inter-noise 2002

The 2002 International Congress and Exposition on Noise Control Engineering
Dearborn, MI, USA. August 19-21, 2002

Noise control system for a specific urban transport bus model

M. Zañartu, D. M. Fox and E. A. Fuentes
Universidad Tecnológica Vicente Pérez Rosales, Departamento de Acústica
Santiago, 685125, Chile.

Abstract

One of the most important noise sources regarding it's contribution to noise impact in Santiago are urban buses, for which the Chilean Environmental Committee has recently dictated a noise emission regulation. Nearly all of the urban buses in Santiago have bodies built locally and their designs don't include acoustical criteria. The purpose of this project is to develop an effective and low-cost noise control method on a rear engine bus system to meet the regulation requirements. The selected model corresponds to the preferred bus type in Chile.

The scope of the design is to reduce the engine's noise emissions with minimum variation of several mechanical variables such as operating temperatures of the engine and cooling system; air flow rate and total pressure generated by the cooling system's fan. In this manner, the design includes a semi-enclosure for the engine's compartment; installation of acoustic louvres at the air intake and outlet of the cooling system; and the use of an electric fan for appropriate removal of heat excess. Besides, mechanical isolation for the engine's exhaust system, including the muffling device is provided.

A theoretical background endorses the effectiveness of the design, which will be verified with acoustical measurements.

1. Introduction

The present paper is the first part of an investigation project developed by the Department of Acoustics from *Universidad Tecnológica Vicente Pérez Rosales* (UPPER) in Chile. The need of this research is directly related to the fact that a noise emission standard for public transportation buses has been developed.

The precarious development of the urban bus branch in Santiago, Chile, characterized by a strong phase of missregulation from the State during the 80's, has turned into the weakest division of the public transport system, due to its low quality and need of management power. Its basic problems are the absence of an intermodal system, the excessive commute time and the lack of quality in the buses themselves.

Nowadays, there are about 7.600 buses circulating in Santiago, of which approximately 75% have bodies built in Chile with imported chassis. None of these buses consider acoustic criteria when being designed.
Old buses of the actual motoring park have mainly rear engines and their seniority never exceeds 12 years. Since the position of the engine is very important concerning inner noise emissions (ECO94)[1], new buses are expected to have rear or middle engines, topic that up to date had not been taken into consideration.

2. Problem Formulation

The Chilean Environmental Committee (CONAMA), has developed a normative that regulates maximum noise emission levels for urban buses used in public transportation[2]. This norm establishes noise limits to new and old buses, for different measurement positions. The measurement procedures are specified under two different tests: the stationary vehicle test and accelerating vehicle test, similar to the ones mentioned in ISO 5130:1982[3] and ISO 362:1998[4].
This norm generates the need of improving the acoustical quality of buses, which is a challenge in Chile, since noise control techniques on this kind of vehicles has not been developed yet.

3. Scope

This study requires creating noise control techniques in a particular bus model, resulting in a system with low implementation costs, whose design will be effective to either new and old buses in circulation. Its effectiveness degree is determined by comparing the actual bus noise emission levels and the most demanding noise limits of the regulation standard in issue. The study must also consider actual values of the most important mechanic variables, associated to a normal bus performance, that are involved in the designing process.

4. Procedure

The model of the selected vehicle to carry out the study is Petrohué Ecológico, one of the best selling buses during the 90's. It was built in 1996 by the Chilean coachwork builder Metalpar S.A.
An analysis was carried out on the bus, establishing the actual noise emission and values of the mechanical variables that interact with the noise control system.

4.1 Acoustical analysis

Acoustic measurements were taken in three different positions for the stationary vehicle test, according to the established procedures. The results of these measurements are shown in the table below:

Table Nº1. Comparison of measured noise levels and noise limits

STATIONARY VEHICLE TEST	Measured level (dBA)	Maximum noise limit (dBA)	Required reduction (dBA)
Exhaust noise emission levels	102,6	92,0	10,6
Engine noise emission levels	95,8	95,0	0,8
Passenger position noise emission levels	85,0	85,0	0
ACCELERATING VEHICLE TEST			
Outdoor position noise emission levels	84,3(*)	81,0	3,3
Passenger position noise emission levels	84,9(*)	81,0	3,9

(*) Reference levels[5]

In the table above, it can be observed that the required reduction for the accelerating vehicle test involves a complete noise treatment, unlike the stationary test, whose results only show a level excess at the engine's exhaust, which must be also treated.
In addition, spectral measurements were undertaken, in order to identify the frequency range and tonal components of interest. The measurement positions were located on the sides and rear of the engine compartment and inside the bus. The highest level was found at the position located on the left side, with differences up to 10dB, because of the nearness to the cooling fan. This shows that the design of the noise control techniques in this section has to be specially empathized.

4.2 Mechanical characteristics of the selected bus

The selected bus has the following features:

- Mercedes Benz Chassis, model OH-1420 with rear engine.
- Mercedes Benz Diesel Engine, 6 cylinders, model MB OM 366 LA6, with Intercooler.
- Engine power: 255kW/211CV@2600RPM.
- ZF S 5 automatic gearbox (5 speed).
- Water cooled engine.

Important considerations:

- The installed radiator is not original and its efficiency has been estimated in 60% from the original one.
- The cooling fan's rotation speed is equal to the bus engine's RPMs.
- The fan's propeller has 10 blades and a 60cm diameter. The air entrance at the radiator's position should have an open area of at least of $0.39m^2$[6]. The actual opening has a lager area, which does not affect the cooling fan's performance.
- The opening for the engine's air intake must have an open area of about $0.039m^2$ and the total pressure drop between atmosphere and a specific point located after the air filter exit should not exceed 255mmcda (@4ºC)[6].
- The engine compartment's floor is uncovered and its walls are coated with glass fiber wool, fulfilling the minimal requirements of thermal isolation, according to technical specifications of Mercedes Benz in Brazil.

4.3 Mechanical analysis

One of the objectives pursued by the noise control system is to maintain certain mechanic variables in their original values, in order to keep the engine's performance in its normal and steady state.

The engine's cooling system has a number of elements with specific pressure drops and the addition of their magnitudes represents the total pressure drop of the system itself[7]. This fact is really important for design purposes since it gives information about the system's characteristics represented by its characteristic curve. The total pressure drop was obtained by measuring the static pressure at a point on the deflector located between the fan and the radiator. The measurement was made with the engine's compartment rear lid open, not being affected by the pressure drop at the fan's exit, constituted by the back pressure generated with the jolt of air in the rear lid.

The air flow speed through the radiator, the cooling system's water temperatures at two specific points – one at the engine's exit corresponding to the system's hot water and the other at the radiator's exit corresponding to cold water – and the temperature inside the engine's compartment were also measured.

4.4 Noise control system

The designed noise control system considers the following treatments:

1. Installation of two acoustic louvers for the cooling system, one at the air entrance for the radiator and the other installed in the engine's compartment rear lid with its center as close as possible to the fan's axis.
2. Implementation of a partial enclosure for the engine, sealing the uncovered floor of the compartment.
3. Lining of the partial enclosure's inner walls with acoustic absorbent material to reduce the inner noise levels.
4. Replacement of the existing exhaust muffler and installation of anti-vibrating supports and acoustic seals where needed.

The design considers keeping the amount of air that penetrates the radiator constant, so the cooling system's efficiency does not get affected. The installation of two acoustic louvers increases the total system's pressure drop carrying out the following associated effects: a variation on the system's characteristic curve, shift of the fan's operation point and therefore, a decrease on the generated flow. The initial conditions must be re-established by either changing the propeller configurations or increasing its rotation speed[7]. From the louvers design data the fan's increase in rotation speed can be estimated in 200RPM, in order to equal its total static pressure (PEV) in presence of the new system pressure drops. By doing this, the flow rate will be maintained, at the expense of 1.3 times the original fan's consumption power.

The acoustic louvers were designed in a V form with a length of 300mm and open areas of 40% and 50% for the sides and back rear respectively. Its *baffles* create opposite 45º angles and are covered with 26mm thick fiber glass wool with a density of 35Kg/m^3, on both sides. Its calculated insertion losses (IL) are about 6 and 7dBA respectively, and its pressure drops are estimated to be 20mmcda for each[8],[9]. The louver on the side of the bus covers a total area of

$0,7m^2$ related to the 33% of the engine's compartment outward surface. This yields into a reduction of 3dBA on the total emissions, because its insertion loss is greater than the one on the material being replaced. The louver on the back, covering a total surface of $0,5m^2$, has a negative effect, since its insertion loss is smaller than the one on the material being replaced. This yields into a reduction of 2dBA on the total emissions. The combined noise reduction of both louvers has been estimated in 1dBA.

The closing of the engine compartment's floor will cause the inner temperature to rise, fact that must be controlled with a forded extraction system. This system must deliver sufficient air removal, so the engine and its components can operate within an allowed temperature range. For that purpose, a 172mm diameter low pressure electro-fan capable of moving 480m3/h of air will be installed in one of the closing's plates.

The closing of the engine compartment's floor is set by five removable and semi-removable 2 mm thick steel plate, fixed to a metallic structure installed at the rear bottom of the bus. The plates are removable in order to facilitate any required mechanical maintenance. Each one has a transmission loss TL of approximately 10dBA, covering altogether 70% of the bottom surface of the engine's compartment, which yields into a reduction of 4dBA over the total engine noise emissions.

Closing the bottom surface of the compartment, will result in an increase of the inner noise level. Therefore, it is necessary to cover the inner walls with porous material that absorbs acoustic reflections in the enclosure. This lining will also help to reduce the noise level inside the bus. The material to be used is a 25mm thick mineral wool with a density of $50Kg/m^3$. The removable metallic plates will not be covered with absorbent material, due to the possible oil stains from the engine that could affect its effectiveness. Finally, the lining surface equals 46% of the total compartment's inner surface increasing its absorptive performance from 12% without material to 70% with porous material. The noise reduction of this treatment has been estimated in 2dBA over the total engine noise emissions.

In order to achieve the desired effectiveness in the proposed solution, acoustic seals will be incorporated in all the existing hatches and lids of the engine's compartment.

Including all the treatments mentioned before, the total reductions of the engine's noise emissions can be presented as follows:

Table Nº2. Treatments considered in the noise control system

Treatment	Estimated effectiveness
Lining of the engine's compartment	-2dBA
Sealing of the compartment's uncovered floor	-4dBA
Acoustic louver on the side	-3dBA
Acoustic louver on the back	+2dBA
Total noise reduction	-7dBA

The existing silencer will be changed for a new one, preferably for the original recommended by Mercedes Benz. Additionally, the gas escape duct will be covered with a high density mineral wool and the existing anti-vibrating mounts will be replaced. This treatment has two benefits: contribute to the inner engine compartment’s temperature decrease and reduce the air and structureborne noise transmission that could be induced from the engine to the duct. These treatments should decrease the escape noise emission level in approximately 11dBA, as the requirements presented in Table Nº1. This reduction is only associated to the noise measurement for the stationary test and does not reflect a decrease in the total emissions of the dynamic test.

5. Conclusion

This paper presents the main considerations and features of the noise control system that confirm the effectiveness of the design on the selected bus. The installation procedure will start on May 2002 and the effectiveness of the installed system will be verified in a later stage of the project. These results will lead to a subsequent optimization of the noise control system.

6. References

[1] MTT. *Reglamento de los servicios nacionales de transporte público de pasajeros*, 2000.

[2] CONAMA. *“Proyecto Definitivo de Norma de Emisión de Ruido para Buses de Locomoción Colectiva Urbana y Rural"*. 2001.

[3] ISO 5130-1982. *Acoustics –Measurements of noise emitted by stationary road vehicles – Survey method.*

[4] ISO362-1998. *Acoustics – Measurements of noise emitted by accelerating road vehicles – Engineering method.*

[5] CONAMA. *Análisis general del impacto económico y social del anteproyecto de norma de emisión de ruido para buses de la locomoción colectiva que prestan servicios de locomoción colectiva urbana y rural.* 2000.

[6] Mercedes-Benz do Brasil S.A. *Manual de Encarroçamento de Ônibus.*2002

[7] ACGIH (American Conference Of Governmental Industrial Hygienists. *Industrial Ventilation*. 1992.

[8] Gerges, Samir. *Ruido: Fundamentos y Control.* 1998.

[9] Beranek, Leo L. & Vér, István L. *Noise and Vibration Control Engineering.* 1992.