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AMPLIFICATION OF THE TOTAL POWER FLOW RADIATED FROM AN EXTENDED NOISE SOURCE OPERATING NEAR ELASTIC BOUNDS

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1. INTRODUCTION

It is commonly accepted to characterize a noise source by the total power flow radiated in the standard conditions, i.e. in the free space. There exist the methods and facilities (intensimeters) to measure this parameter, and in many practical cases it is sufficient for estimating the noise levels produced by the source in bounded space using e.g. the SEA.

At the same time, in some cases the total power flow does not provide reliable estimates for the expected noise levels. This occurs, e.g. when a source operates in a room with distinct resonances or when it is installed near or on an extended elastic structure effectively reradiating sound. In this cases, the total power flow radiated by the source in the bounded space can be many times greater than that radiated in the free field.

It is the purpose of the present paper to estimate possible power amplification in mathematically tractable and physically transparent examples.

Two physical mechanisms of the amplification are discussed here:

1) resonances in bounded media, and

2) reradiation by a more efficient source.

The key role of the near field of the source in both mechanisms is demonstrated. It is shown that the stronger is the near field of the source the greater is the active power flow amplification. The extra power flow is the result of transformation of a part of the near field reactive energy into the active energy flow. The results show that the amplification may be orders (in magnitude). So in practice, it is sometimes desirable to characterize a noise source not only by the standard power flow, but also by a characteristic of its near field which is responsible for a sound power amplification.

2. "POINT SOURCE+SMALL SCATTERER" MODEL

We first try to understand physics of the power amplification on the simples acoustic model - radiation of a point source near a small resonant scatterer in the infinite medium. We compare the fields of three type of point sources - monopole, dipole and quadrupole. It is assumed that in the standard conditions, i.e. in the free space, each of the point sources has the same active power flow, F_0. But the near field of dipole, i.e. the kinetic energy of the added mass, is stronger than that of monopole, and the near filed of quadrupoles are much stronger than that of the dipole and monopole. Therefore the power amplification is expected to be maximum for the quadrupoles and minimum for the monopole. We consider air bubble in water as a small resonant scatterer, which is modelled by single degree of freedom system. Its parameters are the added mass of water, compliance of the air and radiation losses. It should be noted that due to the small dimension of the bubble, the scattered field is of monopole type.

When a point source operates near the bubble, the total filed consists of the standard field of the source and the field scattered by the bubble. The active power flow of the total filed F can be much larger than that of the standard field F_0. We define the amplification of the power flow by the power ratio in dB: $PR = 10\log(F / F_0)$.

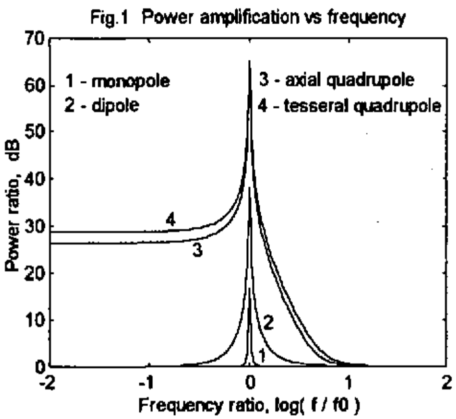


Fig. 1 presents dependencies of PR on frequency f for an air bubble of the radius 1mm at the distance 10mm from a point source in water. The resonant frequency equals f_0=3.5kHz, the quality factor is about 100.

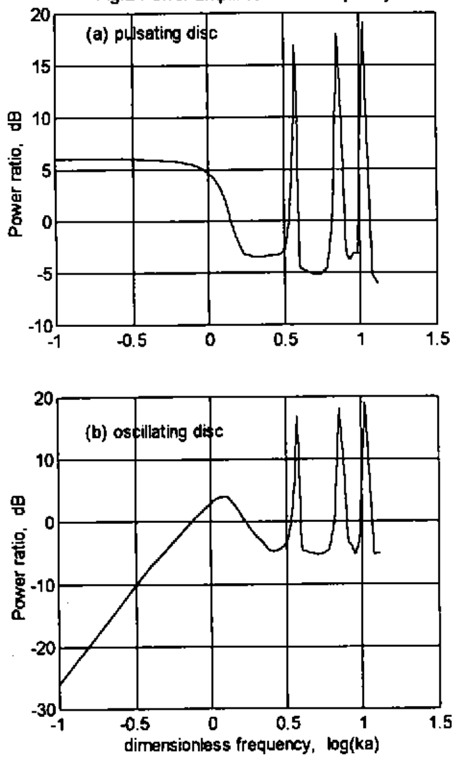
The two mechanisms of the power amplification - resonance, and effective reradiation, - are distinctly seen in the Fig. 1. For effective radiators - monopole and dipole - the power amplification is only due to the resonance of the bubble. For the quadrupoles the second mechanism also works: the power amplification takes place at low frequencies due to effective reradiation of sound by the bubble, i.e. by the secondary source of the monopole type.

3. RADIATION ON A DISC NEAR A RIGID WALL

The second example is the radiation of a circular disc into the halfspace bounded by a rigid wall. (Radiation into the unbounded space is widely investigated [1].) Our goal is to show. that, due to resonances of the cylindrical gap between the disc and wall, the radiation power flow is amplified with respect to the radiation into the free space. The problem was treated numerically by the Equivalent Sources Method [2] with the calculation error not exceeding 0.1.

Some results are presented in Fig. 2, where depicted is the power flow amplification for the pulsating and oscillating discs of radius $a=5h$, at the distance $H=5h$, h is the plate thickness.. At low frequencies, these two sound sources differs from each other: the pulsating disc radiates two times more sound energy in the bounded space than in the free space, while the disc oscillating near the wall is a less efficient source that in the infinite medium. A physical explanation is the following: radiation into a half space with rigid plane boundary is equivalent to the radiation into the free space by two identical sources located symmetrically. At low frequencies, in the free space a pulsating disc is equivalent to a monopole and an oscillating disc - to a dipole. Hence, in the halfspace, the pulsating disc is equivalent to two monopoles in phase or, which is the same, to the monopole with double volume velocity, while the oscillating disc is equivalent to two dipole in conterphase, that is to say, to a axial quadrupole, which is much less efficient radiator than a dipole.

Fig.2 Power amplification vs frequency

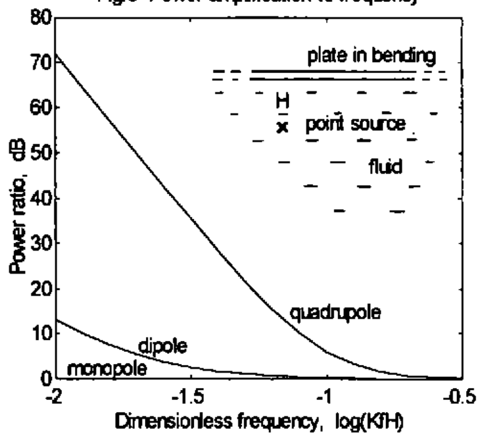


The most salient features of these curves in Fig.2 is the resonances at middle and high frequencies. They show that the rigid wall amplifies 20dB the total power flow of an extended source, regardless to what type of a source it belongs - pulsating or oscillating. Analysis says that the resonant frequencies are the natural frequencies of the gap between the disc and the wall when the height of the gap is an integer of halfwavelengthes.

4. A POINT SOURCE NEAR AN ELASTIC WALL

More impressive can be the amplification effect when a source operates near an *elastic* wall. In this case second mechanism - "reradiation"- works. Fig. 3 illustrates this phenomenon for the radiation of a point source near a bending plate which bounds the air halfspace. The problem was solved analytically using the Fourier-Hankel transform. Analysis of the solution shows that the amplification of the sound power is due to exitation of the plate and further reradiation by the plate, and take place at low frequencies when the plate is within the nearfield of the source. It is found out that the main carrier of the energy is the wave of the Rayleigh type consisting of flexural motion in the plate and evanescent wave in the fluid decaying exponentially with the distance from the plate. It is shown that more than 80% of the energy flow in this wave is concentrated in the plate and it gives the main contribution into the power amplification shown in Fig. 3. Three point sources: monopole, dipole, and quadrupole with equal standard power flow were considered. As seen from Fig. 3 the largest amplification takes place for the quadrupole which has the strongest near field.

Fig.3 Power amplification vs frequency



Conclusions. The analyzed examples has shown that owing to two physical mechanisms - resonances and reradiation, the total power flow of extended acoustic sources can be significantly (orders of magnitude) amplified when installed in a bounded space especially near elastic walls. The amplification is produced by the tranformation of the near field reactive energy into the active power flow: the stronger is the near field of a source the greater is its possible power amplification. The results demonstrate the necessity of characterization of the near field of industrial noise sources.

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References

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