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Sound insertion loss modelling for spark arrestors using two-port theory with experimental verification

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ABSTRACT

Spark Arrestor plays critical role in impeding the embers emission from diesel engines as it arrests and traps the embers and the sparks inside it. Spark Arrestors have a significant impact upon the acoustic performance of diesel engines. Sound Insertion loss is an important parameter for evaluating the overall sound level emitted from diesel engine generators. In this paper the effect of new designed centrifugal trapping type was acoustically modeled and experimentally verified. The acoustics design and simulations were performed using two-port theory where, the Spark Arrestor models are limited to the plane wave range. These models were implemented in SIDLAB software for simulating the propagation of low frequency sound and air flow in ducts. The Spark Arrestor model was tested on a real diesel engine generator of 38 KWm complying with Standard ISO 8528-10:1998(E). The insertion loss simulation model matched the measurement at full engine load at 1500 rpm.

1. Introduction

As a result of the incomplete reaction of the fuel, carbon deposited inside the diesel engine and the exhaust system in the form of particles, which are emitted at high temperature causing fire. [1] Inefficient design for diesel engines, inadequate maintenance and misunderstanding of risks may lead to fire and explosion. [2]

This work focuses on diesel engines Spark Arrestors' acoustic design sound Insertion Loss (IL) prediction. The necessity for Spark Arrestors was established with the introduction of wood burning locomotives in 1830. [3] Many inventions and developments were happened to the Spark Arrestors depending on the ideas of wire netting, wind direction, deflection plates, and gravity. Later, in the 20th century especially on 1964 the interest of noise reduction using Spark Arrestors were started by using absorption materials.

In this paper two ports theory will be used in studying, modeling, and designing of Spark Arrestors in terms of Sound Insertion Loss Acoustical Performance.

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2. Theoretical Background

There are 4 main techniques that are used in arresting Sparks namely; Centrifugal Force, Particles Impact, Refinery Meshing, Electrostatic Charge, and Particles' Grinding. This Study focuses on sound Insertion loss Acoustic performance of Centrifugal Type Spark Arrestor. The sound Insertion loss will be simulated using the two-port transfer matrix method.

2.1. Centrifugal force technique

In this technique, stationary vanes are used to separate the ash or embers from the exhaust gas because of centrifugal force.

For the purpose of acoustic modeling, duct systems or networks are often too complicated to enable direct solution of the governing equations. One method to describe the sound transmission along the system is called the building block method or two-port transfer matrix method as described in references. [4] This method splits the system into several smaller duct parts, acoustic elements, in which the sound propagation is well defined. Plane waves are assumed to propagate between different elements and the sound field can be characterized by two state variables. One convenient choice is to use acoustic pressure and volume velocity. The sound propagation inside each element is analyzed separately and higher order modes can exist inside the element. A 2×2 complex transfer matrix completely describes the sound transmission through each element. The pressure and volume velocity of each element at the inlet and outlet can be related to the following expression (1) [5], [6].

$$\begin{bmatrix} p_1 \\ q_1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} p_2 \\ q_2 \end{bmatrix} + \begin{bmatrix} p_s \\ q_s \end{bmatrix} \quad (1)$$

As q and p are the volume velocity and the pressure, *1* refers to the inlet and *2* refers to the outlet, *Tij* is the element of the two-port transfer matrix, and the p_s and q_s are the source pressure and volume velocity. [4]

The SIDLAB code [5] used in this work is based on the representation of a duct network as a network of two-ports. The two-port elements are then joined and analyzed using the method described in reference. [6] The applied version of SIDLAB couples the elements at each node, using the continuity of pressure and volume velocity. The representation of perforated four-ports in the form of two-ports as described above is attractive since two-port codes are commonly used for muffler analysis and the proposed method makes it possible to model arbitrary complex perforated systems.

3. Design and Modeling

This part shows the configurations and the work theory for the new developed Spark Arrestor.

The newly developed Spark Arrestor [7] (Figure 1 and Figure 2) is of centrifugal collection type according to standard BS EN 1834-3:2000.[8] Particles will pass to the first chamber which will be affected by the centrifugal force because of flow rotation due to the inclined blades which are fixed at each slot opening of the Spark Arrestor part. Then these particles will be trapped before passing to the second chamber as a result of particles weight and the perforated plate number 2, see Figure 1 and Figure 2.

This newly developed Spark Arrestor shown in Figure 2 consists of inlet pipe of length 75 mm (4), expansion chamber of diameter 200 mm and length 300 mm (3), internal perforated plate (2), outlet pipe of 75 mm length (10). And Spark Arrestor part, part number (7) of ten ribs and each rib contains a slot of 2 mm height and 160 mm length. Each slot has a blade that forces the exhaust gas to rotate.

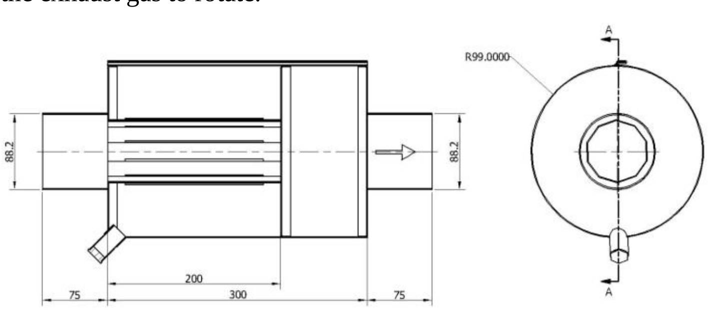

Figure 1 Schematic Drawing of Spark Arrestor.

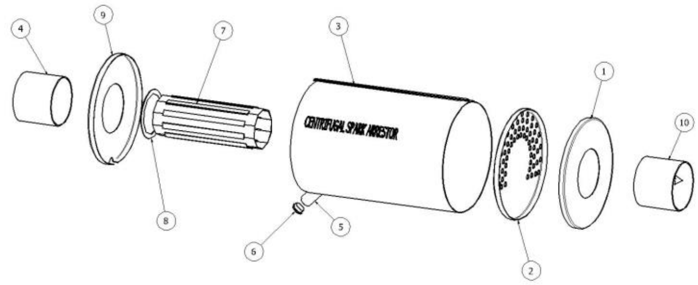

Figure 2 Newly Developed Spark Arrestor Subassembly.

3.1. Theoretical Modeling of Spark Arrestors' Sound Insertion Loss

SIDLAB is used in simulating the sound in ducts as mentioned before. In this study, the SIDLAB is used to simulate the sound IL of the new developed Spark Arrestor and the commercial Spark Arrestor. As in SIDLAB, each Spark Arrestor is classified into several parts with a certain arrangement referred to as: network. Each part dimensions in this network shall be specified. The inlet and outlet points of the network shall also be indicated to specify the air flow direction. In the following part, the network for the Spark Arrestor will be shown.

The New Developed Spark Arrestor Spark Arrestor contains two-port elements only, as shown in Figure 3, as each element connected to two nodes, one at the inlet and the other at the outlet.

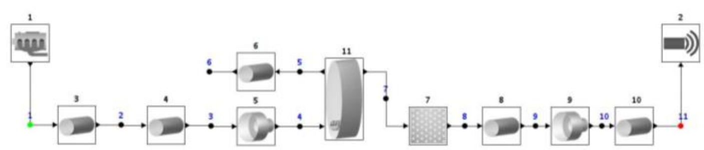

Figure 3 SIDLAB network for the newly developed Spark Arrestor.

4. Experimental Work

In this part, the Spark Arrestors IL was measured using real diesel engine (coupled to alternator) of power 38KWm complying with ISO 8528-10:1998(E).[8] The Engine manufacturer is Cummins of model KZY856724 and type S3.8G4. The Alternator manufacturer is Stamford. The Genset speed is 1500 rpm, and its size (L×W) is 1.7m × 0.69m.

As shown in Figure 4, the test rig consists of diesel engine generator of power 38KWm, 90 degree bending exhaust pipe, the tested Spark Arrestor, sound level meter, and a device for measuring the temperature and humidity.

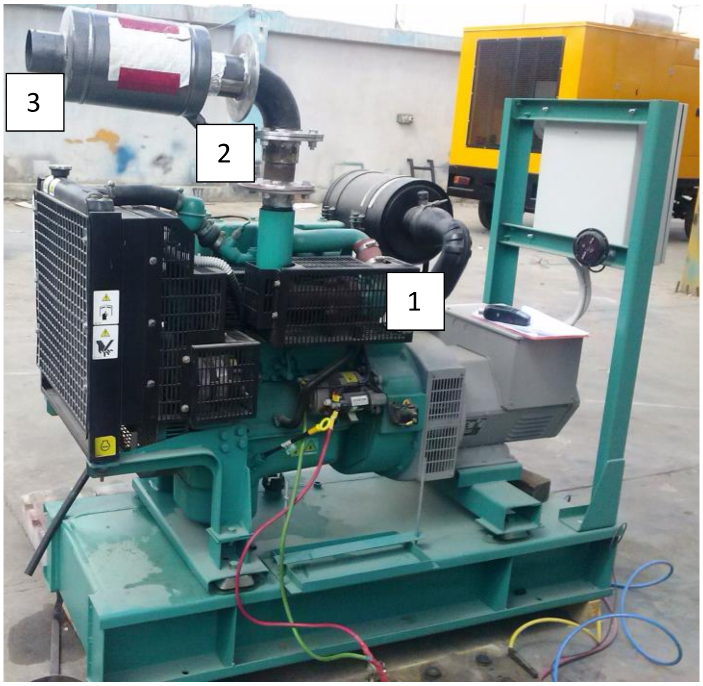

Figure 4 Spark Arrestor IL Test Rig. 1) radiator, 2) outlet pipe, 3) exhaust outlet.

According to ISO 8528-10:1998(E), The diesel engine generating set shall be installed on reflecting noise ground plane surface. The distance between the generating set and the microphone is equal to half the distance between the generating set and the next wall. The microphone shall be placed so that it will not encounter the exhaust gas movements and shall be directed at right angle to the measuring plane which is the outlet of the Spark Arrestor. The Sound Level Meter is adjusted at slow time weighting characteristic. The variation in the A-weighted sound pressure level (SPL) is checked to make sure that the noise is considered steady (less than ±1 dB). The time of measurement shall be at least 10s. The measurement shall show information about the background noise level (noise which is not generated by the generating set). The wind speed shall not exceed 6 m/s.

The SPL of the diesel generator is measured at 3 different points as shown in Figure 4 at different power rates which is 0%, 25%, 50%, 75%, and 100% of the full diesel generator power. Point 1 refers to the turbocharger, point 2 refers to the exhaust pipe, and point 3 refers to the spark arrestor outlet. These measurements will be taken two times, one before installing the Spark Arrestors, and the other after installing it. The background noise effect is measured.

5. Results

This part shows the theoretical and the experimental results for the Spark Arrestors' Insertion Loss.

At 0%, 25%, 50%, and 75% loads the airborne noise from the radiator cooling fan was ~1 dB higher than the exhaust noise. While at the 100% load the exhaust noise was masking the radiator fan noise. The measurement and simulation matched at the 100% load recording insertion loss of 13.5 and 13.2 dB respectively. For the lower loads the measured airborne noise from the radiator fan was subtracted as background noise and the results are shown in Figure 5.

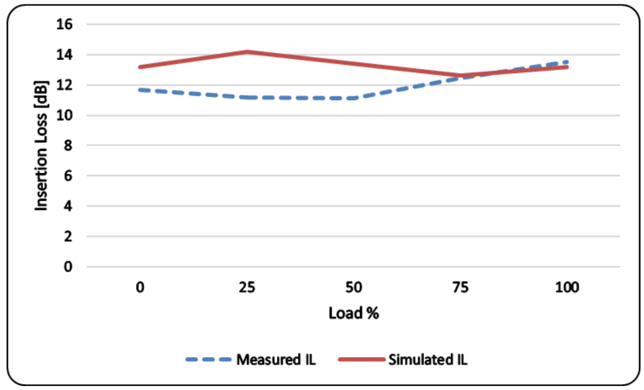

Figure 5 Insertion loss comparison results from 0% to 100% load.

6. Conclusion

The Spark Arrestor is a device which traps the exhaust carbon particles. The sound insertion loss is most appropriate to describe the exhaust system acoustic performance since it depends on the engine loading and rotational speed.

The theoretical modelling for the models was shown to be matched with the experimental verification at 100% load which is the more logic in the genset usage. To measure the insertion loss at lower loads, the contribution of the other noise rotating machines such as the radiator cooling fan noise shall be removed or insulated. The error in measurement was maximum 3 dB at 25% load, which falls in the acceptable measurement error.

Conflict of Interest

The authors declare no conflict of interest.

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