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Possibility of Using a Membrane with Plastic Foil for Transferring Sound Signals of-Human Speech

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The paper presents the results of the investigation of a possibility of sound signal i.e. human speech transfer by a membrane with plastic poly(ethylene terephtalate) foil. The basic terms of poly(ethylene terephtalate) and the acoustic characteristics of polymeric materials are mentioned. The procedures and equipment used for the determination of functional characteristics of a talking membrane containing poly(ethylene terephtalate) foil are described. The obtained results of the investigation of the acoustic properties of the talking membrane (transfer frequency characteristics, speech understandability index and speech reduction factor) are acceptable and they point out to a possibility of using poly(ethylene terephtalate) foil in the equipment for transfering sound signals of human speech

Key words: **plastics, poly(ethylene terephtalate), foil, membrane, acoustic properties, speech transfer, speech signal.**

Introdustion

POLYMERIC materials are used in almost all areas of human activities. It is considered that there are a few thousands of polymeric materials. Owing to a unique set of physical, chemical, thermal, optical, acoustic and other properties, plastic materials are used in different areas such as energy production, civil engineering, medicine, transport, nutrition, clothing, sports, entertainment arts, etc [1]. The possibility of using plastic materials for the production of parts with good acoustic transfer characteristic is of wide interest.

Acoustic characteristics of polymeric materials

The term *sound* implies all phenomena connected with mechanical oscillations the frequency of which is within the sensitivity limits of human hearing [2]. The sound propagates through materials in a form of mechanical waves and the human ear registers a frequency between 20 Hz and 20 000 Hz. The acoustic properties of polymeric materials depend on material composition, homogeneity, density and temperature. The shape and physical state of polymeric materials, especially elastic characteristics, have an important influence on acoustic properties. The sound transfer is affected by sound wave frequencies.

For the propagation of longitudinal waves through polymeric materials, the following equation can be used [3]:

$$C_l = f\left(E/\rho\right)$$

where:

C_l - speed of longitudinal wave propagation, (in m/s),
f - shape material factor,
E - material modulus of elasticity, (in Pa) and
ρ - material density, (in g/cm^3).

The modulus of elasticity or Young’s modulus denotes a material characteristic which is equal to the ratio between the mechanical tension force and the corresponding elongation. Therefore, rigid materials have higher values of the modulus of elasticity than flexible materials. A value of the modulus of elasticity may be temperature dependent and may strongly vary in a narrow temperature range around so-called “glass transition temperature”. The term “glass transition temperature” denotes a property of thermoplastic and other polymeric materials in a particular temperature range in which molecules perform a transition from a “frozen” state into a state with an increased Brownian motion. Therefore, rigid, hard and brittle materials change to elastic, soft and rubber like materials. A value of Young’s modulus of elasticity of the material can strongly vary around the glass transition temperature. Since a glass transition temperature range can also be dependent on the frequency of acoustic waves, the term glass transition temperature, in the context of this application, denotes the glass transition temperature at the respective resonance frequency of the acoustic device. Such a resonance frequency may be between essential 200 Hz and essential 10000 Hz, particularly in the range between 200 Hz and 1300 Hz [4].

The portions of absorbed sound versus sound propagating speed for different materials are presented in Fig.1 [3].

At a temperature of 20^{o}C sound propagates through air at 344 m/s. The velocity of sound propagating through some polymeric materials is higher and through other polymeric materials is lower than the mentioned value. The speed of

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sound propagating through elastomeric materials (depending on elasticity, filler and shape) is from 40 m/s to 1500 m/s. The speed of sound propagating through cellular materials and elastomeric materials of specific composition is very low, i.e. absorption of sound is very high. Owing to the characteristics like this, the mentioned materials are used for soundproofing. However, polymeric materials can act as a source of sound waves. An example is polystyrene, through which sound is moving at 3000 m/s producing a clear, metallic sound. Another example is hard rubber which produces a dark, quiet sound. Owing to the characteristics like this, polymeric materials are used nowadays for the production of music instruments. Some electrical music instruments, as well as pipes for organs, are produced from polystyrene, polymethylmetacrylate and other polymers.

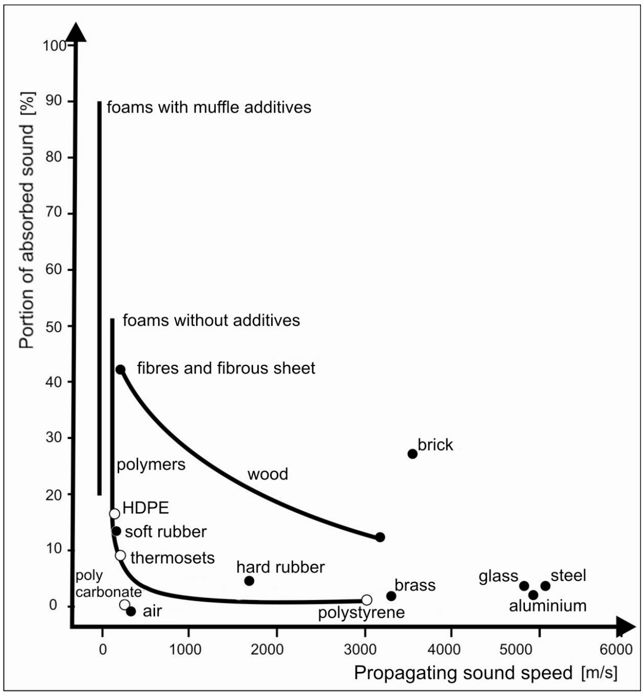

Figure 1. Portions of absorbed sound versus sound propagating speed for different materials

Up to the 1950s, upper parts of drums, i.e. parts that produce sound, were almost exclusively made of animal skin. The upper parts (heads) of modern drums are now almost always made of plastic materials. Materials from polyester group are usually used, out of which poly(ethylene terephtalate) most often.

Poly (ethylene terephtalate)

During the second part of the last century, overall world production of synthetic plastics and fibres was so increased that is now higher than the production of steel materials [5]. It is shown that plastic materials have the lowest energy cost of all comparable materials and cause less enviroment pollution in their production and fabrication [6].

Poly(ethylene terephtalate) is thermoplastic material of a linear structure from the polyester group. The first attempts of saturated linear polyester production were performed by Carothers and coworkers about 1930s. These early aliphatic materials had low softening points and limited hydrolytic stability. An important improvement was made by using aromatic compounds [7].

For polyester production, including poly(ethylene terephtalate), all methods of esterification known in the organic chemistry are used.

Practically, a basic unit of poly (ethylene terephtalate) i.e. bis (hydroxyethylterephtalate) is obtained by the transesterification reaction between ethylene glycol and dimethyl terephtalate.

Poly (ethylene terephtalate) is produced by the polycondensation of bis (hydroxyethylterephtalate) in accordance with reaction [8]:

$$HOCH_2CH_2O\text{-}CO\text{-}C_6H_4\text{-}CO\text{-}OCH_2CH_2OH \rightarrow$$

$$\rightarrow \{\text{-}OCH_2CH_2CO\text{-}C_6H_4COO\text{-}\}_n + HOCH_2CH_2OH$$

Except for polyethylene and polypropylene, polyesters are the most produced polymeric materials. Poly(ethylene terephtalate) is used for synthetic fibres (in excess of 60% wt) of overall production of this polymer, for packaging i.e. bottles for beverages and other liquid products (about wt 30%), for films (about wt 3%), and there are injection moulding types (about 5 wt %).

For the production of drum parts, it is especially important that biaxially oriented poly(ethylene terephtalate) foil, besides acoustic characteristics, has good mechanical properties (impact resistance and puncture resistance) and significant resistance to moisture, heat, sunlight and many chemicals [9, 10].

All this opens possibilites for using polymeric materials for production of parts with good acoustic characteristics, which are then assembled in other products. For example, for the transfer of sound waves of human speech, membranes with parts of polymeric materials are used.

Experimental part

The investigations and measurements in this paper are planed in a way to examine the possibility of transferring sound waves i.e. human speech by membranes with poly(ethylene terephtalate) foils.

The material used is stabilized biaxial oriented polyethylene terephtalate foil, trade name YUBORLEN, produced by the polyester foil plant in Bor.

The membrane, intended for speech transfer, consists of two metal perforated sheets and stabilized biaxial oriented polyethylene terephtalate foil in the middle. A talking membrane is built in a product which protects a user from the surrounding polluted atmosphere.

In this paper the following terms are used:

- transfer frequency characteristic represents a curve of sound pressure versus frequency,
- sound pressure is an amount of the pressure change caused by sound waves that propagate through the fluid,
- according to Weber-Feckner law, physiological senses accept excitation by the logarithm law i.e. hearing sense feels the change of sound intensity as a logarithm of sound intensity [2, 11]. Having in mind the initial definition of the sound level and the dependence of sound intensity versus pressure, an expression for the sound pressure level is obtained as the logarithm ratio of a particular sound pressure and the threshold sound pressure:

$$L = 20 \log P / P_0$$

where is:

L - sound pressure level (in dB),
P - sound pressure (in MPa),
P_0 - threshold sound pressure (in MPa).

The loudness or the sound level of 0 dB i.e. the sound intensity of 10^{-12} W/m^2 represents the threshold of hearing [2].

- average sound pressure level represents the logarithm ratio of the average sound pressure and the threshold sound pressure:

$$L_{SR} = 20 \log P_{SR} / P_0$$

where:

L_{SR} - average sound pressure level (in dB),
P_{SR} - average sound pressure from 20 Hz to 4000 Hz (in Pa),
P_0 - threshold sound pressure (in Pa).

The average sound pressure level can be approximated by a sound pressure level line that intercepts a transfer frequency characteristic in a way to create two equal areas limited by the frequency characteristic curve above and under the average sound pressure level.

- lower limit frequency represents the first intersection of the 10 dB line sound pressure level, under the average sound pressure level, and the transfer frequency characteristic in the raising direction
- upper limit frequency represents the last intersection of the 10 dB line sound pressure level, above the average sound pressure level, and the transfer frequency characteristic in the falling direction
- loss of the sound pressure level represents a difference between the sound pressure level without a talking membrane and the sound pressure level with a talking membrane:

$$S = L_{BGM} - L_{SGM}$$

where:

S - loss of the sound pressure level, (in dB),
L_{BGM} - sound pressure level without a talking membrane, (in dB),
L_{SGM} - sound pressure level with a talking membrane, (in dB).

- speech understandability index is defined as a ratio of the number of correctly received logotomes for the speech with a talking membrane and the number of correctly received logotomes for the speech without a talking membrane:

$$I_m = \Sigma a_{gmi} / \Sigma a_{gi} = R_{gm} / R_g$$

where:

$$I_m = \Sigma\ a_{gmi} / \Sigma agi = R_{gm} / R_g$$

I_m - speech understandability index,
a_{gmi} - number of correctly received logotomes for the speech with a talking membrane,
Σa_{gi} - number of correctly received logotomes for the speech without a talking membrane,
R_{gm} - logotome understandablility for the speech with a talking membrane,
R_g - logotome understandability for the speech without a talking membrane.

- speech reduction factor represents the reduction of the distance at which the speech is understandable with the use of a talking membrane related to the distance at which the speech is understandable without the use of a talking membrane.

The speech reduction factor can be calculated by the expression:

$$F_R = D_{DGM} / D_{SGM}$$

where:

F_R - speech reduction factor,
D_{DGM} - distance from the artificial head without a talking membrane at which hearing and understanding of reproduced speech are complete, (in m),
D_{SGM} - distance from the artificial head with a talking membrane at which hearing and understanding of reproduced speech are complete, (in m).

Characterisics of the talking membrane and testing methods

The following characteristics of the talking membrane were tested:

1. transfer frequency characteristics,
2. speech understandability index,
3. speech reduction factor.

Transfer frequency characteristics

The equipment shown in Fig.2 was used for the determination of transfer frequency characteristics.

Figure 2. Equipment scheme for the determination of transfer frequency characteristics

The marked elements of the equipment are:

TG - tone generator,
MA1 - microphone amplifier,
AM - artificial mouth,
TM - talking membrane,
MM - measuring microphone,
MA2 - microphone amplifier 2 for sound pressure membrane measuring,
RSLP - register of sound level pressure.

The used equipment provides a sinusoidal signal of a constant sound level on the artificial mouth in the frequency range from 20 Hz to 5 000 Hz.

Using the mentioned equipment, the following characteristics of the talking membrane were tested:

- lower frequency limit, (in Hz),
- upper frequency limit, (in Hz),
- insertion loss, (in dB).

Speech understandability index

The procedure for the determination of the speech understandability index consists of the following activities:

- pronouncing and recording the logotomes while the speaker speaks using the talking membrane during the first test and without the talking membrane in the second test,
- reproducing the recorded logotomes pronounced with and without the talking membrane, listening and writing down the mentioned logotomes.

For measuring logotomes, phonetically balanced bisyllabic logotomes of the CVCV (consonant-vowel-consonant-vowel) type were used. Each of two male speakers pronounced six groups of logotomes (one group without the talking membrane and five groups with the talking membrane). Each group consists of 50 phonetically balanced logotomes (a phonetically balanced logotome means that the probability of appearance of individual voices in logotomes corresponds to the probability of their appearance in speech).

The pronunciation and recording of logotomes were done in an anechoic room of the acoustic laboratory at the Faculty of Electrical Engineering, Belgrade (anechoic room, by definition, provides acoustic conditions of free space and removes all disturbing elements). An artificial head Newman, type KU-100, having two microphones (which imitate left and right human ear) was used for logotome recording. The distance between the speaker and the mentioned device was 1 m.

The reproduction of the recorded logotomes was done in laboratory using a digital cassette player Tascam, type DA-P1. One logotome was reproduced every three seconds. The sound level was constant during the whole logotome reproducing process. The sound level was reproduced in a way that good hearing was in the range from 3 m to 5 m from the sound source. Every listener (5 males and 5 females, 25 years of age in average, without problems with the sense of hearing and previous experience in logotome understandability tests) heard the whole logotome material (12 groups i.e. 600 phonetically balanced logotomes) and wrote them down.

Speech reduction factor

The procedure for the determination of the speech reduction factor consists of the following activities:

- -pronunciation and recording a chosen text on a computer,
- -reproducing the recorded text using the computer, amplifier, artificial mouth with and without the talking membrane and megaphone in free space in the listener's direction,
- -registering the distance from the artificial mouth with and without the talking membrane at which hearing and understandability of the text are complete.

The apparatus shown in Fig.3 was used for the investigation of the speech reduction factor.

Figure 3. Apparatus for the investigation of speech reduction factor

The marked elements of the apparatus are:

C - computer,
A - amplifier,
AH - artificial head,
TM - talking membrane,
PwM - phonometer with microphone,
L - listener.

The highest sound level of the reproduced text was measured at 1 m distance from the talking membrane. This sound level was kept at the same value (85 dB) during the whole reproducing process.

Results and discussion

Transfer frequency characteristics of the talking membrane, determined by the mentioned equipment and described conditions, are shown in Fig.4.

Fig.4 shows that the lower frequency limit is 400 Hz, while the upper frequency limit has a value of 4000 Hz. Using the talking membrane caused an insertion loss of 6 dB.

It is estimated that the values of the lower frequency limit, the upper frequency limit and the insertion loss are acceptable regarding the function of the talking membrane.

The speech understandability index is determined as a quotient of logotome speech understandability with the talking membrane and logotome speech understandability without the talking membrane. It was established that logotome speech understanding with the talking membrane has a value of 91.96 % and logotome speech understandability without the talking membrane has a value of 97.3 %. The speech understandability index, as a ratio of two mentioned numbers, is 0.945.

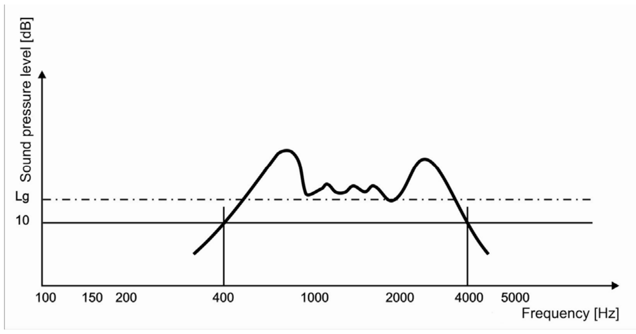

Figure 4. Transfer frequency characteristics of the talking membrane

Based on the speech understandability index, it is considered that the understandability obtained using the talking membrane is at a high level.

The speech reduction factor is determined by the mentioned procedure and the apparatus in free space o under specified conditions. Using the data obtained with and without the talking membrane, a value of 1.33 speech reduction factor was calculated. It means that the distance at which hearing and understandability are complete when the talking membrane is not used, compared with the distance at which hearing and understandability are complete when the talking membrane is used, is one third bigger. This parameter is acceptable.

The talking membrane with poly(ethylene terephtalate) foil is placed nearest to the mouth of an average user, whose liquid in the mouth has slightly acid to neutral values (pH value is from 6 to 7), body temperature (36.5^{o}C) and contains enzymes.

Poly (ethylene terephtalate) is hygroscopic (i.e. absorbs water from its surroundings) and highly sensitive to UV radiation, chemical agents and, especially, hydrolysis process [9, 12, 13]. From the theoretical point of view, chemical, thermal and biological degradation of poly (ethylene terephtalate) foil can happen. Since degradation of polymeric materials means a change of physical, chemical, mechanical, optical, thermal, acoustic and other characteristics, caused by chemical reactions that encircle the cutoff of the links in the backbone and weakening of secondary intermolecular bonds, if a degradation of poly (ethylene terephtalate) foil happens, that can cause a change of the functional properties of the talking membrane [9, 14].

Using a talking membrane with poly(ethylene terephtalate) foil in a certain period of time, a change of functional properties was not recorded, which pointed out that the degradation of poly (ethylene terephtalate) i.e. that change of its properties did not occur.

Conclusion

Based on the abovementioned, it can be stated:

4. It is possible to use a poly (ethylene terephtalate) foil for the production of membranes intended for human speech transfer.
5. Acoustic characteristics of the talking membrane containing poly (ethylene terephtalate) foil in the centre are tested.

6. Lower frequency limit, upper frequency limit, insertion loss, speech understandability index and speech reduction factor are determined.
7. Obtained results of the acoustic characteristics of the talking membrane are acceptable.

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Mogućnost primene membrane od plastične folije za prenos ljudskog govora

U ovom radu prikazani su rezultati istraživanja mogućnosti provođenja zvučnih signala tj. ljudskog govora pomoću membrane sa plastičnom poli(etilentereftalatnom) folijom.
Navedeni su osnovni pojmovi o poli(etilentereftalatu) i akustičnim osobinama polimernih materijala. Opisani su postupci i oprema primenjeni za određivanje funkcionalnih karakteristika govorne membrane, u koju je ugrađena poli(etilentereftalatna) folija. Dobijeni rezultati ispitivanja akustičnih svojstava govorne membrane (frekvencijske karakteristike prenosa, indeks razumljivosti govora i faktor redukcije govora) su prihvatljivi i ukazuju na mogućnost primene poli(etilentereftalatne) folije u uređajima za prenos zvučnih signala ljudskog govora.

Ključne reči: **plastični materijali, polietilentereftalat, folija, membrane, akustičke karakteristike, prenos govora, govorni signal.**

Возможности применения мембраны из пластмассовой фольги для переноса человеческой речи

В настоящей работе приведены результаты исследования возможности переноса звуковых сигналов, т.е. человеческой речи при помощи пластмассовой полиэтилентерефталатной фольги. Здесь приведены основные понятия о полиэтилентерефталату и о акустических характеристиках полимерных материалов и описаны поступки и оборудование применяемые для определения функциональных характеристик речевой мембраны, содержавшей в себе полиэтилентерефталатную фольгу. Полученные результаты исследования акустических характеристик речевой мембраны (частотные характеристики переноса, указатель понимания речи и фактор сокращения речи) приемлемы и общеприняты и указывают на возможность применения полиэтилентерефталатной фольги в аппаратуре для переноса звуковых сигналов человеческой речи.

Ключевые слова: **Пластмассовые материалы, полиэтилентерефталат, фольга, мембраны, акустические характеристики, перенос человеческой речи, речевой сигнал.**

La possibilité de l'emploi d'une membrane à la feuille plastique pour la transmission des signaux sonores de la parole humaine

Ce papier présente les résultats des recherches sur la possibilité de transmettre les signaux sonores notamment la parole humaine à l'aide d'une membrane avec la feuille plastique en poly(éthylène térephtalate). On a cité les notions principales sur le poly(éthylène térephtalate) et sur les caractéristiques acoustiques des matériaux polymériques. On a décrit les procédés et l'équipement appliqués dans la détermination des caractéristiques fonctionnelles de la membrane de parole contenant une feuille de poly(éthylène térephtalate). Les résultats obtenus pour les propriétés acoustiques de la membrane à parole (caractéristiques de fréquence de transmission, index de la compréhension de parole et le facteur de la réduction de parole) sont acceptables et démontrent la possibilité d'emploi d'une feuille en poly(éthylène térephtalate) chez les appareils pour la transmission des signaux sonores de la parole humaine.

Mots clés: **matériaux plastiques, poly(éthylène térephtalate, feuille, membranes, caractéristiques acoustiques, transmission de parole, signal de parole.**