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Konrad Nering orcid.org/0000-0003-4168-5707
knering@mech.pk.edu.pl
Institute of Thermal and Process Engineering, Faculty of Mechanical Engineering, Cracow University of Technology

Krzysztof Nering orcid.org/0000-0003-5281-2663
kj.nering@gmail.com
Faculty of Civil Engineering, Cracow University of Technology

Reduction of acoustic cavitation noise emission with textile materials

Redukcja emisji akustycznej szumu kawitacyjnego przy użyciu materiałów tekstylnych

Abstract

This article presents an examination of the acoustic noise level reduction in piping applications. Hydraulic cavitation is the source of the noise. In order to determine the noise level drop for the insulating material arranged around the pipe – cylindrical geometry – the acoustic spectrum was measured in the range of audible frequencies. Measurements were made for textile materials stacked with varying amounts of layers around the source of noise. There was a decrease in the noise level characteristics for mass law. An empirical formula describing the relative noise reduction for the materials under study was proposed.

Keywords: cavitation noise, acoustic insulation, noise emission reduction

Streszczenie

Niniejszy artykuł przedstawia badania redukcji poziomu dźwięku poprzez zastosowanie materiałów tekstylnych wokół rurociągów. Źródłem hałasu jest szum kawitacyjny. W celu wyznaczenia spadku poziomu hałasu dla materiału izolacyjnego ułożonego wokół rury – geometria cylindryczna – zmierzono spektrum widma akustycznego w zakresie słyszalnym przez człowieka. Pomiary przeprowadzono dla materiałów tekstylnych ułożonych z różną ilością warstw wokół źródła szumów. Zaobserwowano spadek poziomu szumów charakterystyczny dla prawa masy. W ramach opracowania wyników wyznaczono wzór empiryczny opisujący względną redukcję poziomu szumów dla badanych materiałów.

Słowa kluczowe: szum kawitacyjny, izolacja akustyczna, redukcja emisji szumów

1. Introduction

Pipelines in industrial and domestic applications can vary from simple, straight structures to often very complex domains. With increasing level of complexity, flow type changes from laminar to turbulent. In specific conditions, turbulent flow may evolve into cavitation. Due to unstable conditions of liquid pressure inside pipes with rapid periodic fluctuations, vibrations of pipeline may occur [9]. These vibrations are transmitted into the air, where they can be measured or, even heard.

This paper presents experimental studies of cavitation noise, its spectrum, specific conditions and method of reduction without affecting on flow conditions. Similar publications can be found where authors describe flow noise emitted from pipes during turbulent conditions and pressure fluctuations [10–17]. More acoustical measurements are performed in publications [18–20], where cavitation noise is considered.

The main idea of this article is to show how to reduce cavitation noise emission in hearing frequencies. As was stated before, crucial conditions to be fulfilled in this experiment, are to prevent even the slightest change in flow conditions. Due to this fact, reduction of noise emission is done by application of sound insulating membrane at the pipe's outer surface. Different material types and thicknesses are considered.

This paper can be applied in design of high velocity flow pipes with liquid, where cavitation may occur, due to extreme conditions of flow and complexity of its means of transportation.

2. Cavitation phenomenon

Cavitation is a phenomenon caused by a variable pressure field in the liquid. This includes the formation, growth and collapse of bubbles or other closed cavities containing a vapour of a given liquid, gas or vapour-gas mixture. Cavitation breaks the continuity of the liquid, thereby increasing the energy loss during the flow. In hydraulic systems, cavitation occurs in pressure areas below the equilibrium vapour pressure of the liquid. As a result of the pressure drop, bubbles form in liquid and flow to the higher pressure areas (above the vapour pressure). In the higher pressure areas, bubbles (cavities) implode causing short-duration acoustic pulses. In the case of developed cavitation (large areas of reduced pressure), the noise of imploding bubbles is so significant that it causes vibrations in the hydraulic systems and--after some time--fatigue of the material [2]. In industrial processes, the phenomenon of cavitation occurs frequently especially in hydraulic systems with high flow rates (large Reynolds numbers). In the recent years, many authors describe cavitation in various components of the hydraulic systems, such as pumps [1], pipelines [7], tees [8], valves [2], Venturi [6], nozzles [5].

A flow with cavitation phenomenon should be treated as a two-phase flow. The beginning of this kind of flow (cavitation occurrence) is defined in the literature using the so-called Cavitation Number *Ca*. According to [6] this number is referred to the ratio:

$$Ca = \frac{P_2 - P_v}{\Delta P} \tag{1}$$

where:

- P_2 – static pressure measures after cavitation-causing element;
- P_v – equilibrium vapour pressure of the liquid;
- ΔP – pressure drop on the obstacle.

Other authors [3] use a relationship determining the cavitation number using kinetic energy of flow:

$$Ca = \frac{P_1 - P_v}{\frac{1}{2}\rho v^2} \tag{2}$$

where:

- P_1 – static pressure measures before element causing cavitation;
- ρ – density of the liquid;
- v – mean velocity measured before the obstacle.

In this paper, authors will be using relationship (2).

With the increase of flow rate, after exceeding a certain cavitation number (critical Ca_{cr}), there is a certainty that cavitation occurs.

The negative effect of cavitation is the noise generated by the imploding vapour bubbles of the liquid, which are moving from the reduced pressure area to the higher pressure area.

Experimental and theoretical studies show that there is a difference in the mechanism of cavitation noise formation in gas and vapour bubbles [9]. For gas bubbles, acoustic waves are generated by bubble oscillation.

3. Test setup

Measurements were performed using the setup shown in Fig. 1. The cavitation phenomenon was induced in the Venturi shown in Fig. 2. During the test, measurements of flow rate, the pressure drop on the orifice and the pressure on the orifice relative to the ambient (atmospheric) pressure were made. In the test setup, water was the liquid in which cavitation occurs. Based on the results for different flow rates, the cavitation number for each case was determined and set the critical cavitation number indicating the initialization of cavitation (Fig. 3).

In the test setup Wilo MHI 202 pump, the Fuji Electric Portaflow X flowmeter and the Peltron PXWD pressure difference sensors were used. The measurements of acoustic noise were performed for the parameters indicated by triangles on Fig. 3.

In acoustic measurements, 01 dB Metravib Blue Solo SLM (Sound Level Meter) was used. The level meter was set in a 17.5 cm distance from the longitudinal axis of Venturi orifice in order to provide free field conditions from 500 Hz J. Cowan, Building Acoustics, in: Springer Handbook of Acoustics, red. T.D. Rossing, Springer Science, Leipzig 2007, pp 387–425, 390. Noise measurements are set up to the frequency of 25.6 kHz. Analysis of noise level drop was performed up to 1/3 octave band of 20kHz. Two factors are responsible for it. The first one is the reduction of tests to the upper hearing frequency. The second one is the technical limit of SLM used in tests, which provides the highest sample rate at the level of 51.2 kHz. It directly results in Nyquist frequency of 25.6 kHz, which is followed by the fact that only below this frequency, can measurements be done. The full spectrum of cavitation measurement is shown on Fig. 6.

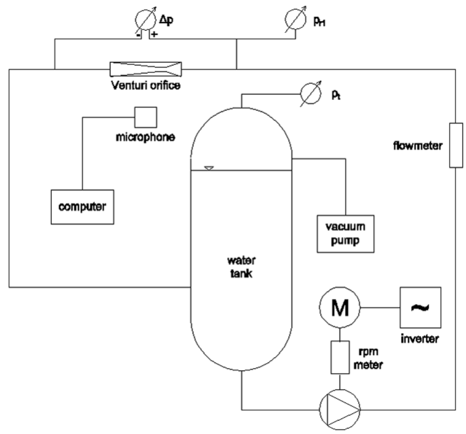

Fig. 1. Test setup

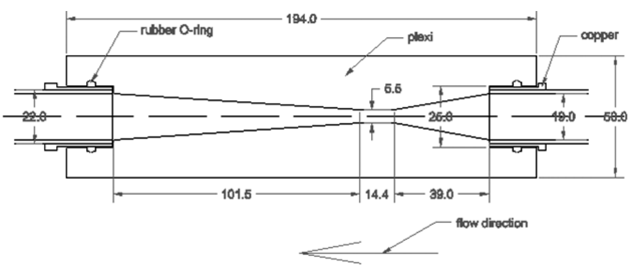

Fig. 2. Venturi orifice

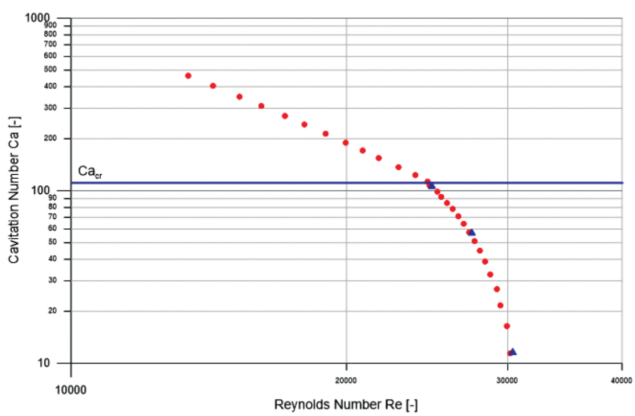

Fig. 3. Cavitation number for different flows using test setup

In order to measure the insulation of pipe covering, Venturi orifice and adjacent elements were lagged with different textiles of varying thickness. Measurements were performed for the given set of coverings:

- textile type 1: 2 layers, 4 layers, 8 layers,
- textile type 2, 4 layers, 8 layers, 16 layers.

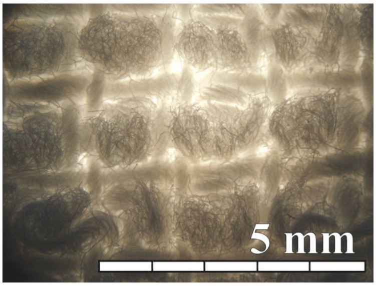

Fig. 4. Insulation textile material type 1

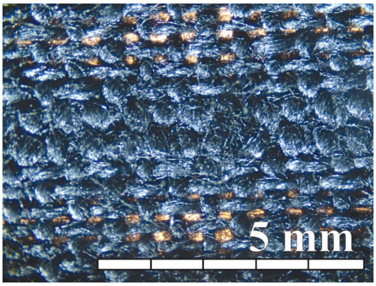

Fig. 5. Insulation textile material type 2

4. Results of measurements

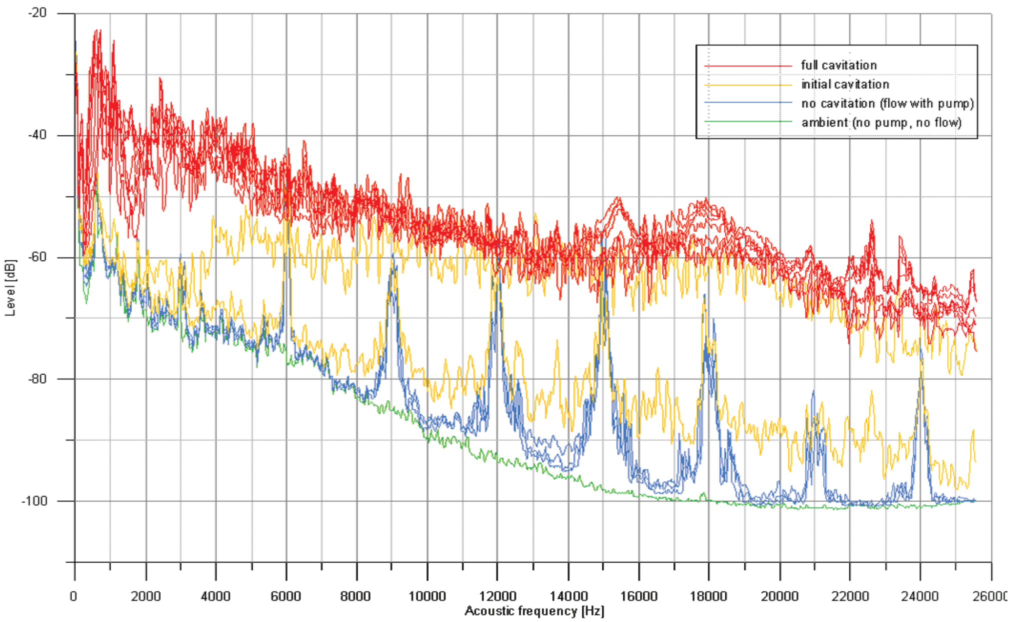

Fig. 6. Spectrum of cavitation noise for different Re number without insulation

5. Results of modified setup measurements

After insulating the Venturi, measurements were conducted in conditions given below in Table 1 and Table 2.

Table 1. Measurement conditions

Pump current frequency [Hz]	Pump [rpm]	Re [–]	Ca [–]
27.9	1612.6	24783	107.6
35.0	2016.1	27411	57.6
43.0	2463.9	30376	11.7

Table 2. Area density of used materials, per one layer

Material	Mass of sample [g]	Area [cm^2]	Area density [kg/m^2]
type 1 (open porosity)	366.22	9380	0.39043
type 2 (open porosity)	516.85	17238	0.29983

The analysis of insulation measurements of chosen textile materials is given below on Fig. 7. The lowest 1/3 octave band is 6.3 kHz due to the fact that below this band there were no transmission losses of cavitation noise. The difference between measured noise and background and pump noise was above 10 dB in each band above 400 Hz.

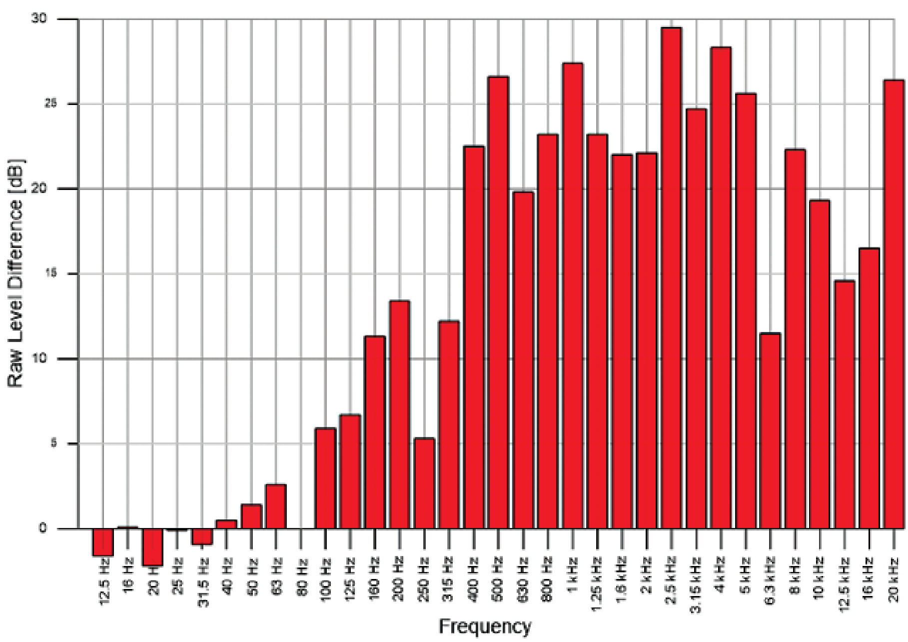

Fig. 7. Raw level difference between average cavitation noise and average background/pump noise

Due to the fact that there were significant instabilities in measurement results with pump current frequency of 27.9 Hz, it was decided to remove these results from the final analysis. It was an initial stadium of cavitation. Additionally, there was a lack of repeatability for textile type 2 with 2 layers mounted, so these measurements were also rejected in further analysis.

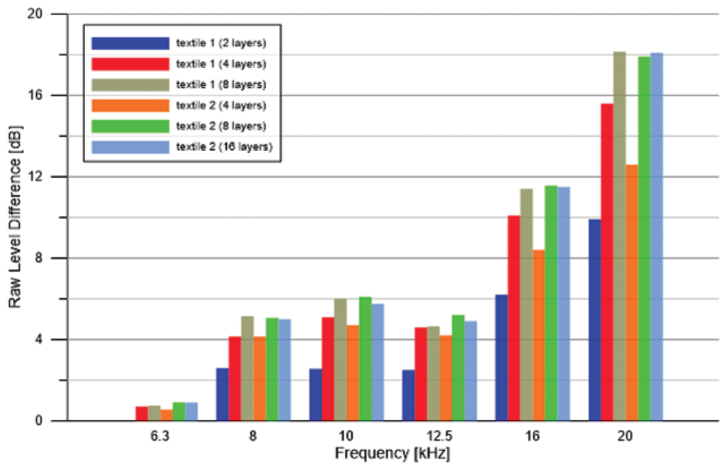

Fig. 8. Measured raw level difference between setup with and without insulation

6. Discussion

As an analogy to measurements of sound insulations of building partitions in standard ISO 16283-1:2014 [23] omnidirectional sound source is replaced by Venturi orifice with cavitation phenomenon inside. Cavitation noise level is sufficient to test level differences occurring in tested materials.

For textile materials tested in this paper, the level difference is found at 8 kHz. In both materials there is a drop in 12.5 kHz. It is probably caused by local resonances of the measuring system. The influence of pump/background noise was excluded. In case of noise level difference generated by pipe covering, the total level values as dBA or dBlin are below 2 dB, which is a prerequisite to reject this method of evaluation,even though noise level reduction is measured. This is caused by the fact, that dBA or dBlin takes into account the whole audible spectrum. In the measured case, only frequencies above 8kHz are evaluated.

In order to describe measured noise level reduction caused by textile pipe covering, the following formula (3) is proposed:

$$\Delta L(f, m') = 10 \cdot \log_{10}\left(f^{3.5} \cdot m'^{0.8}\right) - 136 [\text{dB}] \tag{3}$$

where:

f – frequency band [Hz];

m' – area density of pipe covering [kg/m^2].

Exponents were selected based on best fit and Pearson correlation coefficient squared and showed in Fig. 9.

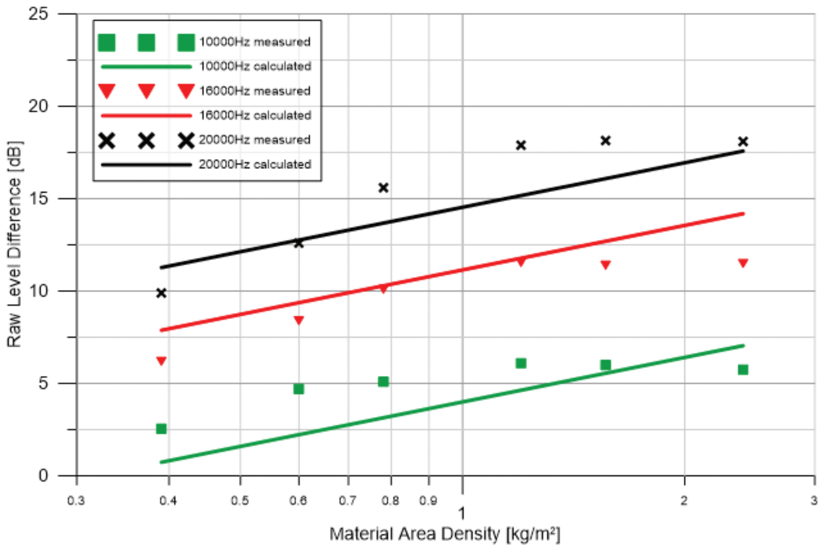

Fig. 9. Comparison between measured raw level difference as function of material area density and calculated values using formula (3)

Table 3. Pearson squared coefficient values for each frequency

Frequency [Hz]	**R^2**
8000	0.7872
10000	0.7181
12500	0.6264
16000	0.8325
20000	0.8619

The given formula (3), based on measured results, is classified as empirical one. It assumes analogous geometry of pipes. This formula is analogous to mass law for homogenous, flat partitions which can be found in David A. Bies, Colin H. Hansen, Engineering Noise Control: Theory and Practice, Fourth Edition, p.191, 2003.

7. Conclusion

After the performed measurements and calculations, the following conclusions can be drawn about cavitation noise and textile pipe coverings:

- textile multilayer materials with area density between 0.4–2.4 kg/m^2 have the ability to decrease cavitation noise starting from frequency of 8 kHz,

- there is a possibility to find empirical interdependence between noise level reduction, and frequency with area density,
- cavitation as a phenomenon is good for insulation measurement, because cavitation itself generates noise in the full spectrum of audible frequencies.

In further studies, verification of extrapolation of empirical formula on frequencies lower than 8 kHz will be performed. Additionally, samples with higher area density will be tested.

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