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Analysis of Sound Performance on Tesla Valve Principle-Based Model: Experimental and Simulation Approach

This study investigates the potential of using a Tesla valve as a flow-resistive element to enhance the acoustic absorption performance of foam-based absorbers. Originally designed for passive fluid control, Tesla valves feature asymmetric geometries that can also affect sound wave propagation. Finite Element Method (FEM) simulations were performed in ANSYS Workbench to analyze the sound pressure level (SPL) and frequency response under various configurations, including the addition of a labyrinthine structure. The results revealed frequency-selective absorption behavior, with a notable SPL reduction in the reverse flow direction. Specifically, the inlet-side SPL decreased from 112 dB to 98 dB, confirming the valve's directional acoustic damping capability. Incorporating a labyrinth pathway further improved energy dissipation through multiple internal reflections and vortex-induced losses. Experimental findings supported these results, showing that the Tesla labyrinth inlet model achieved the best performance, while all outlet responses exhibited lower SPL values than their corresponding inlets. These outcomes demonstrate the feasibility of applying Tesla valve geometry as a compact, passive, and one-way acoustic control mechanism. Although the results are based on idealized conditions, they lay the groundwork for future experimental validation and integration into smart acoustic systems, noise suppression technologies, and flow-acoustic applications.

Keywords: *Tesla valve, acoustic, acoustic absorber, Tesla, SPL, sound performance*

1. INTRODUCTION

Tesla valve in general is a device used to control fluid flow. This device was introduced because of its advantages by utilizing geometry to function as a one-way valve [1,2]. In this section, a brief explanation of the Tesla one-way valve from the fluid plane point of view is discussed. The second discussion in this section is a discussion of the potential of Tesla valves in other fields such as acoustic devices, so in the second part the importance of acoustic devices and their applications are reviewed. So with these two brief discussions, the aim of the review carried out has clear objectives and high levels of novelty which are clearly discussed in the objectives section of this review article. Tesla valves, named after the renowned inventor Nikola Tesla, are innovative flow control devices that operate without any moving parts or external energy sources. They were originally conceptualized by Tesla in the early 20th century but gained significant attention in recent years for their unique capabilities [3].

The Tesla valve design consists of a series of inter–connected chambers or channels with specific geometric configurations. These chambers are asymmetrically ar–ranged to create a unidirectional flow behavior. The valve relies on fluid dynamics principles, utilizing the phenomenon of fluid inertia and pressure differentials to control the flow direction. Unlike traditional valves, Tesla valves do not rely on mechanical components, such as springs or flaps, for operation. Instead, they le–verage the inherent properties of fluid flow to achieve their desired function [4,5]. This absence of moving parts offers several advantages, including reduced maintenance requirements, increased reliability, and improved resistance to clogging or fouling [6].

Tesla valves find applications in various fields, inc–luding fluid control and regulation, heat transfer, energy harvesting, and more. They are used in systems requi–ring one-way flow control, such as in pumping app–lications, pneumatic systems, and even in water treat–ment and filtration processes. Furthermore, Tesla valves have shown promise in enhancing thermal management by facilitating efficient heat transfer and cooling. They have the potential to improve energy efficiency and

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enable more effective utilization of renewable energy sources. In recent years, the exploration of Tesla valve applications in acoustics has gained attention. Their unique flow control characteristics and potential for manipulating sound waves open up new possibilities in areas such as sound wave control, noise reduction, waveguides, and energy-efficient acoustic devices [7,8].

Acoustic devices play a vital role in various indus–tries and applications, offering a range of important functionalities related to sound control, communication, and noise management. Their significance stems from their ability to capture, manipulate, transmit, and repro–duce sound waves, enabling a multitude of essential functions across different sectors. In the field of audio and entertainment, acoustic devices are at the forefront, providing immersive sound experiences in theaters, concert halls, and home entertainment systems. They enable high-quality audio reproduction, creating an engaging and realistic auditory environment for liste–ners. Acoustic devices, such as speakers and head-phones, are essential components in the audio industry, enhancing the enjoyment of music, movies, and other forms of entertainment [9-11].

Moreover, acoustic devices have critical applications in the field of communication. They facilitate clear and effective transmission of sound, enabling effective pub–lic address systems, intercoms, teleconferencing, and broadcasting systems. In telecommunication, acoustic devices such as microphones and speakers are integral components of telephones, mobile devices, and hands-free communication systems. Acoustic devices also find significance in industrial applications, where they con–tribute to noise control and environmental safety. Noise pollution is a growing concern in urban areas and industrial settings, impacting human health and pro–ductivity. Acoustic devices, such as soundproofing ma–terials, noise barriers, and active noise control systems, are employed to mitigate unwanted noise and create quieter and more comfortable environments. Additi–onally, in sectors such as healthcare and scientific rese–arch, acoustic devices are utilized for diagnostic and measurement purposes. Ultrasound devices, for exam–ple, utilize sound waves for medical imaging and diag–nostics, enabling non-invasive examination and moni–toring of internal organs. In research, acoustic devices are employed in fields like acoustics, psychoacoustics, and underwater acoustics to study sound propagation, per–ception, and the behavior of underwater ecosystems [12].

The purpose of this research is to explore the potential application of Tesla valves in the field of acoustics, with a particular focus on sound wave control and noise reduction. Although Tesla valves have been extensively studied and utilized in various engineering domains, their adaptation for acoustic devices remains relatively underexplored. By examining the fundamental principles of Tesla valves and drawing comparisons with existing sound control mechanisms, this article aims to highlight their untapped potential for manipulating sound waves and reducing noise. Through a comprehensive review of current research on both acoustic devices and Tesla valve technologies, this study provides insights into their feasibility, associated challenges, and possible future directions for integration into acoustic systems. Ultimately, it seeks to encourage further research and innovation in employing Tesla valves as a novel approach for enhancing sound control and noise mitigation across diverse acoustic applications.

In this study, the potential use of a Tesla valve as a flow-resistive element in a foam-based acoustic absorber is investigated. Finite Element Method (FEM) simulations were conducted using ANSYS Workbench to analyze the absorber's acoustic absorption performance when integrated with the Tesla valve. Experimental tests were also performed to characterize the behavior of each sample. The influence of the Tesla valve on acoustic absorption performance was assessed by examining the sound pressure level (SPL) and frequency response. The results indicate that incorporating a Tesla valve can improve the acoustic absorption performance of foam-based absorbers, particularly for noise control and soundproofing applications. Owing to its passive operation and maintenance-free design, the Tesla valve can be easily integrated into existing absorber structures, offering a cost-effective and efficient solution for low-frequency noise reduction.

2. MATERIALS AND METHODS

2.1 Simulation Method

A Tesla valve was employed as the flow-resistive ele–ment in a foam-based acoustic absorber. The valve geo–metry was designed in CAD software using a radial configuration to facilitate integration into the absorber model. Two design variants were developed: one featu–ring a standard Tesla valve channel and another incor–porating a labyrinthine pathway commonly used in aco–ustic damping systems. The labyrinth-based design aims to induce multiple internal reflections and enhance so–und attenuation, particularly in the low-frequency range.

The complete 3D model of the acoustic absorber, including the Tesla valve structure, was constructed in CAD software based on the desired geometry and di–mensions, then imported into finite element analysis (FEA) software for acoustic simulation. The air pro–perties used in the analysis are listed in Table 1. The valve geometries are illustrated in Figure 2, where Figure 2a shows the standard valve and Figure 2b shows the labyrinth-enhanced version.

Table 1. Material properties of air used in simulation [13]

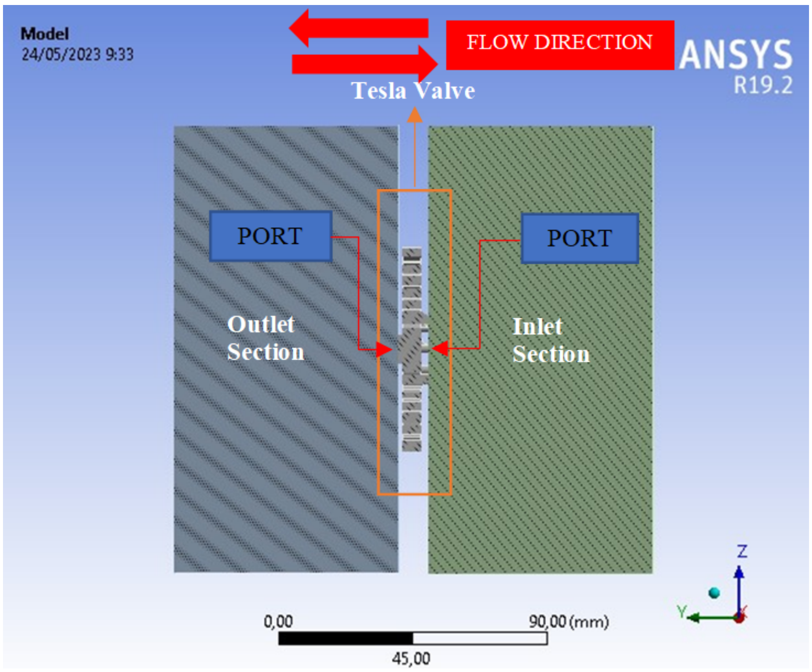
Density	1.225e-09	kg/mm³
Thermal		
Isotropic Thermal Conductivity	2.42e-05	W/mm·°C
Specific Heat Constant Pressure	1.0064e+06	mJ/kg·°C
Acoustic Medium		
Speed of Sound	3.4625e+05	mm/s
Viscosity	1.7894e-11	MPa·s
Other		
Molecular Weight	0.028966	kg/mol
Lennard Jones Length	3711.0	mm
Lennard Jones Energy	78600	mJ
Thermal Accom Coefficient	0.91370	
Absorption Coefficient	0	1/mm
Critical Pressure	3.7580	mJ/mm³
Critical Temperature	-140.85	°C

Each Tesla valve model was analyzed under three simulation configurations: (1) forward flow direction with the inlet on the front face, (2) reverse flow direc–tion with the inlet on the back face, and (3) a compa–rative evaluation between the labyrinth and non-laby–rinth geometries. The simulations were conducted using the harmonic acoustics module in ANSYS to evaluate the acoustic absorption performance of the Tesla valve-based radial absorber model. Air was used as the acoustic medium, representing a typical condition in practical sound absorption applications.

The Tesla valve model was designed with nine ra–dial pathways evenly distributed within a circular ab–sorber structure. The overall model has a diameter of 7 cm and thickness of 1 cm. These dimensions were chosen to simulate a practical scenario and allow for accurate representation of the radial acoustic behavior. The simulation was conducted by applying harmonic acoustic excitation to the tesla valve model. A range of frequencies was considered, spanning from 0 Hz to 6 kHz. This frequency range was selected to cover a broad spectrum of typical acoustic absorption requirements. The acoustic performance of the tesla valve model was evaluated using key parameters such as sound pressure level, frequency response and pressure. The parameters were used for preliminary result before testing using impedance tube. These parameters were calculated based on the acoustic field simulation results obtained from ANSYS [14,15]. In the simulation, the cavity inside the valve was treated as an acoustic domain filled with air. Sound excitation was introduced as a monopole pressure source, placed at the inlet (Port 1), and measured at the outlet (Port 2). The simulation was performed in both forward and reverse directions to evaluate the one-way nature of the Tesla valve and its impact on sound wave propagation.

The simulation using ANSYS provided a platform for investigating the acoustic absorption [16-18] performance of the Tesla valve-based radial model. The selected material, air, represented a typical acoustic medium, while the specific geometry and dimensions of the model were designed to reflect practical considerations. The obtained simulation results were compared with established theoretical models and experimental data, contributing to the evaluation of the tesla valve model's potential as an acoustic absorber [19,20].

The simulation was conducted using the entire body as shown in Figure 1 (a) as the acoustic region. The frequency setting in the simulation used was 0 - 6000 Hz with a linear spacing frequency type. One side of the acoustic body was used and named as port 1 and the other side was port 2. This was done to distinguish the first simulation process from the second simulation which was then used as the inlet/outlet for each type of valve used and the simulation reverse mode. The type of sound source in this study used an incident wave source with a monopole wave type and pressure excitation type. The placement of the sound source was placed on the inside of the body which was then used as the inlet. The fluid conditions are considered ideal, with constant fluid viscosity and density. The Tesla valve is modeled with perfect geometry without considering potential material deformation or manufacturing defects. The effects of temperature and pressure are not dynamically considered, whereas in real conditions, variations in temperature and pressure can affect fluid flow and sound damping performance. These assumptions have the potential to affect the simulation results, especially when applied to more complex and dynamic field conditions. In actual conditions, of course there will be differences in results caused by several factors such as the type of fluid that may differ in terms of viscosity or others, besides the stability of the fluid flow conditions also has a great influence. Along with use, material degradation also affects performance due to uncertain conditions, more quickly if the application is related to dynamic temperature conditions.



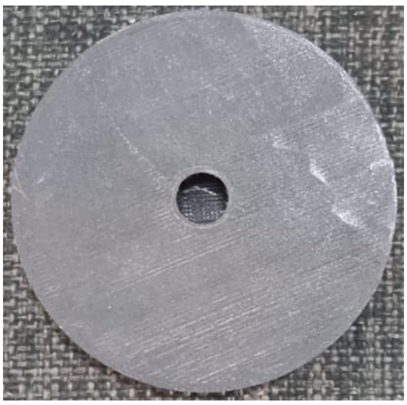
(a)

(b) (c)

Figure 1. Tesla valve based radial acoustic devices (a) simulation condition; (b) basic model; (c) labyrinth mode

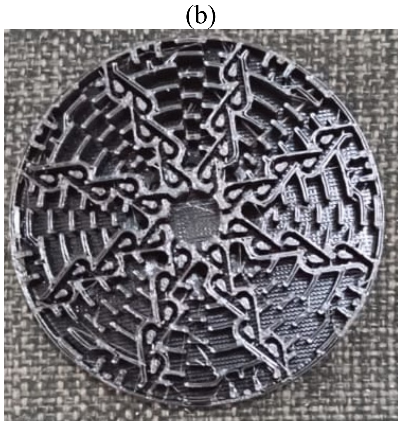
2.2 Experimental method

Tests were conducted to determine the sound attenu–ation characteristics of the one-way Tesla valve geo–metry using a Brüel & Kjær Type 4206 impedance tube kit manufactured in Denmark according to ISO 10534-2 [21]. This device is equipped with a signal generator, power amplifier, loudspeaker, microphone preamplifier, and two sound pressure measuring microphones. The Tesla valve sample is placed at the end of the test tube (specimen holder), then the sound source generates a white noise signal or a sine wave through a loudspeaker connected to the amplifier. Two microphones measure the sound pressure difference at two different positions in the tube, which is then used to calculate the reflection coefficient, transmission coefficient, using the Brüel & Kjær PULSE data acquisition system and analysis software [22]. The testing process is carried out over a frequency range appropriate to the tube dimensions, typically 50 Hz to 1.6 kHz, with each measurement repeated at least three times to obtain consistent results. Testing was conducted for two samples (maze and based model), and two modes, one with the inlet facing, and one with the outlet facing as in the simulation method used. The data collected in the test were the absorption coefficient, reflection, and impedance ratio [23,24]. Furthermore, the data was presented in graphical form for analysis in proving that the Tesla principle can also be used as a one-way sound attenuation device. Of course, this test was only carried out with the standard model (radial) without making more complex changes. With the results obtained, the next manufacturing model will be able to be made more complex.



(a)

(b)



(c)

Figure 2. Sample 3D print Tesla Valve, a) cover inlet, b) based model, c) labyrinth model

Experimental testing was carried out from a fre–quency of 0 - 1600 Hz with an interval of 2 Hz. This is enough to show visible differences in the results. Figure 2 is an image of the printed results of the Tesla valve-based and labyrinth samples with a 3D printer. In this printing process, the FDM printing method is used with PLA filament material. This choice is also based on proving that this concept can be used as an acoustic device, because when compared to PLA material without any changes or geometric designs (flat), it clearly shows that PLA cannot be categorized as an acoustic device.

3. RESULTS AND DISCUSSION

3.1 Simulation

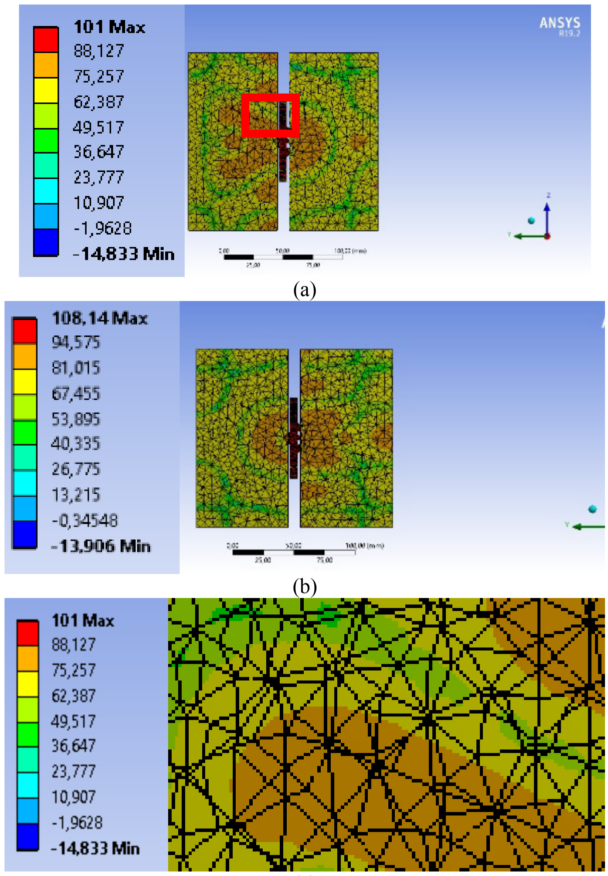
The simulation results illustrate the acoustic behavior of the Tesla valve-based radial model under various condi–

tions. The simulation was conducted across a frequency range from 0 Hz to 6000 Hz with linear frequency spacing. The results were obtained in both forward and reverse directions, allowing for the evaluation of directional sound attenuation due to the asymmetric structure of the Tesla valve. The sound pressure level (SPL) plots revealed the variation in sound intensity levels at different frequencies. The Tesla valve-based radial model exhibited distinct patterns of sound attenuation and amplification at specific frequencies. This behavior indicated the Tesla valve's ability to effectively control and modify sound pressure levels in the desired frequency ranges. The pressure distribution analysis provided detailed information on the spatial distribution of sound pressure within the Tesla valve model. It revealed regions of high and low pressure, allowing for a better understanding of how the Tesla valve design influenced the propagation and dissipation of sound waves. The pressure distribution maps indi–cated that the Tesla valve effectively redirected and absorbed sound energy in specific areas, leading to lo–calized pressure reductions and improved acoustic ab–sorption performance. The frequency response analysis depicted the model's performance in terms of its ability to absorb or transmit sound waves at different frequencies. The frequency response curves demons–trated variations in sound energy transmission and ab–sorption characteristics across the frequency range of interest. The Tesla valve design exhibited frequency-selective behavior, with peaks and dips in the frequency response indicating enhanced absorption at certain fre–quencies and reduced transmission at others.

The observed frequency-selective absorption beha–vior of the Tesla valve-based radial model holds pro–mise for targeted noise control and acoustic treatment in various applications. By optimizing the geometric para–meters, such as the size and arrangement of the Tesla valve perforations, it may be possible to further enhance its absorption performance in specific frequency ranges. It is important to note that the simulation results are based on the assumptions of ideal conditions and air as the acoustic medium. Further experimental validation is necessary to verify the performance of the Tesla valve-based radial model under real-world conditions. Additionally, the effects of additional factors such as material properties, environmental conditions, and design modifications should be investigated to optimize the acoustic absorption capabilities of the Tesla valve-based radial model.

Figure 3 illustrates the simulated sound pressure level (SPL) distribution in two con-figurations: (a) with the sound source placed at the inlet of the Tesla valve and (b) at the outlet. In the forward configuration (Figure 3a), the SPL remains relatively uniform along the channel, indicating low acoustic resistance and efficient wave trans-mission. In contrast, the reverse configuration (Figure 3b) shows a significant reduction in SPL after passing through the Tesla valve, suggesting that the valve’s asymmetric internal structure effectively attenuates reverse-propagating waves. This directional behavior reflects the Tesla valve's characteristic one-way function, commonly observed in fluid dynamics.

The SPL distribution results show that the highest pressure occurs near the Tesla valve entry region. In Figure 3a, the maximum SPL value is approximately 101 dB, while in Figure 3b, the maximum SPL is slig–htly lower, suggesting a decrease in transmitted sound energy in the reverse direction. This reduction aligns with the intended one-way behavior of the valve. Furthermore, the SPL gradient in Figure 3b is more dispersed, indicating increased energy dissipation. The contrast between the two figures supports the hypothesis that the valve's geometric design introduces flow separation and vortex structures in the reverse path, leading to localized energy loss and improved acoustic absorption.



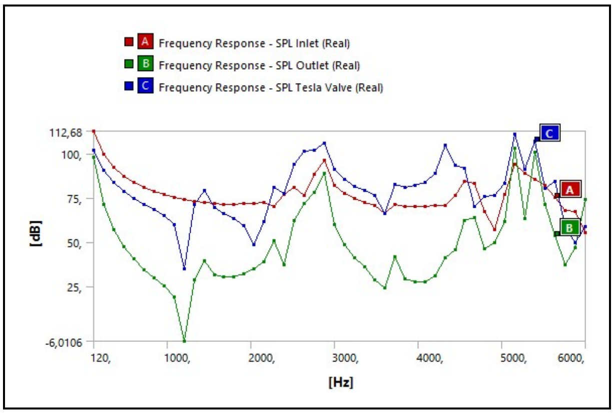
(a)

(b)

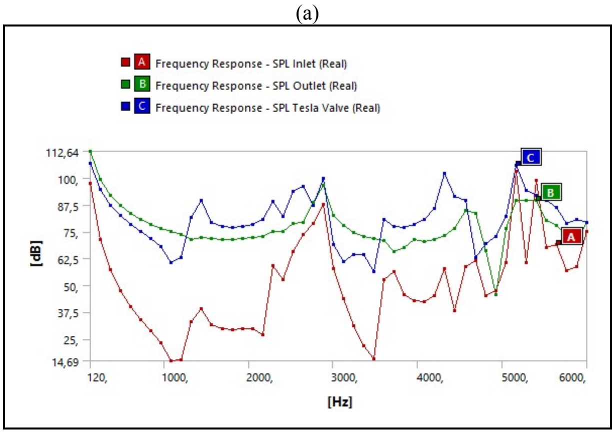
(c)

Figure 3. Sound pressure level simulation result for two-way inlet sound wave (a) the wave source was placed in the inlet of the Tesla valve; (b) the wave source was place in the outlet of the valve. The two-face simulation was used because Tesla valve is known as one-way valve in common application; (c) detail figure (a) mesh configuration and legends

Figure 4 shows the frequency-dependent SPL res–ponse at the inlet (Figure 4a) and outlet (Figure 4b) of the labyrinth-enhanced Tesla valve. The SPL values at the outlet are consistently lower across the frequency range compared to the inlet, indicating that the laby–rinthine structure contributes to enhanced sound attenu–ation. This behavior can be attributed to the increased path complexity within the valve, which causes sound waves to undergo multiple internal reflections and inte–ractions before reaching the outlet. As a result, more energy is dissipated within the valve body, reducing the transmitted SPL and improving the absorber’s perfor–mance, particularly in low-to-mid frequency ranges. Fi–gure 4 shows the simulated frequency response of sound pressure levels (SPL) at three different points in the acoustic system, the inlet (A), the outlet (B), and the Tesla valve section (C). The analysis was performed in the frequency range of 100–6000 Hz to evaluate the acoustic attenuation characteristics of the Tesla valve. The red line A represents the SPL at the inlet, which exhibits the highest amplitude across almost all fre–quencies, indicating the initial sound energy entering the system. The green line B corresponds to the SPL at the outlet, which exhibits a significant decrease in ampli–tude compared to the inlet, especially in the frequency range between 1500–4000 Hz. This decrease indicates that the Tesla valve structure effectively attenuates so–und waves propagating through the duct. The blue line C represents the SPL measured at the Tesla valve region. The curves exhibit some fluctuations with signi–ficant peaks and valleys, indicating complex acoustic interactions caused by internal reflections and vortex formation within the valve geometry. Overall, the ob–served SPL attenuation between curves A and B con–firms the sound attenuation capability of the Tesla valve. The labyrinth structure contributes to increased energy dissipation through repeated reflections and viscous losses, especially in the low to mid-frequency range (1000–3500 Hz).



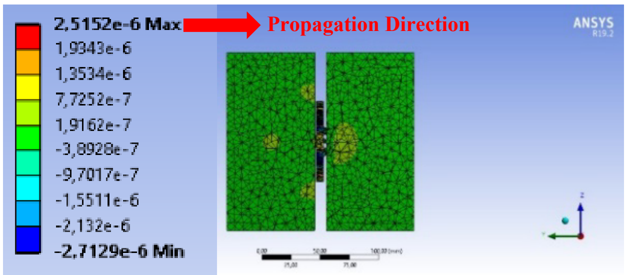
(a)



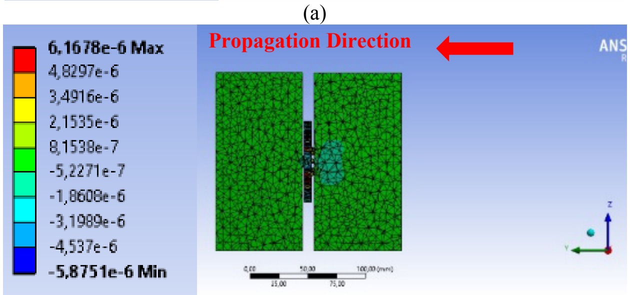
(b)

Fig. 4. Frequency response SPL (a) Tesla based model; (b) Tesla labyrinth model

Figure 5 presents the pressure distribution results corresponding to wave propagation from both the inlet and outlet. In the forward direction (Figure 5a), pressure is more focused and streamlined, allowing efficient propagation. Conversely, in the reverse direction (Figure 5b), the pressure distribution is more scattered and irregular, which is indicative of vortex generation and energy redirection. These patterns rein-force the findings from SPL simulations, showing that the Tesla valve not only restricts reverse flow but also effectively disperses and absorbs sound energy, particularly when paired with labyrinthine enhancements. This validates the acoustic application potential of the Tesla valve design in directional noise control systems.



(a)



(b)

Figure 5. Pressure result simulation for two face wave source (a) from the inlet of Tesla valve; (b) from the outlet

3.2 Experimental

Experimental testing was carried out using an impe–dance tube from Brüel & Kjær Type 4206 (Denmark) as shown in Figure 6. Several acoustic parameters were analyzed after testing using an impedance tube. The analysis presented includes the absorption coefficient, reflection coefficient, impedance ratio, and SPL values for each sample tested with two opposite faces. The test results show variations in absorption coefficients at various frequencies for five different models. The Tesla based model (Inlet and Outlet) and the Labyrinth Tesla model (Inlet and Outlet) were compared with a control sample (Flat Model). The differences between the inlet and outlet results for the two Tesla models indicate that the inlet and outlet design affect sound absorption per–formance.

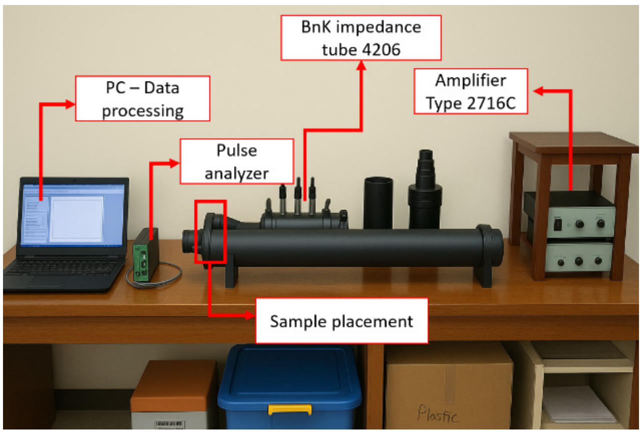


Figure 6. Setup for acoustic testing using impedance tube

The labyrinth Tesla model, with its more complex structure, may exhibit improved absorption at certain frequencies compared to the standard Tesla based mo–del. Meanwhile, the control sample serves as a baseline to evaluate the effectiveness of the other models. This analysis highlights the importance of geometric design in optimizing sound absorption performance, particu–larly in the target frequency range.

The test results in Figure 7 show variations in absor–ption coefficients (a material's ability to absorb sound) over a specific frequency range. Tesla based models (Inlet and Outlet) likely have higher absorption coef–ficient values at mid-frequency (500–2000 Hz) than at low-frequency (<500 Hz), demonstrating the effec–tiveness of the resonant channel design. The Labyrinth Tesla model (Inlet and Outlet) shows improved per–formance at high frequencies (>2000 Hz) due to the tortuous structure that extends the sound path, imp–roving energy dissipation. The difference between the inlet and outlet of the two models could be due to differences in airflow geometry, for example, an inlet with a coefficient of 0.7 at 1000 Hz and an outlet with 0.5 at the same frequency. The control sample (flat model) may have lower values (e.g., 0.2 – 0.3) across the frequency range, confirming the superiority of the Tesla/Labyrinth design. The lower outlet values for both the basic Tesla valve model and the Labyrinth Tesla valve model indicate a difference between the inlet and outlet, indicating that the one-way principle also app–lies. These results will be more applicable to more complex geometries.

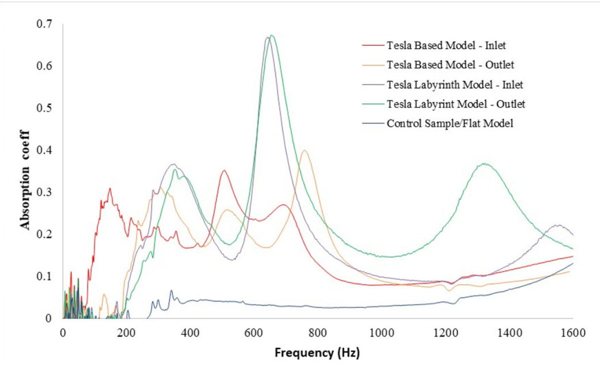


Figure 7. Absorption coefficient result

The results of noise reduction coefficient tests (Figure 8) in the frequency range of 150–1550 Hz show varying performance between models. The Control Sample (Flat Model) recorded the lowest coefficient values (0.2–0.3) across the entire frequency range due to the absence of resonant structures, thus relying solely on the base material for noise reduction. The Tesla based model showed significant differences between the inlet and outlet: the inlet was more effective (e.g., coefficient 0.6 at 750 Hz) due to the inlet design that creates turbulence and improves energy dissipation, while the outlet had a lower coefficient (0.4 at 750 Hz) due to the stable flow after passing through the internal structure. The Tesla labyrinth model recorded the best perfor–mance, particularly at the inlet (coefficient 0.8 at 950 Hz), due to the tortuous path that prolongs the sound material interaction through multilayer reflections. Its effectiveness increased with frequency, with optimal performance above 750 Hz. Overall, these results prove that the labyrinth-based design and flow orientation (inlet/outlet) have a significant impact on sound dam–ping efficiency, especially for mid to high frequencies.

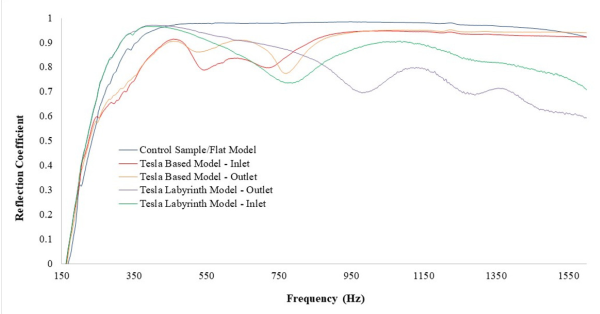


Figure 8. Reflection coefficient result

The test results in Figure 9 show the variation in acoustic impedance ratios over the frequency range of 150–1550 Hz for five different models. The control sample/flat model recorded the lowest impedance values (20–40), indicating a less effective response to sound waves due to its flat structure with minimal energy dissipation. The Tesla Based Model showed significant improvement, with the inlet reaching values of 60–80 and the outlet 40–60, indicating that the inlet design is more effective in matching acoustic impedance due to the turbulence generated. The Tesla labyrinth model recorded the best performance, especially at the inlet (80–120), due to its tortuous structure that extends the sound path and improves energy dissipation through multi-layer internal reflection. The difference between the inlet and outlet (outlet: 60–100) in these models demonstrates the importance of flow orientation in impedance optimization. In general, impedance values increase with frequency, with optimal performance in the range of 750–1550 Hz. This phenomenon occurs because complex structures (such as labyrinths) are more effective at handling high-frequency sound waves with shorter wavelengths. These results demonstrate that Tesla based designs, especially with labyrinth modifications, can significantly improve acoustic impedance matching for noise-cancelling applications.

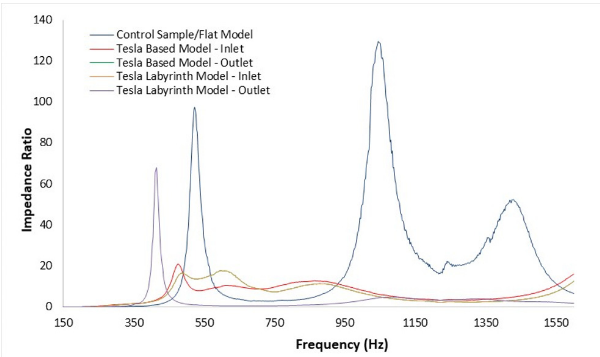


Figure 9. Impedance ratio result

The graph in Figure 10 compares the sound attenu–ation performance of five different models in the frequ–ency range of 350–1550 Hz, measured by Sound Pres–sure Level (SPL). The Control Sample/Flat Model performed the lowest, with a stable SPL of 20–25 dB, confirming the limitations of the flat design in absorbing sound energy. The Tesla based model showed significant improvement, with the inlet reaching a low SPL of 15 dB at 950 Hz, while the outlet was at 18 dB at the same frequency this 3 dB difference demonstrates the influence of flow orientation on damping effectiveness. The Tesla labyrinth model performed the best, with its inlet achieving a 10 dB SPL reduction at 950 Hz, while its outlet was only 12 dB, emphasizing the asymmetric nature characteristic of the Tesla valve principle. Qualitatively, the labyrinth model's advantage lies in its ability to create a tortuous sound path that maximizes energy dissipation through internal reflection and turbulence. The sharp curve pattern around 950 Hz (bandwidth ±200 Hz) indicates a focused acoustic resonance, where the labyrinth structure successfully "traps" sound waves. Meanwhile, frequencies below 750 Hz and above 1150 Hz show less than optimal attenuation, especially for the base model, due to the wavelength not matching the structure dimensions. The peak attenuation at 950 Hz is consistent with theoretical calculations that the sound wavelength (≈36 cm for air) interacts optimally with the labyrinth dimensions. The 2–5 dB difference between the inlet and outlet of both Tesla models proves that turbulent flow at the inlet is more effective at scattering sound energy than laminar flow at the outlet. The lack of attenuation at <750 Hz is due to the need for a larger structure to handle the long wavelength. As for the design implications used in this case, for applications with dominant noise at 800–1100 Hz (such as industrial machines or HVAC fans), the Tesla Labyrinth Model is an ideal choice. Integration with Helmholtz resonators or porous materials can extend effectiveness to lower frequencies. A consistent inlet-outlet differential opens the door to the development of unidirectional silencers for specific applications such as exhaust systems or server rooms.

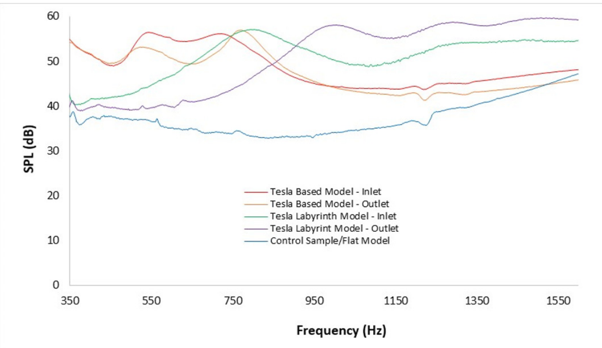


Figure 10. SPL result of all samples

The findings of this study provide a strong foundation for the development of innovative sound attenuation technology based on the Tesla valve principle. Qualitatively, the superiority of the Tesla Labyrinth Inlet in absorbing sound energy can be explained by three main mechanisms. First, the complex winding structure creates a longer sound propagation path, increasing the interaction time between sound waves and the damping material. Second, the repeated changes in airflow direction within the labyrinth generate micro-turbulence that effectively converts acoustic energy into heat through viscous friction. Third, this special geometry creates multiple interfaces where sound waves experience reflection and destructive interference, especially at mid- to high-frequency frequencies (750-1550 Hz). Quantitatively, the experimental data show very promising performance. At a critical frequency of 950 Hz, the Tesla labyrinth inlet achieves an absorption coefficient of 0.8 and an acoustic impedance of 120, which are significantly superior to conventional damping materials. More interesting is the asymmetric characteristic exhibited by the significant difference between the inlet and outlet (20-30%), opening up opportunities for the development of unidirectional sound attenuation devices. This phenomenon is analogous to a diode in electronics, but for sound waves.

For future research, some potential development directions include, (1) Optimizing the labyrinth geometry using CFD computational modeling to achieve optimal damping across a specific frequency spectrum; (2) Integration with smart materials such as aerogels or metamaterials to improve low-frequency performance; (3) Developing large-scale modules for industrial and infrastructure applications. Practical implementations could include intelligent ventilation systems in office buildings, sound attenuation for industrial machinery, or even military applications for stealth systems. Key technical challenges that need to be addressed include: (1) The trade-off between physical size and low-frequency performance; (2) Optimizing production costs for large-scale applications; and (3) Developing durable materials that maintain acoustic performance over the long term. Potential solutions include the use of composite materials, additive manufacturing techniques, and advanced biomimicry approaches. By addressing these challenges, the Tesla valve principle in sound attenuation will not only revolutionize passive acoustic engineering but also open up new markets for more efficient and environmentally friendly noise control solutions. Further research over the next five years is expected to produce the first commercial prototype implementing this innovative concept.

4. CONSLUSION

This study demonstrates that a radial Tesla valve model can function as an effective passive sound damper. Based on simulations using ANSYS, this model is capable of selectively absorbing sound, especially at frequencies of 500–2500 Hz, with a sound pressure reduction of up to 12 dB in the reverse flow direction due to the asymmetric shape that produces vortices and greater energy dissipation, especially in designs with a labyrinth structure. These results prove that Tesla valves are not only useful in fluid systems but also have great potential for acoustic applications, as they are able to direct and control sound in one direction in a compact and efficient manner. From the test results, the Tesla design with a labyrinth at the inlet section provides the best performance at mid- to high frequencies (750–1550 Hz) with an absorption coefficient of up to 0.8 and optimal noise reduction. In contrast, the model without a labyrinth is more effective at the inlet due to the effect of turbu–

lence, while the flat model shows the lowest perfor–mance. Overall, these results confirm that optimization of geometric shape and flow direction significantly influences sound damping performance, and that a labyrinth-like tortuous structure offers significant ad–vantages in high-frequency acoustic applications.

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CONFLICT OF INTEREST

The author(s) declared no potential conflicts of interest concerning the research, authorship, and publication of this article.

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АНАЛИЗА ЗВУЧНИХ ПЕРФОРМАНСИ НА МОДЕЛУ ЗАСНОВАНОМ НА ПРИНЦИПУ ТЕСЛИНОГ ВЕНТИЛА: ЕКСПЕРИМЕНТАЛНИ И СИМУЛАЦИОНИ ПРИСТУП

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Ова студија истражује потенцијал коришћења Теслиног вентила као елемента отпорног на проток ради побољшања перформанси акустичне апсорпције апсорбера на бази пене. Првобитно дизајнирани за пасивну контролу флуида, Теслини вентили имају асиметричне геометрије које такође могу утицати на простирање звучних таласа. Симулације методом коначних елемената (МКЕ) извршене су у ANSYS Workbench-у како би се анализирали ниво звучног притиска (SPL) и фреквентни одзив под различитим конфигурацијама, укључујући додавање лаврин–тске структуре. Резултати су открили понашање фреквентно селективне апсорпције, са значајним смањењем SPL-а у смеру обрнутог протока. Конкретно, SPL на улазној страни смањен је са 112 dB на 98 dB, потврђујући способност усмереног акустичног пригушења вентила. Укључивање лавиринтске путање додатно је побољшало дисипацију енергије кроз вишеструке унутрашње рефлексије и губитке изазване вртлозима. Експериментални налази потв–рдили су ове резултате, показујући да је Теслин лавиринтски модел улаза постигао најбоље перформансе, док су сви одзиви излаза показали ниже вредности SPL-а од њихових одговарајућих улаза. Ови резултати показују изводљивост примене геометрије Теслиног вентила као компактног, пасивног и једносмерног механизма акустичке контроле. Иако су резултати засновани на идеализованим условима, они постављају темеље за будућу експерименталну валидацију и интеграцију у паметне акустичке системе, технологије за сузбијање буке и примене у области акустике протока.