ACTIVE NOISE CONTROL MATHEMATICAL MODELING.

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Abstract

There was modeled a situation that have been considered in the work [1]. The primary source sound falls from one end of hard wall round duct and transmitted to the other end. There are three secondary circular sources in the middle of the duct. The secondary sources excitation arranged so that to muffle the primary sound wave. There are illustrations of solving Helmholtz and telegraph equations. Helmholtz equation is solved in 2D space. Telegraph equation is solved in 1D space.

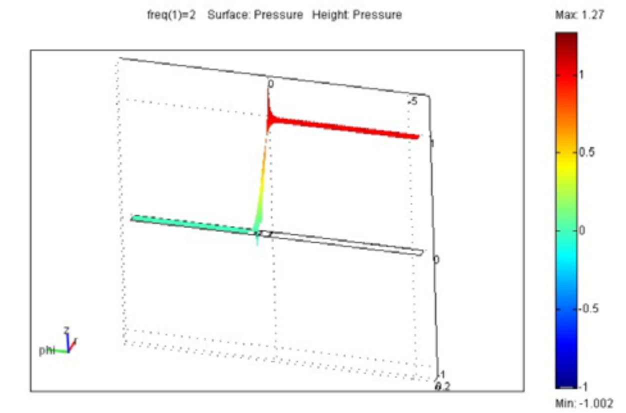
1 Two dimensional space model

The harmonic signal muffling task has been solved in the work [1]. The harmonic signal spread over the circular duct with the hard walls. The falling sound wave was muffled by the vibrations that produced by three rings like sources. The amplitudes and phases of vibrated surfaces depend on amplitude and phase of muffling pressure. Those characters of muffling pressure are registering by the base receiver that is located on the known distance from the three rings like sources.

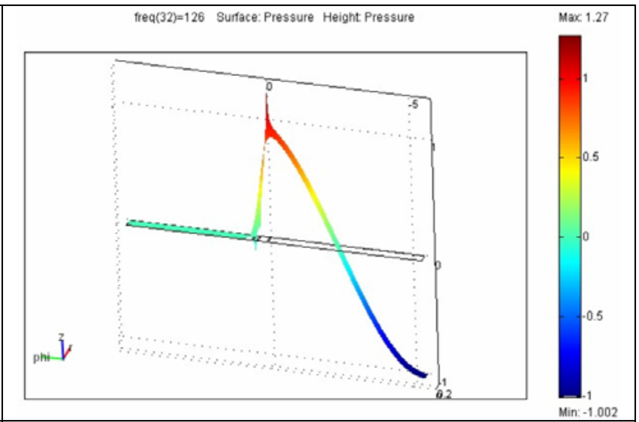
It is possible to restrict solution by two dimensions to illustrate the results of above mentioned task due to the axial symmetry of situation. It is sufficient to illustrate the result along the radius from the centre of tube to the wall but along all the length of the tube from the entrance to the end section.

The spatio-temporal description of the pressure in the tube was made by using applied programs package ***FemLab.*** The object ***fem*** contains all parameters of the task. The command ***rect2(…)*** sets geometrical objects. All they are contained in the ***fem.geom*** field. The cell array contains all task parameters. This cell array is contained in the ***fem.const*** field. There was used the object ***appl*** with the name ***aco***. The solution was made by the command ***femlin(…)*** and the illustrations was made by the command ***postplot(…)*** and by the command ***postmovie(…)***.

There is long rectangle with three strips in the centre of rectangle on the picture. The rectangle is the section of the tube from the centre till the hard wall and along all the length of the tube from the entrance to the end section. Three strips correspond to circle sources with given acceleration on generatrix of cylinder. The sound wave falls from the right side of cylinder. The harmonic sound wave propagation is described by Helmholtz equation. This equation is solved in 2D space. The falling wave interacts with the vibrations that are originated from the wall acceleration. There is zero pressure in the outlet part of the tube i.e. sound wave is muffled. The same situation is observed on the set of frequencies from the lowest analyzing frequency 2 Hz till the frequency of first radial resonance. There is a pressure gradient in the vicinity of circular sources where the falling sound wave and wall vibrations interacts. The gradient directs along the radii and cross to the axe of tube.

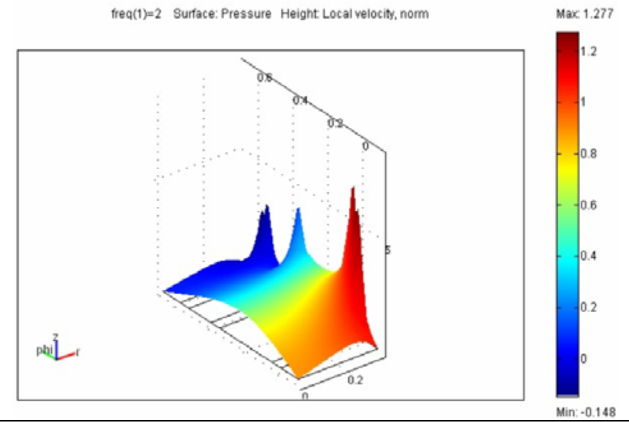


Pic. 1 – Height and coloring corresponds to the pressure. The frequency is 2Hz.



Pic. 2 – Height and coloring corresponds to the pressure. The frequency is 126Hz.

The wave in the nearest vicinity of vibration sources is depicted on the pictures 3 and 4.



Pic. 3 – Triple source. The frequency is 2Hz.

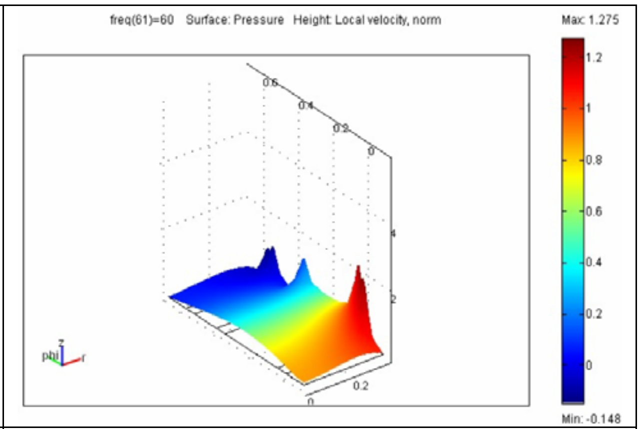


Рис. 4 – Triple source. The frequency is 60Hz.

The height is corresponding to velocity module value and coloring is corresponding to pressure value. The width of each of three sources is 5 centimeters.

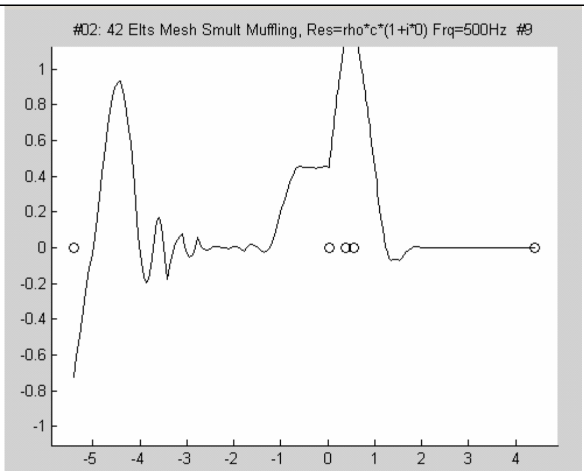
2 One dimensional space model

There are gradients of pressure and velocity only in very narrow vicinity of vibrating surfaces as in the pictures 3 and 4. The wave became practically plane within the distance equal to the source width.

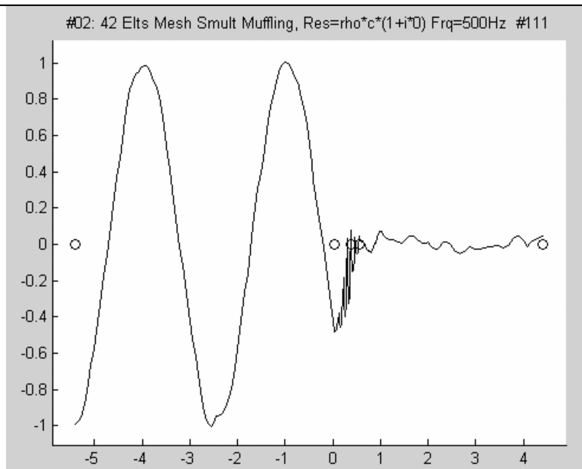
This circumstance makes it capable to decrees the spatio dimension in differential equation that describes the sound wave in the tube to one dimension space. It is possible to describe medium movement by telegraph equation.

The spatio-temporal solution description of telegraph equation was made by using applied programs package ***FemLab.*** The solution was made by the command ***femtime(…)*** and the illustrations was made by the command ***postmovie(…)***.

There are dependence of the pressure from the longitudinal coordinate on the pictures 5 and 6. The wave of pressure falls from the left. Three circular secondary sorceresses are in the middle. Negative coordinates correspond to the area from the entrance of the tube to the muffling sources. The falling wave appeared in the inlet section in the moment when three muffling sources are switched on.



Pic. 5 – The beginning of muffling process. The initial wave in inlet section and secondary sources starts at the same time. Primary and secondary waves have not met yet.



Pic. 6 – The end of muffling process. There is incoming wave in the left half of the tube and is no any wave in the right half of the tube.

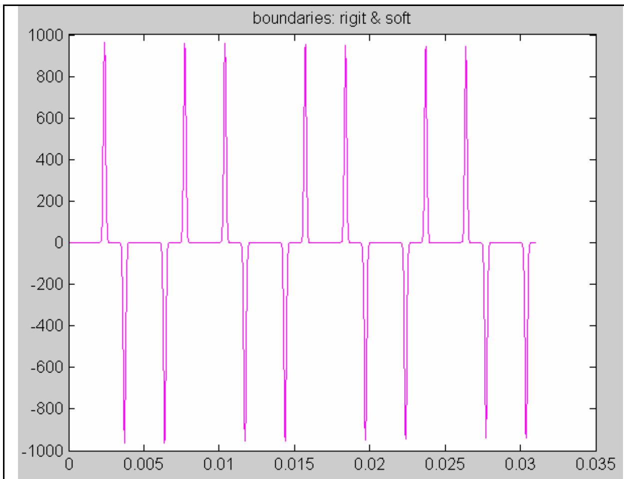
The impedance in the outlet section of the tube is equal to wave impedance of the medium in the tube.

Above adducing illustrations correspond to wave equation solution on pictures 1, 2, 3 and 4 and telegraph equation solution on pictures 5 and 6. The boundary and initial conditions introduced on the surface or on the line for wave and telegraph equations correspondingly.

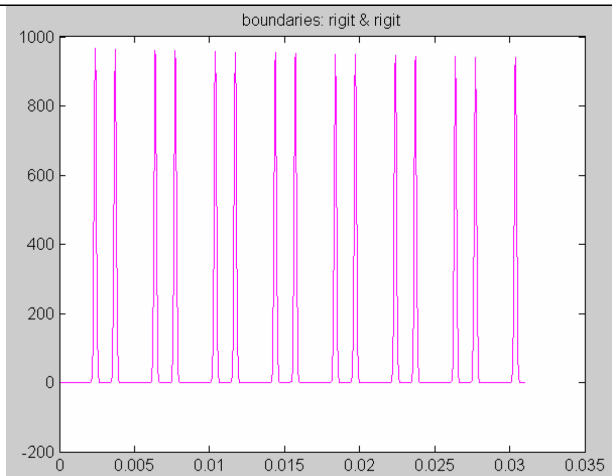
3 State-space model

There is alternative description of above mentioned situation by state-space model in which partial derivative equations replaced by set of ordinary differential equations. This description is the most interesting for the muffling systems. Let demonstrate this possibility on the example of piece of tube with 3 meter length. Let tube has hard walls and different impedance in the inlet and outlet section. The spatio-temporal solution description of telegraph equation was made by using applied programs package ***FemLab.*** The solution can be made by the command ***femtime(…)***, state-space modal was made by command ***femstate(…)*** and the illustrations was made by the command ***postmovie(…)***. The description that was made in ***FemLab*** can be used in ***MatLab*** where solution can be make by command ***lsim(…)***.

Let illustrate signal changes in time on impulse signal. The impulse initiates in the left section and transmits to the right section then reflects and transmits to the left section and so on. There is a sensor inside the tube and the signals on the sensor depicted on later pictures.



Pic. 7. Distance from the left inside section to sensor is 2m, left boundary is absolutely hard right – absolutely soft.



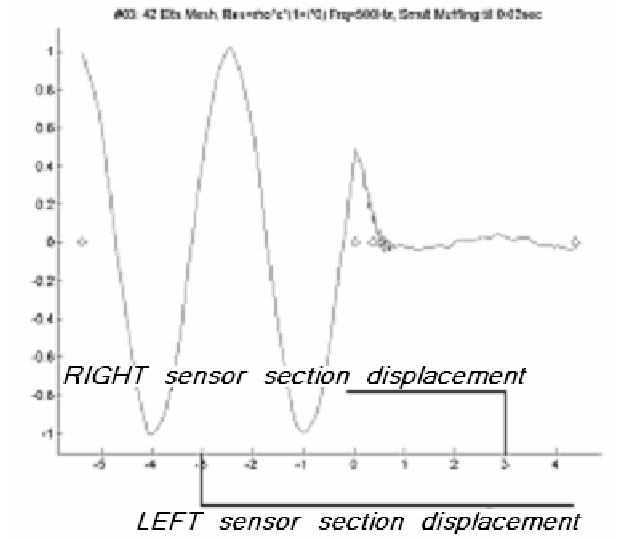
Pic. 8. Distance from the left inside section to sensor is 2m, both boundaries are absolutely hard.

Picture 7 corresponds to absolutely hard left boundary where positive pressure impulse initiates in the initial time moment. The sensor is placed in 2 meters from the inlet section. The right boundary is absolutely soft and impulse changed his phase during the reflection. Then impulse appeared in the sensor in opposite to the initial impulse phase, transmits to absolutely hard boundary and reflects from it without phase changing and so on. There is 0.04sec interval between the crossing the sensor by the wave with the same direction of velocity vector because the impulse transmit the 6 meters distance in the water. Then the situation is repeated.

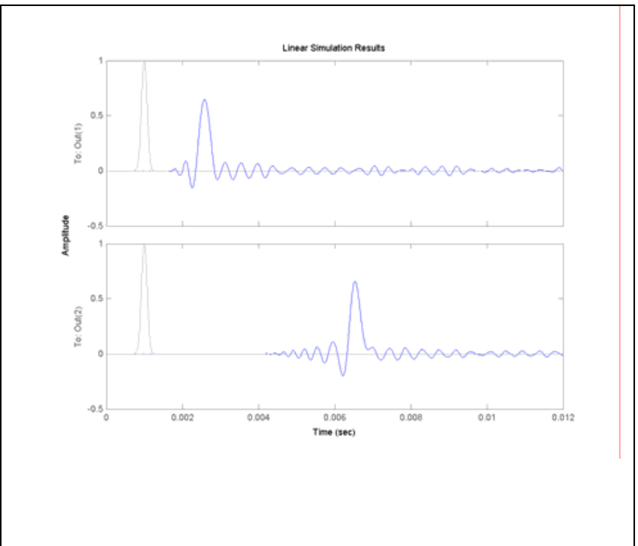
Picture 8 corresponds to absolutely hard both boundaries.

4 Sound muffling in state-space model

Let us use above described state-space model for the muffling task solving under the circumstances of different impedance in the outlet section of the tube. The temporal solution description of telegraph equation was made by using applied programs package ***MatLab.*** It is possible to make the decision for arbitrary point of space as a function of time. The coordinates of this point ought to be inserted in the discrepancy that was made by command ***femstate(…)*** of applied programs package ***FemLab.***



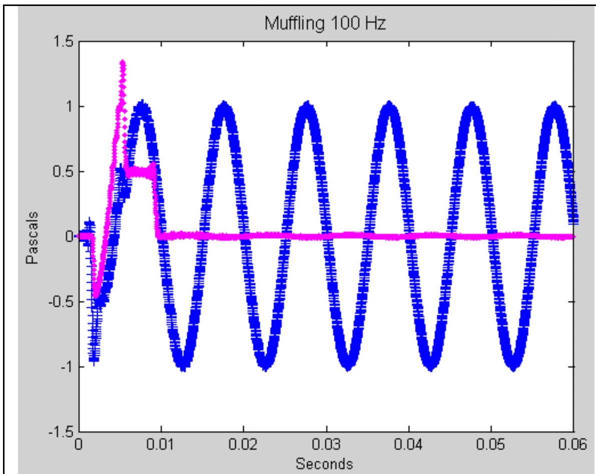
Pic. 9. Sensor displacement in the tube.



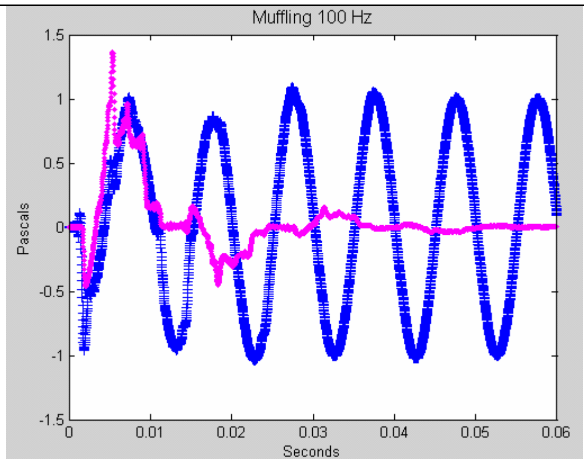
Pic. 10. Impulse transmission in the tube.

Let us displace sensors in three meters before and three meters after the muffling sources. The sensor displacement is depicted on the picture 9 where pressure wave is depicted on the muffled state. There is the illustration of the transmission of pulse in a tube with the impedance in outlet section which is equal to wave impedance of the medium in the picture 10. The probing impulse is depicted in the beginning by the gray color.

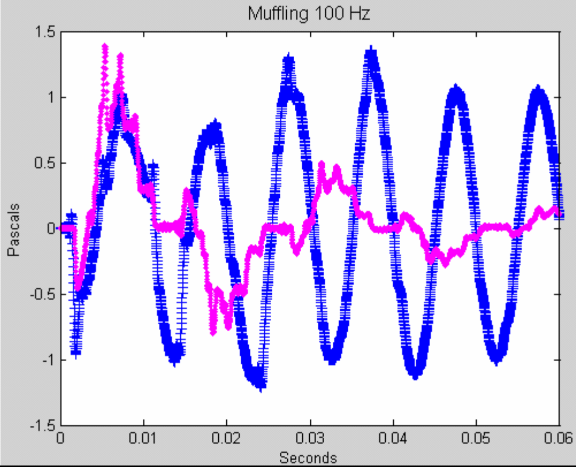
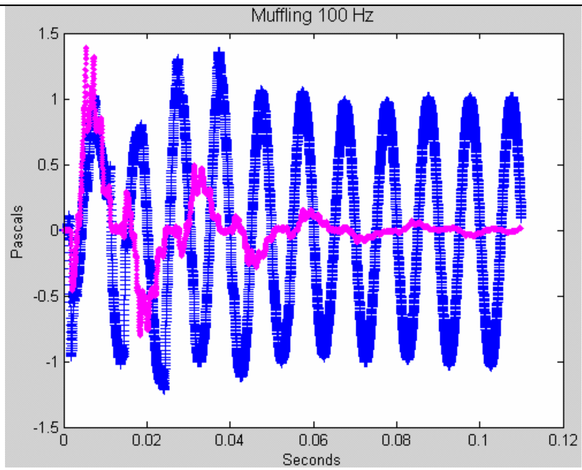
There are signals which are registered in the point before – there are blue crosses – and after – there are lilac (magenta) rhombuses – muffling sources.



Pic. 11. Frequency is 100 Hz. Outlet impedance is equal to wave impedance.



Pic. 12. Frequency is 100 Hz. Outlet impedance is equal to double wave impedance.

	
Pic. 13. Frequency is 100 Hz. Outlet impedance has mass type.	Pic. 14. Frequency is 100 Hz. Outlet impedance has elastic type.

The situation in the outlet section did not depend critically on the outlet section impedance but the transitional process time may be slightly different. There are the same pictures for the different frequency signals which are undertaken of muffling.

References

[1] M. A. Swinbanks. *The active control of sound propagation in long ducts* J. Sound Vib. 27, 411–436 (1973).

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