BNAM 2018
Baltic-Nordic Acoustics Meeting
15-18 April 2018
Harpa, Reykjavík, Iceland

Micro-perforates for duct noise control

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Micro-perforated plates (MMP:s) have dominating resistance over inertia in their impedance making them useful as acoustic absorbers. Originally such plates were suggested by the chinese researcher Maa as panel absorbes for room acoustics. At KTH other applications involving macinery or vehicle noise control have been investigated for over 10 years and this paper will summarize these efforts.

1 Introduction

A MPP can be made of plastic or metal but for machinery or vehicle noise control plates of metal are more useful, since they are more robust and can simply be integrated in an existing design. This is of special interest in vehicle noise control where solutions which do not add weight are essential. For instance MPP:s have the potential to be used instead of porous materials in dissipative mufflers, which not only could save weight but also offer a non-fibrous alternative. Furthermore, since MPP:s have a large steady flow resistance they can be used as acoustically absorbing guide vanes at duct bends or in fans. For many of these new possible applications the MPP:s will both be subjected to flow, high temperatures as well as high sound levels. It was a Chinese scientist Maa [1] that first presented the idea of absorbing sound by a so called micro-perforated panel and presented a model for it. The definition provided by Maa basically defines a MPP as a perforated plate where the hole size and perforation ratio creates a normal impedance with a real part close to the characteristic impedance in air (c:a 400 Pas/m at NTP). To achieve this for plates with a thickness around 1 mm and perforation ratios larger than (say) 1% holes in the sub-millimeter range are needed. The smaller the holes the better the behavior of an ideal MPP plate, with a constant (frequency independent) resistance and a negligible reactance, will be realized. It can be shown that this ideal behavior is reached in the range where the acoustic boundary layer thickness is larger than the hole radius.

2 KTH work on MPP:s

2.1 The effect of flow

Allam and Åbom [2] used a special test case (Figure 1) in order to investigate the effect of flow on the MPP impedance. Based on this formulas for the MPP impedance with flow was proposed for both circular holes and slits [2,3]. The main effect is the same as for all perforated plates i.e. the resistance increase with the grazing flow speed while the reactance (inertia) decrease. Due to the high steady flow resistance of a MPP one can normally assume that any bias is small and only grazing flow is important.

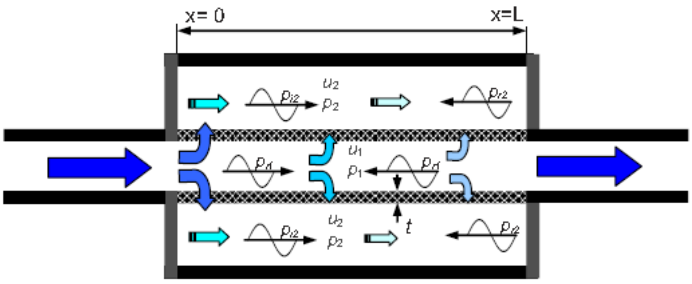

Figure 1: Test case to study the effect of flow on MPP impedance. A micro-perforated tube is inserted into an expansion chamber and then the two-port is measured. Based on a 1-D model (assuming plane waves) of the coupled waves in the main and annular duct, the two-port can be calculated as a function of the MPP impedance. By minimizing the error between the measured and computed two-port the impedance is determined. For details see [2].

Other recent [4,5] work on MPP impedance have investigated the so called viscous end-correction used by Maa in his impedance formula. It is found that this term originating from Ingard, as an estimate of viscous losses created by an oscillating flow just outside a hole, is incorrect. However, in practice especially for cases with flow this error is often quite small and can be neglected.

2.2 Mufflers for automotive applications

The development of the MPP impedance test case lead to the idea of using the design shown in Figure 1 as a dissipative muffler. Preliminary analysis showed that it was advantageous to subdivide the muffler outer part into small cavities in order to create a locally reacting behaviour [6], see Figure 2.

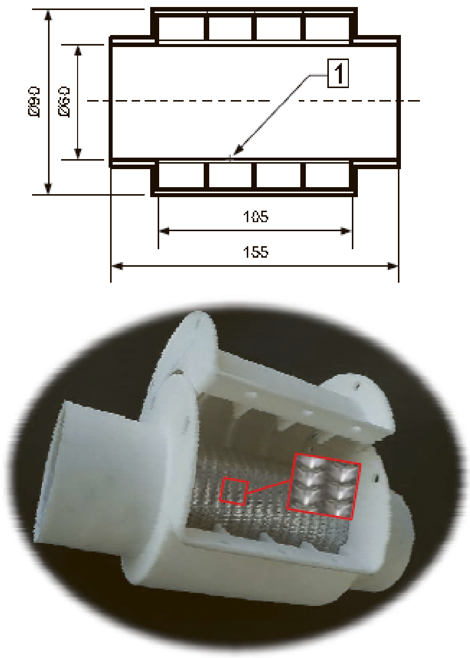

Figure 2: Micro-perforated muffler as proposed by Allam and Åbom [6] with locally reacting chambers. The cavities in the outer part are covered by a MPP tube (marked with 1). The figure and picture is taken from [7,8] showing a prototype built for Volvo cars, to reduce compressor noise in IC-engine intake systems. The dimensions are in mm.

The impedance Z at the MPP wall is given by:

$$Z = Z_{MPP} + Z_{cav} \ , \qquad (1)$$

i.e. it is a sum of the MPP and the cavity impedance. For the classical MPP application of room acoustics [1] the optimum choice is to maximize the absorption for incident plane waves (at the cavity resonance), by choosing the MPP resistance so that it matches the plane wave impedance. For the present case assuming plane waves along the duct it is more appropriate to look for the maximum decay rate ("damping") of the wave along the duct i.e. to maximize the imaginary part of the wave-number. This problem has been investigated by Cremer for rectangular ducts [9] and no flow. Cremer found that there exists an impedance the so called Cremer impedance that maximizes the decay. Later the work of Cremer was extended to circular ducts and to include the effect of a mean flow by Tester [10]. Tester also proposed a general procedure to find such optimum damping for any duct shape and mode order. One limitation in Tester´s treatment was that it assumes high frequencies i.e. well beyond the cut-on of higher order modes. The reason being that his interest was mainly damping of waves in aero-engines. Kabral et al. [8] removed this limitation and studied the case of optimum damping also for low frequencies as is of interest for applications in, e.g., automotive exhaust or intake systems.

By properly selecting the MPP and cavity impedance it is possible as discussed in Refs. [7,8] to match the Cremer impedance at one frequency. At this optimum frequency a damping of several hundred dB/m is typically obtained. This implies that even in a relatively large band around the optimum a high damping is reached. A MPP muffler built using this principle suggested by KTH will be referred to as a "Cremer muffler". As an example of the very large damping which can be created by this kind of muffler the transmission loss for the prototype shown in Figure 2 is presented in Figure 3.

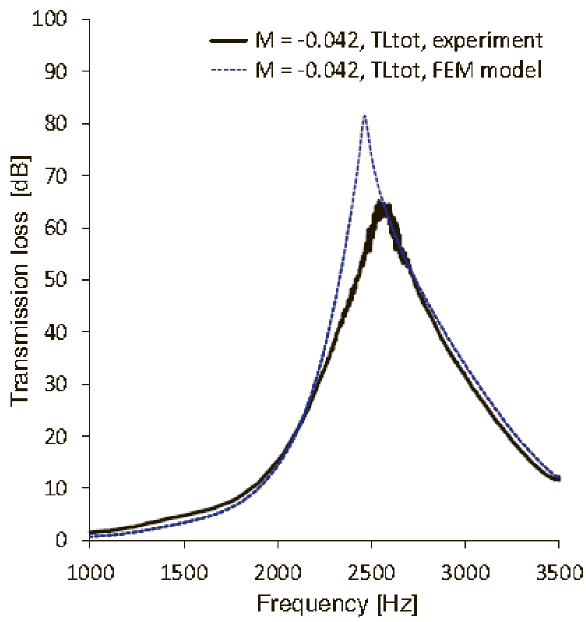

Figure 3: Measured and computed [8] transmission loss for the prototype "Cremer-muffler" shown in Figure 2.

2.3 Cooling fans

In the European project ECOQUEST KTH worked on the control of cooling fan noise using MPP:s. One result was the proposal to build a splitter silencer using micro-perforated plates as shown in Figure 4. A detailed description including testing and modelling can be found in Refs. [11,12]. Some additional results from the ECOQUEST work are found in Ref. [13].

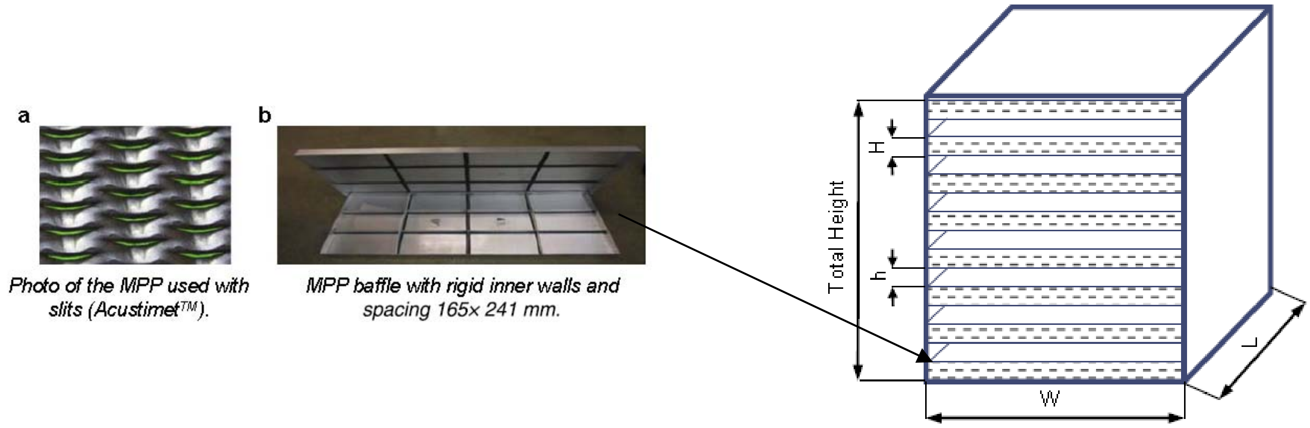

Figure 4: Splitter silencer with the splitters (or baffles) built up from MPP plates with inner solid walls for stiffening and to create a locally reacting behavior. From Ref. [11].

2.4 Modal filters

In a recent EU-project IDEALVENT KTH developed some novel solutions for noise control intended for climate systems on aircrafts. However the solutions can be applied also for other cases with sound propagation in ducts in the mid-frequency range, i.e., plane waves plus a few higher order modes. The concept is based on combining the above mentioned Cremer silencer (see Figure 2) with a so called modal filter [14]. The modal filter is designed to only reflect or attenuate higher order modes and is built up from MPP:s plates arranged parallel with the flow, in a pattern corresponding to the highest mode order that is propagating, see Figure 5.

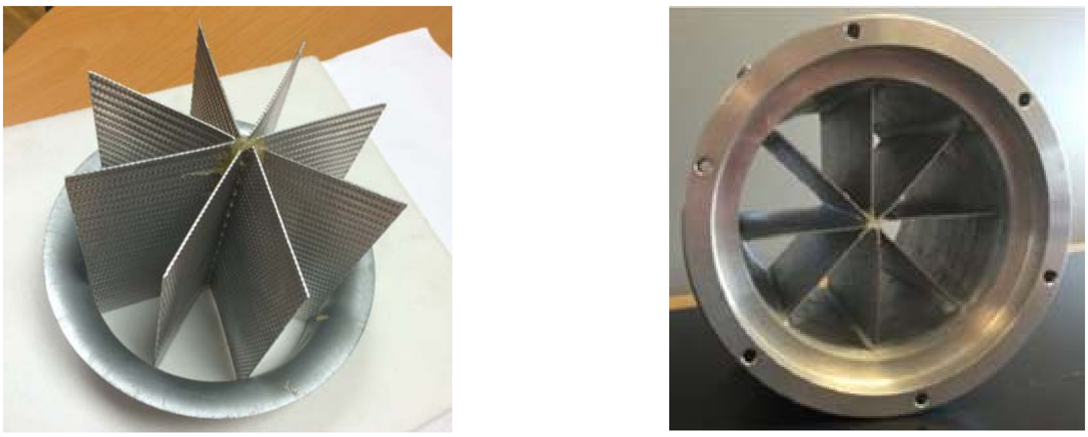

Figure 5: Modal filter consisting of MPP plates inserted along different duct radii. The filter shown is designed to block up to the 2:nd circumferential mode (2,0). Note the plane wave is not affected at all but the (1,0)&(2,0) modes will independent of their orientation induce an acoustic velocity in the MPP plates and suffer damping. From Ref. [14].

3 Summary

Perhaps the most important part of the work at KTH is related to the so called "Cremer mufflers". Not only is this an efficient way to create a dissipative silencer with very good performance, it also gives a solution that eliminates fibers, has a low weight and a low pressure drop. From a theoretical point of view the Cremer impedance concept is also interesting, since with flow it turns out that at sufficiently low frequencies the optimum Cremer impedance requires a negative resistance. Although this would seem to imply that power is supplied to rather than taken away from the acoustic wave the solution still predicts a decaying wave [8]. Presently further work on these aspects is going on in order to understand if this result is indeed correct or an artefact of the model used, which assumes and ideal plug flow i.e. no boundary layers at the wall.

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