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Parametric Muffler

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Abstract – *This paper represents the alternative approach in designing of acoustical mufflers and alternative analytical model of parametric acoustical device. The suggested approach (and device model) provides passing onward of gas flow and reflection back of the acoustical waves, due to very fast temporal modulation of muffler parameters. Using concrete example, it is shown, that parametric muffler can have less wave-gabarits, less energy losses of engine, and less acoustical power at output, than in traditional muffler.* ***Copyright © 2013 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords*: Wave Invertors, Rotary Switching, Sound Reflection, Gas Passing, Sound in Ducts*

Nomenclature

Ξ	Quality factor of muffler
α	Residual relative sound power
β	Wave dimension of muffler
γ	Wideband characteristic of muffler
ε	Relative energy losses of muffler
λ	Wavelength of sound to be damped
D	Geometrical dimension of muffler
ω_{min}	Low border of sound suppression frequency range
ω_{max}	Upper border of sound suppression frequency range
W_0	Rotary power of engine
W_1	Losses of engine rotary power for sound suppression
P_0	Sound power without muffler
P_1	Sound power with muffler
$\hat{A}$, $\hat{B}$	Hard tubes (pipes, waveguides)
h	Cross-sectional width of tubes $\hat{A}$, $\hat{B}$
$\hat{C}$	Fast switch (gate, bolt) of tubes
$\hat{W}$	Walls of tubes $\hat{A}$, $\hat{B}$
L	Length of tubes
T	Temporal period of switching
V_0	Velocity of flow on the output of engine
V_1	Velocity inside the tubes $\hat{A}$, $\hat{B}$
V_B	Velocity of switching bolts in 2D version of parametric muffler
f_0	Rotating frequency of rotary switch in 3D version of parametric muffler
τ_{eff}	Temporal scale of effusion

I. Introduction

Let us consider the following problem. Inside the rigid tube gas moves (with velocity – much less than sound speed) simultaneously with propagation of longitudinal acoustical wave. We need create some device (muffler), which would ensure gas movement and would block the propagation of acoustical waves. To estimate the quality of muffler we will use quality factor of the form:

$$\Xi = 1/\left(\alpha + \beta + \varepsilon + \gamma\right) \tag{1}$$

where $\alpha = \left(P_1 / P_0\right) << 1$-characterizes effectiveness of sound suppression (P_1-sound power on muffler's output, P_0-sound power on muffler's input), $\beta = \left(D/\lambda\right) < 1$ characterizes muffler's wave dimension (λ, D-characteristic wavelength of suppressed acoustical waves, and linear dimension of muffler respectively), $\gamma = \omega_{min} / \left(\omega_{max} - \omega_{min}\right) << 1$ characterizes wide of frequency range of suppression of acoustical waves (ω_{max} and are the maximum and minimum frequencies of sound suppression), $\varepsilon = W_1 / W_0 << 1$ characterizes ratio power W_1 (taken for sound suppression) and W_0 (power of engine). Really we need to maximize factor Ξ.

The most obvious solution is concluded in absorption of the sound resonator Helmholtz [1]. This approach ensures effective sound suppression ($\alpha << 1$), but have a narrow frequency range of absorption ($\gamma >> 1$), and requires large wave dimensions ($\beta >> 1$) with very small energy losses ($\varepsilon << 1$).

Summarizing we can have $\Xi << 1$. Today, the most broad spreading has got the solution in the form of reflecting filter ([2]-[5], without absorption in the simplest formulation): long waves are reflecting atperforated hard wall, but gas flow passes via a lot of small holes in this wall. Muffler's linear dimension D, diameter $\overline{\ell}$ of hole, and minimal distance ℓ between holes are connected by relations $\overline{\ell} << \ell << D < \lambda$. Reduction of the hole's diameter $\overline{\ell}$ plus increase of ratio $\ell / \overline{\ell} >> 1$ are leading to re-

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duction of factor α. But above things (plus reduction factor β) are leading to the growth of expenses ε of energy of the engine, which is pushing the gas through perforated surface.

At present "drum-like" version [6] of the muffler is researched intensively. This version uses the conversion of quick acoustical waves (to be damped) into slow waves of bending in fine flexible steel foil membrane with their absorption (conversion into heat).

This approach is characterized by practically zero energy expenses ($\varepsilon << 1$) and small wave dimensions of muffler ($\beta << 1$). But, due to the resonance-like (or multiresonance) nature of absorption, there are difficulties with providing of $\gamma << 1$ (or of broadband suppression of sound).

The methods of adaptive active control [7] are used also, and they give $\varepsilon << 1$, $\beta << 1$. But this approach meets difficulties, connected with broadband self-excitation of active system.

We shall notice, that all above approaches are founded on devices with parameters, which are not assumed as temporal variables. Reduction of the factor obstructs the getting of at least one of aims $\alpha << 1$, $\gamma << 1$, $\varepsilon << 1$, and, as a consequence, - difficulty to get $\Xi >> 1$ in the system with parameters, which are constant at time. Below we will show alternative path to $\Xi << 1$, by using quick commutation of muffler's parameters in time.

II. Principle of Parametric Muffler

Let's consider two parallel closely spaced identical tubes $\hat{A}$ and $\hat{B}$ (with length L and thin rigid walls) both connected to some input tube (with acoustical waves with velocity c and gas flow with velocity $V << c$) and output tube via controlled switches $\hat{C}$ (gates, bolts…).

We will mean while that switching time scale is extremely small ($\tau \to 0$, really we need $\tau << L/c$). Let's assume that in the temporal interval $0 < t \le T$ switches of tube $\hat{A}$ are opened (we denote this as $A = 1$), but switches of tube $\hat{B}$ are closed (we denote this as B=0).

In this interval sound and flow are passing though tube $\hat{A}$ and are closed in the tube $\hat{B}$. In the next interval $T < t \le 2T$ switches of tube $\hat{A}$ becomes closed ($A = 0$), but switches of tube $\hat{B}$ becomes opened ($B = 1$) … and so on with period T:

$$A(t) = \sum_{n=-\infty}^{\infty} \left\{ J\left[t-(n-1)T\right] - J\left[t-nT\right] \right\} \\ B(t) = 1 - A(t) \tag{2}$$

where $J(t) = 1$ if $t > 0$, $J(t) = 0$ if $t \le 0$. We must note, that at any moment t one of two tubes $\hat{A}$ or $\hat{B}$ is opened for acoustical waves and gas flows.

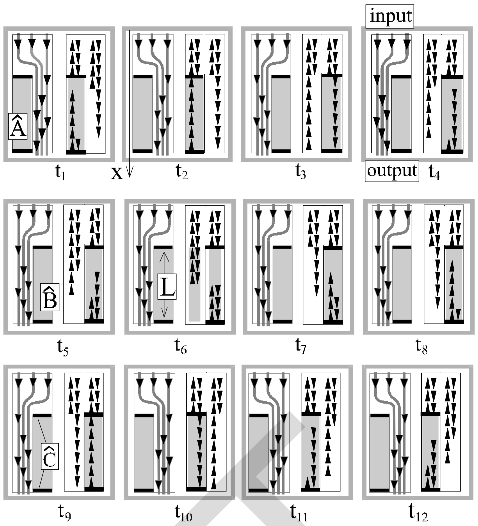

Fig. 1. Concept of parametric muffler: spatial-temporal diagrams of one wave inverter, formed by pair of tubes $\hat{A}$, $\hat{B}$. Each picture represents instant (on the moments $t_1 \div t_{12}$) distributions of gas flow (left side) and wave field (right side)

Now let's look at wave propagation and flow redistribution in the pair of tubes $\hat{A}$ and $\hat{B}$ more thoroughly (see Fig. 1, where running acoustical wave is represented by a sequence of wave elements (like "wavelets"), which are denoted by sequence of arrows). Left part of each moment picture in Fig. 1 represents the gas flow, right part represents wave propagation. We suppose, that:

$$T = L/c \tag{3}$$

($c = 330$ m/s is the sound speed in air at normal conditions and inside the pipes $\hat{A}$ and $\hat{B}$). which are denoted by sequence of arrows). Left part of each moment picture in Fig. 1 represents the gas flow, right part represents wave propagation. Let's assume, that at one initial moment $t_1 = -\Delta$ (where $\Delta = T/6$, see Fig. 1) for $A = 0$, $B = 1$ we have some pictures of current flow distribution (picture on the left) and wave propagation (picture on the right) inside $\hat{A}$ (on the left) and in the tube $\hat{B}$ (on the right). We assume also, that input of the tube pair is located at the top and output is located a down.

On the moment $t_2 = 0$ all wavelets inside $\hat{A}$ (marked by arrows) have become directed to output. On the other hand, the opened tube $\hat{B}$ have become completely filled by "wavelets", directed to the output. On the moment $t_3 = 0 + 0$ (or $t_3 = 0 + \tau$, where $\tau \to 0$) due to the switches $\hat{C}$ we obtain $A = 1$, $B = 0$ (with corresponding redistribution of gas flow). Wavelets, being closed before in $\hat{A}$, begin go out of $\hat{A}$ n direction of system input (to the top), but new wavelets begin to fill $\hat{A}$ (arrows, directed adown). The sequence of pictures, corresponding the moments t_4=Δ, $t_5 = 2\Delta$, $t_6 = 3\Delta$, $t_7 = 4\Delta$, $t_8 = 5\Delta$, $t_9 = 6\Delta$, illustrates the wavelets propagation.

This means: a) step by step inversion of wavelet group inside the closed tube $\hat{B}$; b) coming out from $\hat{A}$ (to the top) of wavelets being closed in $\hat{A}$ during the interval $t_4 \le t \le t_9$; c) filling step by step of opened tube $\hat{A}$ by wavelets, coming from top. On the moment $t_9 = T$, wavelet group inside tube $\hat{B}$ becomes completely inversed and the opened tube $\hat{A}$ becomes completely filled by wavelet group from the top.

On the next moment $t_{10} = T + 0$ (analogously to the moment t_3) due to switches $\hat{C}$ we obtain values $A = 0$, $B = 1$, which mean the change of gas flow and the processes of wave propagation on interval $t_{11} \le t \le t_{12}$, processes, analogous to the ones, during the interval $t_4 \le t \le t_5$. So we see, that all acoustical perturbations of the view

$$\varphi(x \pm ct) \tag{4}$$

(where x - is the coordinate along the pipes $\hat{A}$, $\hat{B}$ see Fig. 1) are fully reflected back from pair of tubes $\hat{A}$, $\hat{B}$, controlled by $\hat{C}$, as was described above (symmetrically for incident waves, arriving to both ends of pipes $\hat{A}$, $\hat{B}$). Periodical redistributions of gas flow are accompanied by radiation of acoustical waves, concentrated on frequencies:

$$\omega = \pm 2\pi m / T \quad (m = \pm 1, \pm 2, ...) \tag{5}$$

causing some losses of engine power. We indicate that switch $\hat{C}$ (here and hereinafter) does not do some mechanical work with acoustic waves (does not radiate and does not absorb their). The waves radiated are receiving energy from the source (the engine), which is pushing flow of the gas via muffler. Below we will call this device by "wave-inverter" and value T by "period of wave inversion" or "period of switching". We note also, that we assumed linear and only one-dimensional wave propagation (4) within tubes $\hat{A}$, $\hat{B}$.

III. 2D-Version of Parametric Muffler

Now we will consider the some modification (see Fig. 2) of the above model of parametric muffler (with clear implementation of switching): initially univariate acoustic falling field and initially univariate flow of the gas push through system of infinite quantity of strips $\hat{W}$ (fixed walls with width L and thickness $\bar{h}$), located periodically (with spatial period $h >> \bar{h}$). Strips $\hat{W}$ are parallel to each other, rigid and fixed rigidly (in relation to acoustical waves in air). Any pair of adjacent strips $\hat{W}$ means walls of waveguide (above described as tubes $\hat{A}$, $\hat{B}$ in Fig. 1).

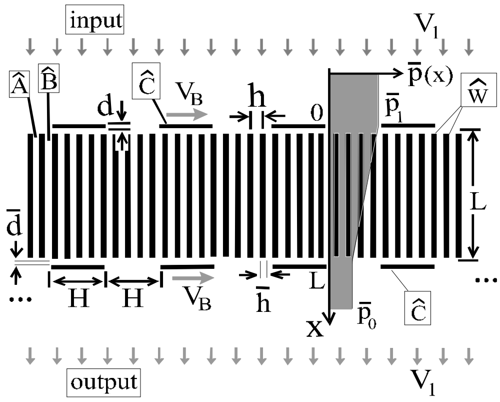

Fig. 2. Two-dimensional infinite system of wave-invertors: $\hat{W}$ - equidistantly spaced parallel fixed rigid walls; $\hat{C}$ -system of commutating hard strips (bolts, gates…), which are shifting horizontally to the right with constant speed V_B

Besides this (Fig. 2), the above construction includes two identical plane systems of infinite quantity of parallel strips $\hat{C}$ (bolts, gates…) with spatial period $2H$, width H, and thickness d. Strips $\hat{C}$ are rigid in relation to acoustical waves in air too. Strips $\hat{C}$ (analog of switches $\hat{C}$ in Fig. 1) are separated from strips $\hat{W}$ (analog of tubes $\hat{A}$, $\hat{B}$ in Fig. 1) by narrow slot of width $\bar{d}$ and run at the speed V_B strictly along vertical directing (Fig. 2). In this version of muffler the switching time is:

$$\bar{\tau} = h / V_B \tag{6}$$

and period of switching (period of wave inversion) can be formulated as:

$$T = H / V_B = L / c \tag{7}$$

We will suppose, that slot width $\bar{d}$, length $d_{free} = 7.3 \times 10^{-3}$ m of the free run of the molecules of the air (at normal conditions) and minimal technologically achievable roughness $d_{tech} \approx 2 \times 10^{-8}$ m of steel surface [9], thickness d of bolts $\hat{C}$ are connected by relations:

$$d_{tech} << d < \bar{d} << d_{free} \tag{8}$$

Below we will call this system of parallel strips by "block of wave-inverters $\hat{I}$" (or $\hat{I} = \hat{W} \cup \hat{C}$). One can represent the gas pressure p_1 on input ($x = 0$) of $\hat{I}$ and gas pressure p_0 on the output ($x = L$) of $\hat{I}$ as the following:

$$p(x,t) = \tilde{p}(x,t) + \bar{p}(x) \tag{9}$$

where: $p(x,t)$ - acoustical pressure, spatially averaged along the plane "x" (horizontal plane, which is perpendicular to the vertical axis "x"); $\tilde{p}(x,t)$ denote oscillatory component of the value $p(x,t)$ with energy, concentrated on frequencies (instead (5)):

$$\omega = \pm 2\pi m / \bar{\tau} \quad (m = \pm 1, \pm 2, ...) \tag{10}$$

$\bar{p}(x) = < p(x,t) >$ denotes temporally averaged value (we note, that $< \tilde{p}(x,t) > = 0$). To push gas through $\hat{I}$, we must ensure difference $\bar{p}(0) - \bar{p}(L) > 0$ between constant components of input and output pressures (the graph $\bar{p}(x)$ of constant pressure is represented in Fig. 2). Relation (8) forms the effusion flow (via narrow slot of width $\bar{d} << d_{free}$) with characteristic time scale τ_{eff}.

The last means time, during which any initial pressure distribution $p(x,t)$ relaxes to the static distribution $\bar{p}(x)$. The mechanical work of pressure difference $\bar{p}(0) - \bar{p}(L)$ is ensured by engine power losses and is used for exceeding of viscous resistance and for producing of commutative acoustical waves on the frequencies (10). Gas pressures, being averaged at time ($\bar{p}_1 = \bar{p}(0)$ at $x = 0$ and $p_1 = \bar{p}(L)$ at $x = L$), are identical on both surfaces (external and internal) of each running bolt $\hat{C}$, due to effusion via narrow slots of width $\bar{d}$.

So we can formulate the frequency range of sound suppression (reflection of all perturbations of the view (4) and, simultaneously, passing of gas flow):

$$\omega_{min} < \omega < \omega_{max} \tag{11}$$

where:

$$\omega_{min} >> 2\pi / \tau_{eff} \tag{12}$$

(the condition, which allows to neglect effusion):

$$\omega_{max} >> 2\pi / \bar{\tau} \tag{13}$$

On the other hand, muffler misses through itself waves on the frequencies:

$$|\omega| \le 2\pi / \tau_{eff} \tag{14}$$

$$|\omega| \ge 2\pi / \bar{\tau} \tag{15}$$

It is easy to see, that we can achieve wideband sound suppression ($\omega_{min} << \omega_{max}$, or $\chi << 1$) by the choice of parameters h, L, $\bar{d}$, $\bar{\tau}$. Frequencies (14) can be interpreted as temporal changes of engine's acceleration regime ("treadle of the gas"). The condition of univariate (4) wave propagation (illustrated in Fig. 1) within the tubes of wave-inverters block $\hat{I}$ (Fig. 2) can be formulate as:

$$h << L, \;\; h << \lambda_{min}, \; \bar{\tau} << T \tag{16}$$

$\lambda_{min} = 2\pi c / \omega_{max}$ is least length of acoustical wave to be reflected by muffler. Now we can see, that gas flow (with velocity $V << c$) is passing through system $\hat{I} = \hat{W} \cup \hat{C}$, due to pressure difference $\bar{p}_1 - \bar{p}_0 > 0$ on very low frequencies $|\omega| \le 2\pi / \tau_{eff}$. On the other hand, the acoustical waves, concentrated on the frequencies (12), are reflecting by the system of wave-inverters $\hat{I} = \hat{W} \cup \hat{C}$.

IV. 3D-Version of Parametric Muffler

Below we will consider 3D rotary analog (with finite dimensions) of the above mentioned spatially periodical infinite 2D structure of wave-invertors $\hat{I} = \hat{W} \cup \hat{C}$.

Fig. 3 represents rotary muffler in its axial section. $\hat{G}$ is input and output pipe-like hard detail with internal radiuses r_0 and $\bar{\bar{R}}_2$ (r_0-radius of muffler's input pipe, $r_0 < \bar{\bar{R}}_2$). Details $\hat{G}$ are tightly pressed to the wave inverters block $\hat{I}$ with internal and external radiuses $\bar{R}_1$ and $\bar{\bar{R}}_1 > \bar{\bar{R}}_2$. Cell-like transverse structure, formed by walls $\hat{W}$, is concentrated between external and internal radiuses $\bar{\bar{R}} < \bar{\bar{R}}_1$ and $\bar{R} > \bar{R}_1$ respectively in the waveguides block $\hat{\Psi}$ (Fig. 4). Cells (analogously to waveguides $\hat{A}$ and $\hat{B}$ in Fig. 1 and Fig. 2) can be of various form and dimensions (and unnecessary identical to each other): square, hexagonal,…etc. For simplicity we will consider square cells of $\hat{\Psi}$; h-dimension of cell, $\bar{h}$-thickness of cell's walls $\hat{W}$ ($\bar{h} << h$). Dimension h should be sufficiently small (to meet the conditions (16)) and sufficiently large (to exclude too large energy losses for pushing viscous gas through $\hat{\Psi}$). Rotary switch $\hat{C}$ (with N_0 "petals", $N_0 = 4$ in Fig. 5) is combined coaxially with waveguides block $\hat{\Psi}$. Petals $\hat{P}$ (with thickness d) have internal and external radiuses $\bar{R}_1 = \bar{R}$ and $\bar{\bar{R}}_1 = \bar{\bar{R}}_2 - \bar{\bar{d}}$ ($\bar{\bar{R}} > \bar{\bar{d}} > 0$) respectively. Narrow slot (with width $\bar{d}$) is spaced between petals $\hat{P}$ and block $\hat{\Psi}$.

Average gas pressure $\bar{p}_1$ (exceeding output gas pressure $\bar{p}_0 < \bar{p}_1$) pushes gas flow through muffler (Fig. 3) with input (and output) velocity V_0 and with velocity:

$$V_1 = 2r_0^2 / \left(\bar{\bar{R}}^2 - \bar{R}^2\right) V_0 \tag{17}$$

within the pipes of waveguides block $\hat{\Psi}$. Only half of total number $N_1 \approx \pi\left(\bar{\bar{R}}^2 - \bar{R}^2\right)/h^2$ of waveguides are opened at every moment of time. Angle width $\overline{\vartheta}_0$ of petals and width ϑ_0 of gaps between adjacent petals are equal at any numbers N_0 (Fig. 5):

$$\overline{\vartheta}_0 = \vartheta_0 = \pi / N_0 \tag{18}$$

In other words the combination $\hat{I} = \hat{\Psi} \cup \hat{C}$ is the 3D equivalent of above mentioned block of wave-inverters with period:

$$T = L / c \quad \text{or} \quad T = \vartheta_0 / \left(2\pi f_0\right) \tag{19}$$

of switching (where f_0 is rotating frequency of rotary switch $\hat{C}$) and with time of switching:

$$\overline{\overline{\tau}} \le h / \left(2\pi \overline{R} f_0\right) \tag{20}$$

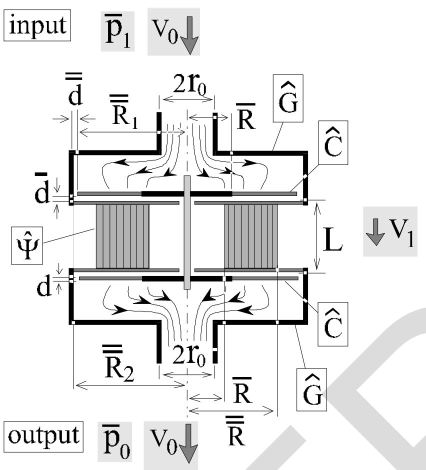

Fig. 3. Axial cut of the muffler: $\hat{G}$ - "input-output" tubes, $\hat{\Psi}$ - block of waveguides, $\hat{C}$ - rotary switch

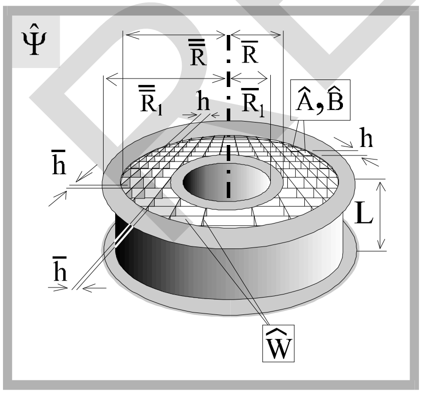

Fig. 4. Cell-like transverse structure of the waveguides block $\hat{\Psi}$. Each square cell represents acoustical waveguide $\hat{A}$ (or $\hat{B}$) with length L and hard walls $\hat{W}$

The effusion time at condition (8) can be estimated [10] roughly as:

$$\tau_{eff} \approx \left(12h^3 L\right) / \left(\pi \overline{d}^3 \overline{\upsilon}\right) \tag{21}$$

where $\overline{\upsilon} = 395.5$ m/s – the most probable velocity of the molecules of the air at normal conditions. By inserting (21) and (20) (instead (6)) into (12), (13) we can obtain the estimation of the frequency range (11) of sound suppression for 3D parametric muffler.

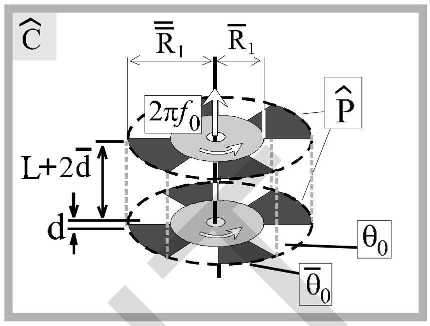

Fig. 5. The construction of rotary switch $\hat{C}$, commutating gas flow and acoustical waves. $\hat{P}$-petals (bolts) with angle width $\overline{\vartheta}_0$ and gaps between them with angle width ϑ_0

V. Technical Estimations

Now we will choose several concrete parameters of parametric muffler (see Figs. 3-5): $r_0 = 0.05$ m, $\overline{R} = 0.06$ m, $\overline{\overline{R}} = 0.16$ m, $N_0 = 2$, $L = 0.2$ m, $h = 0.005$ m, $\overline{d} = 0.0001$ m.

As a typical source of gas flow and sound we consider an automotive 4-piston engine of internal combustion with active volume $1.5 \times 10^{-3}\,\text{m}^3$ and power $W_0 \approx 36750$ W at the automotive velocity about 22.2 m/s with frequency 46.7 Hz of the rotation of the gross of the motor and frequency 186.8 Hz of explosive pulses of engine, characteristic wavelength $\lambda = 1.7$ m of sound.

Also we get the estimations of volume expense $0.07\,\text{m}^3$/s of gas and velocity $V_0 = 8.9$ m/s of gas flow in the pipe of radius r_0, velocity $V_1 = 2.02$ m/s of gas flow inside pipes of waveguides block $\hat{\Psi}$ (Fig. 4) with Much's number $V_1 / c = 0.006$.

Temperature (and sound speed c) of gas is stabilized by engine's thermostat. A typical muffler gives energy factor $\varepsilon = W_1 / W_0 \approx 0.02$ (where $W_1 \approx 735$ W represents energy losses for silencing), wave gabarit factor $\beta = D / \lambda \approx 0.45$, sound suppression factor (in power) $\alpha \approx 0.05$. In accordance with above choice of parameters we get period of switching $T = L / c = 6.1 \times 10^{-4}$ s, time of switching is $\overline{\overline{\tau}} \le 3.2 \times 10^{-5}$ s, effusion time $\tau_{eff} \approx 2.4 \times 10^{3}$ s, the rotation frequency $f_0 = 412$ Hz of switch $\hat{C}$ (Fig. 5).

This frequency is really achievable, if we take into account the maximum rotation frequency 2750 Hz, achieved today in gas turbines [11], [12]. Below we will obtain values $\bar{\alpha}$, $\bar{\beta}$, $\bar{\gamma}$, $\bar{\varepsilon}$ (as analogs of values α, β, γ, ε in (1) respectively, referring to traditional muffler) for muffler with chosen above parameters and estimate ratios $\bar{\alpha}/\alpha$, $\bar{\beta}/\beta$, $\bar{\gamma}/\gamma$, $\bar{\varepsilon}/\varepsilon$.

Taking into account (20), (21), (11)-(13), one can obtain $\bar{\bar{\tau}} \le 3.2\times10^{-5}$ s, $\tau_{eff} \approx 2.4\times10^{3}$ s and, consequently, $\bar{\gamma}/\gamma << 1$. Relation of gabarit factors is about $\bar{\beta}/\beta = 0.4$. In accordance with calculation data and values V_1 and h, we obtain the pressure relaxation $\left(\bar{p}_1 - \bar{p}_0\right)/L \approx 5.0$ Pa/m per meter inside pipes of block $\hat{\Psi}$ (Fig. 4) with energy expenses $W_2 \approx 5$ W, energy factor $\bar{\varepsilon} = W_2/W_0 \approx 10^{-4}$.

The power of high frequency radiation (on the frequencies (10), or about 3.1×10^{4} Hz) we estimate as $W_3 \approx \left(\bar{S}/2\right)\left(\rho c V_1^2\right)$, where $\bar{S} \le \left(hN_0/2\bar{R}\right)\left(\bar{\bar{R}}^2 - \bar{R}^2\right)$ ($\bar{S} \le 1.83\times10^{-3}\,\mathrm{m}^2$), that is to say $W_3 \le 1.6$ W. With addition of energy expenses $W_4 \le 40.3$ W for rotary switch $\hat{C}$ we obtain $\bar{\varepsilon} = \left(W_2 + W_3 + W_4\right)/W_0$ and $\bar{\varepsilon}/\varepsilon \approx 0.06$. Factor of sound suppression for parametric muffler is formed by three components $\bar{\alpha} = \alpha_1 + \alpha_2 + \alpha_3$. Relative suppression error (in power), due to Doppler's effect (in pipes of block $\hat{\Psi}$) is $\alpha_1 \approx (2\pi)^2 \left(V_1/c\right)^4 \left(L/\lambda\right)^2 = 2.5\times10^{-3}$.

By addition component $\alpha_2 \le \left(h/\bar{R}\right)^2 = 1.7\times10^{-3}$ (caused by finite time $\bar{\bar{\tau}}$ of switching) and component $\alpha_3 = \left[\bar{d}/\left(2\pi/\bar{R}\right)\right]^2 = 7.1\times10^{-8}$ (caused by infiltration of the sound through slots), one can obtain $\bar{\alpha}/\alpha = 0.9\times10^{-2}$.

So, having $\bar{\alpha}/\alpha < 1$, $\bar{\beta}/\beta < 1$, $\bar{\gamma}/\gamma < 1$, $\bar{\varepsilon}/\varepsilon < 1$, we can expect some advantage with parametric muffler in comparison with traditional one. In other words quality factor $\bar{\Xi} = 1/\left(\bar{\alpha} + \bar{\beta} + \bar{\varepsilon} + \bar{\gamma}\right)$ of parametric muffler can exceed quality factor (1) of traditional muffler (or $\bar{\Xi} > \Xi$). Rotary switch $\hat{C}$ can be driven by small power electromotor with stabilized rotation frequency f_0. Now a few words about thickness $\bar{d}$ of petals of switch $\hat{C}$ and thickness $\bar{h}$ of walls $\hat{W}$ of the wave inverters block $\hat{I}$. The values $\bar{d}$ and $\bar{h}$ must be sufficiently large to guarantee acerbity $\hat{C}$ and $\hat{I}$ to acoustical wave. On the other hand, $\bar{d}$ and $\bar{h}$ must be sufficiently small to guarantee the small resistance to the moving of gas flow. Pair "steel and air" allows such compromise (unlike the pair "steel and water"). We note, that parametric systems, which were being suggested in this paper, are fully symmetrical for changes "input-output".

VI. Conclusion

An analysis of muffler alternative version has been represented. Besides silencing of exhaust gases sound of engine of internal combustion the above device can be used in the ventilation ducts. Parametric muffler does not absorb acoustical energy, but only reflects acoustical waves and misses gas flow through itself.

Due to very fast commutation of parameters (based on the contemporary level of technology) of acoustical chain, its wave dimensions can be much less, than the length of wave to be suppressed. Using concrete example of traditional pair (piston engine)+(perforated muffler) we showed, that parametric muffler version can provide the superiority in sound suppression, in energy losses and wave dimensions of muffler and frequency range of sound suppression.

References

[1] J.M. De Bedout et al, Adaptive-passive noise control with self-tunning Helmholtz resonators, *Journal of Sound and Vibration, 2021 (1997), 109–123.*

[2] S.N. Pzhevkin, *Course of lectures on the theory of sound.* (Published by Moscow University, 1960, 155-157).

[3] R.H. Lyon, Noise reduction of rectangular enclosures with one flexible walls, *J. Acoust. Soc. Am., 35, (1963), 1791−1796.*

[4] J. Kang et al, Predicting the absorption of open weave textiles and micro-perforated membranes backed by an air space, *J. Sound Vib., 220, (1990), 905−920.*

[5] K.V. Horoshenkov et al, A method to calculate the acoustic response of a thin, baffled, simply supported poroelastic plate, *J. Acoust Soc. Am. 110, (2001), 904−917.*

[6] Y.H. Chiu et al, Drum-like silencers using magnetic forces in a pressurized cavity, *Journal of Sound and Vibration, 297, (2006), 895-915.*

[7] M. Cuesta et al, Active control of the exhaust noise radiated by an enclosed generator, *Appl. Acoust., 61, (2000). 83−94.*

[8] V.V. Arabadzhi, *Solutions to Problems of Controlling Long Waves with the Help of Micro-Structure Tools*, (Bentham Science Publishers, Sharjah, U.A.E. Chapter 1, 12-17, 2011), http://benthamscience.com/ebooks/9781608052752/index.htm.

[9] www.besteel.ru

[10] D.V. Sivuhin, *Kurs Obshej fiziki, Tom 2. Thermodynamics and Molecular Physics.* (Published by Fizmatlit, 2005, 370).

[11] http://www.jetcatusa.com/p60.html

[12] Hamdi Nassereddine, Benmansour Saad, Jean Louis Kueny, Interface Tracking between Two Phases for Pelton Turbine Injector Using a Velocity Method, (2012) *International Review of Physics (IREPHY)*, 6 (3), pp. 310-317.

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