AUTOMOTIVE ENGINE MUFFLER PERFORMANCE MEASUREMENTS

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الملخص

تستخدم الكاتمات للإقلال من الضوضاء الصادرة عن غازات العادم بالمحركات وتصمم بحيث تعمل بكفاءة عند ترددات غازات العادم وبسرعات مختلفة للمحرك الترددي. هذه الورقة تتناول دراسة ديناميكية الضجيج والتحليل الطيفي لكواتم الضجيج الخاص بمحركات السيارات من خلال اجراء تجربتين. تم في الاعداد الاول (التجربة الاولى) قياس ديناميكية الضجيج لكاتم سمعي بتردد معلوم وبموجة سمعية جيبيه حيث جمعت البيانات باستخدام مجمع بيانات متطور National (Instrument) يعمل ببرنامج لاب فيو (LabVIEW). أما في الاعداد الثاني (التجربة الثانية) فكان الكاتم مثبت على محرك سيارة سعة 1500 سم^3، حيث تم قياس معدل الاشعال للمحرك من خلال منظومة العادم (EFR) والتي أستخدم فيها نفس التقنية المستخدمة في التجربة الاولى عند سرعات مختلفة للمحرك (1400 الى 3000 لفة في الدقيقة). بينت هذه التجارب مقدار الانخفاض الكبير في مستوى الضجيج على مدى واسع من الترددات كما أوضحت النتائج أنه لا تأثير في انخفاض مستوى الضجيج في نطاق ضيق جدا للتردد واظهرت النتائج حدوت تضخم للضجيج في بعض الترددات التي يجب عدم تشغيل الكاتم عندها. كما تبين ان معدل الاشعال للمحرك بأنبوب العادم متفق تماماً مع التحليل النظري لتردد الاشعال بالمحرك. النتائج العملية في هذه الدارسة تساهم في تطوير النمذجة النظرية لتحسين اداء الكاتمات كما تبين أيضا أهمية الكاتمات في تخفيض الضوضاء بطريقة التحكم السلبي (Passive control).

ABSTRACT

A muffler in the exhaust pipe is used for reducing noise. Due to varying noise frequencies of the exhaust gas flow at different engine speeds, the muffler must be designed to work at best performance in the frequency range of maximum sound level; which is a very difficult task due to the wide range of noise spectrum. Hence, good design of the muffler should give the best noise reduction and offer optimum backpressure for the engine. In this paper, two test rigs are examined to analyze the muffler in terms power spectrum. In the first test rig, the task is to scan the muffler which is acoustically excitedby known frequencies by using signal generator. In the second test rig, measurements of noise power spectrum were carried out using the microphone system for a car engine at different engine speed (1400-3000rpm). A National Instrument DAQ card and LabVIEW software have been utilized for data acquisition, monitoring and analyses. This study makes available very detailed spectra of the muffler, and the method of cross-correlation has also been applied. In the first rig, the results show that there is a great potential for the muffler system to attenuate the noise over a wide range of excited frequencies. Results showed that, the effective reduction of noise was in the wide frequencies range and only a very narrow range was destructive. In the second test rig, the results show that the measured of engine firing rate (EFR) Harmonics are in very agreement with the theoretical analysis and that the pulse repeats at the firing frequency of the engine. Results show that the muffler is very important for a passive control and reduction of noise in internal combustion piston engines applications.

KEYWORDS: Muffler; Power Spectrum; Firing Rate; Passive Control; Acoustics

INTRODUCTION

The exhaust pollution has become one of the important problems of environment pollution with applications in automobile industry, and the exhausted muffler has been paid attention to improve the performance of engines. The exhaust from the automobiles is at a high pressure and leads to generation of noise while rejection to the atmosphere. To reduce the exhaust pressure and subsequently to reduce the noise a muffler is improvised in the exhaust system of the automobiles. [1]

Daniel (2005) [2] Discusses the general principles of muffler design and explain the main advantages of various styles of mufflers, and explained that several functional requirements that should be considered, such as insertion loss, minimal backpressure, space constraints, cost effective and aesthetically pleasing.

The level of noise reduction by using the muffler depends upon the design, construction and the working procedure of mufflers. Unbearable noise level can be observed from muffler of the engine, which causes a significant fuss [2]. The most of the advances in the acoustic filters and exhaust mufflers came out in last four decades. Hence good design of the muffler should give the best noise reduction and offer optimum backpressure for the engine [3].

Shubham et. al (2014) [4] Use the tunable resonator length can be varied by using a piston that can be set at different positions. Noise level is also measured at the different positions of resonator to check the effect of variation of length on silencer performance, which shows that the smaller the resonator size better is insertion loss. A muffler for stationary petrol engine (engine test rig) has been designed. Sound level is measured before and after the muffler installation at different position of resonator piston, they studied the effect of resonator length on the fuss damping.

Internal combustion engines are typically equipped with an exhaust muffler to suppress the acoustic pulse generated by the combustion process. A high intensity pressure wave generated by combustion in the engine cylinder propagates along the exhaust pipe and radiates from the exhaust pipe termination. The frequency content of exhaust noise is dominated by a pulse at the firing frequency, but it also has a broadband component to its spectrum which extends to higher frequencies. Exhaust mufflers are designed to reduce sound levels at these frequencies; the muffler design methodology for the engine involves some steps. One of the main steps is the Target Frequencies, Target frequency is required to more focus on transmission loss. For calculating the target frequencies engine max power rpm is required and calculation follows, Hypothetical Computation. The exhaust tones are calculated using the following Formula [5].

For four stroke engine, the Engine Firing Rate (EFR) is calculated by the equation;

$$f = \frac{(Engine\ speed\ (rpm) \times number\ of\ cylinder)}{120}. \quad (1)$$

For two stroke:

$$f = \frac{(Engine\ speed\ (rpm) \times number\ of\ cylinder)}{60} \quad (2)$$

This paper, for more understanding the performance of the muffler, a full mapping of the automotive muffler acoustically excited by loudspeaker with known frequencies has been carried out in terms of acoustic pressure. A microphone system and modern

DAQ system are used to capture the acoustic signals and analyzed, also the DAQ system is used to measure Engine Firing Rate (EFR) for Automotive Muffler system.

EXPERIMENTAL SETUP

The overview of the experimental set up of this test rig is shown in Figure (1). It consists of a Muffler type Walker-Typho. V16-20 system, a signal generation, and data collection system. In this case, of study a muffler is used to reduce the noise as shown the Figure (1).

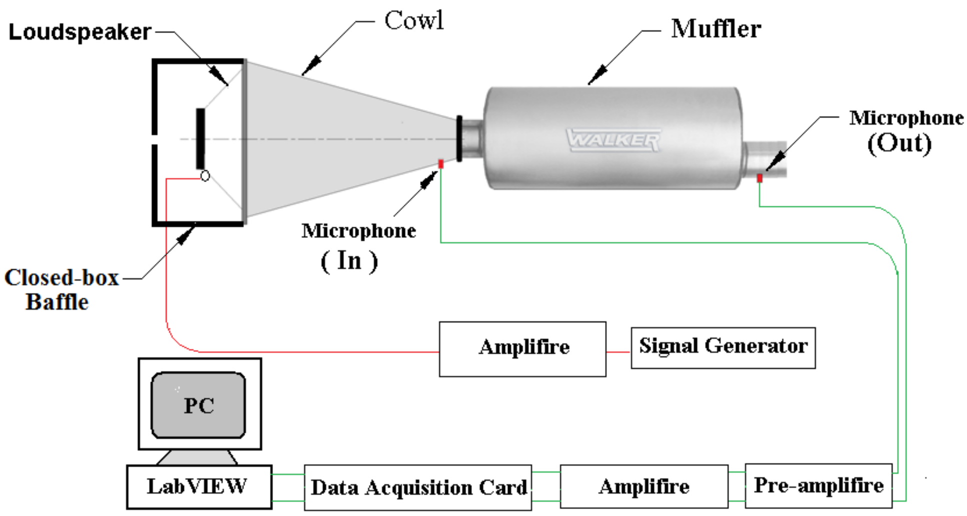


Figure 1: Overall experimental setup of the Muffler system.

The test rig consists of a Muffler with Helmholtz cavity, a signal generator system, and two microphone systems. The Muffler is acoustically excited by a signal generating system includes a signal generator (type Peak Tech.), an amplifier, and a loudspeaker. Since the loudspeaker has a larger diameter than the input muffler tube, a cone tube (cowl) is used to connect the loudspeaker and the muffler tube to ensure that as much of the sound as possible is transferred to the test section. The bottom part of the cowl is acoustically 'sealed'; the rear side of the loudspeaker diaphragm is enclosed by a box, which ensures the loudspeaker is a monopole source (Closed-box Baffle loudspeaker). The amplitude of the supply voltage for the signal generator is kept constant during these experiments, and the loudspeaker has a maximum power of 250 W and a frequency range from 20 Hz to 4000 Hz. Its effective diaphragm radius is 0.06 m. In this paper, sinusoidal signal mode has been selected to excite the air in the muffler. Almost every acoustic measurement arrangement contains microphones that normally convert sound pressures into electrical signals, which in turn can be displayed, stored, and analyzed by analogue or digital techniques; an electrostatic (capacitor) type of microphone is used in these experiments for the measurement of sound pressure. One is installed just before the muffler and the other after the muffler. In this study of muffler performance, two microphones system have been used, one of microphone is mounted at the entrance of the muffler (Muffler in) and the other is located at outlet of the muffler (Muffler out) as shown in the Figure (1), to gain captured signal by microphone, a pre-amplifier and amplifier have been used. National Instrument DAQ card and Labview software have been applied for data acquisition, monitoring and analyses.

RESULTS AND DISCUSSIONS

The experimental investigation included a spatial mapping of the muffler in terms of acoustic pressure emission at different operating modes are presented in this study. The pressure power spectrum is analyzed for two test rigs. In the first rig, the discussion of the results is to analysis the input and output acoustic characteristics across the muffler excited with loudspeaker mounted at the inlet and output of the muffler. In the second rig, also a microphone system has used to measure the engine firing rate (EFR) Harmonics, where the microphone located at the end of the exhaust system of the car, the engine specifications used are, petrol engine, 4-stroke, and 2000cc.

Test Rig I: Muffler excited with known frequency.

The rig is explained in details in the previous section (experimental set up). The most commonly used type of loudspeaker is an enclosed box in which the loudspeaker is mounted. In the type discussed hereafter, the backside of the loudspeaker is isolated from the front. The closed-box sides are as rigid as possible using a suitable material (plywood, 1 cm thick). A small air leak is provided in the box so that changes in the atmospheric pressure do not displace the natural position of the diaphragm.

The excitation frequency applied was varied from 50 Hz, which is the lowest frequency response of the loudspeaker, to 1500 Hz with an increment of 5 Hz. The voltage applied to the loudspeaker was maintained at 8 volts. By using the data acquisition system, the digital signal generator is connected to the loudspeaker, and the signals picked up by the microphones which are connected to the data acquisition system through the analogue to digital (A/D) channels. Figure (2) presents the pressure *(rms)* in volts as a function of excitation frequency at inlet and outlet of the muffler. It can be seen from the figure that the pressure *(rms)* peaks appears with very high amplitude at inlet to the muffler, and strongly damped at the outlet of the muffler for all exited frequencies. Results also show, at the range of excited frequency (f_e) (900 to 1030 Hz) the muffler working as a noise gain.

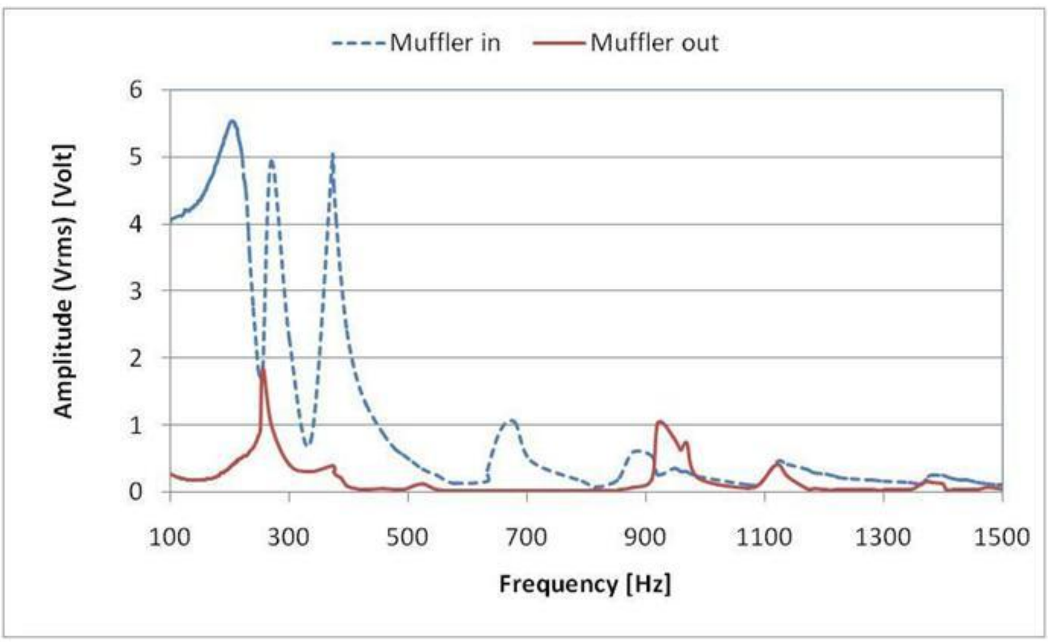


Figure 2: the *rms* acoustic pressure as a function of the excitation frequency(f_e).

Figure (3) shows the attenuate and destructive percentage of muffler the noise emissions. From the result of Figure (2), for reduction noise frequencies three excited frequencies have be selected (203, 372, and 678 Hz) also for destructive frequency 920 Hz is selected and for no effect 1090 Hz is selected, to calculate the power spectrum and signal correlation these equations are used:

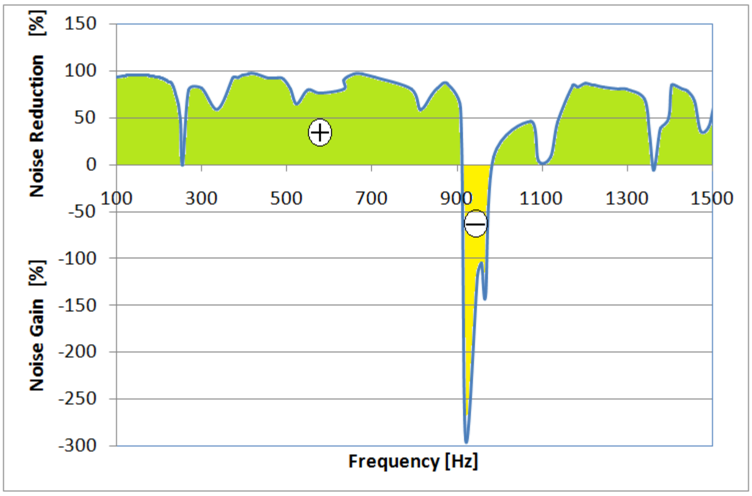


Figure 3: Noise reduction and gain percentage of the Muffler as a function of excitation frequency (f_e).

Cross-correlation

Consider two signals g and f at time t, the relationship between g and f at two different times is very often expressed as the cross-correlation function, which is simply given by:

$$\Re_{gf}(\tau)=\lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} g(t)f(t+\tau)dt \quad (3)$$

The idea of cross-correlation function is similar to the auto-correlation, but it is used to compare between two signals at different instants of time.

Power Spectrum

The autocorrelation function of the random process is directly related to its frequency measurement by the Fourier integral relationship given by (Dowling and Williams, 1983, Nelson and Elliott 1992) [6]

$$\hat{\Re}_g(\omega)=\int_{-\infty}^{\infty}\Re_g(\tau)e^{-i\omega\tau}d\tau=2\int_0^{\infty}\Re_g(\tau)\cos\omega\tau d\tau \quad (4)$$

where, $\hat{\Re}_g(\omega)$ is the Fourier transform of autocorrelation function $\Re_g(\tau)$.

This relationship is known as the power spectrum of the signal.

Figures (4 to 8) show the time series, power spectrum, and cross-correlation between inlets to output of acoustic signals ($R_{inlet.–out\ let}$) for the selected excitation frequencies. The sampling rate is 10000 samples per second and the duration of each sampling is one second.

In this confgurations of setup, subfigures (A) of results show the time series of two signals of acoustic emissions. It is clear from the figures that, for attenuate the noise-selected frequencies, the reduction in noise was very strong, and the reduction reaches to more than 90%. Subfigures (B) of results show that the dominant frequencies of the acoustic emission of both channels are the same and equal to the excited frequency.

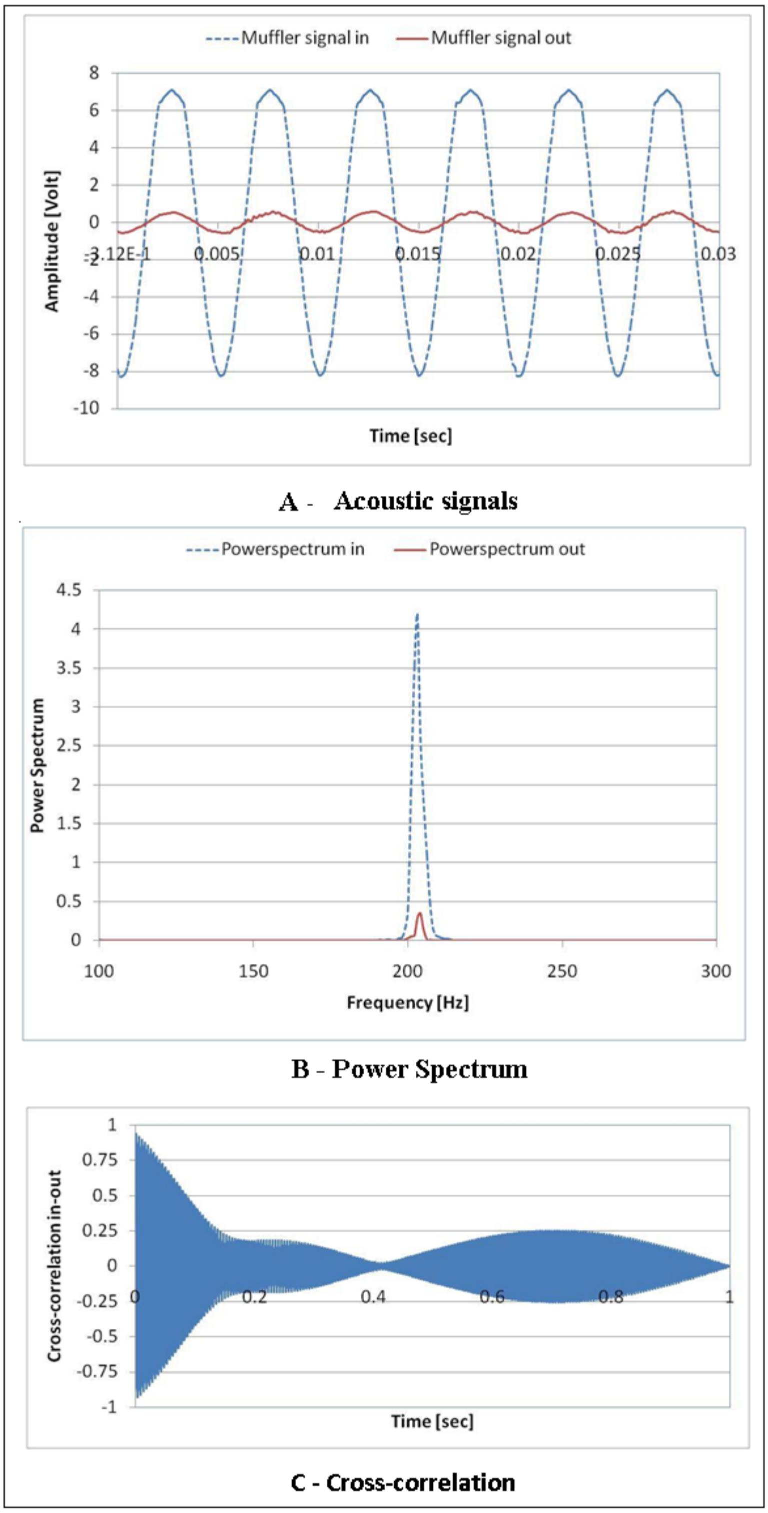


Figure 4: Time series (A), power spectrum (B), and cross-correlation of ($R_{inlet-outlet}$) (c) at exciting frequency of 203 Hz.

It can be seen from power spectrum analysis for attenuate the noise that the power spectrum amplitude at the outlet acoustic pressure of the muffler is very small compared at the inlet position. Subfigures C of this test rig of the results show the cross-correlation. It can be seen also that the cross-correlation of the two signals are strongly correlated.

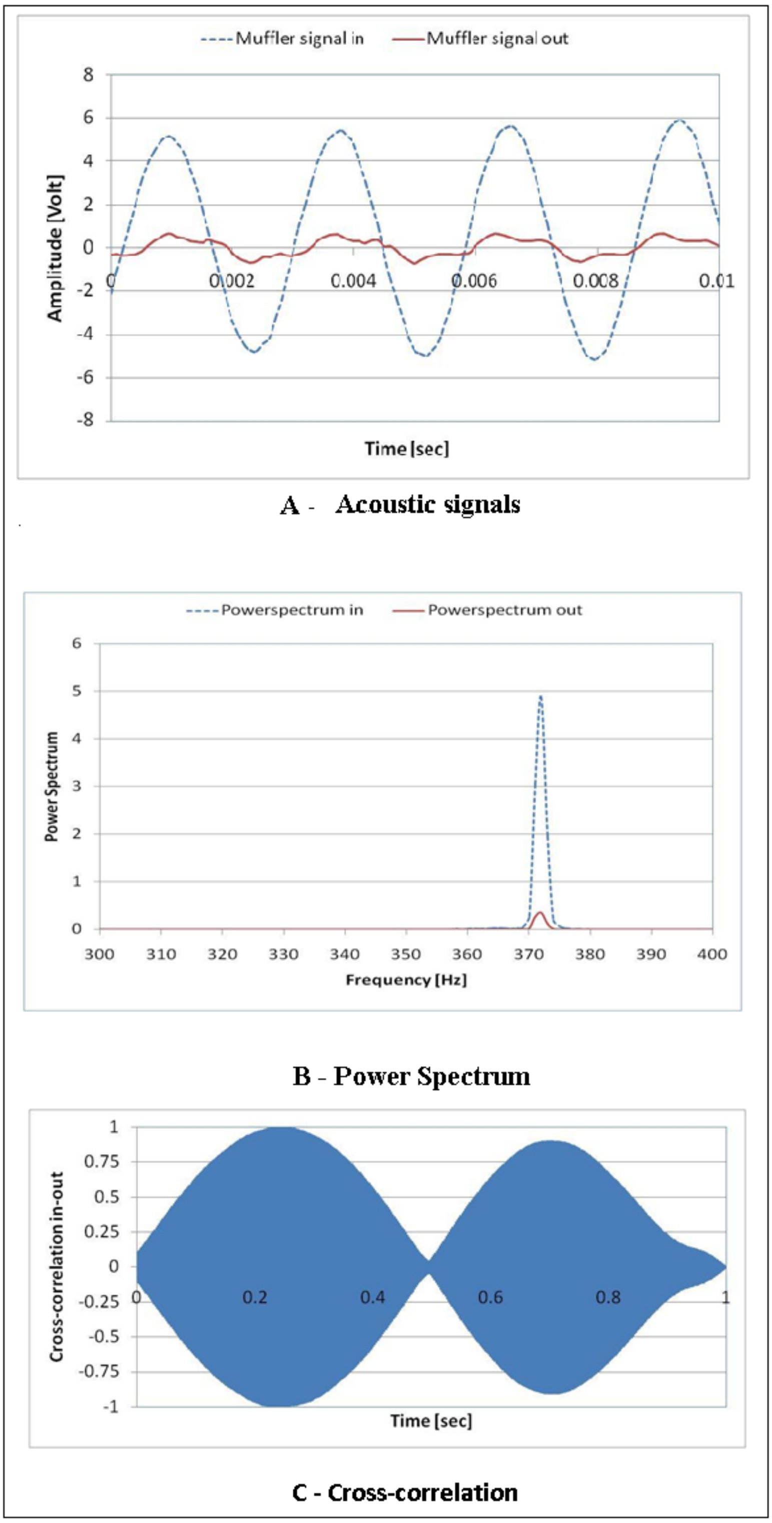
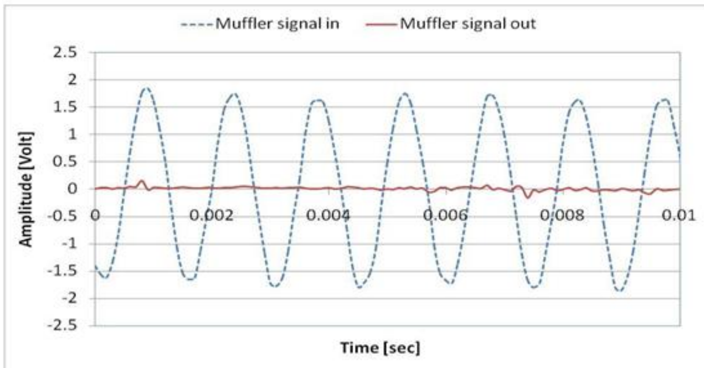
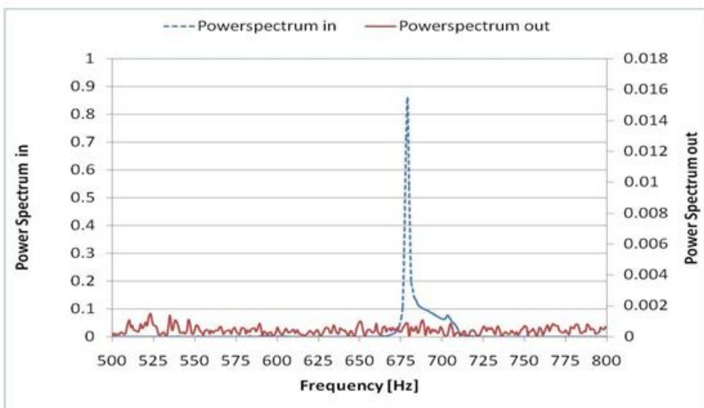


Figure 5: Time series (A), power spectrum (B), and cross-correlation of ($R_{inlet-outlet}$) (c) at exciting frequency of 372Hz.

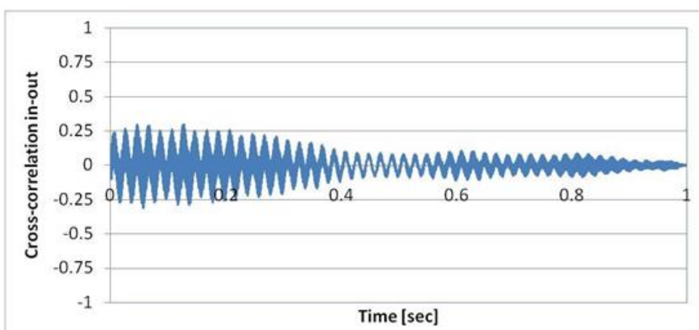
Except at frequency at 678 Hz, the signal outlet of the muffler was random; because of strong reduction was occurs in this excited frequency, it has been observed that, in an exited frequency the sine wave from signal generator is strongly eliminated, that is why the correlation was very weak.



A - Acoustic signals



B - Power Spectrum



C - Cross-correlation

Figure 6: Time series (A), power spectrum (B), cross-correlation of ($R_{inlet-outlet}$) (c) at exciting frequency of 678 Hz.

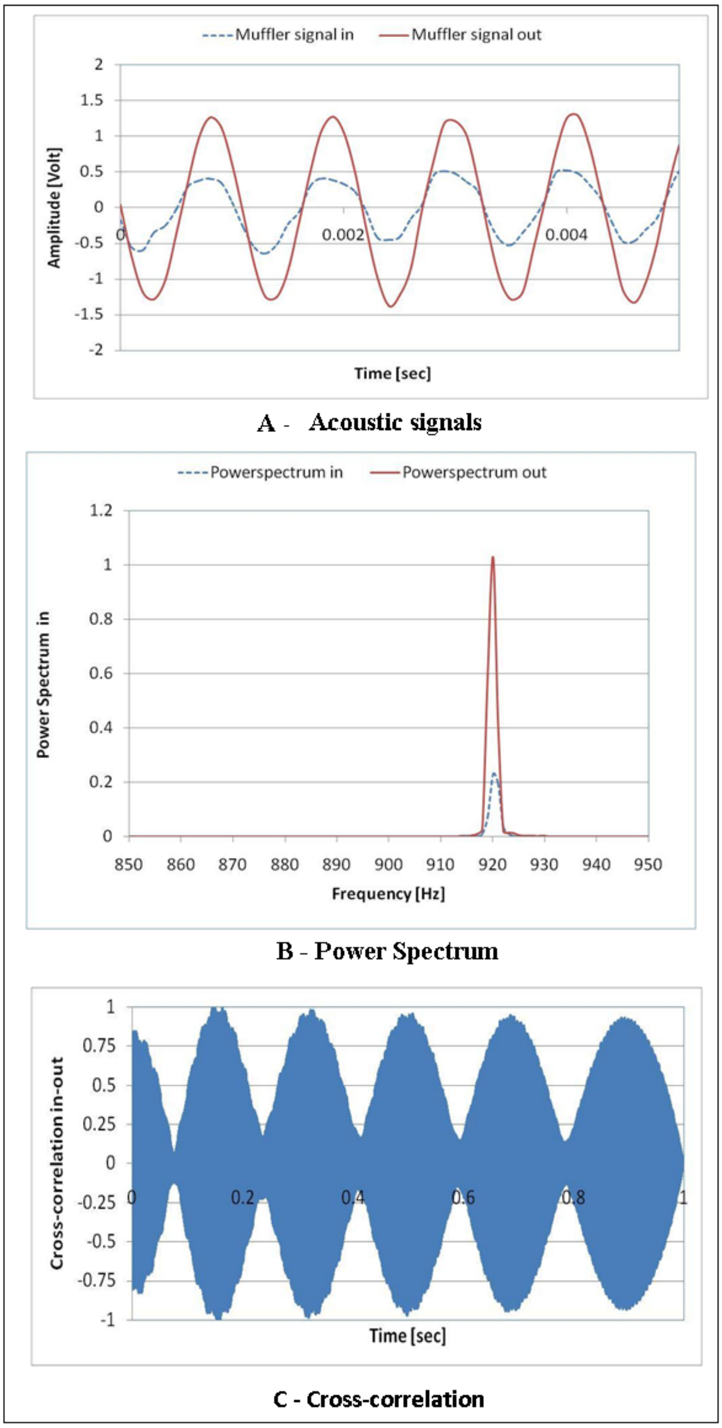


Figure 7: Time series (A), power spectrum (B), cross-correlation of ($R_{inlet-outlet}$) (c) at exciting frequency of 920 Hz.

From Figure (8), the results show that, at frequency reach 920 Hz the output signal bounce and exceed the input signal, which indicates that the muffler efficiency at that frequency is very low, this could be caused by many reasons one of them is in event of muffler resonant. In this condition of excitation, the muffler works as a gain device of the noise, which indicates that the muffler effectiveness has been reduced at this frequency of excitation, and the signal was amplified rather than reduced.

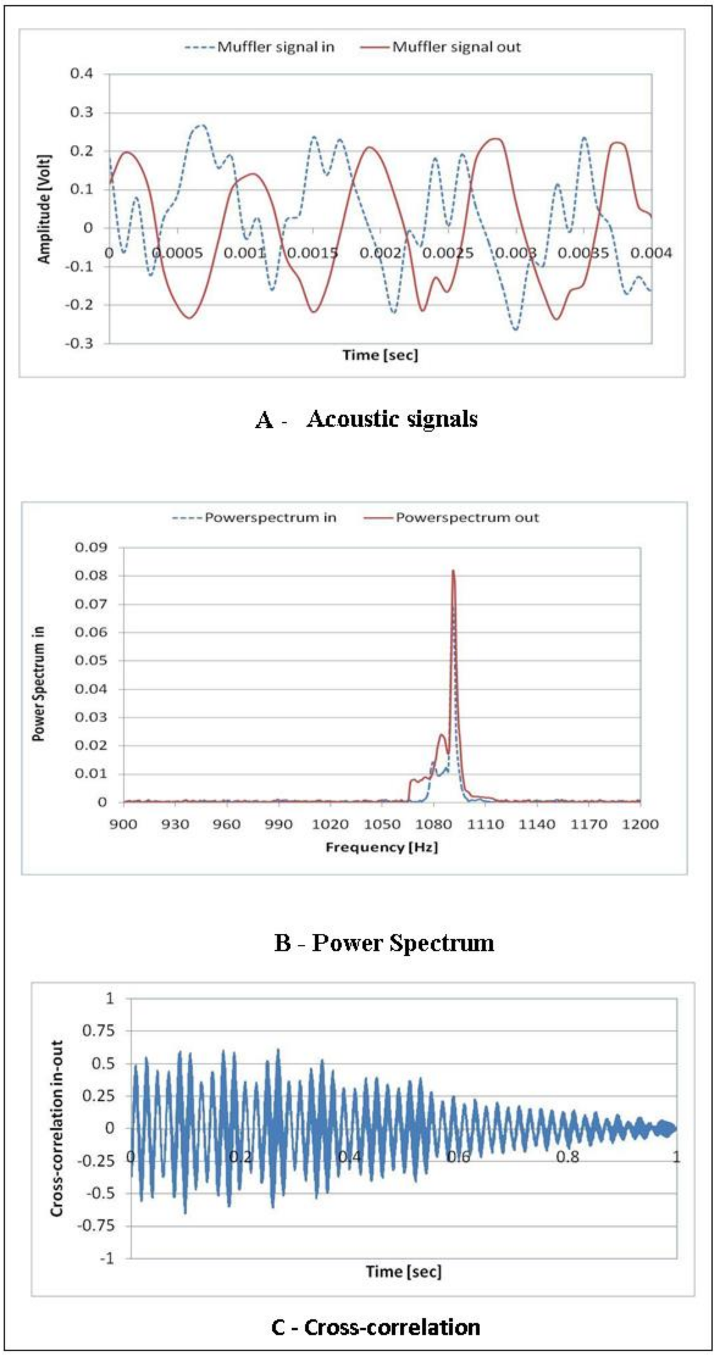


Figure 8: Time series (A), power spectrum (B), cross-correlation of ($R_{inlet-outlet}$) (C) at exciting frequency of 1090Hz.

Test Rig II: Engine Exhaust Tones

The exhaust noise spectrum is always contain strong tones associated with the rate of cylinder firings. In 4-cycle engines each cylinder fires once *every other revolution* of the drive shaft. Cylinders fire once every rev in 2-strok engines. The lowest tone is always the CFR, which is the firing rate for any one cylinder. The engine-firing rate is generally the strongest tone in the exhaust spectrum.

Figure (9) shows the rate of cylinder firings for 4-strok engines, with four cylinders (n = 4) when the engine speed is 1400 rpm each cycle time duration is 0.077745 sec (720 deg crank angle).

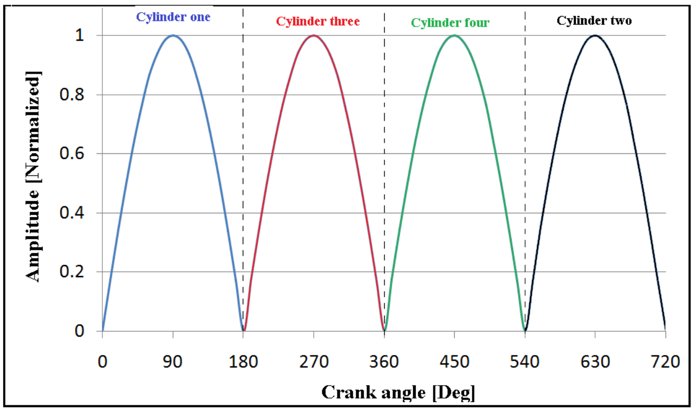


Figure 9: Exhaust Valve timing for four-stroke with four-cylinder engine.

Figure (10) shows the acoustic pressure signal at the end of Muffler system of the Automotive Engine.

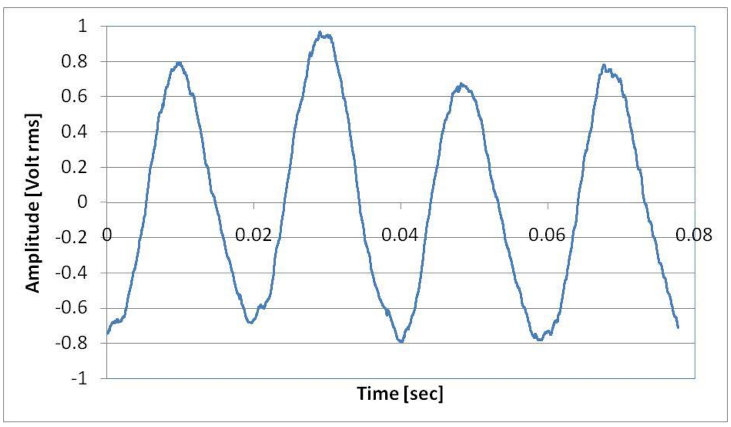


Figure 10: Acoustic signal for 4-stroke with four-cylinder engine.

Table (1) show the measured EFR by using a microphone system and calculated EFR.

Table 1: Calculated and Measured Engine Firing Rate (EFR).

Engine speed [rpm]	Noise (rms) [Volt]	Measured Harmonics [Hz]	Calculated Harmonics [Hz] (using eq. 1)
1400	3.628959	46.85784	46.66667
1500	4.165471	50.8064	50
1750	2.296449	57.54472	58.33333
2000	1.078643	66.55454	66.66667
2250	0.652807	78.46864	75
2500	0.701693	85.995	83.33333
2750	0.536342	92.61	91.66667
3000	0.612546	101.43	100

Figure (11) shows relationship between engine speed and exhaust flow frequency, by using a microphone system and by using EFR equation. The Figure demonstrate that the experimental result of EFR have the same results of theoretical EFR.

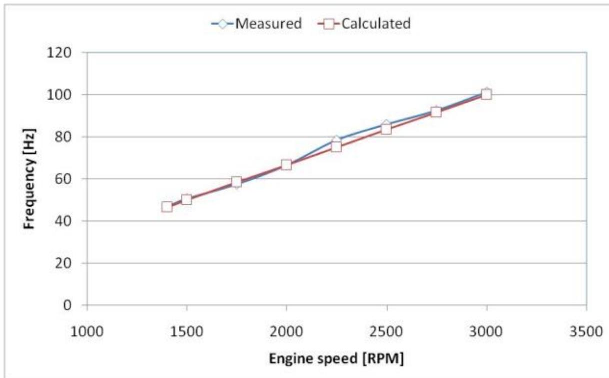


Figure 11: Experimental and theoretical EFR of Automotive engine.

CONCLUSION

It is recommended that a muffler is designed to meet all functional requirements such as engine speed and back pressure. It is good practice to design a muffler to work in the frequency range which varies per the engine speed. A high-pressure fluctuation generated by combustion in the engine cylinder propagates along the exhaust pipe and generates very high level of noise. The high-pressure fluctuation is studied in terms of firing frequency of the engine which is defined by f= (engine rpm x number of cylinders)/120 for a four stroke engine. In this paper, two test rigs are examined to analyze the muffler in terms of the power spectrum. A National Instrument DAQ card and LabVIEW software have been utilized for data acquisition, monitoring and analyses. The first test rig, full scanning of the muffler which is acoustically excited by known frequencies is done, In the second test rig measurements of noise power spectrum were carried out using the microphone system for a car engine at different engine speeds. In the first test rig, the results showed that there is a great potential for the muffler system to attenuate the noise over wide range excited frequencies. In the second rig, the results show the measurements of engine firing rate (EFR) Harmonics is in very agreement with the theoretical analysis. Results showed that the effective reduction of noise was in the wide frequencies range.

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