Рабочая программа дисциплины

1. Название дисциплины:
Theoretical fundamentals (principles) of acoustics. Part 2
(Propagation of acoustical waves in bounded media)

2. Лекторы. Lecturers.

2.1. PhD, Associate Professor Pavel N. Kravchun, Department of Acoustics, gedackt@mail.ru, tel. +7-916-382-80-62.

2.2. PhD, Senior Researcher Vladimir G. Mozhaev, Department of Acoustics, vgmozhaev@mail.ru , tel. +7-495-939- 29-27.

3. Аннотация дисциплины. Annotation.

The course presents a systematic description of basic theoretical concepts and methods of the classical linear acoustics, which permit to descript emission and propagation of sound waves in bounded media (waveguides, resonators, closed volumes) and solid bodies. The consideration is accompanied by mathematically rigorous treatment of phenomena, as well as analysis of assumptions and approximations adopted in the mathematical statement of problems. Knowledge of the basic theoretical concepts is necessary for further learning of the acoustical disciplines in the Department of Acoustics, and for independent practical studies.

4. Цели освоения дисциплины.

As a result of the learning of this discipline student will be able to use methods of mathematical physics for analytical description of acoustical waves in different problems of acoustics of bounded media. Student will know the physical laws of emission and propagation of linear acoustical waves in different situation.

5. Задачи дисциплины.

Tasks of the course are:
(1) systematic description of the theory of propagation of linear acoustical waves in bounded media (gases, liquids, solid bodies);
(2) use of the theory for solving of the typical problems of acoustics connected with the propagation of waves in bounded media;
(3) introduction to applied problems of acoustics of bounded media, examples from practice.

6. Компетенции.

6.1. Компетенции, необходимые для освоения дисциплины.
ПК-1, ПК-6

6.2. Компетенции, формируемые в результате освоения дисциплины.
ПК-3, ПК-4

7. Требования к результатам освоения содержания дисциплины

As a result of learning of the discipline student must know basic physical and mathematical models connected with propagation of acoustical waves in bounded media, methods of the mathematical description of acoustical waves in waveguides, resonators, closed volumes, plates and other solid

bodies, properties of waves and principles of functioning of different acoustical devices; be able to calculate parameters of acoustical fields in bounded media, know examples from practice.

8. Содержание и структура дисциплины.

Вид работы	Семестр			Всего
	7			
Общая трудоёмкость, акад. часов	72			72
Аудиторная работа:				
Лекции (lections), акад. часов	36			36
Семинары, акад. часов				
Лабораторные работы, акад. часов				
Самостоятельная работа, акад. часов	36			36
Вид итогового контроля (зачёт, зачёт с оценкой, экзамен)	зач.			

N раз-дела	Наименование раздела	Трудоёмкость (академических часов) и содержание занятий		Форма текуще-го кон-троля
		Аудиторная работа	**Самостоятельная работа**	
		Lections		
1	Acoustical waves in bounded liquid media. Regular waveguides.	*Lection No.1 (2 hours)* Normal waves in regular waveguides with rigid walls. Propagating and non-propagating (evanescent) modes. Cut-off frequencies. Dispersion of normal waves. Phase and group velocities.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	Home work (HW), Control work (CW)
		Lection No.2 (2 hours) Representation of a mode as a sum of plane waves. Waves in the flat layer at least one of which boundary is acoustically soft (model of a shallow sea). Cut-off frequencies. Low-frequency band of attenuation. Asymptotic of long ranges.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	
2	Waves in pipe sections. Acoustical four-terminal circuits. Resonators.	*Lection No.3 (2 hours)* Pipe section as a four-terminal circuit; characteristic matrix, input impedance (low-frequency approximation). Resonance frequencies of pipe section (eigen frequency spectrum of open and closed pipes).	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	HW, CW
		Lection No.4 (2 hours) Non-regular waveguides. A joint of two waveguides of different cross sections: the effect of impedance transformation. The Helmholz resonator, its resonance frequency.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	
3	Waveguides of slowly varying cross section.	*Lection No.5 (2 hours)* Equation for the wave propagation in waveguides of slowly varying cross section. The Webster equation. Decision of the Webster equation. Effective radius of waveguide. Cut-off frequency.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	
		Lection No.6 (2 hours) Conical, exponential and catenoidal megaphones. Decisions of the Webster equation for them. Megaphones and concentrators. Input impedance of megaphone, its frequency dependence. Input impedance of the conical megaphone, its specific properties. Examples of practical use.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	HW, CW
4	Principles of acoustical matching. Flat layer as a	*Lection No.7 (2 hours)* Acoustical matching systems. The solution of the matching problem for one flat layer (for one frequency). The characteristic matrix and	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	HW

	matching system.	input impedance of the flat layer. A short review of multi-frequency and broadband matching methods. Examples of practical use.		
5	Acoustic fields in closed volumes. Reverberation.	*Lection No.8 (2 hours)* Methods of description of acoustical fields in closed volumes. The statistical theory (a diffuse field), balance of acoustical energy in the closed volume. The standard reverberation time. The Sabine formula. Connection of absorption coefficient with impedance of surface. Local reacting impedance.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture. Preparing to the colloquium.	HW, C
		Lection No.9 (2 hours) *(1 hour)* Fundamentals of wave theory of reverberation. Axial, tangential and oblique modes. Reverberation of modes. Acoustical quality criterions for rooms and halls. *(1 hour).* Colloquium with tasks on themes of parts 1-5. General discussion on themes of parts 1-5.	*(2 hours)* Working with the lecture material and reading the recommended literature. Preparing to the colloquium.	
6	Упругие волны в изотропных твердых телах.	*Лекция №10 (2 часа)* Тензоры деформации и напряжения. Закон Гука. Уравнения движения изотропных твердых тел. Продольные и поперечные волны в твердых телах.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	HW, CW
7	Отражение и преломление акустических волн на границах раздела сред.	*Лекция №11 (2 часа)* Граничные задачи акустики твердого тела. Условия на границах раздела.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	HW, CW
		Лекция №12 (2 часа) Отражение горизонтально и вертикально поляризованных сдвиговых волн от свободной границы твердого тела.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	
8	Распространение акустических волн в ограниченных твердых телах.	*Лекция №13 (2 часа)* Метод отражения в задачах распространения граничных волн.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	HW, CW
		Лекция №14 (2 часа) Акустические волны на свободной поверхности твердого тела, на границах раздела твердых тел, твердого тела и жидкости.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	
9	Упругие волны в твердых пластинах.	*Лекция №15 (2 часа)* Определение характеристик горизонтально поляризованных мод методов потенциалов.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	HW, CW
		Лекция №16 (2 часа) Дисперсионные соотношения Рэлея-Лэмба.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture.	
10	Вертикально	*Лекция №17 (2 часа)*	*(2 hours)*	

	поляризованные моды твердых пластин.	Продольные и изгибные волны в твердых пластинах.	Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture. Preparing to the colloquium.	C
		Лекция №18 (2 часа) *(1 час)* Волны Лява: парциальное представление и дисперсионные свойства. *(1 час).* Коллоквиум по разделам 6-10 с решением задач по всем разделам. Общая дискуссия по разделам 6-10. Круглый стол.	*(2 hours)* Working with the lecture material and reading the recommended literature. Solving tasks on the theme of lecture. Preparing to the colloquium.	

Предусмотрены следующие формы текущего контроля успеваемости:

1. Home work (HW);
2. Colloquium (C);
3. Control work (CW);

9. Место дисциплины в структуре ООП ВПО

1. Дисциплина по выбору (без альтернативы).
2. Вариативная часть, профессиональный блок, спецкурс кафедры.
3. The course is based on the mathematical physics, general physics and the introductory course of the Department of acoustics “Introduction to acoustics”. The course is connected with some themes of the course “Theory of waves” which is read in the same semester.
   3.1. Дисциплины, которые должны быть освоены для начала освоения данной дисциплины:
   Mathematical analysis, General physics, Theoretical mechanics, Introduction to acoustics.
   3.2. Дисциплины, для которых освоение данной дисциплины необходимо как предшествующее:
   Further courses of the Department of Acoustics, scientific practice, research work.

10. Образовательные технологии

The course is exposed mainly in traditional way (on the desk). Some themes are illustrated by computer and projection equipment or color photographs. General discussions are held during two colloquiums. Final general discussion is held in the form of round table (students and lecturers).

11. Оценочные средства для текущего контроля успеваемости и промежуточной аттестации

Вопросы к зачету по спецкурсу «Теоретические основы акустики. Распространение акустических волн в ограниченных средах»

1. Normal waves in regular waveguides. Propagating and non-propagating (evanescent) modes. Cut-off frequencies.
2. Normal waves in flat layer. Cut-off frequencies. Asymptotic $kr>>1$.
3. Conical megaphone, its input impedance. Exponential and catenoidal megaphones.
4. Reverberation in closed volumes (statistical theory). Diffuse field. Balance of acoustical energy in closed volume.
5. Acoustical resonators of small wave size. The Helmholz resonator (input impedance, resonance frequency).
6. Flat liquid layer. The characteristic matrix and input impedance of the flat layer.
7. Non-regular waveguides. A joint of two waveguides of different cross sections: the effect of impedance transformation.
8. Equation for the wave propagation in waveguides of slowly varying cross section (the Webster equation). Decisions of the Webster equation.
9. Acoustical matching systems. The solution of the one flat layer matching problem (for one frequency).
10. Acoustic fields in closed volumes. The statistical theory, diffuse field. The standard reverberation time. The Sabine formula.
11. Fundamentals of wave theory of reverberation. Axial, tangential and oblique modes. Reverberation of modes.
12. Propagating and non-propagating (evanescent) modes in regular waveguide. Cut-off frequencies. Dispersion of normal waves. Phase and group velocities. Representation of a mode as a sum of plane waves.
13. Pipe section as a four-terminal circuit; characteristic matrix, input impedance (low-frequency approximation).
14. Тензоры деформации и напряжения. Закон Гука для изотропных тел.
15. Модули упругости при различных деформациях изотропных твердых тел (безграничное тело, пластина, стержень).
16. Метод поверхностей рефракции для анализа отражения и преломления упругих волн. Общие закономерности отражения и преломления акустических волн на границах

изотропных тел (условия фазового синхронизма, связь углов отражения и преломления, трансформация типов волн, критические явления).
17. Продольные и поперечные волны в твердых телах (уравнения движения, поляризация, связь между скоростями).
18. Волны Стоунли: условия существования, структура смещений и дисперсионные соотношения.
19. Коэффициенты отражения SV-сдвиговых волн от свободной границы изотропного твердого тела. Критические и брюстеровские явления при отражении.
20. Неоднородные упругие волны: фазовая скорость, поляризация, структура смещений и кривые рефракции.
21. Метод отражения в задачах распространения граничных волн. Комплексные углы отражения и неоднородные волны. Парциальное представление упругого возмущения на границе твердых тел. Определение скорости и поляризации граничной волны.
22. Волны Рэлея: решение методом отражения, дисперсионные характеристики и структура смещений.
23. Характеристики SH-мод в твердых пластинах (решение методом отражения, модовый состав, структура смещений).

Образцы задач для контрольных работ.
Examples of tasks for control works

1. The Helmholz resonator has the resonance frequency F_0=500 Гц at temperature t_0=20°C Calculate the resonance frequency of resonator for air with temperature t_1=200°C and t_2=-170°C. Consider air as ideal gas.
2. Calculate the lowest cut-off frequency for shallow sea with depth H=75 m.
3. Calculate the ratio of resonance frequencies of the Helmholz resonator with hydrogen and air. Gases consider as ideal, density of air is equal to 1,3 kg/m^3, hydrogen - 0,09 kg/m^3.
4. Calculate the input impedance of the conical megaphone (x_0=10 sm) in air for frequency 50 Hz.

Вопросы к коллоквиумам по спецкурсу «Теоретические основы акустики, часть 2»
Questions for colloquium

1. Determine the average absorption coefficient of the surface for diffuse field and calculate it for room with total square of surfaces S and volume V, if the reverberation time is equal to RT. Calculate for S=600 m^2, V=1000 m^3, T_p=1,5 s.
2. Determine the impedance matching. Calculate the thickness of flat layer and wave impedance of output medium for layer with wave impedance Z_0 and sound velocity c_0. Frequency of matching is *f*. Wave impedance of input medium is Z_1.
3. Resonators in architectural and aircraft acoustics (general description). Resonance equation in terms of input impedance of resonator. Calculate the resonance frequency for resonator of small wave size in air with pipe *l*=10 sm, $2r_0$=4 sm and spherical volume 2R=20 sm.
4. Show the vertical dependence of sound pressure in shallow sea with depth H for 3 lowest modes for rigid bottom and soft bottom.

Образцы задач для самостоятельного решения (домашних заданий)
Examples of tasks for home works

1. Calculate the frequency range in which the sea with depth H=75 м and soft bottom will not transmit acoustic waves. Draw the depth dependence of sound pressure and phase and group velocities for 3 lowest modes. Bottom consider flat, sound velocity independent on depth (c=1500 m/s).
2. Calculate density of medium, if the Helmholz resonator has pipe l=4 sm and r=1 sm, volume V=1260 sm^3, and resonance frequency f=850 Hz (gas is ideal).

3. Flat layer with thickness l, wave impedance z_0 and sound velocity c_0 matches 2 media, wave impedance of one of them is z_1. Calculate wave impedance of the second medium and frequency of matching.
4. Calculate the output impedance Z_l for the pipe with length l and cross section S ($\sqrt{S} << \lambda$), for which the input impedance is equal to Z_l.
5. Определить частоты перехода и построить дисперсионные кривые для первых трех мод Лява в структуре CdS-SiO. Скорости поперечных волн в этих материалах равны, соответственно, 2.5 и 3.5 км/с.
6. Рассчитать частоту отсечки моды $\mathbf{a_3}$ в стальной пластине толщиной 1 см. Построить ее дисперсионную кривую.
7. Определить толщину алюминиевой пластины, в которой на частоте 1 МГц возможна упругая волна со скоростью, равной скорости звука в воздухе.
8. Чему равно приближенное значение фазовой скорости 5-й моды Сезавы в структуре ZnO-SiO на частоте 1000 МГц? Толщина пленки ZnO – 100 мкм. Скорости сдвиговых волн в пленке и подложке равны, соответственно, 3 и 3.5 км/с.

12. Учебно-методическое обеспечение дисциплины

Basic literature:

1. M. A. Isakovich. General Acoustics. Nauka, Moscow, 1973 (in Russian).
2. E. Skudrzyk. The Foundations of Acoustics. Springer - Verlag, Wien - New York, 1971.
3. S. N. Rzevkin. The Course of Lectures on the Theory of Sound. Moscow University Press, Moscow, 1960 (in Russian).
4. Pierce A. Acoustics: An Introduction to Its Physical Principles and Applications. – Acoustical Society of America, 1989.
5. V.A.Krasil'nikov, V.V.Krylov. Introduction to physical acoustics. – Nauka, Moscow, 1984 (in Russian).
6. L. M. Brekhovskikh. Waves in Layered Media. Academic Press, New York, 1960.
7. P. M. Morse. Vibration and Sound. McGrow - Hill Book Co., Inc., New York, 1948.
8. Ландау Л.Д., Лифшиц Е.М. Теория упругости. – М.: Наука, 1965.
9. Auld B.A., Acoustic fields and waves in solids, N.Y.: Wiley & Sons, v.II, 1974.
10. I. A. Victorov. Sound surface waves in solids. Nauka, Moscow, 1981 (in Russian).
11. Гринченко В.Т., Мелешко В.В. Гармонические колебания и волны в твердых телах. - Киев: Наук. думка, 1981.
12. Acoustics in tasks (edited by S.N. Gurbatov and O.V. Rudenko).–M. Nauka, 1996. (in Russian).

Additional literature:

1. L. Brillouin, M. Parodi. Wave Propagation in Periodic Structures. Masson et C-ie , Dunod editeurs, Paris, 1956, (in French).
2. V.V.Krylov. Fundamentals of theory of emission and scattering of sound. - Moscow: Moscow State University Publ., 1989 (in Russian).
3. Acoustics in tasks (edited by S.N. Gurbatov and O.V. Rudenko).– M.: Fizmatlit, 2009. (in Russian).

Web site:: http://acoustics.phys.msu.ru

13. Материально-техническое обеспечение

In accordance with the requirements of p. 5.3 of the MSU educational standard on the direction "Physics".
Lecture-room No 3-65.