INDUSTRIAL NOISE SERIES

PART VII: SILENCERS

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TABLE OF CONTENTS

Introduction	2
Types of Silencers	2
Standard Silencers	4
Self-Noise	6
Flanking Noise and Breakout Noise	7
Insertion Loss (IL)	8
Noise Reduction (NR)	9
Transmission Loss (TL)	9
Performance Criterion	10

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INTRODUCTION

The requirement for a silencer is generally developed by determining some amount of noise reduction needed to reduce noise emissions from some machine in order to meet a compliance requirement or environmental noise limit. Silencer performance may be specified using three parameters, noise reduction (NR), transmission loss (TL) and insertion loss (IL). In general, citing any of these three parameters will result in meeting the requirement; particularly, if it is to only meet an overall sound level reduction but there will be some variances in the very low frequencies that are discussed in following sections. In general, one can fairly well assume,

$$NR \approx TL \approx IL \quad dB \tag{1}$$

It is when encountering very demanding octave or one-third octave band performance requirements that careful and highly sophisticated analysis is required that definitely takes a few days if not weeks to perform; particularly if having to guarantee performance. In the case of having to upgrade or replace an existing unit, field measurements are needed.

Other important parameters that affect the design and performance of a silencer are the type machine, flow rate of the gas or fluid, the operating temperature (not design temperature), and sound data of the source (one-third or octave band sound power levels) including identifying principal frequencies. Another important parameter to consider is the pressure loss limit. It is also beneficial to know the speed of the device (rpm) and the power (kW or hp).

It is important to note that the only way to absolutely guarantee meeting a criterion is to develop the silencer on the engine or machine. Theory only gets close to the solution thus almost all designs incorporate a safety margin to account for uncertainties that are inherent in the measurement of the sound as well as the calculation of performance.

TYPES OF SILENCERS

There are numerous types of silencers and the reason is they must be designed specifically to the application to effectively and economically reduce the noise. Most machines fall into two principal types of acoustic sources, pulsation or continuous-steady type noise mechanisms. A positive displacement device such as a piston pump, low speed rotary pump or reciprocating engine produces pulsation type energy. A continuous-steady type of device is a blower, fan, or turbine. But there are machines that have both characteristics that require what is called a combination silencer.

In general, there are two basic types of passive silencers, reactive and absorptive with their characteristics shown in Figure 1. Both types have no mechanisms or other features that would require routine maintenance but absorptive packing materials can be lost or degraded if installed in a harsh service application.

Reactive silencers are principally designed to attenuate low frequency sound, generally less than 150 Hz, whereas absorptive silencers are designed to attenuate middle and high frequencies. By combining the two types, a silencer can easily achieve a wide frequency range. Many reciprocating internal combustion engines now incorporate a turbocharger thus the need for a combination silencer.

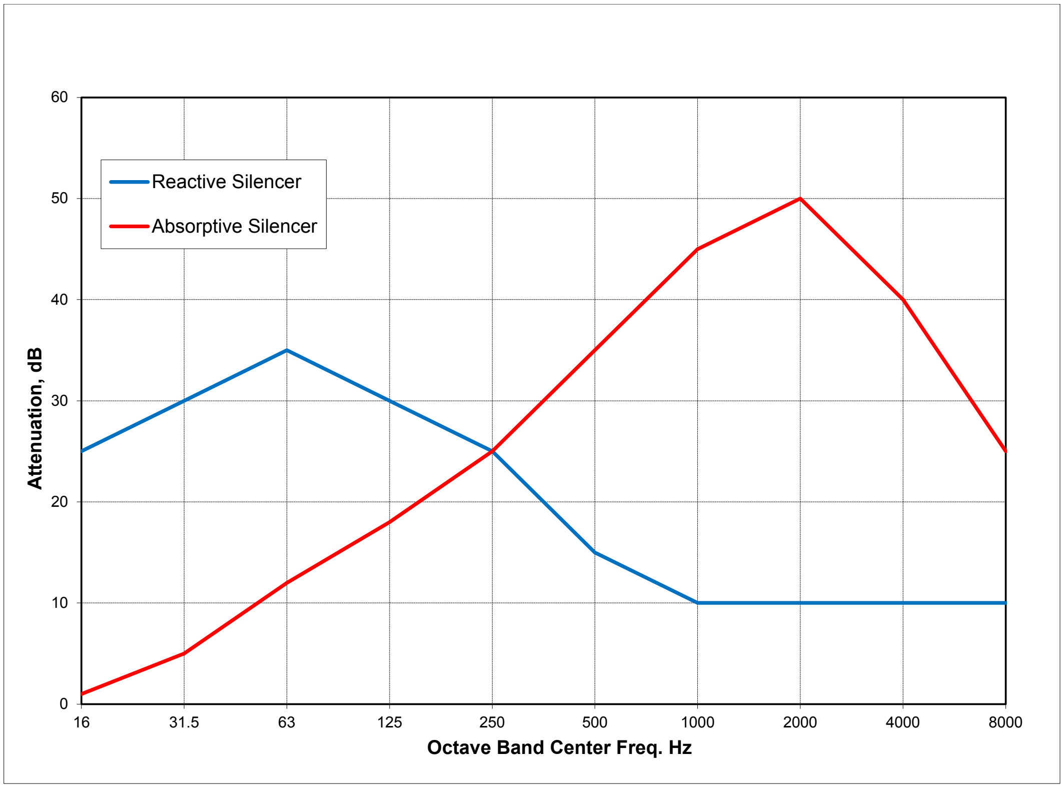

Figure 1 – General Attenuation Characteristics of Silencers

One special silencer application is for rotary pumps or blowers. These devices may be pulsation or continuous noise sources depending upon the speed of the machine. The change over from pulsation noise to continuous noise is termed the *transition frequency* which is a function of speed and size of the drive gear (sometimes called the timing gear). A machine that operates near the transition frequency needs a silencer that is both reactive and absorptive.

The material composition of the silencer must also be compatible with the gas or fluid moving through the silencer, environmental conditions, as well as the physical limitations in terms of allowable size and weight. These all play a factor in performance. In very demanding requirements it may not be possible to meet the three general parameters of size limit, pressure loss limit, and acoustical performance; generally, only two of the three can be met. Thus it is very important to capture all the information and requirements when initiating a design.

STANDARD SILENCERS

There is seldom a true *standard* silencer, particularly for reactive silencers categorized by grade level. The following table presents silencer performance from five makers. It is evident that more than a qualitative description is necessary to ensure meeting performance requirements and to ensure one company's unit is quantitatively equivalent to another company's unit.

Table I – Silencer Grade and Performance (Decibels)

Grade Level	Universal	Company A	Company B	Company C	Company D
Industrial	15-20	15-20		15-25	12-18
Commercial	20-30	20-25	20-25		
Suburban	30-40	30-35			
Residential	40-50	35-40	25-32	20-25	18-25
Hospital	50-60	40-50	35-42	35-40	35-40
Critical	60-70	50-60	30-38	25-30	25-34

The Electrical Generating Systems Association (EGSA) recently adopted a classification system for silencer performance as listed in Table II.

Table II – EGSA Grade and Performance Range (Decibels)

	A-Wtd Reduction Range, dB	
Grade	**Low**	**High**
EGSA Class 1	10	15
EGSA Class 2	15	20
EGSA Class 3	20	25
EGSA Class 4	25	30
EGSA Class 5	30	35
EGSA Class 6	35	40
EGSA Class 7	40	45
EGSA Class 8	45	50

Always investigate the application of a "standard" silencer; it could be the same engine but if operating at different speed or temperature then the results may be disappointing. Very high or very low sound power levels and the distribution of the energy across the frequency bands will impact overall silencer performance as demonstrated in Tables III and VI; the only difference between the two tables is the sound power level (PWL) of the source listed in the second row. The identical silencer is used in each table.

Table III – Example of Source PWL on Overall Performance

OBCF:	16	31.5	63	125	250	500	1k	2k	4k	8k	A-wt
Source PWL	112	116	122	124	124	137	142	146	141	134	149
Silencer TL	1	1	2	4	7	10	16	29	17	6	
PWL1	111	115	120	120	117	127	126	117	124	128	
Self-Noise	96	96	88	79	76	74	72	76	74	68	
PWL2	112	115	120	120	117	127	126	117	124	128	132
DTL =	0	1	2	4	7	10	16	29	17	6	**18**

Table IV – Example of Source PWL on Overall Performance

OBCF:	16	31.5	63	125	250	500	1k	2k	4k	8k	A-wt
Source PWL	136	154	156	151	138	136	135	133	133	131	142
Silencer TL	1	1	2	4	7	10	16	29	17	6	
PWL1	135	153	154	147	131	126	119	104	116	125	
Self-Noise	96	96	88	79	76	74	72	76	74	68	
PWL2	135	153	154	147	131	126	119	104	116	125	134
DTL =	1	1	2	4	7	10	16	29	17	6	**8**

Standard or catalog silencers must be carefully evaluated for each application as demonstrated in the preceding tables. Very high or very low sound power levels or the distribution of the sound energy across the bands can easily impact the attenuation provided by a silencer.

Please note that silencer performances listed in catalogs are generally measured under ambient conditions and may or may not include flow. In some cases, the catalog may present data based on some elevated temperature for exhaust applications. When the operating temperature is significantly higher than what is reported in a catalog, the attenuation curve shifts higher in frequency thus the lower frequency bands will result in lower attenuation. This is because as the temperature increases the wavelength and the speed of sound (c) increases. Assuming nominal atmospheric pressure, the speed of sound is a function of temperature where the operating frequency is factored by the ratio of the two absolute temperatures,

$$f_{Operating} = f_{ambient}\left(\sqrt{\frac{T_o}{T_a}}\right) \text{ Hz} \qquad (1)$$

To provide a simple example, say at 125 Hz the TL is 10 dB but at a higher operating temperature, assuming a T_o/T_a ratio of 4, the 125 Hz performance now shifts to 250 Hz.

If the performance data is on an octave band or one-third octave band basis then simple scaling as shown above does not work because the performance is based on bandwidth. The best method is to convert to wavelength-based performance and interpolate the new NR/TL/IL based on the wavelength that corresponds to the center frequency of the band at the operating temperature. The wavelength is $\lambda = c/f$ where f is the center band frequency. Some caution is warranted in scaling absorptive silencers as the packing material's characteristics are strongly dependent upon temperature and viscosity of the gas and it is difficult to scale those properties.

Note that a silencer cannot be simply designed to provide an overall sound level reduction. Say a sound level of L_A 97 dB at some location needs to be reduced to 80 dB. The spectrum of the sound energy is required; whether octave band, one-third octave band or narrowband data, so the designer knows where to focus or tune the silencer to achieve the required attenuation. Tables III and IV illustrated the importance of using a noise spectra.

Another factor to consider is pressure drop or loss and is largely a function of the velocity through the silencer. The calculation of acoustical performance must be balanced with pressure loss and the available area for the silencing system. In critical applications for high acoustical performance, low pressure loss, and limited size, the general rule is "pick any two."

SELF-NOISE

When air or gas flows through a baffle or silencer, the interaction of the fluid flow, particularly at the exit, causes flow disturbances resulting in flow noise. As the velocity increases the flow noise increases and there are no simple algorithms to calculate this affect as the geometry of the baffles and silencers are highly variable: viscosity of the gas, temperature, velocity, baffle geometry, entry and exit geometry, vortices and flow separation. Most published algorithms are fairly conservative because of the complexity of all the variables that affect flow and self-noise generation Virtually all self-noise data are reported as a sound power level (PWL) because velocity is a form of energy. Silencer manufacturers will develop a catalog of data and most all HVAC catalogs provide self-noise data for their products.

Reactive silencers (exclusive of connections) are generally low velocity units especially for low pressure loss limits or units that incorporate a spark arresting section. On small to midsize engines, most self-noise is created by high velocity gas exiting the tail pipe.

When low noise requirements are specified the self-noise may limit performance. Self-noise is a sound power level adjustment to the resulting attenuated sound power level (PWL). The following table presents the effect of self-noise on performance. The velocity between the baffles is 164 ft/s (9855 fpm, 50 m/s) and causes degraded performance in the 1k and 2k octave bands by 4 dB (compare PWL1 to PWL2). As can be seen, this reduces the effective insertion loss in those bands resulting in what is termed the dynamic transmission loss (DTL) since it includes the effect of self- noise. Increasing the velocity will eventually affect all the bands and result in degrading the overall sound level reduction.

Table V – Example of Self Noise on Performance, decibels (dB)

OBCF:	31.5	63	125	250	500	1k	2k	4k	8k	A-wt
Source PWL	126	124	130	131	123	124	123	122	122	131
Silencer TL	3	6	14	27	41	59	53	34	13	
PWL1	123	118	116	104	82	65	70	88	109	109
Self-Noise	**91**	**83**	**74**	**71**	**69**	**67**	**71**	**69**	**63**	**76**
PWL2	123	118	116	104	82	69	74	88	109	109
Delta =						**+4**	**+4**			
DTL =	3	6	14	27	41	55	49	34	13	22

Flow noise generally affects the middle bands and for very low noise requirements can be problematic resulting in large silencers to obtain a low velocity but with the added benefit of low pressure drop. However, the self-noise is a power level that is also a function of the face area of the silencer. As the silencer area increases to reduce velocity, there may be an increase in the self-noise PWL because of the area increase. PWLs are an absolute value and do not change but in the case of flow noise, the increase in area also causes more self-noise energy to be present. This becomes very problematic in very low noise applications or if the sound power level of the source is very low as the self-noise floor can then be higher than the source's PWL.

FLANKING NOISE AND BREAKOUT NOISE

Flanking noise also limits silencer performance and is difficult to grasp because it is not related to the silencer design but its shell construction. The noise traveling down a duct or pipe is in two forms, fluid or air-borne and structure-borne. The base design of the silencer is focused on the fluid-borne (air or gas) path and not so much on the structural path. The in-duct noise couples to the duct wall and re-radiates noise in two directions: back into the duct or pipe downstream of the silencer or outside the silencer duct itself (breakout noise).

Figure 2 illustrates the flanking noise path, but to avoid clutter, imagine the noise that couples to the duct wall also radiates outward into the environment – generating near field and far field sound levels. It is the breakout noise that can compromise silencer performance particularly if the silencer is located outside an enclosure or building.

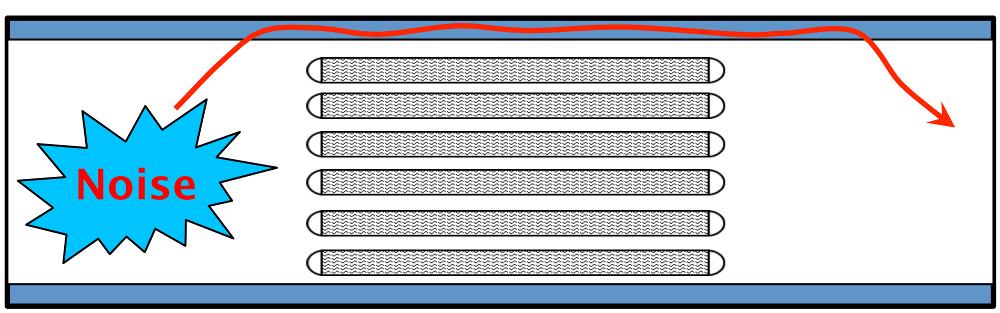

Figure 2 – Flanking Noise Around Baffles (or even through baffles)

Flanking noise is very complicated and expensive to analyze so empirical limits are established. HVAC type silencers (22-24 gauge construction) and thin gauge shells on silencers generally have a 50 decibel limit. Heavier ducts (generally, 3/16 inch or 4-5 mm) typically have a limit of 60 dB. So what do these limits mean? For example, say calculations show a silencer achieving 62 dB reduction but it has a light weight duct wall thus its TL limit is set to 50 dB, a 12 dB loss in performance (by truncation).

Silencers that require high transmission loss or limited breakout noise will require careful analysis and special designs to include double wall ducts with heavy shell insulation and damping. Expansion and isolation joints isolate the engine or machine from the duct/pipe and silencer that aid in reducing breakout noise.

INSERTION LOSS (IL)

The majority of the time, it is either insertion loss (IL) or dynamic insertion loss (DIL) that is specified for silencer performance. Insertion loss or dynamic insertion loss is specified at a location some distance from where the sound energy enters the space or environment in question.

It is critical to realize what is being specified and what is required to determine and verify IL or DIL. IL/DIL can be determined by two methods: 1) In order to calculate the insertion loss, a detailed system description along with detailed machine data to include its acoustic impedance is required. The acoustic impedance is incredibly difficult to measure and is not performed by OEMs because it is very expensive, time consuming and the results are just as problematic. But importantly, every time there is a change in any ducting or arrangement the insertion loss must be recalculated but the DIL can only be verified by testing as self-noise cannot be accurately calculated. 2) The silencer is developed on a full scale system duplicating the actual field installation and using the identical machine where the IL/DIL is determined as discussed next.

It is important to know that IL or DIL is the difference in <u>sound pressure level</u> with and without the silencer in place as illustrated below. The overall duct lengths are identical

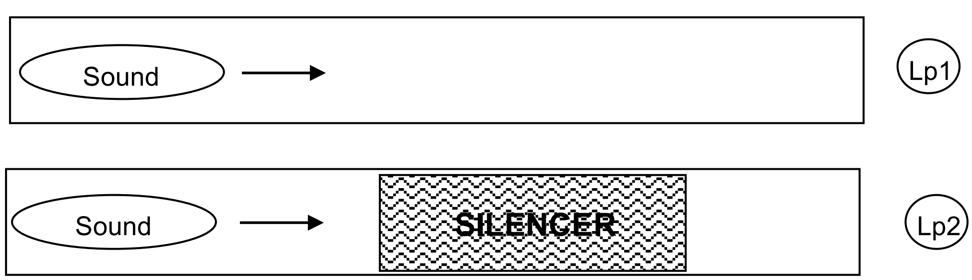

Figure 3 – Insertion Loss Measurement

$$DIL \text{ or } IL = L_{P1} - L_{P2} \quad dB \qquad (7)$$

Obviously, to verify performance would be expensive by having the equipment and manpower to swap out the silencer for an empty duct section and make measurements. Recall that IL is measured under no flow conditions and DIL includes flow.

NOISE REDUCTION (NR)

NR is the relative noise reduction across a device including silencers. The measurement involves inserting a microphone in the duct upstream and downstream of the silencer and making measurements. The measurement method then also captures any end effects or reflections, which can skew the results – particularly for reactive silencers that are designed to create reflections.

TRANSMISSION LOSS (TL)

When specifying silencer performance, a more convenient method is to specify the transmission loss (TL) of the silencer, the reduction of sound power level provided by a silencer. Universal calculates the TL (as was shown in the above tables) and includes self-noise, thus effectively showing the dynamic transmission loss (DTL). The TL is used because it is very rare that a full system description is provided when a silencer is requested and frequently, system arrangements change during project development.

The following exercise demonstrates that TL is a good approximation of IL. We start with the classical approach of measuring insertion loss or defining the sound levels (L_P) with and without the silencer in place associated with insertion loss measurement. The sound power emitted from the duct is noted as L_{W1} and L_{W2} for the two measurement conditions.

$$L_{P1} = L_{W1} + K \quad \text{dB (with the silencer)} \tag{8a}$$

$$L_{P2} = L_{W2} + K \quad \text{dB (without silencer)} \tag{8b}$$

$$IL = [L_{P2} – L_{P1}] = [(L_{W2} + K) – (L_{W1} + K)] = L_{W2} – L_{W1} \quad \text{dB} \tag{8c}$$

$$TL \approx L_{W2} – L_{W1} \quad \text{dB} \tag{8d}$$

Assuming K is constant for both boundary conditions, with and without the silencer, it is shown that the insertion loss (IL) is approximately equivalent to the TL. Now there are some liberties here as TL is based on an anechoic termination (no end/exit effects). But lacking detailed design data, this shows that TL works fairly well for estimating the IL of a system. The uncertainty is mainly in the very low frequencies which are generally not important for meeting an overall sound level (A-weighted) reduction but in the case of having to meet octave or one-third octave band reductions this assumption then becomes invalid.

PERFORMANCE CRITERIA

It is critical to clearly state the requirements of the silencer to be supplied and understand what is being specified and how it will be measured for compliance. The following information should be provided as a minimum:

a. Acoustical criterion or criteria.
b. Flow rate, operating temperature and pressure loss limits.
c. Machine data and operating conditions.
d. Machine acoustical data – must be frequency-based.
e. Connection data, orientation, and size limits including weight.
f. All specifications and standards related to the performance requirements.
g. All specifications and standards related to measurements.

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