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SILENCER NOISE MINIMIZATION USING LINEAR PROGRAMMING TECHNIQUE

B. O. BOLAJI [(1)] AND M.I.A. ONIPEDE [(2)]

[(1)]Department of Mechanical Engineering, University of Agriculture, P.M.B. 2240, Abeokuta, Nigeria. E-mail: bobbolaji2007@yahoo.com
[(1)]Department of Mechanical Engineering, Federal Polytechnic, P.M.B. 5351, Ado-Ekiti, Nigeria

ABSTRACT

This paper presents the process involved in the optimization of vehicle silencer in order to minimize the noise level of the exhaust gases. Various performance parameters of vehicle silencer were optimized using linear programming technique. The results obtained from the optimization process formed the parameters used for the construction of the new silencer. The optimized silencer was tested on selected motor cars and the results obtained revealed that, to the large extent, it is effective in minimizing the car exhaust noise level. An average noise level of 23.3 dB (experimental) was obtained using the optimized silencer as against 40.4 dB, obtained with the unmodified car silencer. The experimental value is however slightly higher than 21.2 dB which is the theoretical value obtained from optimization process. The average percentage of noise reduction is found to be 43.3 % and the process efficiency also is 89.1 %.

Keywords: Noise, linear programming, optimization, silencer, vehicle.

INTRODUCTION

Technological advancement is an important desirable and necessary ingredient for economic and social growth. It has made it possible for a large number of persons to enjoy the goods of life. The introduction and the use of inappropriate technologies often destroy the productive potential of ecosystems. The expansion of technology has been at the expense of other forms of life (Bolaji, 2005).

Noise by its own nature, is propagated from a source in all directions in form of sound energy which may be heard or not by the human ear whose perception of sound is limited to frequencies of about 16 – 20,000 Hz (Olufemi, 2003). Generally the subjective loudness of the measured sound is compared to a standard sound with frequency of 1000 Hz. In most cases the intensity of noise is measured in decibel (dB), which is the ratio of two sound pressures in which one has been chosen as reference. Whenever mechanical power is generated or transmitted, a fraction of this power is converted into sound power and radiated into the air. Since most of the vehicles on roads are mechanically operated they produce sound and when the sound produced is above certain level, it becomes unwanted, unpleasant to ears and causes discomfort to people (Ajueyitsi and Bolaji, 2003).

The Wilson committee final report of 1963 (Wilson Report) on the problem of noise stated that of 1400 people interviewed about noise in 1948, 25 % said they were disturbed by noise but by 1961 the proportion and doubled to 50 %. However, gradually over the last decade a growing concern about noise has developed. Many people now regard noise as a pollution component that contributes to a deterioration of the environment (Barber, 1992). It is therefore, important to seek appropriate strategy for the control of vehicle noise in order to sustain the environment.

The spark-ignition and the diesel engines, both internal combustion engines, are the only engines in wide-spread use in the world's automotive transportation systems. The fuels, which these engines burn, are highly refined products currently almost completely derived from petroleum (John, 1981). In this era of decreasing fuel availability and rapidly rising fuel cost, optimization of automobile silencer performance is highly needed to improve fuel economy and reduce noise level of exhaust gases.

The function of vehicle silencer is to filter the spent combustion gases from the engine and discharge them to the atmosphere and at the same time, to reduce both exhaust back-pressure and the noise level of the exhaust gas to an acceptable level. Excessive exhaust back-pressure has a detrimental effect on engine performance in that more work has to be expended on pushing the exhaust out of the engine which will result in loss of power and increase in specific fuel consumption (William and Tobold, 1986).

A survey carried out by Heinz (1975) shows that 25 % of vehicles on roads produce large amount of combustion emission and noise of high decibels both of which serve as pollutants. The emission is the product of combustion process in the combustion chamber between oxygen from air and fuel in the presence of heat being the reactant (Dolan, 1972).

Silencer does not remove the gaseous emission, as it is what enters the exhaust manifold that will pass through the silencer and out through the tail pipe. But it reduces the noise level, pressure and temperature of the exhaust gas through expansion and absorption of the exhaust pulsation effect before getting into the atmosphere.

In some silencer designs, according to William and Tobold (1986), the noise reduction also generates back-pressure which impairs the efficiency of the engine. This occurs as some parts of the exhaust gas will flow back to the combustion chamber and form residual gases. This will reduce the volumetric efficiency of the engine. In this study, linear programming was used to determine the best performance parameters that will give optimum silencer efficiency in order to minimize silencer noise level.

OPTIMIZATION USING SIMPLEX METHOD

Nicholson (1991) describes simplex method as one of the approaches used in linear programming which is the technique for the optimized allocation of resources subject to constraints. It is capable of handling problems with literally hundreds of constraints and variables.

In order to form a model equation for the performance parameters, the following design parameters were considered:

(i) Pressure drop (ΔP) in the silencer (Wardsmith, 1980),

$$\Delta P = \tfrac{1}{2} k \rho . v^2 \quad (1)$$

where, k = dimensionless coefficient

v = velocity of the exhaust gas

ρ = density of the exhaust gas

(ii) Velocity drop (Δv) of the exhaust gas (Wellington and Asmis, 1996),

$$\Delta v = \frac{\sqrt{1.4}\Delta P}{\rho} \quad (2)$$

(iii) Porosity (γ) of the baffles in the silencer muffler (Wardsmith, 1980),

$$\gamma = \frac{\pi N_h d^2}{4A} \quad (3)$$

where, A = cross-sectional area of the pipe

N_h = number of holes of diameter 'd' in the perforated baffle.

METHODOLOGY

In carrying out the research, four different Peugeot 504 cars were selected being the available cars in the venue of the tests (Automobile Workshop of Mechanical Engineering Department, Federal Polytechnic, Ado-Ekiti, Nigeria). Performance parameters were calculated for each of the silencers of the selected cars using Eqns (1) to (3). The results obtained are shown in Table 1.

Table 1: Performance parameters for the silencer of the selected cars

	Silencer Performance parameters		
Car	ΔP (Nm^{-2})	Δv (ms^{-1})	γ
A	17	0.15	0.48
B	12	0.13	0.17
C	141	1.66	0.86
D	21	0.22	0.43

Also, the noise level of the silencers was measured using sound level meter (Monarch 325, range 33 to 130 dB, S/No. IEC651) and the results are shown in Table 2.

Table 2: Noise level of the silencer of the selected cars

Car	**Silencer Noise Level (dB)**
A	40.62
B	41.34
C	40.08
D	39.51

The following model equations for the performance parameters were formed, using data on Tables 1 and 2, by putting x_1, x_2, x_3 and Q to represent optimal values for pressure drop (ΔP), velocity drop (Δv), porosity (γ) and noise level, respectively:

$$17x_1 + 0.15x_2 + 0.48x_3 \leq 40.62 \quad (4)$$

$$12x_1 + 0.13x_2 + 0.17x_3 \leq 41.34 \quad (5)$$

$$141x_1 + 0.166x_2 + 0.86x_3 \leq 40.08 \quad (6)$$

$$21x_1 + 0.22x_2 + 0.43x_3 \leq 39.51 \quad (7)$$

The average value of LHS of Eqns (4) to (7) represent the objective function:

$$Q = 48x_1 + 0.54x_2 + 0.49x_3$$

or $$Q - 48x_1 - 0.54x_2 - 0.49x_3 = 0 \quad (8)$$

The functional constraints in terms of inequalities are expressed as equations by the introduction of slack variables. The slack variables are w_1, w_2, w_3 and w_4 (Hillier and Lieberman, 1997). Therefore,

$$17x_1 + 0.15x_2 + 0.48x_3 + w_1 = 40.62 \quad (9)$$

$$12x_1 + 0.13x_2 + 0.17x_3 + w_2 = 41.34 \quad (10)$$

$$141x_1 + 0.166x_2 + 0.86x_3 + w_3 = 40.08 \quad (11)$$

$$21x_1 + 0.22x_2 + 0.43x_3 + w_4 = 39.51 \quad (12)$$

The simplex tableau was formed using Eqns (8) to (12) and the following results were obtained from the computation carried out on the tableau:

Pressure drop, x_1 = 291 Nm^{-2}

Velocity drop, x_2 = 2.7 ms^{-1}

Porosity, x_3 = 2.45

Noise level, Q = 21.2 dB

The results formed the performance parameters used for the construction of the new silencer.

Silencer Dimensions

The Dimension of the silencer muffler was determined by the application of the Lagrange multiplier approach of optimization. For a cylindrical muffler, the surface area is calculated as follow:

Surface area = $2\pi rL + 2\pi r^2$, therefore, the objective function is

$$f(r, L) = 2\pi rL + 2\pi r^2 \quad (13)$$

The functional constraints is the equation for the volume of a cylinder ($v = \pi r^2 L$)

The functional constraints $f(r, L) = 2\pi rL$

The functional constraints f(r, L) = $2\pi rL$ (14)

where, r = radius of the muffler

L = length of the muffler

The Lagrange function z for the problem is

$= 2\pi rL + 2\pi r^2 + \lambda(\pi rL - v)$ (15)

where, λ = Lagrangian multiplier

Partial differentiation of Eqn (15) with respect to r, L and λ will gives:

$= 2\pi rL + 4\pi r + 2\pi rL\lambda = 0$ (16)

$= 2\pi r + \pi r\lambda = 0$

(17)

$= \pi rL - v$ (18)

From Eqn (18), $v = \pi rL$ and

Substitution of L in Eqn (16) gives:

$$\frac{2v}{r} + 4\pi r + \frac{2\lambda v}{r} = 0$$

or $$\lambda = -\left(\frac{1}{r} + \frac{2\pi r^2}{v}\right)$$

Substitution of λ in Eqn (17) gives:

$$2\pi r - \pi r - \frac{2\pi^2 r^4}{v} = 0$$

or $$r = \left(\frac{v}{2\pi}\right)^{\frac{1}{3}} \qquad (19)$$

Therefore, the radius of the muffler is determined using Eqn (19). The volume of the exhaust gas as given by Wellington and Asmis (1996) is:

$$v = \frac{S}{\sqrt{n} \cdot N} \qquad (20)$$

where, S = stroke of the engine

n = number of cylinders

N = revolution per second

From Eqn (3), the number of holes (N_h) of diameter (d) on the perforated pipe is

$$N_h = \frac{4A\gamma}{\pi d^2} \tag{21}$$

CONTRUCTION OF AN OPTIMIZED SILENCER

The optimized silencer was constructed using the materials that are easily obtainable from the local market. Fig. 1 shows the diagram of the optimized silencer. The silencer has four main features viz: the inlet pipe, the muffler casing, the muffler perforated pipes and the tail pipes.

Inlet pipe: The inlet pipe is a mild steel pipe of 40 mm diameter and 160 mm in length. The pipe was bent with the aid of a pipe bender for easy installation and support of the silencer underneath the vehicle.

Muffler casing: The muffler casing was fabricated with mild steel sheet of 18 gauge to form a cylindrical pipe of 460 mm length and 165 mm diameter. The front and the rear ends of the muffler were covered with end plates. The front end plate contains 44 mm diameter hole where the inlet pipe is fixed, the rear end plate contains two holes of 44 mm diameter (Fig. 1) where the two tail pipes are connected with two muffler perforated pipes. The muffler casing also housed the baffle brackets. These brackets were used to support the perforated pipes in the muffler.

Muffler perforated pipes: These are perforated pipes of 40 mm diameter, 120 mm in length and 5 mm diameter of perforation over the surface area of the pipes as shown in Fig. 1. The pipes are fixed inside the muffler casing and they are four in number; two of the pipes are fixed in the front end and the rest two are fixed in the rear end of the muffler between the end plates and the baffler brackets.

Tail pipes: The tail pipes are mild steel pipes of 40 mm diameter and 160 mm in length. They are connected to the perforated pipes in the rear end of the muffler.

RESULTS AND DISCUSSION

In order to evaluate the performance of the optimized silencer, the silencer was tested on the selected motor cars one after the other. The test was carried out in the workshop under idle speed in which the engine was allowed to run for 30 minutes on each car during which the noise level of the silencer was measured using sound level meter. The results obtained are shown in Table 3. As shown on this table, the use of optimized silencer has drastically reduced the car exhaust noise level. The average car exhaust noise level using initial car silencer is 40.39 dB while the noise level using the optimized silencer is 23.30 dB, this is 42.3 % reduction in noise level. The noise level using the optimized silencer is slightly high when compared with the theoretical value obtained from the optimization process (21.2 dB). The difference is due to the level of accuracy of the machines and the processes used for the fabrication of the silencer.

The process efficiency can be calculated as follows:

$$\text{Process efficiency}, \eta = \frac{\text{Actual reduction in noise level}}{\text{Optimized reduction in noise level}} \times 100\%$$

$$\eta = 89.1\ \%$$

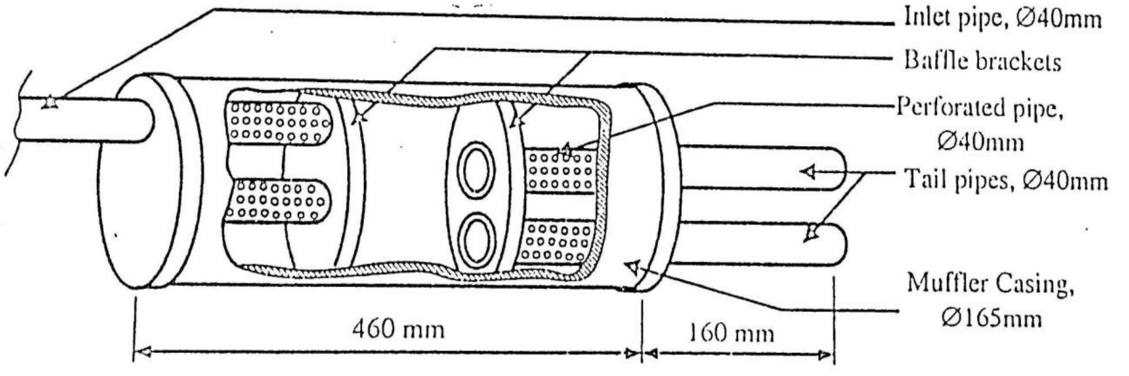

Fig. 1: Optimized silencer

Table 3: Noise level of the optimized silencer under workshop test of idle speed compared with the initial car silencer.

Car	Noise level (dB)		Reduction in noise level (%)
	Initial car silencer	Optimized silencer	
A	40.62	23.38	42.4
B	41.34	23.50	43.2
C	40.08	23.11	42.3
D	39.51	23.19	41.3
Average	40.39	23.30	42.3

CONCLUSION

In order to improve the efficiency and to reduce the environmental problem of noise pollution associated with the vehicle exhaust systems; this paper applies linear programming using simplex method to optimize the performance parameters of vehicle silencer. In carrying out this research, four Peugeot 504 cars were selected and performance parameters were calculated for each of the silencers. These parameters were optimized using simplex method and the results obtained formed the parameters used for the construction of the new silencer. The optimized silencer was tested on the selected motorcars and the results revealed that, to a large extent, it is effective in reducing the car exhaust noise level.

During the test, the average noise level using the initial car silencer was 40.39 while the average noise level using the optimized silencer was 23.3 dB (practical). Although the later value is slightly higher than the value obtained from optimization process (theoretical), the silencer was able to achieve 42.3 % reduction in noise level. The process efficiency is also found to be 89.1 %.

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