A Comprehensive Study of Acoustic Techniques in Different Mufflers

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***Abstract*: Literature review for the years 2015 and 2016 has been presented in this paper. A brief Note on acoustic methods developed by various authors for different muffler application like compressor, marine diesel engine, industrial and exhaust automotive system were been discussed.**

***Keywords*: acoustic, muffler, marine engine and noise.**

Introduction:

Wang, C., Shen, Y., Chen, C., Li, M. [1] Presented in their technical paper the influence of steam on the corrosion behavior of 439 stainless steel for automotive mufflers was studied by means of cyclic hot air oxidation-immersion in condensate test and cyclic hot air oxidation-immersion in condensate-exposure to steam test as well as electrochemical measurements, SEM, XRD and pitting depth analyses. The results show that all the specimens, after cyclic hot air oxidation-immersion in condensate test and then with and without subsequent exposure to steam test, suffered from pitting corrosion with similar corrosion products. However, the specimens show lower corrosion resistanction and deeper corrosion pits when they had experienced the exposure to steam test rather than those only experienced the cyclic hot air oxidation-immersion in condensate test. The exposure to steam may facilitate the growth of corrosion products and pits.
single diesel engine was the characteristic of China internal combustion engine industry. But the environmental pollution is more serious and the large quantity of the single diesel engine is one of the main pollution sources. The exhaust after-treatment is a good measure of the diesel engine to reduce the emissions. In order to improve the emission performance of single cylinder diesel engine through external purification, the one-body purification muffler was designed. The functions of the one-body purification muffler were noise elimination and emission purification. The internal velocity uniformity was one of the most important aspects of the structure design of the one-body purification muffler. Numerical simulation and performance test were adopted in the structure design and performance optimization of the one-body purification **muffler** to optimize the catalytic performance, acoustic performance, aerodynamic performance and structural performance. Numerical simulation was used to analyze the internal airflow velocity field of one-body purification **muffler** to optimize the internal structure. The reasonable internal structure of the one-body purification **muffler** could effectively improve the catalytic conversion efficiency and the service life. Performance test was used to analyze the catalytic performance, acoustic performance and aerodynamic performance of the one-body purification **muffler**. According to the results of the performance test, the internal structure of the one-body purification **muffler** was improved. The results of overall performance test showed that the test prototype with the third scheme of one-body purification **muffler** had the advantages of low power loss, low flow resistance and high noise elimination. The power loss of the one-body purification **muffler** based on the third scheme was 1.18%, which was reduced by 28.5% compared with the original **muffler**. The flow resistance of one-body purification **muffler** based on the third scheme was lower than the original**muffler**. With the third scheme of one-body purification **muffler**, the engine noise was 108.6 dB, which remained the same compared with the original **muffler**. The results of overall emission test showed that the test prototype with the third scheme of one-body purification **muffler** had the advantage of low exhaust emission value.

The measured values of carbon monoxide (CO), hydrocarbon (HC) and particulate matter (PM) were 0.94, 0.46 and 0.4 g/kW·h respectively, which were reduced by 85.4%, 70.5% and 28.6% respectively, compared with the original **muffler**. But the measured value of nitrogen oxide (NO_x) remained the same compared with the original **muffler**. Besides, the measured values of CO, HC and PM of the third scheme of one-body purification **muffler** were reduced by 21.0%, 25.8% and 7.0% respectively compared with the second scheme of one-body purification **muffler** because of the optimizations of the aerodynamic performance and the structural performance. After the endurance test, the exhaust emission values of the third scheme of one-body purification **muffler** still met the third phase limits. The third scheme of one-body purification **muffler** can improve the emission performance of single cylinder diesel engine through external purification effectively and optimize the catalytic performance, the acoustic performance, the aerodynamic performance and the structural performance. The research provides theoretical and technical references for the design of the one-body purification **muffler** of the single diesel engine

Kyeom Lee, J., Seung Oh, K., Woo Lee, J. [3] presented in their technical paper an acoustical topology optimization problem to optimally design a partition layout inside the expansion chamber of a **muffler**. The lower-limit insertion loss value at a target frequency is constrained, and the partition volume is selected as an object function. In this study, we calculate the insertion loss outside the duct, while to determine the noise-attenuation performance, we use the insertion loss value calculated inside the duct or transmission loss value obtained in a previous study. We employ the finite-element model for acoustical analysis, and we

determine the transmission of an incident acoustic wave through each finite element using the functions of design variables that change continuously between "0" and "1." The rigid body elements, which totally reflect incident waves, build up partitions. Finally, we compare optimal topologies that depend on the target frequency and the allowed lower-limit value of insertion loss.

Talegaonkar, S., Agrewale, M.R.B, Chhaganlal Vora, K. [4] presented in their technical paper the Exhaust Noise was one of the major noise pollutants. It was well-known that for higher noise reduction, the engine has to bear high back pressure. For a race car, back-pressure plays a major role in engine's performance characteristics. For a given condition of engine rpm & load, conventional muffler has a fixed value of back-pressure and noise attenuation. Better acceleration requires low back-pressure, but the exhaust noise should also be less than the required (Norm) value (110 dBA). This contradicting condition was achieved here by using a 'Butterfly Valve' in this novel exhaust muffler. The butterfly valve assumes 2 positions i.e. fully open & fully closed. When the valve was fully closed, the noise reduction will be higher, but the back-pressure will also shoot up. When open, noise reduction will be less and so the back-pressure. So, when better performance was required, the valve was opened and back-pressure was reduced. The muffler was designed for a 4 cylinder 600 cc engine. The sound transmission loss , which was the measure of effectiveness of the muffler, was also verified experimentally. The reduction in the back pressure at 11000 engine rpm was around 40% with open valve, as compared closed valve condition. The increase in sound transmission loss , with closed valve, was around 15~20 dB higher when compared to open valve condition.

Liu, S.-J. Zeng, J.-J. Han, W.-W. Chen, Y. Wang, J. [5] presented in their technical paper to optimize emissions and performances of a single-cylinder water-cooled swirl chamber diesel engine, intake and exhaust system was optimized by computational fluid dynamics and steady flow test method. The configurations and performances of intake and exhaust port, air filter and muffler were optimized for reducing flow resistance, increasing charge amount and lowering residual exhaust gas, leading to the improvement of engine performances and emissions. Testing results show that, with the optimized intake and exhaust system, the volumetric efficiency increased and the brake specific fuel consumption of rated condition reduced by 3.0%. The measured values of CO, HC+NO_x and PM were 2.209, 4.520, and 0.561 g/(kW·h), decreasing by 26.7%, 7.0%, and 9.3%, respectively compared with the original engine.

Wang, P., Li, J., Wu, T.W. [6] presented in their technical paper a simplified method to model perforated tubes in mufflers was the equivalent transfer impedance approach. Various empirical formulas that consider the porosity, hole diameter, wall thickness, and flow type have been proposed to date. They normally work very well under the conditions that the formulas are intended for. In this paper, we propose a simple boundary element method-based numerical procedure to determine the transfer impedance from a small perforate sample, and then send the transfer impedance to the **muffler** BEM model for analysis purposes.

Chen, Y. Lv, L. [7] presented in their technical paper integrated, compact, diesel after treatment system that combines selective catalytic reduction for NOX control with a reactive muffler to reduce exhaust noise was designed and evaluated under various conditions. Considering the installation size, noise reduction, performance of selective catalytic reduction , exhaust back pressure and its effects on engine performance, it provides the basis for the design of the Integrated selective catalytic reduction–muffler. Based on the two-load method and engine model established by AVL/Boost, the source impedance of engine has been found out. The transfer matrix of **exhaust** system was calculated from three-dimension finite element method which used equivalent fluid to describe the problem of wave propagation in the catalyst. On the basis of computational results, comprehensive analysis of noise reduction was made, the computed insertion loss of original muffler, selective catalytic reduction and Integrated selective catalytic reduction–muffler was 32.1, 23.5 and 32.8 dB(A), respectively. The computational fluid dynamics simulation results prove that the Integrated selective catalytic reduction-muffler was capable of increasing homogeneity of NH3 and improving NOX reduction efficiency due to the effect of silencing elements including perforated pipe and perforated plate, even though the pressure loss increased considerably when compared with selective catalytic reduction .

Mann, A., Kim et al [8] presented in their technical paper the main purpose of the system was to reduce the intensity of the acoustic pulses originating from the engine exhaust valves, the back pressure induced by these systems must be kept to a minimum to guarantee maximum performance of the engine. Emitted noise levels have to ensure comfort of the passengers and must respect community noise regulations. In addition, the exhaust noise plays an important role in the brand image of vehicles, especially with sports car where it must be tuned to be “musical”. A natural candidate for this type of problem was the use of a Lattice-Boltzmann Method solver as a computational fluid dynamics tool. It has already been successfully applied and validated to quantify self-induced noise of mufflers as well as complex acoustic devices performance like acoustic liners. In this paper, a muffler baseline geometry self-induced noise was assessed using the commercial Lattice-Boltzmann Method solver Power FLOW. Noise generation mechanisms are identified and design modifications are proposed to atone it. The given baseline and iterations designs noise mechanisms are analyzed and the obtained noise reductions are compared and discussed.

Elsahar, W., Elnady, T. [9] Presented in their technical paper two-inlet single-outlet mufflers are possible to encounter in exhaust systems. They are usually used to merge two exhaust streams from two similar engines or from two sides of an engine. They have an advantage of reducing the back pressure on the engine. There is a lot of published research on the analysis of single-inlet single-outlet mufflers acting as a two-port. On the other hand, there are a few publications on the analysis of two-inlet single-outlet mufflers due to their complexity representing a three-port. A three-port is characterized by a 3×3 Scattering Matrix. The nine elements of this matrix represent the three reflection coefficients at each port, and the six transmission coefficients between the three ports in both directions. In this work, a two-inlet single-outlet muffler is studied. The elements of the scattering matrix were measured using the two-source two-microphone technique with and without flow. These elements were also calculated from

1D simulation using a set of two-port elements representing the internal dimensions of the muffler, and compared to those obtained from the measurement. A similar 1D simulation was performed using Flow two-ports in order to analyze the flow distribution inside the muffler and the pressure drop across both flow paths.

Fu, J. et al [10] presented in their technical paper to improve the acoustic attenuation performance of an exhaust muffler of a 175 series of agricultural diesel **engine**, automatic matched layer method of finite element is adopted on the basis of LMS Virtual. Lab software to simulate the non-reflecting boundary conditions, which can avoid the complex calculation and then figure out the value of propagated sound power directly and finally obtain the transmission loss of the exhaust muffler. Compared with the experimental data, it can be found that the error between the simulation and measured values was small, and it can be accurately simulated for the acoustic performance of the **exhaust muffler** at the frequencies smaller than 3000 Hz, which verifies the validity of the acoustic solution. An improved design that properly distributes the insertion length of intubation, increases the length-diameter ratio, and adds the length of the first expansion cavity is proposed for the poor acoustic attenuation performance in low and medium frequencies. Compared with the original design, the transmission loss value at low and medium frequencies obviously increases, so the acoustic attenuation performance at the frequencies becomes better.

Xu, J. Zhou, S.[11] presented in their technical paper double mode **muffler** that can automatically adjust the **exhaust** resistance according to the **engine** speed was designed. Based on computational fluid dynamics theory, the governing equation and turbulent equations for numerical simulation of **muffler** were established. The pressure loss and the internal flow characteristics of the double mode **muffler** were analyzed by computational fluid dynamics software. The influence of the distance between the main and sub-**muffler** on the flow field of **exhaust** system was researched. The internal pressure distribution, the turbulence intensity distribution and the velocity vector diagram of the dual mode **muffler** were obtained. The pressure loss of double mode **muffler** mainly distributes in the area of air mutations. Main silencer plays a leading role in the entire **exhaust** system. The trend of the pressure loss of the **exhaust** system with the change of the distance between main and auxiliary **muffler** was obtained. When the distance between the main and auxiliary silencer changed from 50 mm to 300 mm, the pressure loss of **exhaust** system **muffler** increases first and then decreases, and then continue to increase. The results will provide a theoretical basis for designing complex **exhaust** system.

Wu, H.S. et al [12] presented in their technical paper a design scheme of non-road diesel **engine** emission particulate purifier and **muffler**. Combined with the particle purification principle and noise elimination principle, optimum design and computational analysis is carried out for the device including its working principle, size parameters, and particle filtering and noise elimination model. The amount of noise elimination can reach 15-20 dB by calculation and analysis.

Poggiani, C. et al [13] presented in their technical paper emissions standards for two- and three-wheeled powered vehicles are getting more and more stringent, and measurement procedures require to perform driving cycles with **engine** cold start. Therefore, a fast activation of the **exhaust** catalytic converter is of primary importance. In this work a numerical and experimental study of the **exhaust** system layout of a 125cc scooter has been carried out with the main objective of reducing the catalytic converter light-off time, without affecting **engine** performance and component cost. First, a one dimensional engine model has been developed to evaluate the impact of the component modification on **engine** performance. Then, a computational fluid dynamics three dimensional analysis has been performed to assess and evaluate the velocity and temperature fields of the gases inside of the **muffler**. After the numerical study, several prototypes have been designed and built for experimental tests. The **engine** has been installed on the dynamometric bench and instrumented. The **exhaust** system prototypes have been tested focusing on the **engine** brake performance and on the **exhaust** temperatures during warm-up transients. The latter has been monitored in several points inside the **muffler**, in order to obtain information about the catalytic converter operating conditions. The best prototype configurations have been installed on the vehicle and further road tests. The vehicle experimental results in terms of **exhaust** gas temperatures at the catalyst inlet and outlet highlight the improvements with the best **exhaust** prototype compared to the original configuration.

Liu, H. et al [14] presented in their technical paper the order noise in low-frequency band has great impact on the sound quality of **exhaust** noise. The **muffler** with valve becomes one of the means to eliminate low-frequency noise. The actual **muffler** with valve is analyzed by experiment and three-dimensional numerical simulation methods. It is found that the resonance frequency shift towards high frequency as the valve's opening degrees increase. Further, a sub structural unit, named adjustable lumped inertance resonator ,was extracted from the actual **muffler** with valve. Three-dimensional numerical simulation and an in-line lumped element model are used to calculate the lumped inertance of the valve structure with different opening angles. The lumped model of adjustable lumped inertance resonator was established. The results show that the lumped inertance, which changes with the valve's opening degrees, was the key factor on the shifting of resonance frequency.

Wang, T. Zhang, X [15] presented in their technical paper marine diesel engine exhaust noise and radiated noise affect the normal work and life of the mariners when the ship was running. This paper researches the noise control technology of marine diesel engine to reduce the diesel engine noise of a forty-meter long ship. Based on the exhaust noise spectrum and cabin space dimensions, an exhaust muffler was designed to reduce the exhaust noise. The design of the exhaust muffler was combined with the fluid and acoustic calculations. In order to decrease the radiated noise, this paper designs acoustical enclosures installed in the cabin. Acoustical performance, ventilation and the ease of operation staff are considered in the process of designing acoustical enclosures. This paper computes the transmission loss and the air intake flux of acoustical enclosures through finite element

method simulation. An air intake muffler was installed in acoustical enclosures to reduce intake noise, and a fan was installed to improve the ventilation.

Palsule, A. et al [16] presented in their technical paper development of split Catalytic Converter-muffler system was done to be used in front engine low floor bus from perspective of cost saving, modularity and reduction in complexity. This system is developed as an alternate to an existing solution of integrated Cat-Con and muffler. The paper describes the development of a split Cat-Con and muffler exhaust system for a front engine low floor bus, so as to meet cost and time considerations. The development also had to achieve a feasible solution, which could be installed within the packaging volume of the existing configuration of front engine low floor while meeting the regulatory requirements for pass by noise and at the same time conforming to backpressure limits set for optimum engine performance. Multiple design - prototypes - test iterations were carried out to meet the pass by noise PBN and back pressure target for front engine low floor front engine low floor bus. The final solution was developed which achieved both the requirements within the specified space constraints. Solution is based on configuration used in Front Engine Semi Low Floor Bus where a split Cat-Con configuration was already used as it had higher scope for volume where pass by noise and back pressure conflict didn't rise.

Su, H. , Wu, P. et al [17] presented in their technical paper a new noise control method was proposed to reduce the dominant components of exhaust noise by using out-of-phase acoustic cancellation and to reduce the regeneration noise from diesel muffler by using split-stream rushing. To this end, a single-cylinder diesel engine CG25 was chosen for the simulation and experimental analysis of the acoustic characteristics for a new muffler. The results show that the noise reduction of the new out-of-phase and split-stream-rushing muffler was noticeable around the frequency as low as 110 Hz and between 300~500 Hz. In addition, the insertion loss of the new muffler **was** almost twice as that of the original muffler at the rated speed of 2200 r/min.

Šteblaj, P. Čudina, et al [18] presented in their technical paper an adaptive muffler upgrades the conventional muffler with a variable geometry to extend its working range. Adaptive muffler systems, described in the available literature, operate on the principle of controlling only a single property of the muffler to tune its working range. During the adaptation process of these systems, the basic principle of operation was not changed. Based on the literature review, the question arises of whether it would be possible to control the principle of operation. At one instant it would work as a Helmholtz resonator, in the other as an expansion chamber or side branch resonator. Analytical calculations provided a positive answer, and a muffler with four active valves was designed and constructed to confirm the theoretical expectations. The properties of proposed muffler were simulated with the finite element method, and the results of simulations were validated with measurements. Finally, simulations of the proposed muffler were performed, working at different operating condition. Simulations have shown that the proposed system allows the tuning of the muffler to a wide working frequency range. Such an approach to muffler design eliminates the need for additional mufflers in exhaust systems.

Xu, X.-M. Jiang, H.-B.Gong, R. [19] presented in their technical paper aiming at catalytic mufflers with different air inlet structures and shapes of medium-heavy duty truck, the air inlet uniformity of carrier front face and the total pressure difference between the inlet and outlet were calculated by Fluent software, and the flow field characteristics were analyzed. Calculation result indicates that the flow field characteristics of catalytic muffler are related to engine exhaust. The air inlet uniformity of carrier front face and the total pressure difference between the inlet and outlet are very important for analyzing the flow field characteristics. The air inlet uniformity and the total pressure difference increase after adding baffle, and the flow field characteristics are best after adding erect baffle. The flow field characteristics are good when inlet pipe diameter shrinks by 40 mm and outlet pipe diameter expands by 40 mm. After optimizing catalytic muffler, the air inlet uniformities of carrier front face respectively increase by 1.2% and 1.6%, and the total pressure differences between the inlet and outlet respectively decrease by 57.5% and 63.9% compared to the values before optimization when engine rotation speeds are 900 $r \cdot min^{-1}$ and 1 900 $r \cdot min^{-1}$ respectively, which shows that structure optimization significantly decreases the total pressure difference. Compared to barrel shape catalytic muffler, the air inlet uniformity of carrier front face for box shape catalytic muffler increases. Spatial arrangement and utilization efficiency should be considered as well for choosing catalytic muffler.

Om Ariara Guhan, et al [20] presented in their technical paper the current scenario of high growth rate of automobile usage, the automobile industry is forced to adopt the government emission norms to keep the environment green. Latest technologies have been developed in the automotive exhaust system to acknowledge the emission norms. Diesel oxidation catalyst and muffler both are playing major roles in reducing emission and noise level as well. Diesel oxidation catalyst reduces CO and unburned HC emissions. Muffler reduces noise level of exhaust gases. Nowadays automobile industry is using computational fluid dynamics software extensively to analyze the flow properties inside the diesel oxidation catalyst and muffler. Flow analysis helps to optimize the geometric design of Diesel oxidation catalyst to oxidize the CO and unburned HC of exhaust gases. In this present work we studied pressure drop and uniformity index of an existing exhaust system which consists of close couple catalytic convertor, under body catalytic convertor and muffler. Exhaust system has been modeled by using CATIA V5 which was advanced computer aided design software. The substrate has been modeled as porous medium for analysis purpose. These models have been imported in computational fluid dynamics tool for analysis. After importing the computer aided design data inside the computational fluid dynamics software, with proper boundary conditions, the computational fluid dynamics analysis has been carried out. Based on the study, individual system contributions to the total pressure drop and flow uniformity have been analyzed and improvement areas of the existing system for better flow uniformity have been suggested. .

Mimani, A.[21] presented in their technical paper the axially short circular/elliptical cylindrical chamber was often used as a flow-reversing or straight flow end-chamber in a multi-pass perforated duct muffler, a typical component of a modern-day automotive exhaust system. However, due to its small expansion volume, such short end chambers yield low acoustic attenuation expressed in terms of transmission loss in the low-frequency range, induce a large back pressure and increasing the chamber length results in the occurrence of a trough (due to the first axial mode) at a lower frequency that deteriorates the transmission loss performance. In view of these limitations, the use of a different geometry, namely, a rigid-wall hemispherical cavity as a flow-reversal end-chamber muffler was investigated for potentially enhancing the transmission loss performance over a wider frequency range, especially at low frequencies. In this paper the transmission loss performance of a hemispherical end-chamber muffler having a single end-inlet and single/double end outlet by means of a three dimensional semi-analytical formulation based on the modal expansion of the acoustic field and the Green's function approach was presented. The three dimensional acoustic field inside the rigid-wall hemispherical end-chamber was expressed in terms of the orthogonal modal functions. The hemispherical end-chamber muffler system was characterized using the uniform piston-driven model in terms of the impedance matrix parameters obtained by computing the average of the three dimensional Green's function over the surface area of the ports which are modeled as rigid pistons. The transmission loss graphs computed by using the three dimensional semi analytical formulation are found to be in an excellent agreement with that obtained from the three dimensional finite element approach, thereby validating the technique used here. Furthermore, the three dimensional modal expansion method enables one to take into account, the relative polar angular location between the ports and also determine their optimal radial offset distance (corresponding to appropriate pressure nodes on the end face) to obtain a broadband transmission loss performance.

Storm, M.C. [22] presented in their technical paper solo inventors can become emotionally attached to their perceived breakthroughs and may experience difficulty in recognizing or acknowledging technical or commercialization challenges. This can lead to waste of resources and loss of marketing opportunities. To avoid such potential waste, and in an effort to get impartial and critical feedback on the commercial prospects of a new kind of engine exhaust muffler, one inventor planned a request of his peers to band together and conduct a "tiger team" invention review. Consistent with this type of problem-solving diligence that is more widely known in the realms of aerospace and information technology, response from invited subject matter experts would ideally include concepts to help overcome identified technical flaws and market application limitations. This paper describes both the proposed review process and the type of information it would yield as an example of how rigorous voluntary critique of a proposed new noise control technique or product could help an innovator face and better adapt to what might be uncomfortable realities with his invention.

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