

# **To Arrive At Solution for Sine Pattern Problem Occurring on Gear Involute during Shaving Operation of Gear Manufacturing Process Using Root Cause Analysis**

Raveen John<sup>1</sup>, Dr. Y. S. Varadarajan<sup>2</sup>, Paul Pereira<sup>3</sup>

P.G. Student, Dept. of Industrial and Production Engineering, The National Institute of Engineering, Mysore, India<sup>1</sup>

Professor, Dept. of Industrial and Production Engineering, The National Institute of Engineering, Mysore, India<sup>2</sup>

Chief Technical Advisor, Dept. of Engineering and Development, Oerlikon Fairfield, Belgaum, India<sup>3</sup>

**ABSTRACT:** Modern gearboxes are characterized by high torque load demands, low running noise and compact design Gear assemblies, gear box and quality of its components (referring to gears) play an important 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 are carried out so as to attain definite solutions to the encountered problems. 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 occurring during part's processing. The present paper deals with Sine Pattern problem occurring during processing of new development part i.e. spur gear. Sine pattern occurrences have to be controlled stringently as per K sheet specifications. 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 tried as final resort and hence implementation of modified shaving cutter during shaving stage helped in achieving the corrected sine pattern profile within the required K sheet specifications.

**KEYWORDS:** Cause and Effect Diagram, Spur gear, Sine pattern, Root Cause Analysis (RCA), Shaving Cutter modifications.

## **I. INTRODUCTION**

Gears are used in most types of machinery so as to transmit power. The automobile normally uses spur and helical gears in the transmission and bevel gears in rear end. Gear manufacturing method and gear quality are to decided based on gear application. Basically gear manufacturing process consist the following steps Raw material (forgings procured), Blanking, Gear Cutting(hobbing, shaping, etc), Auxiliary operations( milling, drilling, etc), Gear Finishing( shaving), 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.

There are three different ways by which an involute of gear teeth can be finished by involving a gear like tool rolling with the work on a crossed axis: Shaving, Rolling and Honing operations. Gear Shaving process is strictly a finishing operation which is much faster process when compared to gear grinding. But gear finishing operation is carried out during soft stage ( i.e. pre heat treatment) and gear grinding is carried after hard stage( i.e. post heat treatment).

Shaving is a corrective process where shaving cutter and work gear form a crossed axes gear set where relative motion between any two contacting surface composes a rolling motion in direction of involute and a sliding motion

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

along tooth length. The rolling motion along the involute has no effect on shaving process. The removal of chips is solely caused by the lateral sliding motion. The tooth surfaces of shaving cutter are provided with plurality of serrations or gashes whose sharp edges exert a cutting action. When external gears are shaved, the engaging tooth profiles are both convex surfaces and hence a relative low contact pressure is sufficient to cause the cutting edges to generate shaving action on surfaces of work gear teeth.

The present work is carried out at Oerlikon Fairfield where difficulty occurred during shaving process while developing a new spur gear. Spur gear was facing the occurrence of “S” pattern formation on profile of gear teeth during shaving process. Sine pattern which was getting generated during shaving operation was not acceptable as it causes variations in profile/ gear involute and this variation results in the occurrence of major problems like uneven meshing, backlash problems, damage problems, noise problems. Hence efforts are made to maintain the accuracy of required gear profile so that Sine pattern does not occur. Finding the root cause of distorted involute by using quality tools like Root Cause Analysis Techniques so as to eliminate sine pattern problem by finding the root cause becomes imperative. 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.

## II. LITERATURE REVIEWS

Jim Cladwell [1] based on his studies gives an information regarding the machine marks and feed marks affecting the gear involute. Ideally, the shaved gear tooth surface should be smooth with very light, uniform feed marks and have a soft, no glossy appearance. He discusses the problems, preventive measures and solutions occurring during gear shaving operations. Problems like consistent heavy feed marks, random marks or irregular scratches, tearing or gouging near tooth tip, etc.

At Samputensili [2] , studies was carried out based on resharpener and on machine measurements of shaving cutters. Samputensili developed serrating machine to cut serrations on shaving cutters to the strictest tolerances. They have intensely worked out on improvement of design and optimization of shaving cutter as per customer specifications on areas like formation of undercut, serration correction of shaving cutter grooves, profile grinding correction of teeth, turning of shaving cutter body, etc

John P. Douglas[3], discusses the importance of gear shaving basics. He focuses on the crossed axes principle where he discusses about how during the shaving cycle, the work is reciprocated parallel to its axis across the face of the cutter and up-fed an increment into the cutter with each stroke of the table. He also gives the consequences of improper cutting and guiding action, different shaving methods, improper coolant problems, Variations of speeds and feeds, etc. He also details on vitality of high rigidity of machine requirements.

Denis Gimpert [4] , reported on gear inspection trouble shooting tips. Inspection of gears is to make sure that the best gears are being produced. His study reveals that guarding gear deviations in every stage of gear processing is vital. The study also focuses on how hobbing errors i.e. preshaping operation errors can actually cause problems during shaving process. He discusses about size variations, composite errors occurring, profile inspection with sinusoidal wave, etc.

## III. PROBLEM IDENTIFICATION, METHODOLOGIES AND EXPERIMENTATIONS

The present work focuses on solving the sine pattern formation problem occurring on gear involute and this was encountered during gear shaving process. As per customer’s requirement and design, it is vital that the profile generated during shaving is/must be within the K-sheet specifications. Figure 1a) represents an example of “S” pattern getting generated on gear teeth profile during gear shaving operation. The main objective is to arrive at authentic solution for the sine pattern problem encountered during Shaving Process along with meeting quality, cost and delivery criterion.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

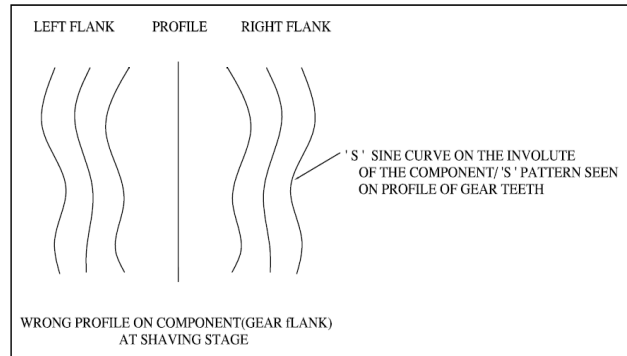


Figure 1 a): Sine Pattern Problem

Hence efforts are made to A) identify the problems (machining related), carry out investigations on the same so as to understand and thus recommend solutions to them. B) Arrive at the appropriate setting parameters, machining parameters, tool specifications and modifications, etc for the manufacturing of undertaken gear/part so that these problems don't recur during PPAP lot.

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 the distorted involute occurring during shaving operation.

## A. Cause and Effect Diagram for Sine Pattern Problem

To identify the root causes, the Cause and Effect diagram is used .

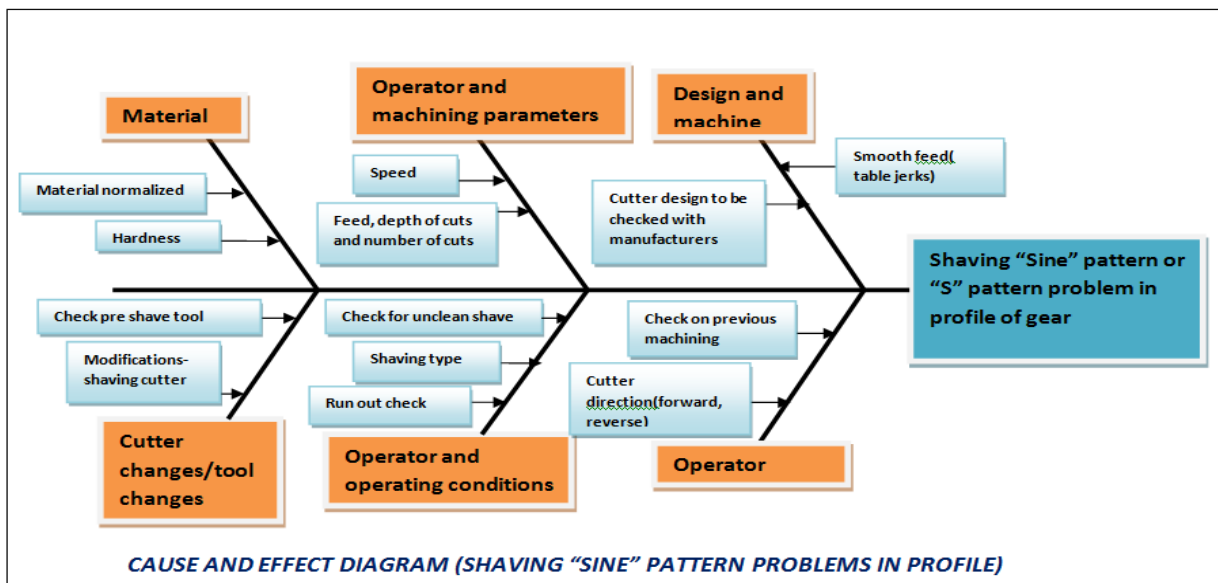


Figure 2: Cause and Effect Diagram for sine pattern problem occurring during shaving process.

Using Cause and Effect diagram, causes and their effects were understood and based on the same, experimentations were carried out so as to eliminate the "S" pattern formation problem encountered during shaving

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

operation. Combination of DMAIC and PDCA was used to solve this problem. Figure 2, represents the Cause and Effect Diagram for Sine pattern problem occurring during shaving operation.

### B . Experimentations carried out to find out and solve Sine (S) Pattern Problem

The following experiments were carried out in order to eliminate the Sine pattern problem occurring during shaving operation.

#### 1)Variations of machining parameters

The following machining parameters were varied during shaving operation so as to check and eliminate the occurrence of sine pattern formation problem. Different variations and combinations for speed(160 rpm, 180 rpm,170rpm), feed(1.6inch/min, 1.8inch/min,2.2 inch/min), number of cuts(4, 6, 8) and shaving direction( forward, reverse) were experimented/ tried out to check whether these machining parameters were influencing the formation of Sine pattern. But results obtained showed that “S” pattern still existed. Hence it was understood that sine pattern formation was not caused due to machining parameters.

#### 2)Variations in types of shaving process

There are three major types of shaving operations.

- a)Conventional Shaving.
- b)Diagonal Shaving.
- c)Underpass Shaving.

Both Conventional Shaving and Diagonal Shaving were tried. Underpass Shaving was not tried as it is carried out mainly for shoulder gears.

Conventional shaving is also referred as axial traverse shaving or parallel shaving, where shaving cutter is traversed relative to work gear in the direction of work gear longitudinal axis. At the end of each stroke, the cutter and work gear are moved into slightly closer mesh (incremental up feed). Work gears of any width can be machined.

In Diagonal shaving, also called angular traverse saving, the direction of shaving cutter is set at an angle of 15o known as traverse angle (relative to work gear axis).

After trying both types of shaving methods, results obtained indicated that the “S” pattern was not being eliminated.

#### 3) Checking for feed marks and patch marks generated during previous Machining operation (hobbing)

The occurrence of “S” pattern could be because of crossed feed marks and patch marks generated during hobbing operation. Feed marks generated during hobbing operation on the flanks of gear teeth were scrutinized. No patch marks, varied crossed feed marks were evident. Due to the absence of patch marks, the shaving operation performed was clean (i.e. unclean shaving of parts was not evident). If shaving operation was unclean, then this would have been an indication and the reason the reason for “S” pattern formation. Hence probability of “S” pattern formation due to the above reasons was eliminated; “S” pattern problem still existed.

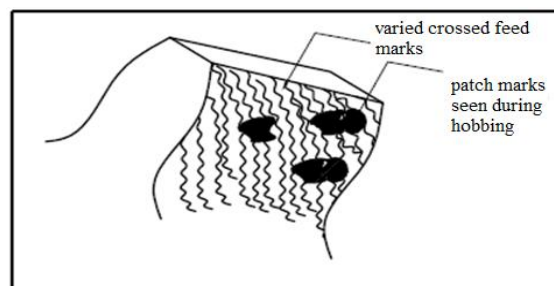


Figure 3:Patch marks and varied crossed feed marks

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015



Figure 4: No Patch marks and Varied Crossed Feed marks evident after hobbing operation

The varied crossed feed marks and patch marks could take the shape as shown in Figure 3. Figure 4 represents the feed marks generated on flank of gear teeth during hobbing operation which is normal without any problem. Patch marks were also not evident.

#### 4) Checking for hobbing graph profile (work gear profile after hobbing operation)

Hobbing graph profile of work gear was checked and found that hobbing graph profile was accurate as per specifications. If Hobbing profile was showing “S” form (and deviation above 30 microns) then by default, shaving operation also would have been affected. Hence the occurrence reason for S pattern forming would have still remained.

#### 5) Checking the Machine

Smooth feed or table jerks was checked for machine and was found that the machine had no table jerks and hence the feed was smooth. Thus the occurrence of “S” pattern is not due to this.

#### 6) Checking on various shaving operation parameters

Shaving operation parameters like shaving cutter settings, shaving mandrel settings, alignments of cutter and work gear were checked. After checking it was noticed that:-

- a) Shaving cutter settings was found correct.
- b) Shaving mandrel settings and shaving mandrel’s face run out was within limits..
- c) Alignment of cutter and work gear was proper.

“S” pattern problem was still evident even after shaving cutter settings, shaving mandrel run outs and alignments were precisely and accurately set/ maintained.

#### 7) Shaving Cutter modification

Finally shaving cutter modification was required in order to eliminate the occurrence of profile’s sine pattern formation during shaving operation. Shaving teeth profile correction/modification was necessary because by modifying the shaving cutter’s teeth profile, there were chances that the depth of “S” pattern getting generated on work gear’s teeth profile would be improved. Hence shaving cutter was sent for modification and after modifying the shaving cutter twice, required profile of shaved teeth of work gear was achieved. Figure 5 depicts the shaving operation and pictorial representation of shaving cutter teeth.

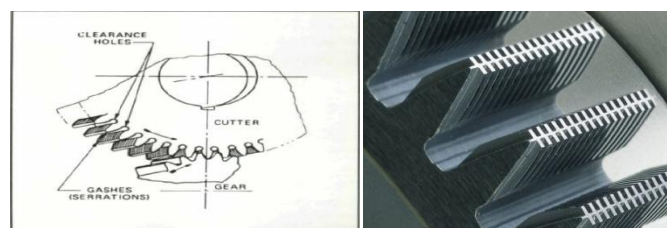
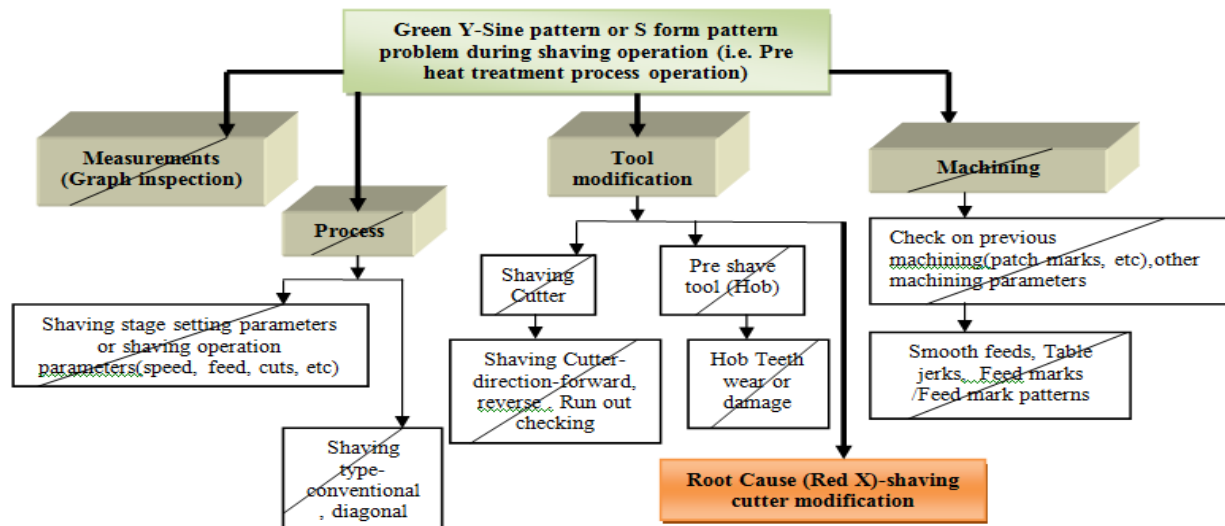


Figure 5: Shaving operation and Shaving Cutter teeth

Shainin diagram for Sine pattern or S pattern problem during shaving stage





**RCA-SHAININ METHODOLOGY (for Shaving S pattern Problem)**

In the depicted Shainin Solution/ Tree Diagrams, the “Green Y” or problem statement for the problem encountered is Sine(S) pattern formation and this problem has to be eliminated before the part is processed for next processing phases. In order to find “Red X-Root Cause” for the problems encountered, investigations and experiments have been carried out at various phases of work gear’s processing and the correct phases, processes, experiments are eliminated in order to arrive or identify the root cause of problem. After elimination of correct processes, phases, experiments which are not causing problems, the anticipation of problem’s root cause converges and focuses to a problem causing area. Hence Shainin Techniques are much simpler than the factorial designs, response surface designs, orthogonal arrays of the conventional Design of Experiments (DOE) techniques, but at the same time are considered as very powerful and effective tools in solving especially chronic problems that plague most manufacturers.

**IV. RESULTS AND DISCUSSIONS**

Shaving operation produces improved quality and surface finish of gears. Shaving operation removes the hob feed marks, waviness and surface irregularities caused during hobbing operation. Thus it is important that shaving cutter profile must be/is very accurate.

After various trials were carried out to eliminate the occurrence of sine pattern on work gear profile by varying different parameters and it was established that these parameters were not influencing the occurrence of sine wave pattern during shaving operation. Hence shaving cutter was sent for modification so as to change/modify the shaving cutter’s teeth profile. Shaving cutter was modified in accordance with work gear’s K sheet specifications.

By modifying the shaving cutter’s teeth profile accurately/as desired, required profile of work gear is achieved. Correction of work gear’s profile is important as correct profiles result in/helps in uniform load distribution over the teeth, hence withstanding higher load capacities and increased service life. Figures 7 a), 8 a) and 9 a) show the shaving cutter profile graphs without and with cutter modifications. Figures 7 b), 8 b) and 9 b) represent the corresponding profiles generated on the work gear by using these shaving cutters.

Shaving cutter’s modification graphs along with gear’s shaving graphs are shown

Figure 7 a) represents the initial profile of shaving cutter without modification. Figure 7 b) shows shaving graph/profile of work gear attained after shaving operation using shaving cutter without modification.

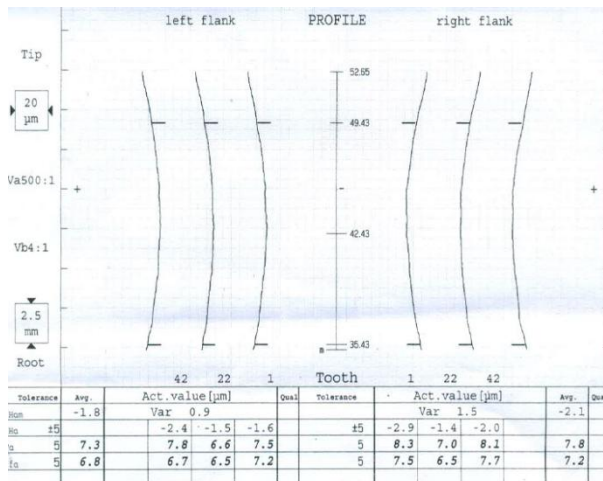


Figure 7 a): Shaving cutter profile without modification

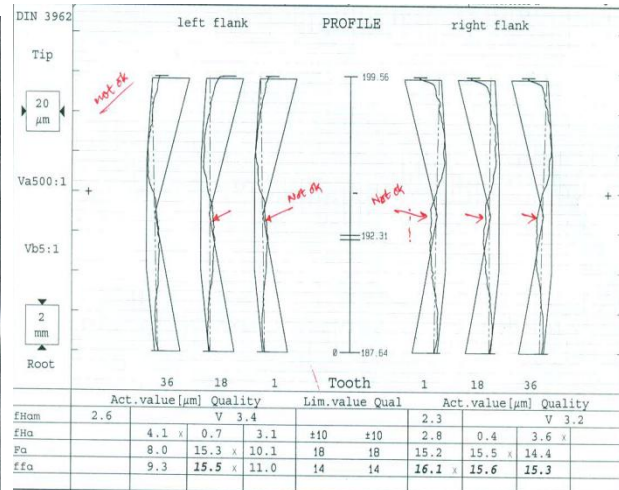


Figure 7 b): Work gear's shaving profile obtained by using shaving cutter without modification.

In Figure 7 b), when initial shaving cutter without modification was used, sine pattern occurred on profile of work gear. The evident “S” pattern/sine pattern profile of work gear was also falling outside the K sheet specifications, indicating Profile Form errors occurring on both right and left flank of gear teeth. This “S” pattern is unacceptable as “S” pattern indicates a waved profile and hence this waviness has to be eliminated. The elimination/correction of “S” pattern occurring on work gear profile would also result in profile getting generated within the K sheet.

Initial shaving cutter's upper profile depth (i.e. profile depth from centre line of shaving cutter teeth profile to top of cutter profile) was 0.003mm-0.005mm. Further studies suggested that the shaving cutter's upper profile depth had to be increased in order to eliminate the occurrence of “S” pattern profile of work gear. Hence shaving cutter had to be modified.

Following Figures show further modified shaving cutter graphs and the corresponding shaving graphs/ profiles attained on the work gear. Figures 8 a) and b) show the shaving cutter's profile graph and work gear's shaving graph attained after 1st modification of shaving cutter.

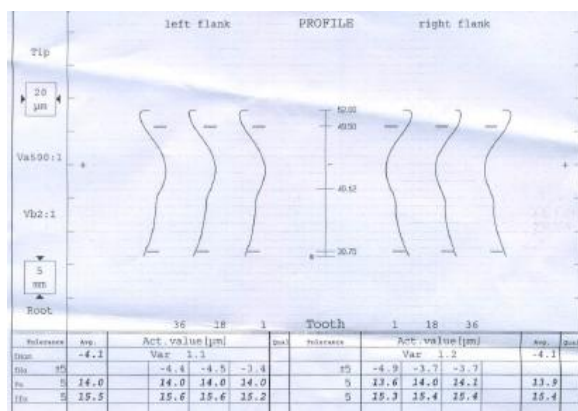


Figure 8 a): Shaving cutter's graph after 1st modification

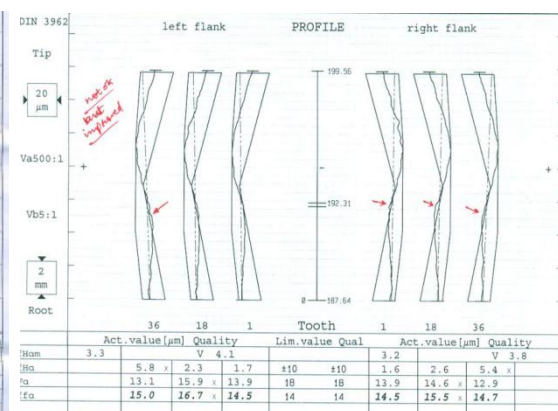


Figure 8 b): Work gear's shaving profile obtained after 1st modification of shaving cutter

Figure 8 a), the modifications done on shaving cutter profile is evident. During the first modification of shaving cutter, the shaving cutter's upper profile depth was increased from 0.003mm-0.005mm to 0.007mm-0.009mm. After shaving operation was carried out using modified shaving cutter, an improvement was seen/ witnessed in the sine

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

pattern of work gear's profile (Figure 8 b) and due to this; the profiles of work gear fell on the borders of K sheet. Hence Profile Form errors were partially corrected. But still further improvement was imperative as work gear's both left and right flank profiles must be within the K sheet.

Figures 9 a) and b) indicate the shaving cutter's profile graph and work gear's shaving graph obtained after 2nd and final modification of shaving cutter.

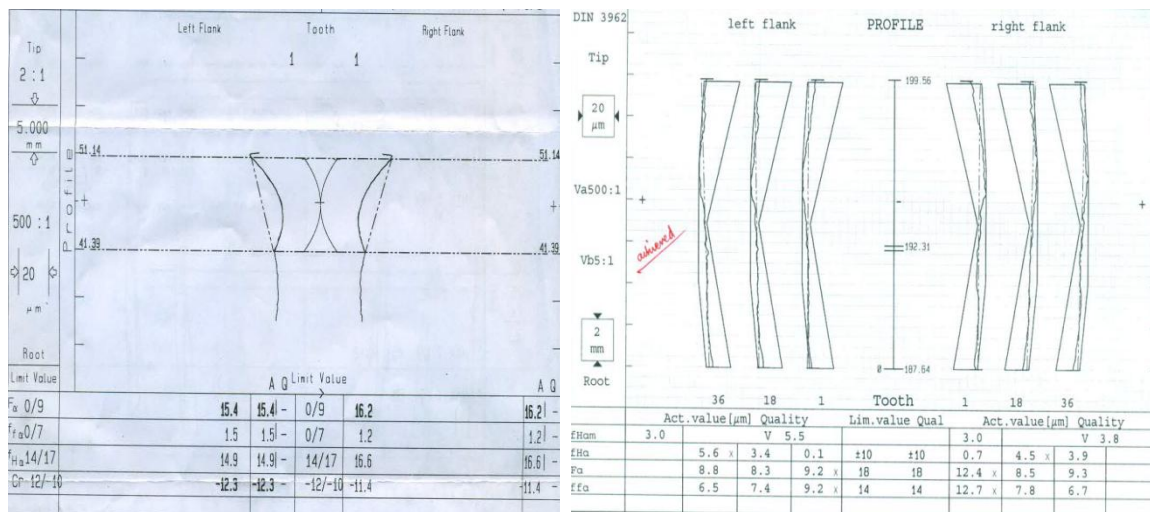


Figure 9 a): 2nd Modification- shaving Cutter's graph Figure 9 b): Work gear's graph- improved Sine pattern within K sheet

In Figure 9 a), final modification changes done on shaving cutter profile is evident. During the 2nd and final modification of shaving cutter, shaving cutter's upper profile depth was further increased from 0.007mm-0.009mm to 0.012mm-0.014mm. When shaving operation was carried out using this final modified shaving cutter, the "S" pattern profile on work gear was eliminated i.e. the required profile was achieved (Figure 9 b) and due to this; the work gear's left and right flank was observed to be lying within the specified K sheet, indicating correction of Profile Form errors.

Hence after the 2nd and final modification of shaving cutter, the problem of sine pattern occurring on the profile of work gear during shaving operation was solved.

## Understanding Shaving Cutter Modifications

It is important to understand the shaving cutter graphs and work gear's shaving graphs attained prior shaving cutter modifications and after different shaving cutter modifications. For better understanding of profile of shaving cutter's without and with modifications and the corresponding profiles which they generate on the work gear, AutoCAD drawings of these are represented in Figures 10 a), b) and c).



# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

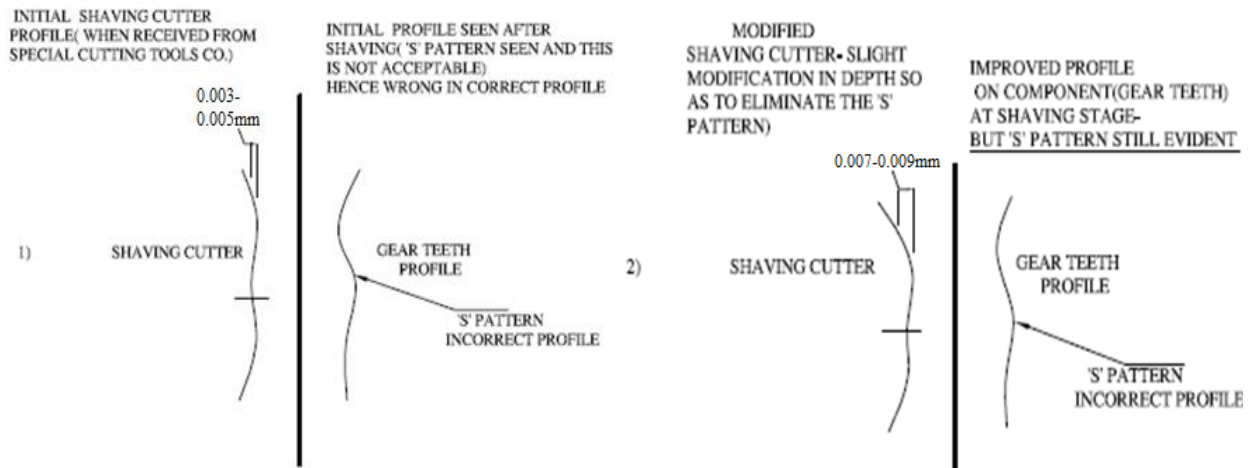


Figure: 10 a)

Figure: 10 b)

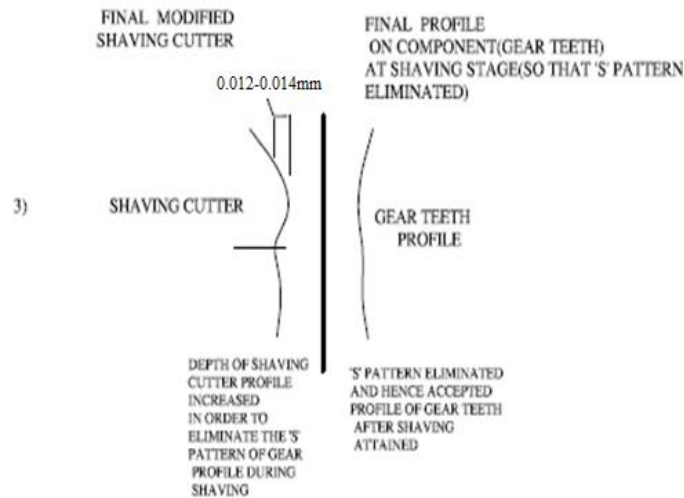


Figure: 10 c)

Figure 10 a): Shaving cutter's profile and the corresponding work gear profile (without cutter modification).

Figure 10 b): Shaving cutter's profile and corresponding work gear's profile (with modified cutter).

Figure 10 c): Shaving cutter's profile and corresponding work gear's profile (with final modified cutter).

The profiles of the work gear teeth before and after modifications of shaving cutter is represented with AutoCAD drawings (Figure 11 a) and b)

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

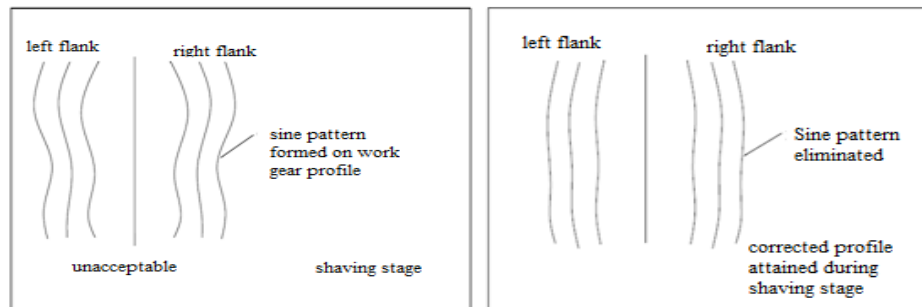


Figure 11 a): Sine pattern seen on work gear profile prior shaving cutter modification

Figure 11 b): Corrected work gear's profile after cutter modification

### V. CONCLUSION

- 1)By using RCA techniques, sine pattern problem occurring on work gear during shaving process 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 Tree Diagram helped in finding the root cause for the occurrence sine pattern problem by eliminating the other probabilities which were experimented. Measurement oriented, process oriented experiments were eliminated and finally the 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. Cogitated analysis led to improvements in shaving cutter modifications and finally after successful correction of shaving cutter , work gear's involute distortion occurring during shaving process was corrected i.e. sine pattern was eliminated.

### ACKNOWLEDGEMENT

We take this opportunity to thank especially Mr.Deva Jacob for giving an opportunity to carry out project at Oerlikon Fairfield. Sincere thanks to all production and quality department people and the entire Engineering Team, for their constant guidance and support.

### REFERENCES

- [1] Jim Cladwell, "Machine marks on gear flanks, their causes and prevention", Gear Technology India, Vol 3, Issue 2, 2007, 34-35.
- [2] Samputensili, "Shaving cutter production and Resharpener", Company of Meccaferrri Industrial group, Jan 2004, 49.
- [3] John P. Dugas, "The Process of gear shaving", Gear Technology, Jan-Feb 1986, 45-48.
- [4] Denis Gimpert, "Gear Inspection Trouble shooting tips" Gear Solutions, February 2007, 36-43
- [5] Gear technology Magazine.
- [6] Gear Solutions Magazine.
- [7] Gear Design Handbook.