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STUDY ON HEAT DISTORTION AND NOISE LEVEL OF TRANSMISSION GEARS

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Abstract- *Power transmission gear manufacturing for industrial applications requires an understanding of many factors, heat treatment process related variables (pre-treatment, load arrangement, process selection and technique, quench considerations and equipment design) and the component related variables that influence distortion. (material chemistry, harden-ability, part geometry, design considerations, and steel quality) in transmission gear parts manufacturing includes many processes included starting from receiving of turned blanks to final assembly. Each process needs to be checked thoroughly after every operation, beginning from inspection of raw materials, machining operation (broaching, shaving, spline rolling, deburring, heat treatment, grinding, assembly) quality control tests (performance test) are the usually carried out tests.*

One of the tests is distortion test which is done after soft machining, heat treatment and plug quenching operation. It is very important to check distortion occurrence in gears, as it plays a major role in determining smooth meshing, life and reliability of the part. The tests are conducted by measuring the dimensions of the gear before and after heat treatment. Required dimensional standards are met, by measuring major diameter, minor diameter, BBD (Between ball diameters), OBD (Over Ball diameters) at bottom, mid, top of gear and spline respectively by trial and error basis. At regular shifts the parts are checked randomly to ascertain the dimensions obtained are within the specified limits or not. The noise test is also carried out to check the sound emitted by the transmission assembly when it is in operation. If there is any variation or deviation in the dimensions noticed, it is rectified by checking the heat treatment cycles or by varying the dimensions during soft machining process, so that the final dimensions are within the required specifications.

Keywords: Major Diameter, Minor Diameter, Profile, Lead, Spec, OBD, BBD.

1. INTRODUCTION

1.1 Distortion in Steels

Distortion in Steels refers to change in size and shape of heat treated component due to thermal and structural stresses. [1]

Dimensional changes occurs during heat treatment

- Thermal expansion till austenite conversion phase
- Contraction on transformation to austenite
- Thermal expansion on austenite on further heating
- Thermal contraction on cooling to transformation temperature
- Expansion on diffusion to diffusion less decomposition of austenite
- Thermal contraction on further cooling to room temperature
- Contraction on tempering of martensite

The dimensional changes may give rise to distortion in steels. When steel is heated to elevated temperature and cooled slowly, there is a very small temperature gradient. Thermal and transformational stresses occur uniformly throughout the section.

Due to combination of thermal and structural stresses, when steel component is heated and cooled at a fast rate internal stresses develop in the steel component because of differential expansion and contraction of steel component. This occurs due to dimension changes after hardening, which takes place as a result of volume change due to phase transformation. Total distortion occurs because of the following,

- Presence of residual stress in the component before heat treatment
- The introduction of internal stresses in the component during heat treatment

The two main type of distortion are,

- Size distortion which refers to change in volume
- Shape distortion which relates to change in geometrical form of steel

Distortion is influenced by rate of heating, shape, size, wall thickness and geometry of the part chemical and structural in homogeneities, rate of cooling and Sub zero treatment. Table 1 gives the details of the possible process for size and shape distortion which takes place during and after heat treatment.

1.2 Distortion control

The distortion after heat treatment can be minimized by considering following aspects:

Design: Abrupt changes, sharp corner and thin walls should be avoided in component.[2]

Composition: Size distortion can be minimized by proper selection of steel.

Initial condition: Uniform microstructure and uniform temperature in the furnace should be maintained.

Machining Procedure: Rough machining to dimensions account for size distortion during heat treatment.

Table -1: Possible process for size and shape distortion during heat treatment

Operation	Sequence	Size Distortion	Shape Distortion
1. Hardening	Heating & holding at austenitzing temperature	a) Formation of Austenite b) Dissolution of Carbides	a) Relief of residual stresses b) Thermal Stresses c) Sagging (Due to wg. of component)
	Quenching	Formation of martensitic & non martensitic phases	a) Thermal stresses b) Transformation stresses c) Introduction of residual stresses
2. Sub Zero Treatment	Cooling & holding to sub Zero temperature & returning to room temperature	Formation of martensite	a) Thermal stresses b) Transformation stresses c) Introduction of residual stresses
3. Tempering	Heating & Holding to tempering temperature	a) Decomposition of martensite b) Transformation of retained Austenite	a) Stress Relief b) Thermal stresses
	Cooling from tempering temperature	Transformation of retained austenite	a)Thermal stresses b) Introduction of residual stresses

1.3 Distortion reduction methods

Size and shape distortion cannot be controlled during heat treatment. Size distortion can be controlled by proper selection composition of steel, by adjusting machining allowance and controlling the amount of various phases present in the steel after heat treatment. Shape distortion can be reduced by the following methods:[3]

- Stress Relieving
- Heating Rate
- Pre heating
- Quenching Media
- Press Quenching
- Trays, Fixtures and Supports

2. Machining Flow Chart of the Transmission Gears

1. Raw Material (Forged Parts)
2. Receiving & Inspection
3. Soft Machining
4. Heat Treatment
5. Hard Machining
6. Assembly
7. Quality Inspection

2.1 Receiving & Inspection

Table -2: Material Quality Requirement Tests

1. Tensile Test	2. Shock Resistance Test
3. Hardness Test	4. Facture Toughness Test
5. Bending Test	6. Fatigue strength
7. Compression, Shear, Twisting Tests.	8. Creep Strength

2. Soft Machining

Gear cutting is any machining process for creating a gear. The most common gear-cutting in soft machining processes include

Table -3: Soft machining operations details

• Broaching	• Hobbing	• Shaping
• Milling	• Finishing	• Shaving
• Chamfering	• Burnishing	• Lapping
• Deburring	• Honning	

2.3 Heat Treatment

Table -4: Heat Treatment Operations

1. Jig Setting	8. Unloading
2. Furnace Loading	9. Storage
3. Degreasing	10. Material Movement
4. Carburizing	11. Shot Blasting
5. Quenching	12. Shot peening
6. Washing	13. Straightening
7. Tempering	14. Dispatch

- Graph showing Conversion of steel from Austenite to Tempered Martensite

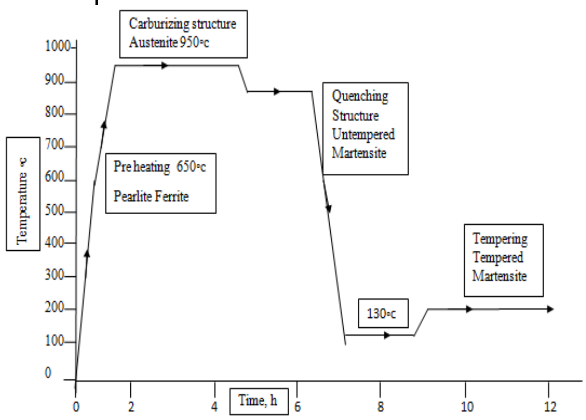

Fig -1: Conversion of steel from Austenite to Tempered Martensite

2.4 Hard Machining

Grinding

Grinding is an abrasive machining process that uses a grinding wheel as the cutting tool. Grinding is a process of finishing the surface of tool so as to make it use for various operations. Abrasive materials are used for grinding process.

3. EXPERIMENTAL DETAILS

The details of the experiments carried out on "Study on Heat Distortion and Noise level of Transmission Gears" are presented under the following headings.

3.1 Methodology

The following figure 2 gives the flow chart of the experiments carried out.

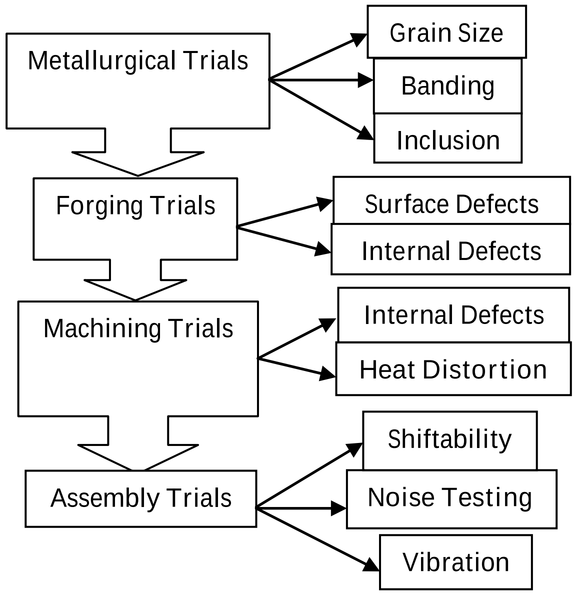

Fig -2: Experiments carried out

These are general routine tests which are carried out. However the main aim of this investigation was to carry out Heat Distortion Studies and Noise Level Tests. Hence the results for these two have been presented in detail.

- Heat Distortion

The distortion variation is measured by using dial gauge with a sensing tip i.e. the ball indenter. There are different types of ball indenter based on the diameter of the ball to measure a specific part dimension. The dimensions are measured at thee different stages i.e, soft machining, hard machining and plug quenching operation.

Procedure

- For the study N= 12 Parts are considered
- Between Ball Diameter(BBD): This is used to measure the pitch circle diameter in the external gears along the axis 0◦,90◦,270◦ at Top, Middle and Bottom regions of gear tooth respectively.
- Over ball Diameter (OBD): This is used to measure the pitch circle diameter in the Splines (Internal gears) 0◦,90◦,270◦ at Top, Middle and Bottom regions of gear tooth respectively.
- Major and minor dia are measured by using vernier calipers for gears.

These data are noted down by trial and error method certain standards are created for each part i.e. by varying dimension in soft machining process to get required dimension after distortion with a certain tolerance(Spec).

Finally based on data obtained the judgement is made. Figure 3 and 4 show the measurement of OBD and BBD respectively

Fig -3: Between Ball Dia

Fig -4: Over Ball Dia

4.1.4 Assembly Trials

- Noise and Vibration test
  - Machine used: Performance Tesing Machine
- Test Rig

The rig is of the recalculating power type and consists of two identical gearboxes, connected to each other with two universal joint shafts. Torque is applied by tilting one of the gearboxes around one of its axles. This tilting is made possible by bearings between the gearbox and the supporting brackets. A hydraulic cylinder creates the tilting force. The torque is measured with a load sensor placed between the cylinder and the gearbox. The test rig principle is shown in figure 5.

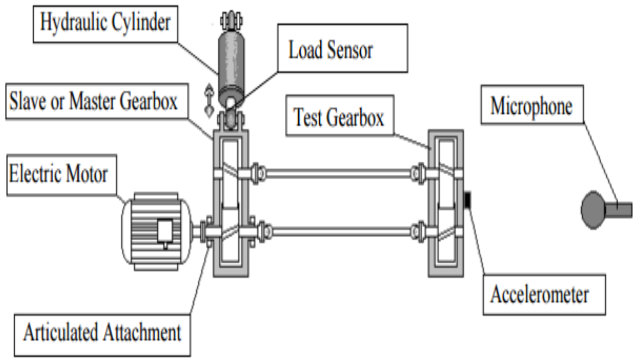

Fig -5: Schematic skketch of test rig.

- Test Cycle

The noise and vibration measurements were carried out at three different torque levels, +60, -40 and +120 Nm. For each torque level, measurements were made for 50 seconds each at constant speeds of 1000, 2000 and 3000 RPM and as speed uniformly (linearly) increased from 500 to 3500 RPM.

- Instrument description

The instrumentation consists of one optical tachometer, three microphones and three accelerometers. The shaft rotational speed is estimated by attaching a piece of reflecting tape to the part of shaft 1 in front of the gearbox figure 6, so that one pulse is registered per revolution of this shaft. The three microphones are positioned in front of the gearbox, as shown in figure 6. Additionally, the three accelerometers are attached to the front of the gearbox as shown in figure 7. Accelerometer 1 registers vibrations in an axial direction, accelerometer 2 registers vibrations in a radial direction, at an angle corresponding to the direction of the gear mesh contact force, and accelerometer 3 registers vibrations at a right angle to the direction of accelerometer 2.

Vertical positions:

Microphone 1 : 30 cm above table.

Microphone 2 : 45 cm above table.

Microphone 3 : 74 cm above table.

Microphone horizontal positions:

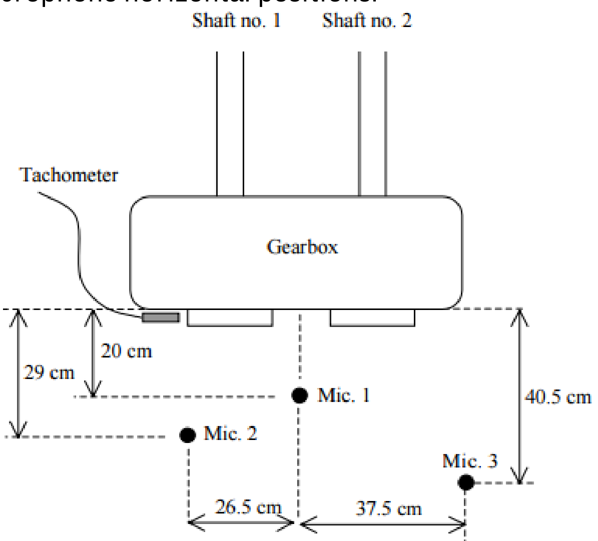

Fig -6: shows the top view of gearbox with tachometer and microphone positions.

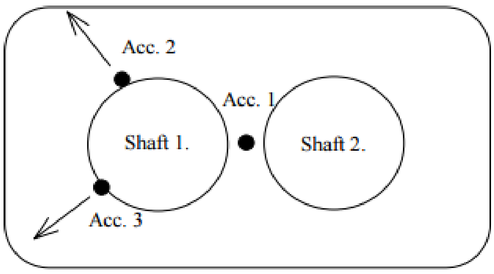

Fig -7: Gearbox shown from front view

This test is done to know the different variations in the gear box when it is put to working condition(Whole Assembly), such as sound emitted at particular points. This is measured by keeping sound detectors (mic). This signals are converted in to electrical signals. Figure 8 shows the performance testing machine in operation.

Procedure:

- Transmission assembly is mounted on to the performance testing machine
- For the study N= 30 Parts are considered i.e, one part per assembly.
- The graphs are obtained i.e, Decibels vs RPM at three different torque +60Nm, -40Nm and +120Nm.
- The graph obtained are unique for all 30 parts, and the repeatability of each part is studied, based on the graph the conclusion are arrived.
- The sound should be less than 150 decibels.

This test is also used to check if there is any jumpout of gears when meshing with each other at different RPM, sudden shifting of gears, sudden braking, when vehicle is overloaded.

Fig -8: Performance Tester Machine

4. RESULTS

4.1 Distortion Studies

These are carried out to study the distortion of the components. The details are presented here under.

- Quantity of parts machined: N=25
- Parts Quantity for Distortion Study: N=12
- Heat Treatment: Carburzing Furnace

Figure from 9 to 44 show the details of the results of the distortion test carried out. After performing each of these tests the results or judgement is arrived. Comments regarding existance or non existance of major or minor distortion is reported.

- Judgement Criteria:

1. Distortion results should be same as old steel parts
2. (Soft spec $\pm 3\sigma$+ Distortion)$\leq$ Heat spec/Same as old steel parts.

INPUT SHAFT

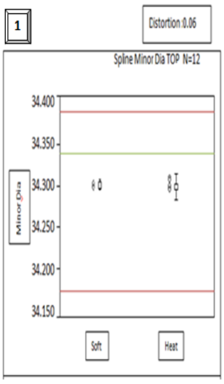

Fig -9: Spline Minor Dia TOP

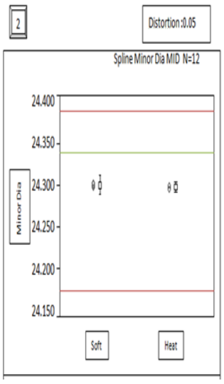

Fig -10: Spline Minor Dia MID

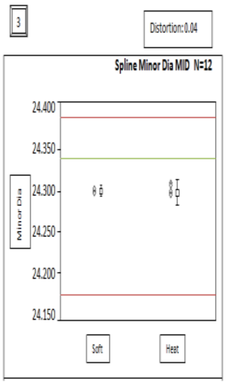

Fig -11: Spline Minor Dia BOT

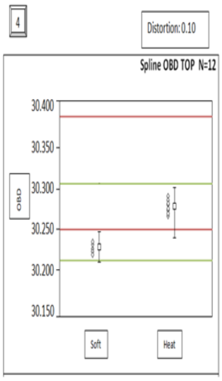

Fig-12: Spline OBD TOP

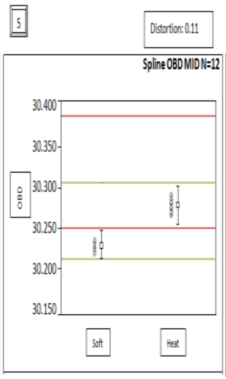

Fig -13: Spline OBD MID

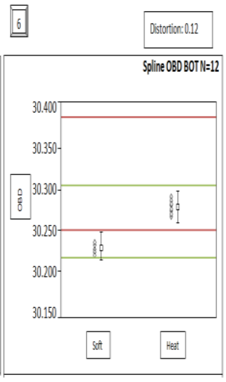

Fig -14: Spline OBD BOT

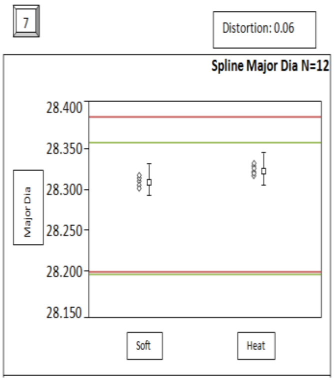

Fig -15: Spline Major Dia

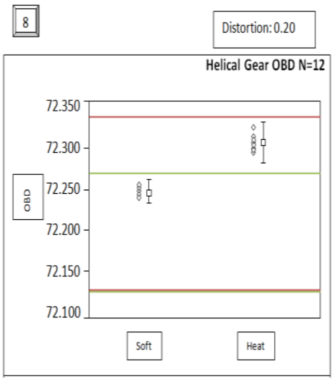

Fig -16: Helical Gear OBD

Table -5: Distortion Values for Input Shaft

Part No.	Distortion Values
1	0.06
2	0.05
3	0.04
4	0.10
5	0.12
6	0.12
7	0.06
8	0.20

GEAR REVERSE

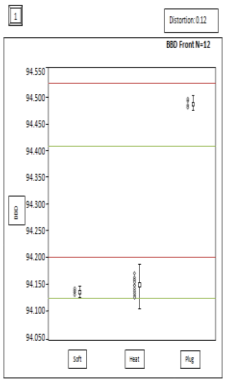

Fig -17: BBD Front

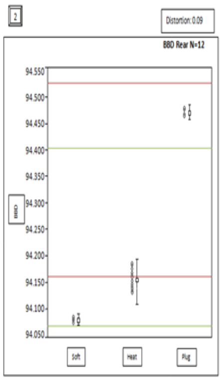

Fig -18: BBD Rear

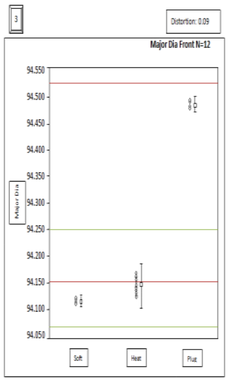

Fig -19: Major Dia

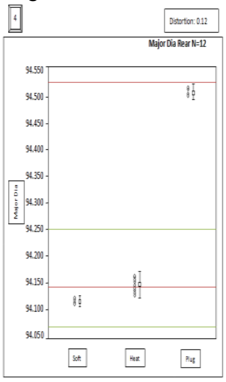

Fig -20: Major Dia Rear

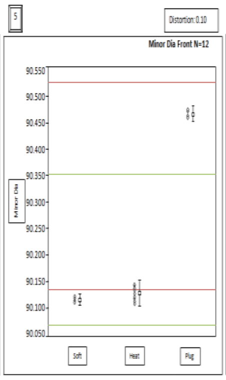

Fig -21: Minor Dia Front

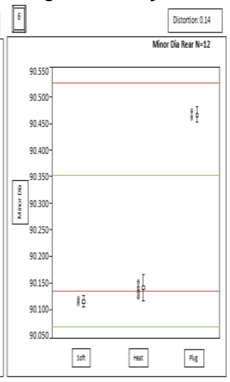

Fig -22: Minor Dia Rear

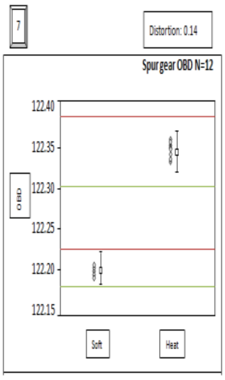

Fig -24: Spur Gear OBD

Table -6: Distortion Values for Gear Reverse

Part No.	Distortion Values
1	0.12
2	0.09
3	0.09
4	0.12
5	0.10
6	0.14
7	0.14

GEAR 1ST

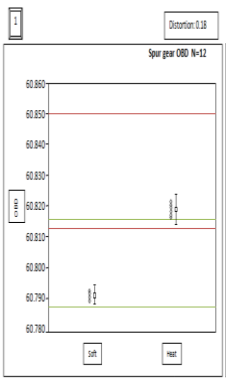

Fig -25: Spur Gear OBD

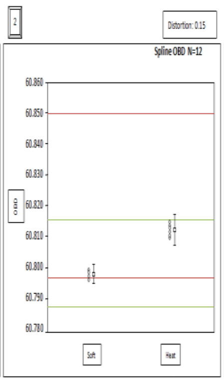

Fig -26: Spline OBD

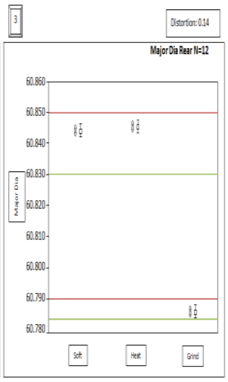

Fig -27: Major Dia Rear

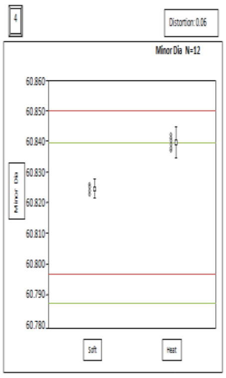

Fig -28: Minor Dia

Table -7: Distortion Values for Gear 1st

Part No.	Distortion Values
1	0.18
2	0.15
3	0.14
4	0.06

GEAR 2ND

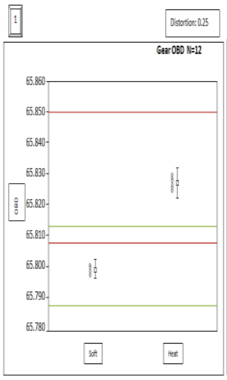

Fig -29: Gear OBD

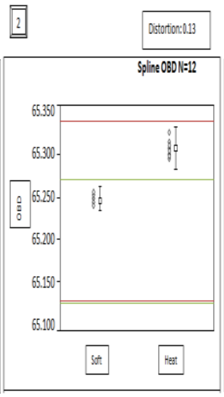

Fig -30: Spline OBD

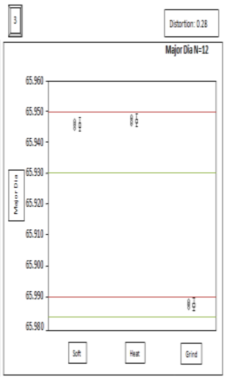

Fig -31: Major Dia

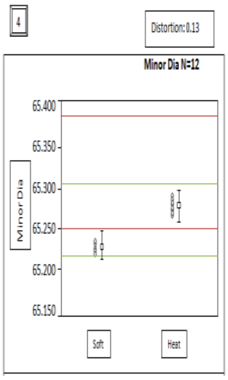

Fig -32: Minor Dia

Table -8: Distortion Values for Gear 2nd

Part No.	Distortion Values
1	0.25
2	0.13
3	0.28
4	0.13

GEAR 3RD

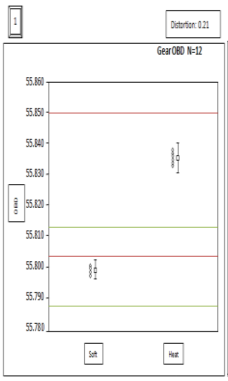

Fig -33: Gear OBD

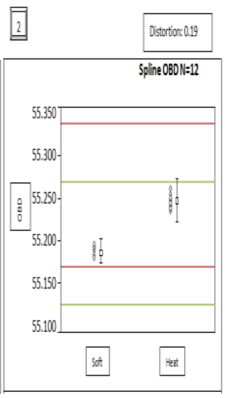

Fig -34: Spline OBD

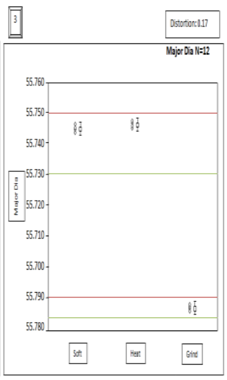

Fig -35: Major Dia

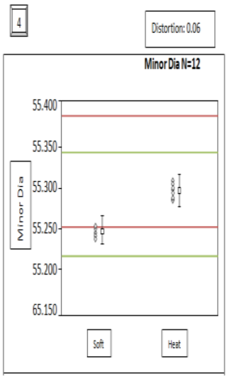

Fig -36: Minor Dia

Table -9: Distortion Values for Gear 3rd

Part No.	Distortion Values
1	0.21
2	0.19
3	0.17
4	0.06

GEAR 4TH

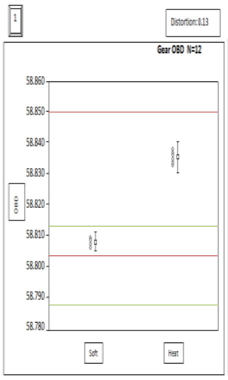

Fig -37: Gear OBD

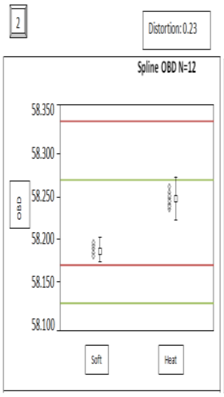

Fig -38: Spline OBD

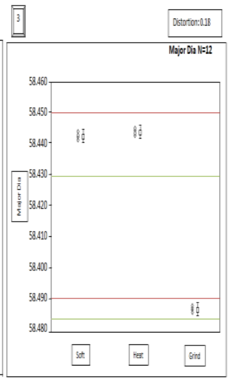

Fig -39: Major Dia

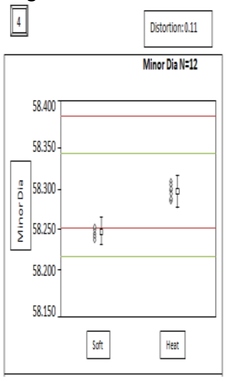

Fig -40: Minor Dia

Table -10: Distortion Values for Gear 4th

Part No.	Distortion Values
1	0.13
2	0.23
3	0.18
4	0.11

GEAR 5TH

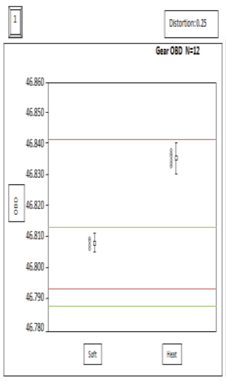

Fig -41: Gear OBD

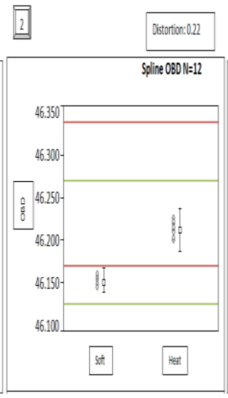

Fig -42: Spline OBD

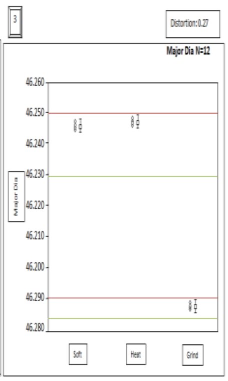

Fig -43: Major Dia

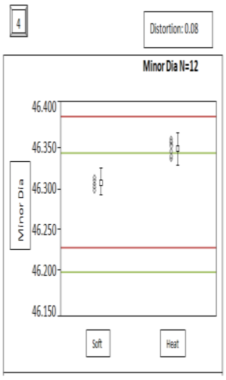

Fig -44: Minor Dia

Table -11: Distortion Values for Gear 5th	
Part No.	Distortion Values
1	0.25
2	0.22
3	0.27
4	0.08

- ❖ ——— Soft Spec Control Band, ——— Heat Spec Control Band
- ❖ All Units are in Microns (µ)

Judgment: There is no major distortion

4.2 Noise Data for after Assembly (N=30)

These are carried out to study the noise level in working transmission assembly. The details are presented here under

Details:

- Machine Used: Performance Tester
- Number of parts considered N=30
- Judgement Criteria: Sound variations should be within the spec line.

Figure 45 to 50 shows the details of the results of the noise tests carried out. The tests are carried out at three different torques i.e., +60Nm, -40Nm and +120Nm respectively. After carrying out each of these tests the results or judgment is arrived.

Gear 1

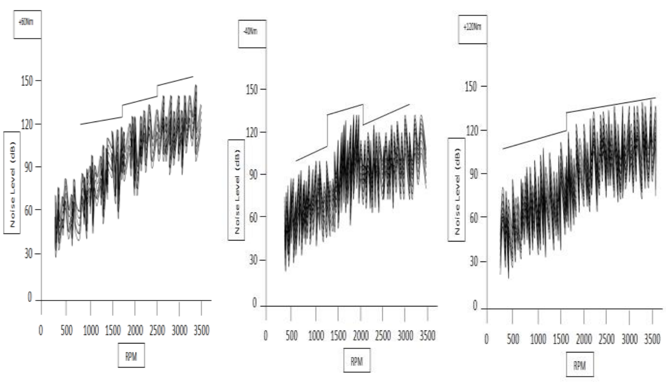

Fig -45: Gear 1 Noise Data (+60Nm,-40Nm,+120Nm)

Gear 2

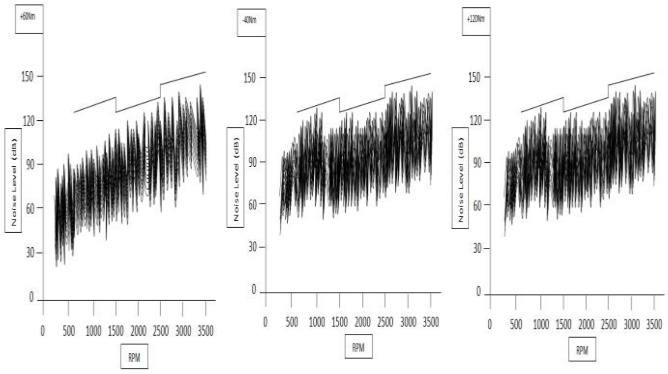

Fig -46: Gear 2 Noise Data (+60Nm,-40Nm,+120Nm)

Gear 3

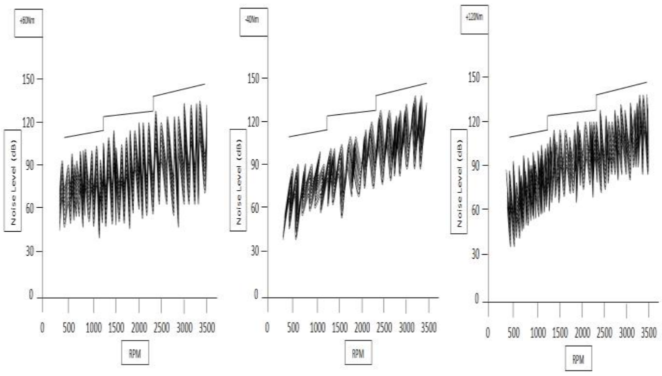

Fig -47: Gear 3 Noise Data (+60Nm,-40Nm,+120Nm)

Gear 4

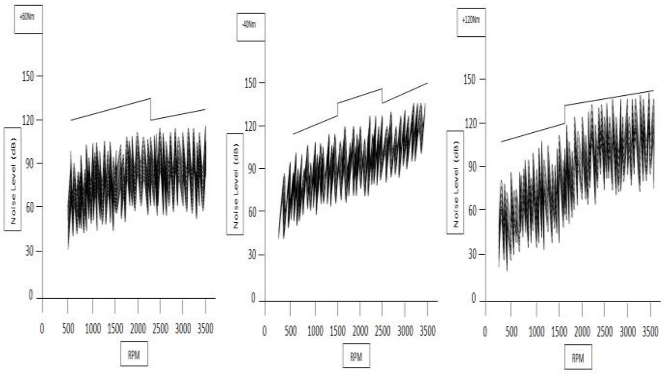

Fig -48: Gear 4 Noise Data (+60Nm,-40Nm,+120Nm)

Gear 5

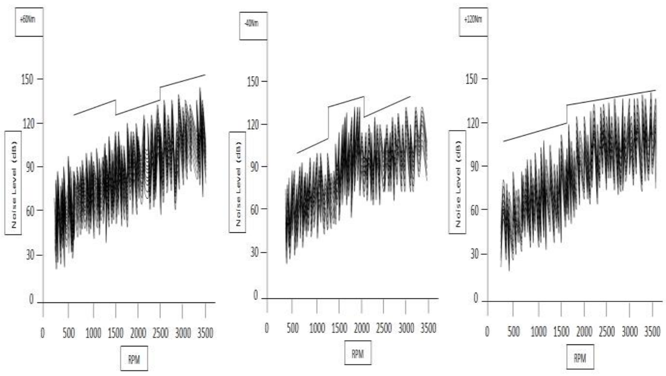

Fig -49: Gear 5 Noise Data (+60Nm,-40Nm,+120Nm)

Reverse Gear

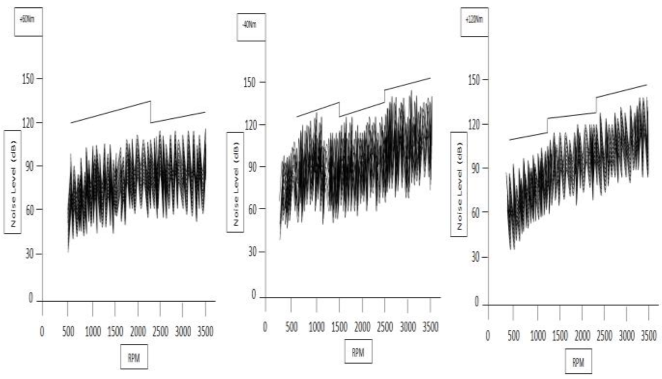

Fig -50: Reverse Gear (+60Nm,-40Nm,+120Nm)

❖ ___________ Spec line

Judgment: It has been seen that the sound variation are within the spec limit.

5. CONCLUSION

It has been found that the there is not much of distortion and variation in noise level.

In some of the cases the values of the distortion occurred was going out of spec. This has occurred for two reasons:

- A problem in heat treatment cycle. This can be rectified by checking each parameter, such as time taken for each cycle, or any breakdown in the cycle.
- During machining: This problem can be rectified by trial and error method by changing the dimension of the part in soft machining and checking after heat treatment and hard machining, the variation occurred should be within the spec.
- The part which was going out of spec was rectified by using above two methods. The distortion level was found to be in the range of (0.05μ to 0.30μ) which is acceptable.
- The Noise Tests performed shows that the level is within the spec line. The average noise level was found to be within the range of (30dB to 150dB) which is allowable.
- The OBD (over ball diameter) for gears and BBD (between ball diameters) for splines, major diameter, minor diameter, was measured. It has been found that there is not much variation in the dimensions.

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