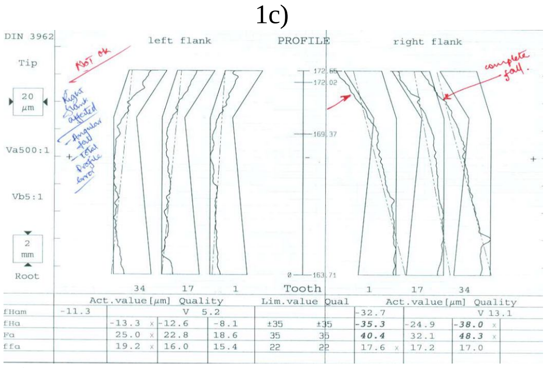
Shaving cutter's graph- 2nd modification of shaving cutter. This was done as heat treated part's graph was still falling on the border of K sheet and hence 2nd modification was required.

3)b)



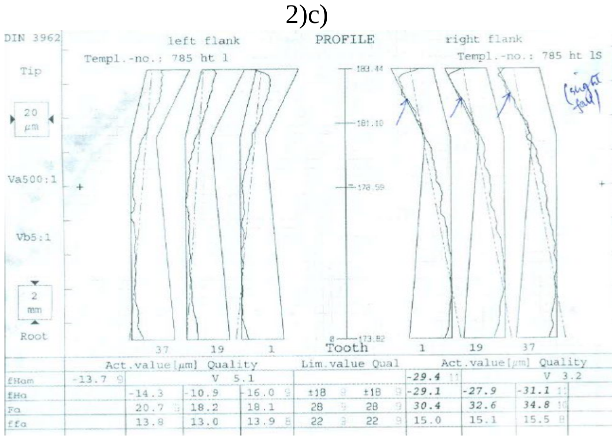
Part's Shaving graph for 2nd modification of shaving cutter.Below graphs show the graphs of parts(gears) that were shaved using 1st cutter, 1st modified shaving cutter and 2nd modified shaving cutter after the same parts(gears) which were shaved and then heat treated heat treated.

1c)



Complete fall of profile/ involute of gear noticed when initial shaving cutter was used for shaving and the same part being heat treated.The fall of graph explains the amount of profile distortion occurring after Heat Treatment process ie after the part was heat treated. This is unacceptable and hence changes were required to be done in shaving cutter itself as control of part's profile fall was inevitable.Hence shaving cutter was sent for modification with changes and amount of modifications required . Modification details are shown in previously explained cutter changes diagrams.

2)c)



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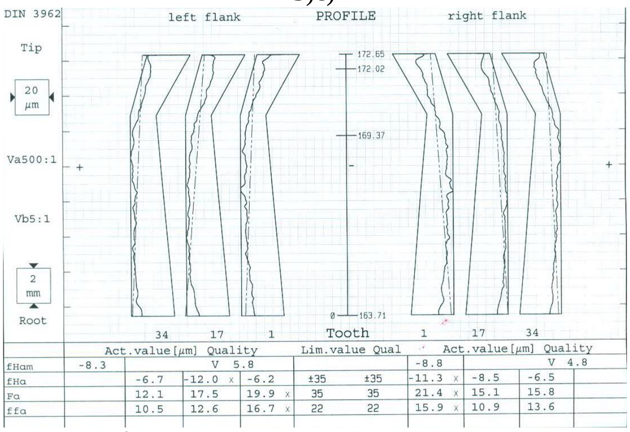
Fall of profile/ involute of gear noticed on the border of K sheet when 1st modified shaving cutter was used for shaving and the same part being heat treated.Improved graph of profile is witnessed when compared to the later heat treated part's graph. The profile fall is seen on the border of K sheet which depicts still improvement was required to attain the final graph within the K sheet.Hence 2nd modification for shaving cutter was imperative in order to achieve better and acceptable results.

3)c)



Correct or as required profile/ involute of gear noticed within the K sheet when 2nd time modified shaving cutter was used for shaving and the same part being heat treated Successful results were achieved as gear profile was within the K sheet.

The graph shows the left flank and right flank of gear within the K sheet.

Hence heat treatment distortion problem (profile fall problem) was solved via successful modifications of shaving cutter after carrying out various experiments.

V. CONCLUSIONS

1)By using RCA techniques, profile distortion problem was corrected.Combination of PDCA cycle, Cause and effect diagram with Shainin Methodology helped in identifying the root cause and hence finding authentic solution for the same.

2)Shainin Methodology application helped in finding the root cause for profile distortion problem by eliminating the other probabilities which were experimented. Measurement oriented, process oriented experiments(experiments carried on change in Heat treatment cycles, Heat Treatment parameters, change in loading patterns,change in quench oil temperatures,etc) were eliminated and finally need for shaving cutter modifications was focussed.Hence shaving cutter modifications requirement formed the Red X(Root cause).

3)DMAIC 6 sigma break through methodology helped in defining the process, measuring and analysing the results.Proper analysis led to improvements in shaving cutter modifications and finally after successful correction of shaving cutter , gear teeth's profile distortion problem was ammended and the same was controlled.

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