Application of Shainin DoE tool to Explore Unknown Variables causing 'Ghost Noise' in 5th Gear Cycle of Transaxles during NVH Testing

R. Khavekar[1*], H. Vasudevan[2], H. Desai[3]

[1]TPO, D J Sanghvi College of Engineering, Mumbai
[2]Principal, D J Sanghvi College of Engineering Mumbai
[3]UG student, D J Sanghvi College of Engg. Mumbai
{khrajendra@rediffmail.com}

Abstract: As the automotive industry is growing at an increasing pace today, there is severe competition and pressure to produce vehicles, which meet the ever increasing expectations of the consumers. The demand for increased vehicular refinement ensures that many manufacturers implement stringent Noise, Vibration and Harshness (NVH) testing. This study focuses on the analysis done at an automotive manufacturer 'M', on the transaxles used in a certain hatchback model. The attempt was to resolve the issue of a high pitched 'ghost noise' origination from the transaxle heard during the 5th Gear cycle at the End of assembly Line (EOL) testing. A DOE tool associated with Shainin Methodology, namely Component Search was applied to find the root cause of the problem.

Keywords: ***NVH, DOE, Shainin, Multi-Vary analysis, Component search***

1 Introduction

At the End of Line testing rig of the transaxle assembly of model 'K,' more than 300 specifications broadly classified under 3 main parameters: NVH, drag torque and gear shifting force, are measured to ensure that they confine to the limits set by the manufacturer. NVH of the transaxle is measured by contact method using an accelerometer. The 5-MT transaxle is tested in the all 6 gears (5 forward and 1 reverse), each gear having 3 test cycles each: 1. Track up (TU) - Input shaft is rotated from low to high rpm, 2. Steady Track (ST) – Input shaft is rotated at a constant high rpm, 3. Track down (TD) – Input shaft is rotated from high to low rpm. If the measured NVH levels in a test cycle are observed to be acceptable (below the pre-set limit), the transaxle is marked as 'OK' and is then sent for buy-off to be mated with the engine. If the measured NVH level goes above the set limit, it is marked 'NOT OK' and is then sent for 'rework', where it will be disassembled and reassembled after replacing the defective component.

Andrew Thomas [1] illustrated how Shainin Variable Search Method has been used in identifying the influencing variables that control the joint strength of honeycomb composite tongue and slot joints within an aerospace company. The Shainin DOE technique permits the luxury of considering as many variables as can be identified and are useful for implementation of Six Sigma in a manufacturing industry. Martín Tanco [2] used three different approaches to DoE (Taguchi approach, Classical approach OFAT {one factor at a time} and Shainin technique). OFAT (one factor at a time) strategies are successful in companies. However, this does not prove that they are the only techniques useful in improving quality. Shainin technique can be used during in process production. Shainin methods are more suitable for medium to high volume processes. Taguchi Methods is also not recommended, when numbers of variables are more than four. In those cases, Shainin can be used for carrying out several on-line experiments in a diagnostic stage to analyse and characterize the problem before actual experimentation must be considered.

Nagaraja Reddy K M [3] Bosch Production System (BPS) successfully implemented 'Shainin tools for the root cause identification and Design of Experiments (DOE) techniques for analysis of the quality related issues. A Cam shaft key way tight problem was resolved by using Shainin component search tool.

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Changing milling cutter size for key way milling operation of size 3mm and 4 mm keyway has resulted in 0% rejection ofcamshafts due to keyway being tight. According to R. B. Heddure[4], Shainin tool works on elimination principle. To find out root cause of slag and porosity rejection in CI foundry, the Shainin BOB and WOW tool was used. Carbon Equivalent Percentage (CE) & Carbon value was the reason for the slag and porosity problem. By keeping Carbon Equivalent 3.98 to 4.10 & % Carbon value from 3.38 to 3.52, rejection of casting due to slag and porosity was reduced and achieved at 95% confidence level. Stefan H. Steiner [5] over-viewed the shainin system. Shainin tools such as Multivari Chart, Isoplot, Group comparison, Component search, Precontrol and BvsC provide for industrial problem solving systems. They include the application of Pareto principle to find out the contribution of the causes and use observational investigations in the diagnostic journey. To identify dominant cause, they used the process of elimination. Shainin System, is best suited in medium to high volume production companies.

2 SHAININ DOE Methodology

To achieve the required performance of the part, it is necessary to manufacture parts within specified limits. Relevant tools are required to find out the suspect variable causes for processes variation. Shainin says ‘‘The Parts are smarter than the Engineers!’’ Shainin Variables search methodology (VSM) is useful, when an experimenter is interested to study four or more variables in a process or system. Shainin refers to the most important variables as the “Red X” the second most important variables as the “Pink X” and then “Pale Pink X”, and so on.

3 Implementation

Table 1. List of all the possible causes with their corresponding observations and conclusions.

Table 1 Possible Causes

Sr. No	Possible Cause	Testing and Observations	Conclusion
1	SOP not followed	From 2A and 2B conducted, it was confirmed that the operator was adhering to the SOP.	Invalid
2	Foreign material inside transaxle	After opening problem transaxle, no chips/ burrs or extra material observed in it.	Invalid
3	NVH sensor not calibrated	NVH sensor calibrated before SOP	Invalid
4	NVH accelerometer is damaged	On verification, NVH accelerometer did not confirm to any physical damage. Not ok transaxle and Ok transaxle retested, the data was consistent.	Invalid
5	Change in limits / parameters of evaluation	From trend plot, it was observed that EOL limit value remained unchanged	Invalid
8	Gear Geometry Not OK	No non-conformance was observed after initial measurement, but further analysis was required	Valid
9	Chips/ burrs getting generated during testing	Upon opening a Not ok assembly for rework, no burning marks/ wear/ foreign material was observed inside the transaxle.	Invalid
10	Final Drive (FD) Gear Geometry Not OK	No non-conformance was observed after initial measurement, but further analysis was required	Valid
11	Counter Shaft Geometry Not OK	No non-conformance was observed after initial measurement, but further analysis was required	Valid

3.1 Analysis to find probable cause

The accelerometer has been programmed to record Noise data up to 250 orders in any gear. For each testing mode, the range of orders, which were worked upon was restricted to only the 1st and 2nd Harmonic for each gear. There was a possibility of identifying an abnormality by comparing Order spectrums of OK and Not OK transaxles for higher orders. Then, it was needed to check the following to move further with the analyses (steps A to C):

A. Is it a possibility that a higher order for 5th drive gear or 5th driven gear was at play in causing a high O_Rms noise in 5th gear?

Fig.1 and Fig.2 show the comparison between the D5-ST order spectrum graphs of an OK and Not OK transaxles.

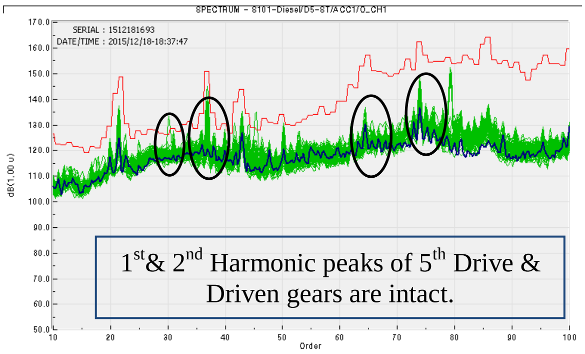

Fig. 1. OK Transaxle Order Spectrum

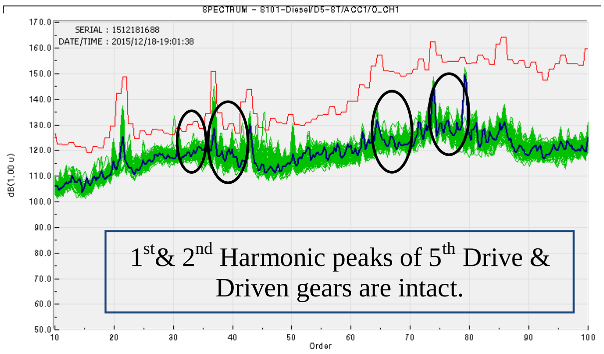

Fig. 2. Not OK Transaxle Order Spectrum

The 1st and 2nd harmonic peaks of both 5th drive and 5th driven gears were observed to be intact in both cases. Since no difference was observed between the graphs, the possible cause was invalidated.

B. Is it a possibility that a higher order of Countershaft or FD gear is giving a resultant high O_Rms noise? In such a case, why isn't the O_Rms noise for other gears not getting affected?

Fig.3 and Fig.4 show the comparison between the D5-ST order spectrum graphs of an OK and a Not OK transaxles.

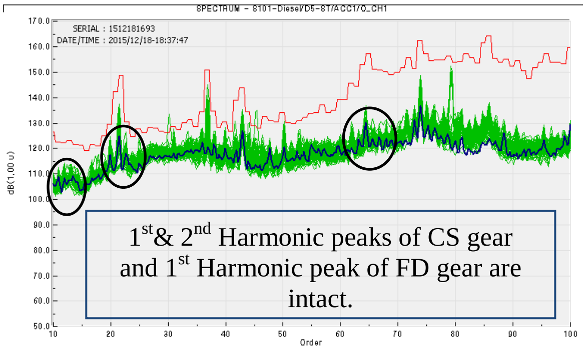

Fig. 3. OK Transaxle Order Spectrum

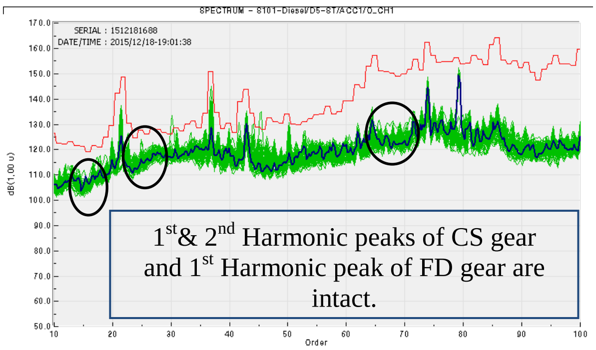

Fig. 4. Not OK Transaxle Order Spectrum

The harmonic peaks of both FD and Countershaft gears were observed to be intact in both cases. Since no difference was observed between the graphs, the possible cause was invalidated.

C. Is it a possibility that an order not corresponding to any of the gears is causing a high O_Rms noise? In NVH terms, such orders are termed as ghost orders.

Fig.5 and Fig.6 show the comparison between the D5-ST order spectrum graphs of an OK and a Not OK transaxles.

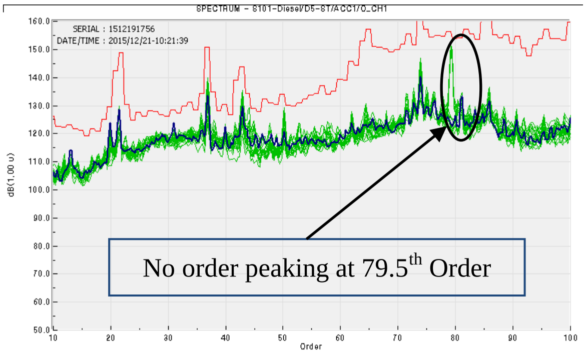

Fig. 5. OK Transaxle Order Spectrum

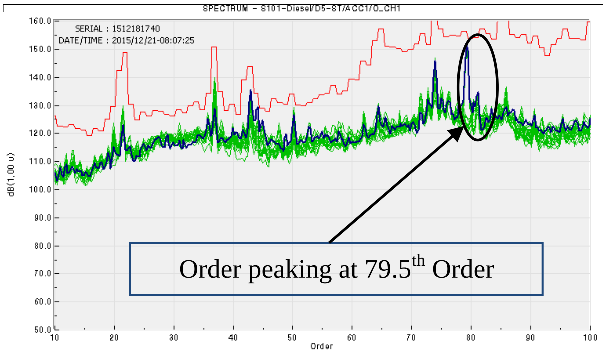

Fig. 6. Not OK Transaxle Order Spectrum

Observation on testing: All NOT OK transaxles showed a spike at the 79.5th order, which was not seen on any OK transaxles.

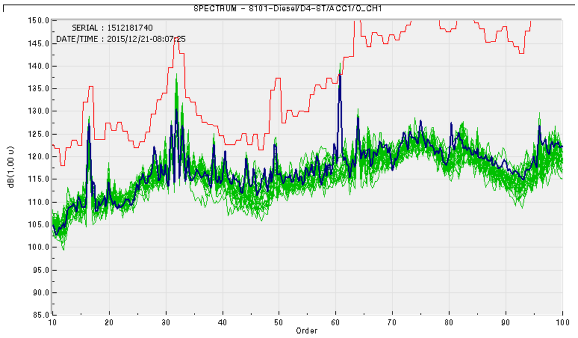

Fig. 7. Ghost Order present in 4th Gear at 60.75

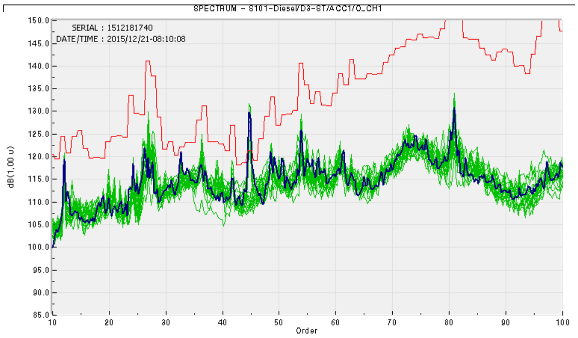

Fig. 8. Ghost Order present in 3rd Gear at 44.75

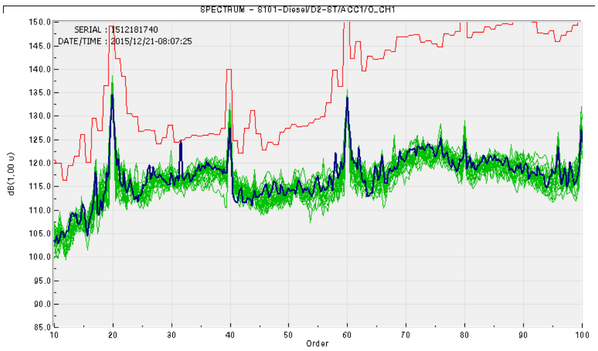

Fig. 9. Ghost Order present in 2nd Gear at 31.5

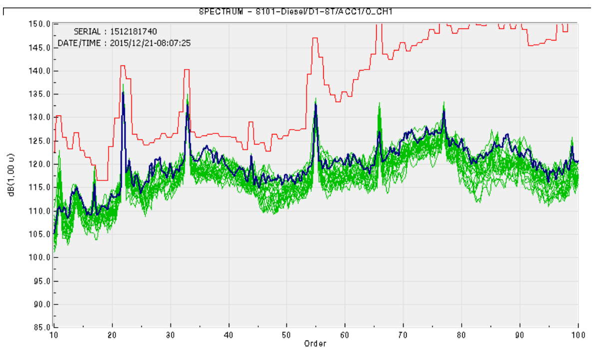

Fig. 10. Ghost Order present in 1st Gear at 17

The Ghost order was there in every gear. This order does not correlate to any of the main gear order (or side bands) or their harmonics or bearing ball passing frequency. Since the only two components that remain in constant mesh for all the gears are the FD gear and the countershaft, we needed to check if the problem was carried in either of them.

3.2 Testing of hypothesis using 'Component Search' technique

Two transaxles were selected: One with Ghost Order (Worst of Worst) and other without ghost order (Best of Best). The Order-Spectrum plots of both are shown in Figure 11 and Figure 12.

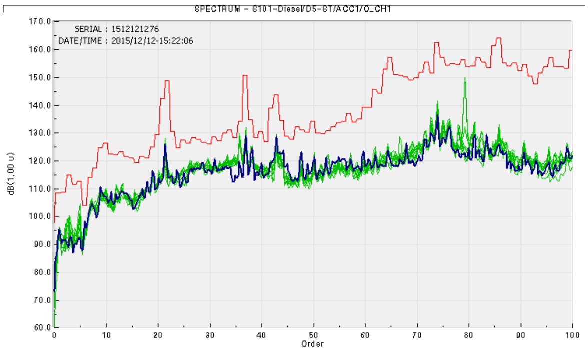

Fig. 11. OK T/A before FD gear swap

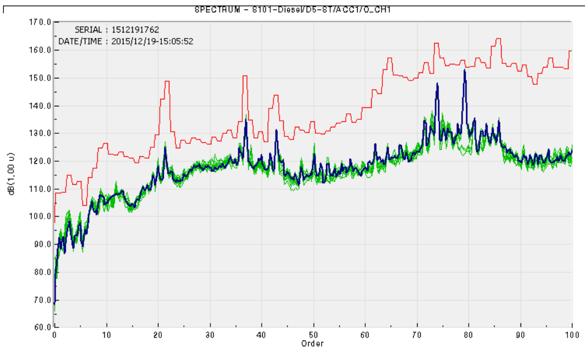

Fig. 12. Not OK T/A before FD gear swap

The FD gear of the Not OK transaxle was swapped with the one from the OK transaxle. The Order-Spectrum plots of both transaxles after the swap are shown in Fig.11 and Fig.12

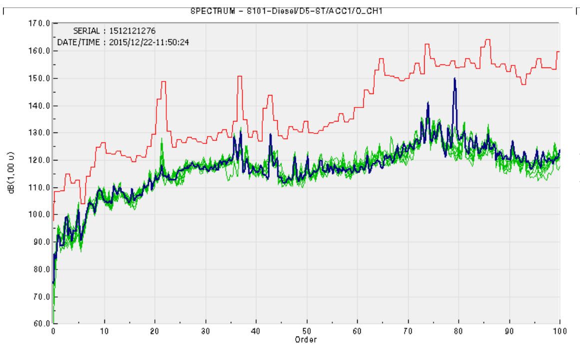

Fig. 13. OK T/A after 1st FD gear swap

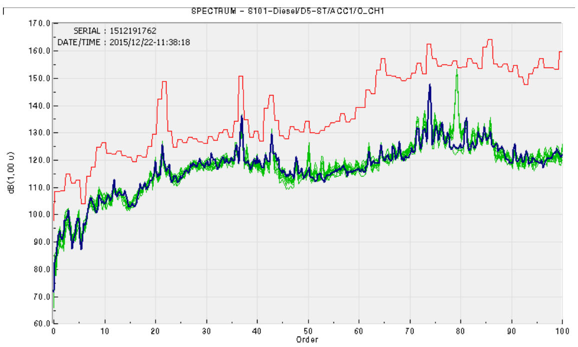

Fig. 14. Not OK T/A after 1st FD gear swap

It was observed that the spike, which was present in the Not OK transaxle at the 79.5th order before the swap now appeared in the OK transaxle, resulting in a high 'D5-ST O_Rms' value (ie. OK transaxle became Not OK). At the same time the spike in the Not OK transaxle dissapeared after the swap (ie. Not OK transaxle became OK). To reconfirm the hypothesis, the FD gears of both transaxles were swapped again (Figure 15 and Figure 16).

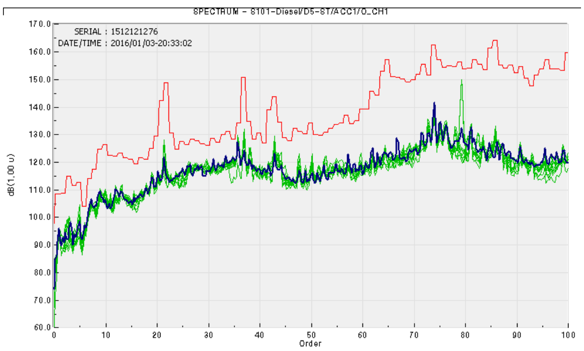

Fig. 15. OK T/A after 2nd FD gear swap

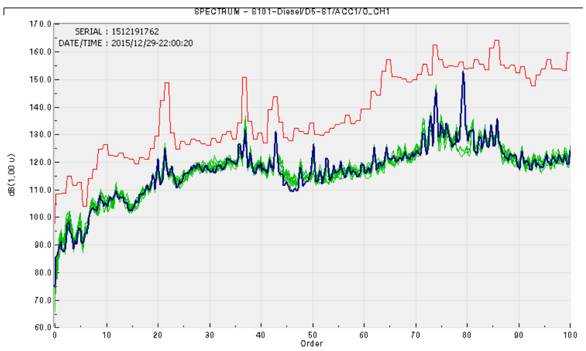

Fig. 16. Not OK T/A after 2nd FD gear swap

As expected, after the orignal FD gears were put in the respective transaxles, the same results were observed (ie. OK transaxle became Not OK and vice versa).

4 Results and Discussion

From this exercise, it was concluded that the problem lies with the FD gear. From detailed teeth to teeth measurement, it was observed that there was increased variation in pressure angle & helix angle in the teeth of Not OK FD gears as compared to OK FD gears. This pointed to a problem in the grinding process during gear manufacturing. For 5th gear, Detailed Spectrum Analysis showed, Contribution from 79.5th order that is causing the O_Rms Vibration to cross the limiting value. Order-Spectrum plots in other gear conditions were evaluated to check, if the problem was present in other gears & it was found that ghost order was present in all gear conditions. The supplier was made aware of the inference and was told take suitable corrective action in the grinding process, after which the problem no longer persisted. Shainin DoE could be used in assembly for finding suspected variable.

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