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Research Papers

"NOISE SOURCE IDENTIFICATION & REDUCTION IN SINGLE CYLINDER DIESEL ENGINE"

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Abstract

In India, Three Wheeler is being used as a mode of public transport & also as a source of income for Bottom of Pyramid (BOP) segment. Since BOP segment is very price sensitive, low cost single cylinder air cooled diesel engine being used as prime mover for three wheeler vehicle.
High noise & vibration is inherent feature of diesel engine & it is predominant in single cylinder diesel engine. In order to maintain low cost of product, less attention is given on overall noise of vehicle. Engine noise is major contributor for vehicle noise. As on today only regulatory requirements are met in terms of noise. Recently customer demands are increasing & also to sustain in competitive market, most of the engine manufacturers have started working on engine noise reduction.

So the research work need to identify for reduction of engine noise in single cylinder air cooled diesel engine. Also Literature survey need to carry out to identify the methodologies of noise source identification & remedies to reduce from identified source.

So this paper gives, engine selection, experimental test set up preparation to identify engine noise sources is completed. Overall study clearly indicates that it is possible to reduce engine noise to the tune of at least 1.5 dB; scope exists for overall reduction of engine noise

KEYWORDS:

Bottom of Pyramid (BOP), single cylinder air cooled diesel engine, Vibration (dB).

INTRODUCTION

Overview of Engine Noise

The study of engine noise has been carried out since the early stages of engine development.

In 1931, Ricardo first found a descriptive relationship between the combustion pressure rise and the noise produced. Later, a number of parameters in determining the noise developments were investigated which include the first and second derivatives of cylinder pressure. These methods were effective in revealing the relationship between engine combustion and noise. Some of them still play an important role in identifying the sources of engine noise.

Although there are a number of engine noise sources, one of the most fundamentals is the Combustion - induced noise. It occurs towards the end of the compression stroke and subsequent expansion stroke. The rapid pressure change due to the combustion transmits through engine structures and forms a part of the airborne noise. This pressure change also causes the vibration of the engine components such as the cylinder head, pistons, connecting rods and engine body. The vibration of these components then provides another part of the overall engine noise (12). Together these noise sources account for over 80% of total engine noise. The combustion-induced noise is however the dominant source. It occurs around the top dead centre (TDC).

Other noise sources are due to engine functions such as the injection of fuel and the operation of inlet and exhaust valves. These sources usually produce low level noise and make up a fraction of the overall noise. Yet all have designated times of occurrence in terms of crank angles. For instance, fuel injection is usually performed around before the TDC in the compression stroke. The exact instances of these events depend on the individual design of the diesel engines.

Although the above engine noise sources have distinctive time instances, it is still difficult to resolve them accurately based on noise measurement. This is because the occurrences of each noise source are too close together. A variety of signal processing methods including statistical analysis, spectral analysis, time frequency analysis and wavelet transform have been used to analyse engine noise. These methods are applied to investigate the noise-generation mechanisms and to reveal the individual features of the sources. Each method is based upon component energy contributions to retrieve information about engine noise. Firstly, the noise signals are represented by using either the time domain, frequency domain or the joint time frequency domain. The noise sources are then identified by the energy variations of the represented signals. As such methods are all based on energy conservation; they are useful for finding predominant information such as combustion peaks.

The other low-level noise sources cannot be identified successfully, using the methods mentioned above. This is because these methods retain the signal energy information from one domain to another. The low-energy noise sources are either buried by the combustion events or too small to be recognised. Hence, these signal energy conservation based methods are unable to recognise such noises induced by fuel injections or valve movements, which contain relatively small energy. It is well accepted that the major noise sources in internal combustion engines include the following categories: combustion-related process, mechanical movements, and intake and exhaust systems

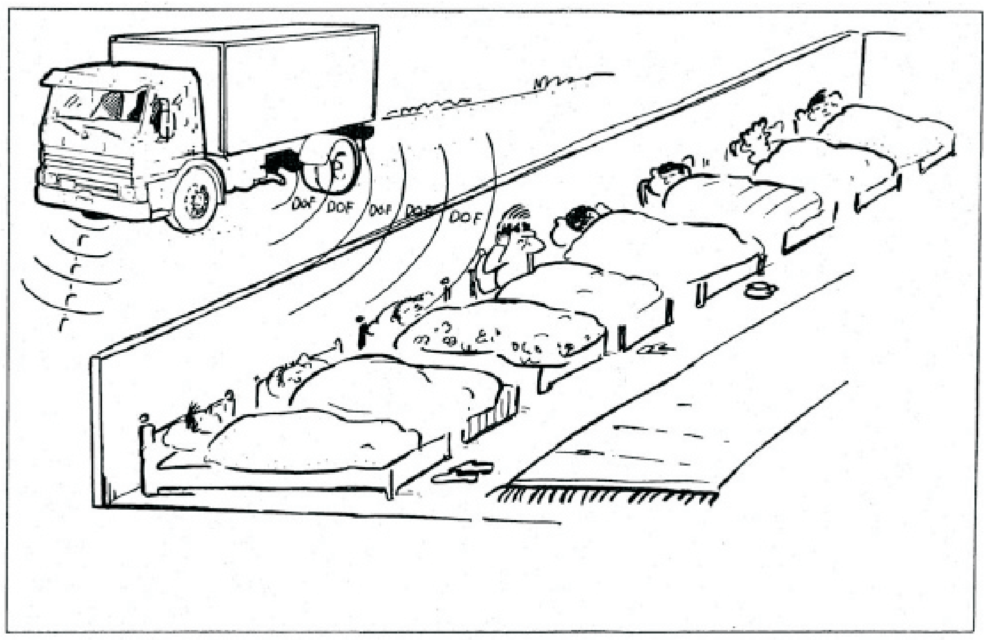


Figure 1: 25% of population is exposed to equivalent sound levels above 65 dB (A) & get there sleep disturbed.

MEASUREMENT OF EXTERIOR VEHICLE NOISE

The sound level measured for vehicle should not exceed the following limits

However
- For vehicles of categories 2.1.1 and 2.1.3, the limit values are increased by 1 dB (A) if they are equipped with direct injection diesel engine.

	Vehicle categories	Values expressed in dB(A) (decibels(A))
2.1.1.	Vehicles intended for the carriage of passengers, and comprising not more than nine seats including the driver's seat	74
2.1.2.	Vehicles intended for the carriage of passengers and equipped with more than nine seats, including the driver's seat; and having a maximum permissible mass of more than 3,5 tonnes and:	
2.1.2.1.	with an engine power of less than 150 kW	78
2.1.2.2.	with an engine power of not less than 150 kW	80
2.1.3.	Vehicles intended for the carriage of passengers and equipped with more than nine seats, including the driver's seat; vehicles intended for the carriage of goods:	
2.1.3.1.	with a maximum permissible mass not exceeding 2 tonnes	76
2.1.3.2.	with a maximum permissible mass exceeding 2 tonnes but not exceeding 3,5 tonnes	77
2.1.4.	Vehicles intended for the carriage of goods and having a maximum permissible mass exceeding 3,5 tonnes:	
2.1.4.1.	with an engine power of less than 75 kW	77
2.1.4.2.	with an engine power of not less than 75 kW but less than 150 kW	78
2.1.4.3.	with an engine power of not less than 150 kW	80

Sound level limits for vehicles

PASS BY NOISE MEASUREMENT

According to 70/157/EEC directive, vehicle pass by noise is measured which should not exceed the sound limits mentioned in above table.

For measurements, the A-weighted sound level of sound sources other than those of the vehicle to be tested and of wind effects must be at least 10 dB(A) below the sound level produced by the vehicle. The measurements are considered valid if the difference between two consecutive measurements on the same side of the vehicle does not exceed 2 dB (A).

Results are calculated as the arithmetic mean of the highest SPLs recorded in 2nd Gear and 3rd Gear.

The measurement maneuver was performed on the track as seen in Figure 2. The vehicle approaches to the line AA' at a steady speed of 50kph. When the front side of the vehicle reached the AA' line, the throttle is completely opened until the vehicle rear end pass the BB' line. Between these two lines, the gear is not shifted. The test manoeuvre is performed in 2nd and 3rd gear positions. The vehicle maximum SPL is acquired between AA' and BB' lines. This manoeuvre performs for both sides of the vehicle

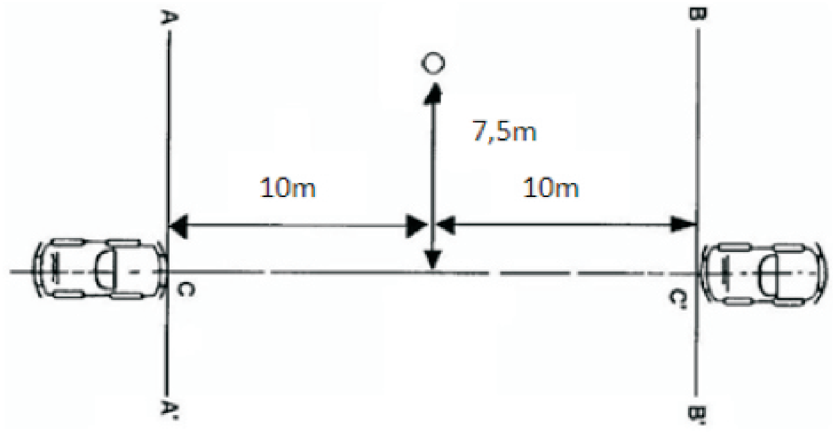


Figure 2 microphone positions for measurements of moving vehicle

SOUND IDENTIFICATION OF VEHICLE NOISE & VIBRATION

Fig 4.3 highlights the individual sources of noise at overall vehicle level, from this figure it is clear that major contribution of noise is from base engine & its related components

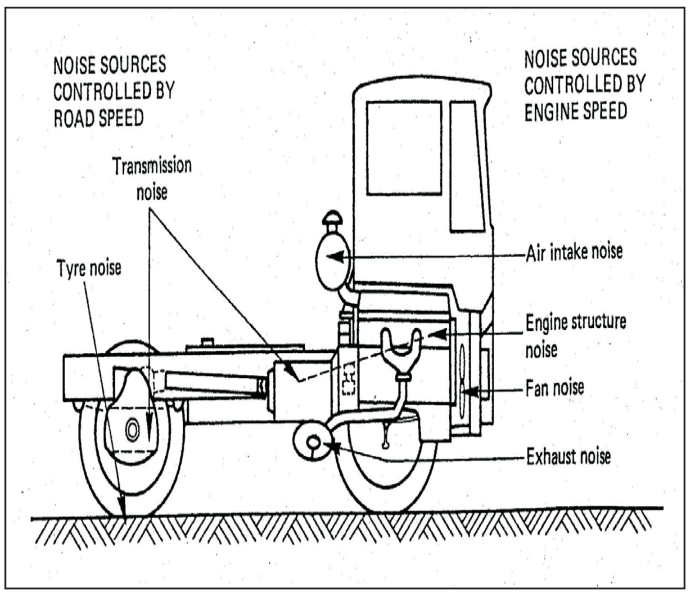


Figure 3 Main sources of noise at vehicle level

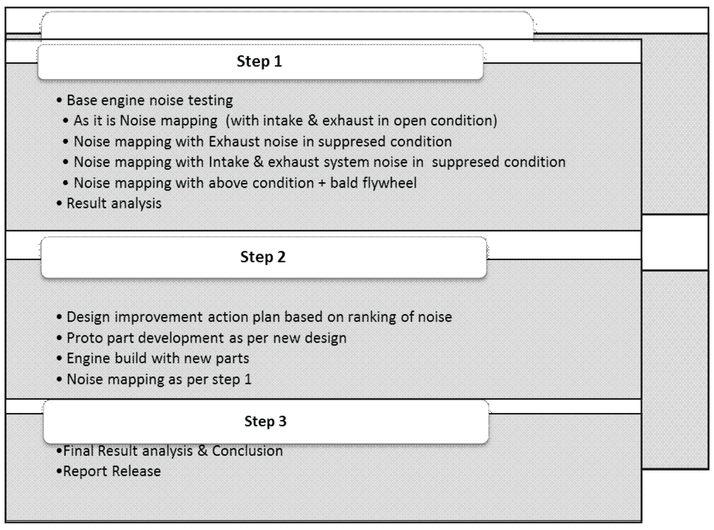
Since engine noise is major contributing factor for noise pollution, major focus is given on reduction of noise from engine

ENGINE NOISE CONTROL

-Engine noise is caused by various types of force generation within the engine and is transmitted to the radiating outer surfaces.
-The transmission path properties are determined by the vibration modes of the structure.
-The properties of the outer surface will also influence the sound radiation.
-number of ways in which the final sound radiation may be influenced:
oReduction at the source of combustion forces and mechanical forces.
oReduction of the vibration transmission between the sources and the outer surface.
oReduction of the sound radiation of the outer surface.

-Reduction of combustion pressures is intimately coupled to changes in the combustion process or combustion chamber shape.
-Since any changes to the design of the combustion chamber or to the combustion process will also have an effect on engine performance and exhaust gas emissions this is a difficult path for a noise control engineer.
-Unfortunately most design changes which would reduce noise would also increase exhaust emissions.
-Piston slap can be reduced by redesign of the piston and cylinder or by oil film injection.
- Gear and bearing noise can be reduced by improved design of these components for instance attention to gear tooth profiles and bearing clearances.
-To reduce the transmission of vibrations to the engine outer surface the crank case and cylinder block can be redesigned.
-One example is strengthening and stiffening of the structure.
Other more advanced redesigns can be made involving extensive simulation the dynamics using finite element modeling.

EXPERIMENTAL SETUP



Engine Selection

From literature survey, it was identified that most of the automotive vehicle manufacturers are working on noise reduction of all types of vehicles which are mainly powered by diesel engines. Since population of three wheeler commercial vehicles is more in India, slowly automotive engineers are focusing on noise reduction of overall vehicle. Since major source of noise from vehicle is engine, work is also focused on noise reduction of engine.

Single Cylinder 415-435 cc, air cooled Direct Injection diesel engine is identified to complete development work related to noise reduction. At present this engine is already meeting regulatory requirement, however to improve overall engine performance in terms of NVH, development work initiated on same engine

Engine Technical Specifications

Engine specifications

Sr. No.	Parameter	
01	No. of cylinders	01
02	Engine Capacity, cc	415-440
03	Type of cooling	Air cooled
04	Combustion system	DI Diesel
05	FIE System	PF based Mechanical
06	Power, Hp	6.2-8.0 Hp @ 3600-3400 rpm
07	Torque, N-m	16-20 N-m
08	Alternator	FMA, 18 pole, 17A, 13.5V
10	EGR system	Electrical EGR – ON off type
11	Emission Compliance	BSIII

EXPERIMENTAL TESTING

Testing Agency

In Automotive Research Association of India, Pune, NVH testing facility is available (7). The state of art Noise, Vibration & Harshness (NVH) laboratory with its advanced experimental & computational facilities provides 'end to end' solutions to the automotive industry. With the experience & expertise available in this lab, it provides customer oriented time bound solutions to meet the evolving stringent legislative & competitive requirements in the areas of NVH.

This facility is well equipped with –

Semi anechoic chamber
Engine dynamometer of 5 to 400 Kw
100 channel data acquisition system
Radiated noise measurement as per various international standards
Linear vibration measurement using accelerometers laser micrometer
Steady speed sound intensity mapping
Microphone

Figure NVH testing laboratory at ARAI, Pune

Engine mounting set up

Engine is mounted on engine dynamometer which is placed in anechoic chamber, following instruments will be used

Engine dynamometer with speed & torque measurement facility
Fuel consumption meter
Temperature sensors – Thermocouple for measurement of oil temp, exhaust temp
Pressure sensors – pressure transducers to measure air intake depression, exhaust back pressure, oil pressure
Microphones – 6 numbers
Accelerometers – 20 numbers
Data acquisition system

Engine mounting

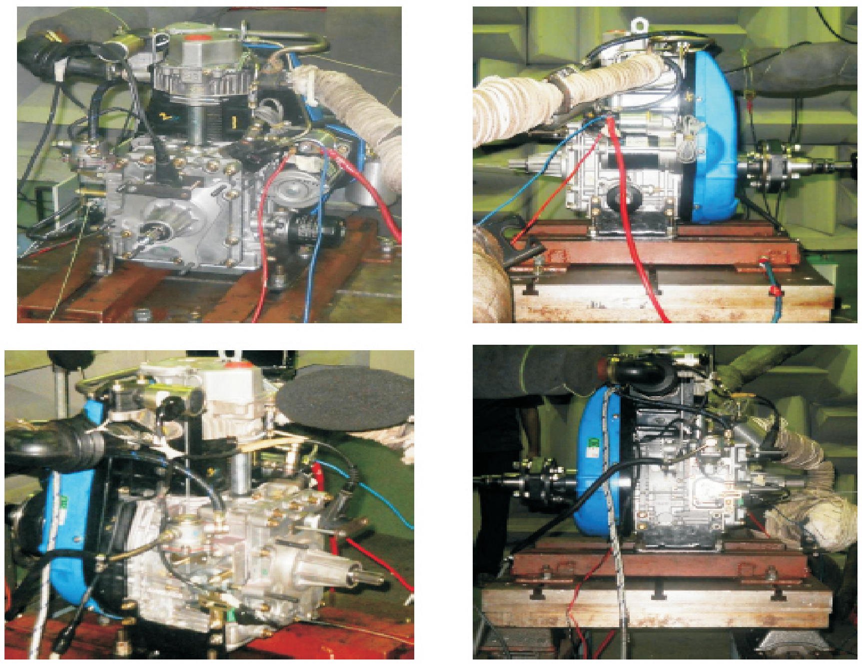
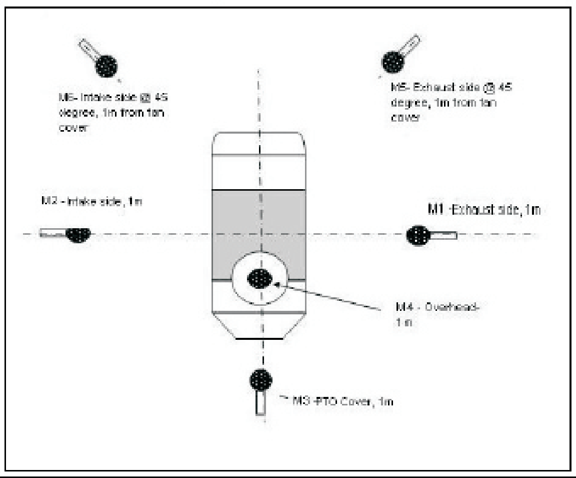


Figure – Engine mounting set up in anechoic chamber

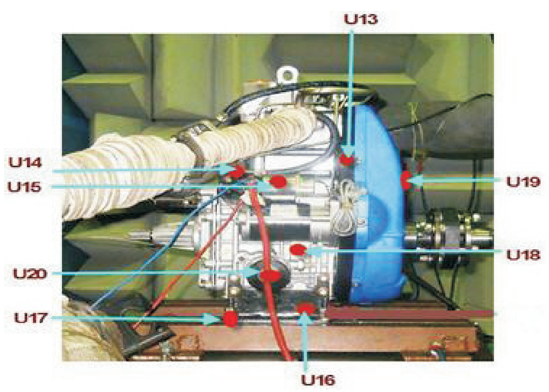
Radiated Noise Measurement Set up – Microphone Positions

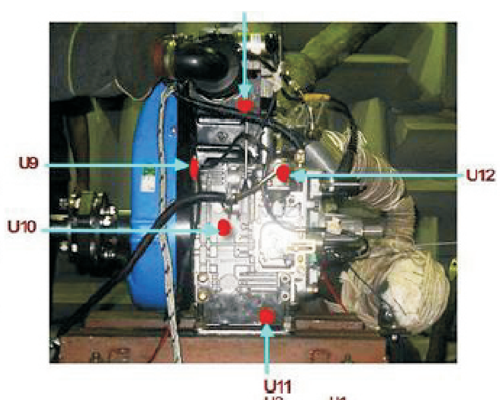


Microphone Positioning				
	Side	Distance	Height/ Axix	Position
M1	Exhaust Side	1m from Crank Case	Half height of Crank Case	Mid length of crank case
M2	Intake Side	1m from Crank Case	Half height of Crank Case	Mid length of crank case
M3	PTO Cover Side	1m from PTO cover	PTO Shaft centre	PTO Shaft centre
M4	Overhead	1m from Rocker cover	Crank Shaft Axis	Mid length of Rocker Top
M5	Exhaust Side	45 degree, 1m from Fan cover	45 degree from fan cover	Mid length of crank case
M6	Intake Side	45 degree, 1m from Fan cover	45 degree from fan cover	Mid length of crank case

Figure Microphone position

Accelerometer positions for linear vibration measurement:





Transducer ID	Transducer Position	Transducer ID	Transducer Position
U1	Rocker Cover Top	U11	Engine bracket RHS
U2	EGR Valve	U12	Fuel Feed Pump
U3	Intake Manifold	U13	Back Plate LHS
U4	Cylinder Front	U14	Fuel Injection Pump
U5	Front Cover	U15	Starter Motor
U6	Oil Pan Bottom	U16	Engine Feet LHS
U7	Crank Case Top	U17	Oil Pan Front
U8	Baffle Plate RHS	U18	Crank Case LHS
U9	Back Plate Front	U19	Air Shroud Back
U10	Crank Case RHS	U20	Oil Filter LHS

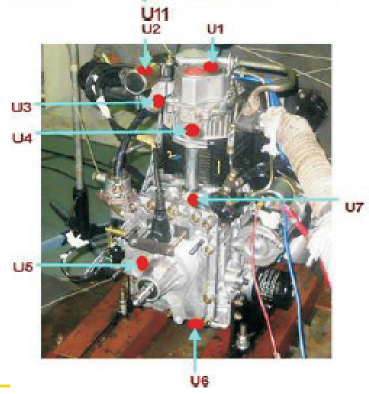


Figure Accelerometer positions for linear vibration measurement

NOISE CONTROL TECHNIQUES

Number of ways in which the final sound radiation may be influenced:
Reduction at the source of combustion forces and mechanical forces.
Reduction of the vibration transmission between the sources and the outer surface.
Reduction of the sound radiation of the outer surface.

Engine Noise Control techniques

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Unfortunately most design changes which would reduce noise would also increase exhaust emissions.
Piston slap can be reduced by redesign of the piston and cylinder or by oil film injection.
Gear and bearing noise can be reduced by improved design of these components for instance attention to gear tooth profiles and bearing clearances.
To reduce the transmission of vibrations to the engine outer surface the crank case and cylinder block can be redesigned.
One example is strengthening and stiffening of the structure.
Other more advanced redesigns can be made involving extensive simulation the dynamics using finite element modeling.

MODIFIED COMPONENTS

Comparison between Old & modified components

Baffle Plate, Oil Pan, Back Plate

TEST RESULTS

Components	Baseline SWL, dB(A)	Modified SWL, dB(A)	% Reduction
Baffle Plate	90.78	88.15	45.40
Back Plate	86.28	84.45	34.39
Oilpan	82.22	80.58	31.44
Rocker Cover	83.71	83.85	-3.15
Fan Cover	91.76	90.67	22.11
Total Engine	97.56	95.70	34.84

SUMMARY OF TEST RESULTS

Meas. Set	Activity	NVH Measurement	Results/ Remarks
1	Baseline Measurement	Radiated Noise @ speed sweeps at no load and full load.	The baseline measurements are repeated to have accurate comparison.
		Sound intensity mapping @ full load rated rpm	
2	Baseline Engine + Sheet metal oil pan, Baffle plate and Back plate with Sandwich material+ Damped rocker cover	Radiated Noise @ speed sweeps at no load and full load.	Overall Engine Noise is reduced by 2-3 dB(A) throughout the speed range.
		Sound intensity mapping @ full load rated rpm	The sound power of Sheet metal oil pan, Baffle plate and Back plate has reduced by 30%. However, the there is no change in sound power of rocker cover.
		Linear vibration measurement @ no load and full load speed sweeps	Overall vibration are reduced substantially on modified components
3	Measurement Set 2 + Light weight Flywheel	Radiated Noise @ no load and full load speed sweeps	Overall noise increases around 1500 rpm and 2700 rpm sharply due to imbalance created by light flywheel
4	Measurement Set 2 + Static Injection timing retarded to 7° bTDC	Radiated Noise @ no load and full load speed sweeps	Overall Engine Noise is reduced by 4 dB(A) throughout the speed range at full load. However, the no load results are inconclusive due to engine hunting problem
5	Assessment of Noise Contribution of Transmission to Overall Powertrain Noise	with and without transmission cladded with lead and foam at no load and full load speed sweep conditions.	The transmission contributes around 2 dB(A) at no load and full load indicating sound power contribution of 30%

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