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Simulation of Acoustic Characteristics in the Vector-Phase Field of the Horn at Low Frequencies

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Methods of computer technology are widely used in modern acoustics. They are used to visualize the structures of wave fields, when the geometry of the boundaries and the physical properties of the region where the waves propagate are known. When using these methods, the location of the emitters and receivers is usually controlled. At present, known methods based on the use of information recorded only by pressure transducers have reached the limit. Vector-phase characteristics methods have previously been used to study the spatial distribution of the main characteristics of sound and infrasonic fields. But to study the structure of the acoustic field in the speakers of finite length, they have not been used so far. This is the relevance of the chosen topic. In this work the research of acoustic characteristics of a catenoid loudspeaker at low frequencies and a vector - phase field of a loudspeaker by numerical methods is given. The following tasks are solved: compiling an analytical review of research methods of sound fields; description of the mathematical apparatus of wave propagation in the catenoid mouthpiece; simulation of acoustic characteristics in the vector - phase field of the loudspeaker at low frequencies in ANSYS. In loudspeakers, nonlinear distortions associated with the heterogeneity of the magnetic field in the gap of the magnetic circuit and, in violation of Hooke's law, are not so significant. The defining moment in the development of the theory of wave radiation by loudspeakers was the publication of Webster's work, in which the wave equation is given. Although the membrane performs a simple harmonic oscillation. The problem of amplifying the action and direction of the acoustic signal was solved, during which a catenoid horn was chosen. The propagation of the wave is no longer sinusoidal, and contains in addition to the main harmonics of higher orders. That is, nonlinear effects inside the speaker are detected. Previously, the design of sound generators did not provide structural elements that reduce or eliminate completely nonlinear effects in the speaker, which reduced the efficiency of generating the sound of the fundamental tone. The solution of the problem of modeling the process of propagation of the second harmonic along the horn is considered. In order to calculate the acoustic characteristics in the cavity of the catenoid loudspeaker, it is necessary in ANSYS CAD.

Keywords: Low-Frequency, Vector-Phase Characteristics, Modeling, Process, Propagation, The Second Harmonic, Horn, Catenoid, ANSYS.

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1. INTRODUCTION

So far, the existing methods based on usage of the information registered only by pressure transducers reached their limits [1]. In his doctoral dissertation, N. A. Umov pointed out the importance of acoustic field characteristic received by means of multiplying instantaneous pressure values in wave and oscillation speed of environment particles known as Umov Vector [1].

Vector-phase characteristic methods were previously used to examine special distribution of general sound and infrasound field characteristics. Though they hadn’t been used to examine the structure of acoustic field in finite length horns until now. This is why the chosen topic is so significant.

Computing technology methods have become widely used in modern acoustics [1-4]. Though they are applied to visualize the structures of wave fields when geometry of the borders and physical properties of wave distribution area are known. The location of oscillators and transducers is well-controlled while using these methods.

The aim of this paper is studying the structure of acoustic field at low frequencies in the horn cavity, examining acoustic characteristics of the catenoidal horn at low frequencies and vector-phase field of the horn by means of numerous methods.

The following tasks are solved herein:

– Composing an analytical review of sound field examination methods.

– Describing the mathematical tool of wave distribution in the catenoidal horn.

– Modelling acoustic characteristics in the vector-phase horn field at low frequencies in ANSYS.

2. ANALYTICAL REVIEW OF SOUND DISTRIBUTION IN HORN CAVITY

Infrasound frequency range hasn’t been analyzed in famous papers dedicated to examining wave radiation by sound generators with horns before.

The defining moment in the development of the theory of wave radiation by horns was publishing the paper by A. G. Webster [1] where a wave equation was presented in the form of

$$\varphi = c^2 \frac{\partial^2 \varphi}{\partial x^2} + c^2 \frac{\partial \varphi}{\partial x} \cdot \frac{\partial}{\partial x} (\lg S), \qquad (1)$$

where φ-potential, c-sound speed, x-actual position along the horn axis, S-intersection area.

In the research papers dated the first half of the 20th century, wave distributions in the horn cavities in the framework of linear acoustics were analyzed. Those were the papers [5-7]. Distribution of acoustic waves in the horn cavities was analyzed while receiving them of infinite length, finite length, as well as resonance phenomena in the finite length horn cavities [1].

In the following papers final amplitude waves were analyzed. This is the case when a high amplitude wave is being transformed into a shock wave while distributing and breaks into separate harmonics [8]. In horns, nonlinear distortions are connected with nonhomogenity of the magnetic field in the magnetic circuit gap and, due to breaking the Hooke's law, not so significant. The factors connected with nonlinear phenomena in the horn and the prehorn camera are the most significant here. At the same time, although the membrane performs simple harmonic oscillation, wave distribution already takes place not according to the sinusoidal law and comprises high-order harmonics in addition to the general one. So, nonlinear effects inside the horn are recognized.

The exact shape of a horn determinates the law of change of cross-sectional area. The longitudinal sections of the most often occurring horns are depicted in Fig. 1.

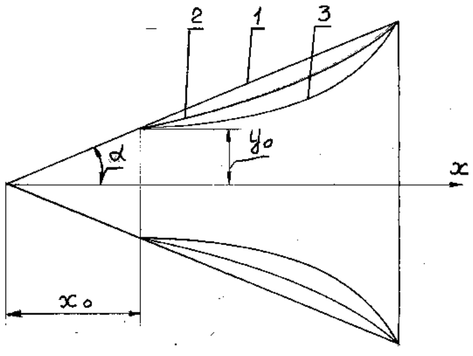


Fig. 1 – The shapes of horns: 1 – the conical shape; 2 – the exponential shape; 3 – the cathenoid shape; x_0, y_0 are coordinates of the initial cross-section of a horn throat; α is apex angle

It propagates along the horn and the nonlinear acoustical effects have become significant at some distance from the horn throat. This appears in transferring of the energy part of a fundamental tone wave to the higher order harmonics [8], the largest share of energy falling on the second harmonic. It is necessary to realize damping the second harmonic to guarantee effective emission on a major tone frequency.

The sound pressure in each harmonics propagating along the axis of the horn is described by equation, binding the value of sound pressure (*p*) in any point (*x*) along the longitudinal axis *OX* of the horn, the peak value of sound power in the horn throat (pm) and the exponent of the horn extension (β).

To the horn exponential form.

To the first and second harmonics the equation (1) is written in the form of

$$p_i = p_{mi}\exp(-0.5\beta x). \quad (2)$$

Let us consider the process of changing of the sound pressure amplitude in the second harmonic $p_{2\Sigma}$ along the axis of the horn not only at the expense of axial section changing, but also at the expense of nonlinear effects' appearing.

The theory of wave of finite amplitude lets us know that as range of the wave the amplitude of second harmonic is changed by the law

$$p_2 = Cp_1^2 x \ , \quad C = \frac{1}{4}\cdot\frac{\gamma+1}{\gamma P_0}\cdot\frac{\overline{\omega}}{c_0}. \quad (3)$$

Where *C* is parameter, γ is specific gravity of air, p_0 is air pressure, ω is circular frequency, c_0 is speed of sound in a medium.

The sound pressure amplitude of the first harmonic $p_{1\,cath}$ and the second harmonic p_{2cath} along the horn in cathenoid shape is changing along the axes according to the relations

$$p_{1\,cath} = p_{m1}/ch\,(\beta x) \ , \ p_{2\,cath} = p_{m2}/ch\,(\beta x). \quad (4)$$

$I = 1, 2.$

Changing the sound pressure of the second harmonic $p_{1\,cath}$ at small value in the horn throat p_{m1} is depicted in Fig. 2.

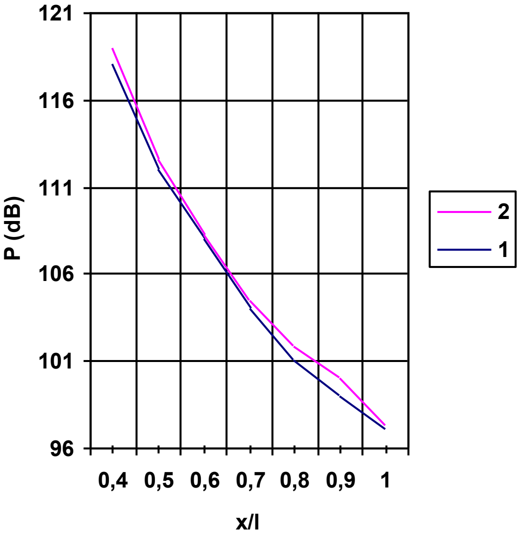


Fig. 2 – Changing 1 – harmonic along the axes of a horn. the theoretical curve; 2 – the experimental values

It is shown that at low frequencies catenoidal horns should be used for effective sound radiation [1].

Previously, there were no structural elements in sound generator design to reduce or completely eliminate nonlinear effects in a horn, so the effectiveness of the fundamental tone sounding was impaired. But below we can see the task solution on modelling the second harmonic distribution along the horn, which helped to define the place for positioning of the second harmonic dampers [8].

A mathematical analytical tool for equation solution was developed in [8].

In accordance with technique we can define $p_{2\Sigma}$ as:

$$p_{2\Sigma} = \frac{2Cp_{m1}^2}{\beta}[\exp(-0.5\beta x) - \exp(\beta x)]. \quad (5)$$

The rate of change of the second harmonic amplitude is solved by the equation [8]

$$\frac{dp_2}{dx} + \frac{\beta}{2}p_2 = Cp_{m1}^2\exp(-\beta x). \quad (6)$$

In sound's broadcasting horns of the exponential form are commonly used for the reproduction of high frequencies. Now the attention is paid to the efficient reproduction in the low-frequency region. In this case using of horns of catenoid shape is more profitable [8].

Let a wave of finite amplitude with quantity of sound pressure $p_{2\Sigma}$ be realized in a horn throat. The walls of the horn are considered absolutely stiff in comparison with the air quality filing it.

Then we are finding the expression for the nonlinear distortion nonlinearity coeficient vcath and for the second harmonic amplitude p_{2cath} in case of horn in form of a cathenoid. The particular equation solution meeting the indicated boundary condition for a catenoidal horn is [8]:

$$p_{2\,kam} = \frac{2Cp_{m1}^2}{\beta ch(\beta x)}[arctg(\exp(\beta x)) - arctg(1)]. \quad (7)$$

Now, having a formula (7) for calculating the second harmonic amplitude, we can write down the expression of the nonlinear distortion ratio [8]:

$$v_{kam} = 2Cp_{m1}[arctg(\exp(\beta x)) - arctg(1)]/\beta. \quad (8)$$

We can see from the indicated papers that the mathematical tool for defining the sound pressure in low and high amplitude waves in different horn cavities has already been defined. But for now, more up-to-date research methods have appeared with the usage of software environment. Let us consider one of the methods based on the usage of ANSYS.

3. PROBLEM DEFINITION

Modelling acoustic characteristics in the vector-phase horn field at low frequencies in ANSYS.

The solution of linear and nonlinear, stationary and nonstationary spatial problems of deformable body mechanics and construction mechanics (including nonstationary geometrically and physically nonlinear problems of contact construction element interaction), the problems of fluid mechanics, heat transfer, electrodynamics, acoustics, related filed mechanics is now performed by means of using the up-to-date computing system ANSYS.

Using modelling and analysis in some industry fields helps to avoid expensive and long-term development cycles like 'engineering – producing – testing'. The system is based on the geometric kernel Parasolid. With the help of ANSYS the visualization tools for the dynamic 3D-printing segment are used. ANSYS solutions help to design products for 3D-printing made of various materials, including the SLM laser printing with fine powder metal.

Now the ANSYS solutions are spreading to almost all the segments of the engineering field starting from heavy engineering, defense industry, aerospace engineering and up to microelectronics, medicine, as well as simulators for software testing.

In order to calculate acoustic characteristics in the catenoidal horn cavity, the following steps in the CAD system ANSYS should be performed [9, 10]:

1) launch the software, upload the preliminary generated 3D-model of the horn to ANSYS,

2) select the option 'Modal' in the context menu and click on it,

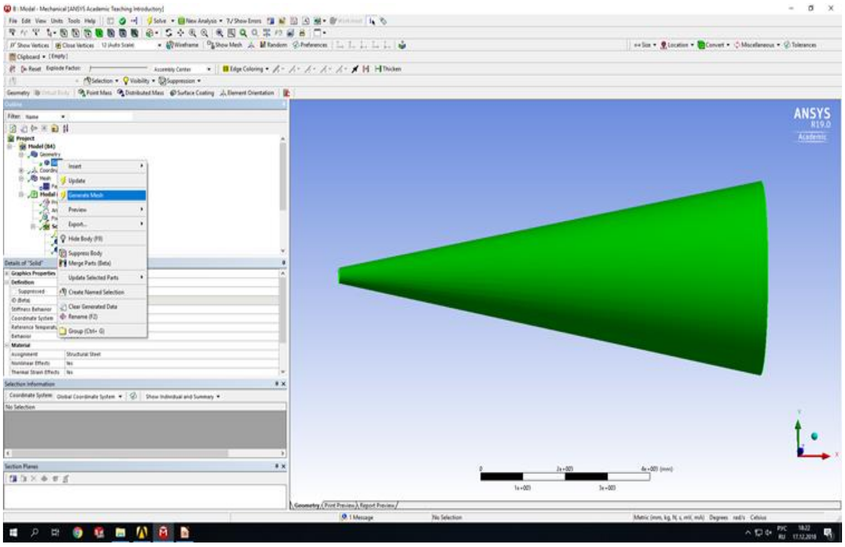
3) generate the grid of the horn 3D-model in ANSYS by means of selecting 'Generate Mesh' in the context menu (see Fig. 1),

4) select the option 'Fixed Support' in the submenu 'Modal' (b5) and use it,

5) select 'Mesh' in the submenu 'Modal', then right click on 'Face Meshing' and select 'Generate Mesh' in the context menu,

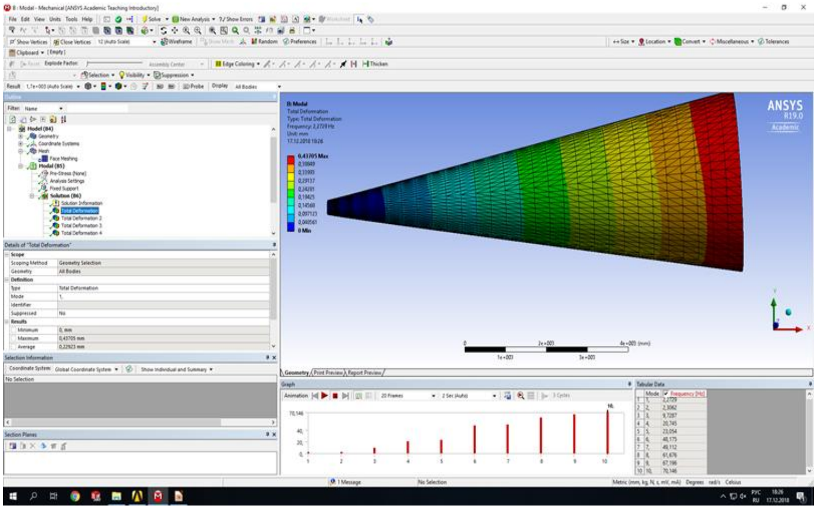
6) after ANSYS processes all the data and generates 3D-models of the horns at low frequencies, we have got the results.

Figures 2, 3, 4, 5 represent the pictures of acoustic wave distribution in a horn at separate frequencies. Fig. 2 – for the frequency 2.745 Hz. Fig. 3 – for the frequency 5.034 Hz. Fig. 4 – for the frequency 9.7287 Hz. Fig. 5 – for the frequency 20.745 Hz.



Assignment: Structural Steel
Nonlinear Effects: Yes
Thermal Strain Effects: Yes
Coordinate System: Global Coordinate System
Show Individual and Summary
No Selection

Fig. 3 – The grid of the horn 3D-model in ANSYS



B: Modal
Total Deformation
Type: Total Deformation
Frequency: 2,2729 Hz
Unit: mm
17.12.2018 18:26

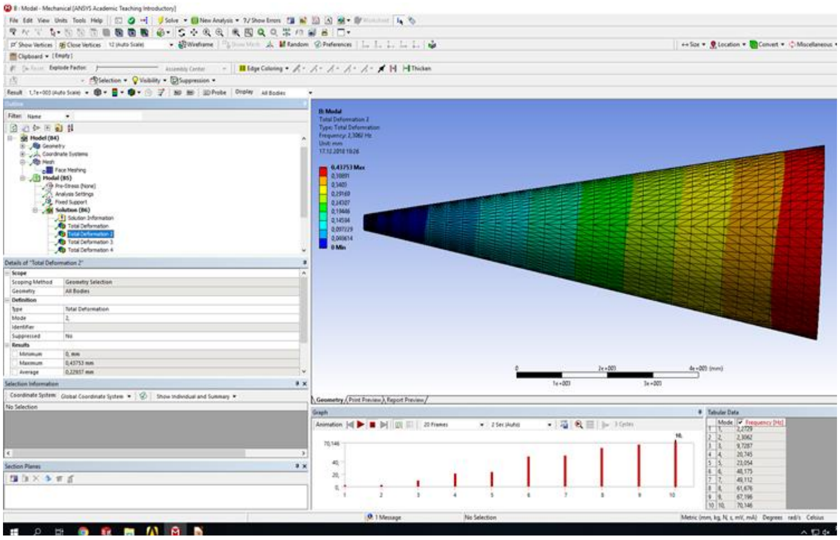
Details of "Total Deformation"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
Mode	1,
Identifier	
Suppressed	No
Results	
Minimum	0, mm
Maximum	0,43705 mm
Average	0,22923 mm

Tabular Data

	Mode	Frequency [Hz]
1	1,	2,2729
2	2,	2,3062
3	3,	9,7287
4	4,	20,745
5	5,	23,054
6	6,	48,175
7	7,	49,112
8	8,	61,676
9	9,	67,196
10	10,	70,146

Fig. 4 – The picture of acoustic wave distribution in a horn at the frequency of 2.745 Hz



B: Modal
Total Deformation 2
Type: Total Deformation
Frequency: 2,3062 Hz
Unit: mm
17.12.2018 18:26

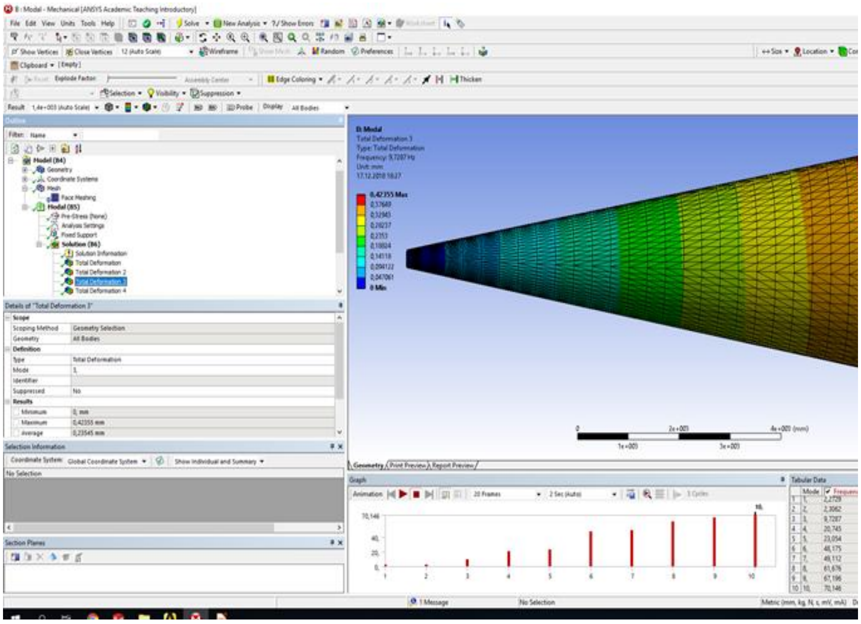
Details of "Total Deformation 2"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
Mode	2,
Identifier	
Suppressed	No
Results	
Minimum	0, mm
Maximum	0,43753 mm
Average	0,22937 mm

Tabular Data

	Mode	Frequency [Hz]
1	1,	2,2729
2	2,	2,3062
3	3,	9,7287
4	4,	20,745
5	5,	23,054
6	6,	48,175
7	7,	49,112
8	8,	61,676
9	9,	67,196
10	10,	70,146

Fig. 5 – The picture of acoustic wave distribution in a horn at the frequency of 5.034 Hz



B: Modal
Total Deformation 3
Type: Total Deformation
Frequency: 9,7287 Hz
Unit: mm
17.12.2018 18:27

Details of "Total Deformation 3"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
Mode	3,
Identifier	
Suppressed	No
Results	
Minimum	0, mm
Maximum	0,42355 mm
Average	0,23545 mm

Tabular Data

	Mode	Frequen
1	1,	2,2729
2	2,	2,3062
3	3,	9,7287
4	4,	20,745
5	5,	23,054
6	6,	48,175
7	7,	49,112
8	8,	61,676
9	9,	67,196
10	10,	70,146

Fig. 6 – The picture of acoustic wave distribution in a horn at the frequency of 9.7287 Hz

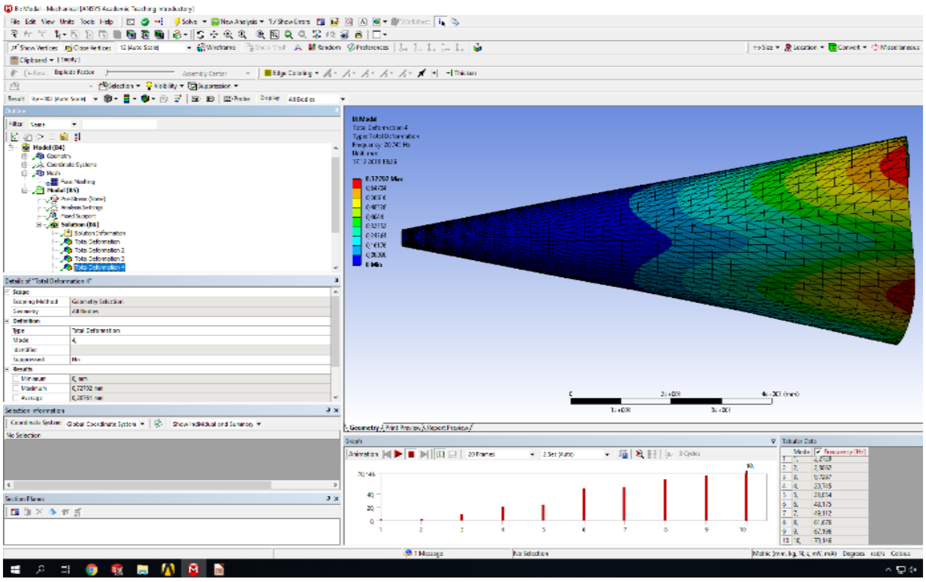


Fig. 7 – The picture of acoustic wave distribution in a horn at the frequency of 20.745 Hz

4. CONCLUSION

The research papers dedicated to sound distribution in horn cavities were analyzed.

Modelling of acoustic characteristics in vector-phase horn field at low frequencies with the help of ANSYS was developed.

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Моделювання акустичних характеристик у векторно-фазовому полі рупора на низьких частотах

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У сучасній акустиці широко застосовуються методи обчислювальної техніки. Вони використовуються для візуалізації структур хвильових полів, коли відомі геометрія кордонів і фізичні властивості області, де поширюються хвилі. При використанні цих методів зазвичай контролюється розташування випромінювачів і приймачів. В даний час відомі методи, засновані на використанні інформації, що реєструється тільки датчиками тиску, досягли межі. Для дослідження просторового розподілу основних характеристик звукового та інфразвукового полів раніше використовувалися методи векторно-фазових характеристик. Але для вивчення структури акустичного поля в колонках скінченної довжини вони досі не використовувалися. У цьому і полягає актуальність обраної теми. У роботі наведено дослідження акустичних характеристик катеноїдного гучномовця на низьких частотах та векторно-фазового поля гучномовця чисельними методами. Вирішуються наступні завдання: складання аналітичного огляду методів дослідження звукових полів; опис математичного апарату поширення хвилі в катеноїдному мундштуку; моделювання акустичних характеристик у векторно - фазовому полі гучномовця на низьких частотах в ANSYS. У гучномовцях нелінійні спотворення, пов'язані з неоднорідністю магнітного поля в розриві магнітопровода і порушенням закону Гука, не настільки значні. Визначальним моментом у розвитку теорії випромінювання хвиль гучномовцями стала публікація роботи Вебстера, в якій наведено хвильове рівняння. Хоча мембрана здійснює прості гармонійні коливання. Вирішено задачу посилення дії та направлення акустичного сигналу, при цьому обрано катеноідний рупор. Поширення хвилі більше не є синусоїдальним, а містить крім основних гармонік вищих порядків. Тобто виявляються нелінійні ефекти всередині динаміка. Раніше в конструкції звукогенераторів не передбачалися конструктивні елементи, що зменшують або повністю усувають нелінійні ефекти в гучномовці, що знижувало ефективність генерації звуку основного тону. Розглянуто рішення задачі моделювання процесу поширення другої гармоніки по рупору. Щоб розрахувати акустичні характеристики в порожнині катеноїдного гучномовця, необхідно в ANSYS CAD.

Ключові слова: Низькочастотні, Векторно-фазові характеристики, Моделювання, Процес, Розповсюдження, Друга гармоніка, Рупор, Катеноїд, ANSYS.