

## Microprocessor System for Thermoacoustic Plants Efficiency Analysis Based on a Two-Sensor Method

<sup>1</sup>Yuriy KONDRATENKO, <sup>2</sup>Volodymyr KOROBKO,  
<sup>3</sup>Oleksiy KOROBKO

<sup>1</sup> Department of Intelligent Information Systems,  
Petro Mohyla Black Sea State University,  
10 68th Desantnykiv st., Mykolayiv, 54003, Ukraine,  
Tel.: +380512400939

<sup>2</sup> Department of Marine and Stationary Power Plants,

<sup>3</sup> Department of Computerized Control Systems,  
Admiral Makarov National University of Shipbuilding,  
9 Geroyiv Stalingrada ave., Mykolayiv, 54025, Ukraine,  
Tel.: <sup>1</sup>+380506504509, <sup>2</sup>+380504936282

E-mail: [y\\_kondratenko@rambler.ru](mailto:y_kondratenko@rambler.ru), [volodymyr.korobko@nuos.edu.ua](mailto:volodymyr.korobko@nuos.edu.ua),  
[oleksii.korobko@nuos.edu.ua](mailto:oleksii.korobko@nuos.edu.ua)

*Received: 15 May 2013 /Accepted: 16 August 2013 /Published: 30 August 2013*

---

**Abstract:** The article is devoted to the dependency analysis of the thermoacoustic devices performance from acoustic wave parameters (frequency, pressure magnitude etc.). Detailed study of electroacoustic parameters impact on the overall productivity of loudspeaker driven thermoacoustic systems is given. Authors proposed the structure and algorithm basis of the microprocessor system for automated electroacoustic performance calculation. Proposed by Fusco et al. [1] two sensor method is implemented in digital signal processing algorithm for real-time acoustic power calculation. Synthesized microprocessor system is tested during the experimental research of the loudspeaker driven standing wave thermoacoustic refrigerator performance measurements. Analysis of the results obtained shows that the proposed microprocessor system with implemented data processing algorithm can be used for calculations of the thermoacoustic devices overall efficiency. *Copyright © 2013 IFSA.*

**Keywords:** Microprocessor system, Thermoacoustic device, Two-sensor method, Parametric identification, Electroacoustic performance.

---

### 1. Introduction

One of the important components of developed industry is the use of heat engines that convert heat energy into mechanical or electrical. Conventionally, heat machines can be divided into two groups: direct

effect mechanisms (heat engines) and reverse action mechanisms (heat pumps, refrigerators). The most common are the mechanical heat machines in which the mutual energy conversion is based on the use of special mechanical devices, such as piston mechanisms (internal combustion engines, steam

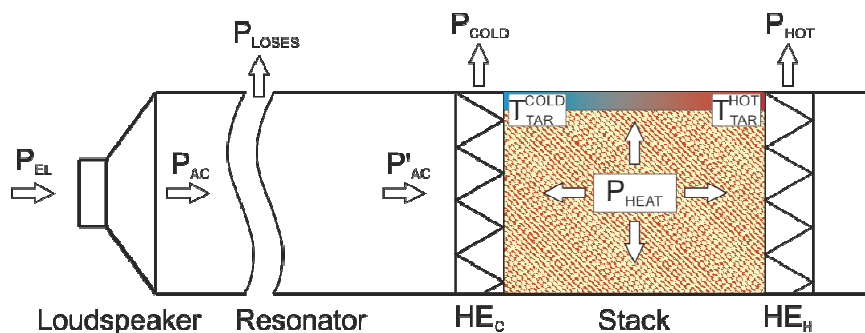
engines, Stirling engines) and rotary devices (gas and steam turbines).

Thermoacoustic devices (TAD) are the newest type of unconventional heat engines [2] whose work is based on the use of acoustic energy as “the moving” mechanism. The use of acoustic waves as a carrier of energy significantly simplifies the design of these machines compared to traditional. There are two types of thermoacoustic devices [2-4]: engines (convert thermal energy into acoustic) and heat pumps or refrigerators (transform acoustic energy into heat). In this paper, as research plant, authors considered loudspeaker driven standing wave thermoacoustic refrigerator [5-7].

Fig. 1 shows the schematic of thermoacoustic refrigerator (TAR). The main components of which are the cavernous resonator, which is filled with the

working medium (air, helium, etc.), the generator of sound waves (loudspeaker), highly compact heat exchange surface (stack) for conversion of acoustic energy into heat and heat exchangers  $HE_H$ ,  $HE_C$  for heat input and output from the TAR cavity.

Lack of moving parts not only significantly increases the reliability of thermoacoustic devices, but also reduces energy losses in the mechanical connections. Through the interaction of the working medium particles with the surface of the stack, acoustic wave forms the temperature difference [8] on its opposite sides ( $\Delta T = T_H - T_C$ ) [3, 5, 7]. This temperature difference is the main factor of thermoacoustic device working process and depends on the power of acoustic waves and the efficiency of heat exchangers  $HE_H$ ,  $HE_C$  (Fig. 1).



**Fig. 1.** Schematic of energy exchange of the loudspeaker driven thermoacoustic refrigerator  
 $P_{el}$  – supplied electric power;  $P_{ac}$  – acoustic power generated by loudspeaker;  $P_{loses}$  – energy losses power;  
 $P'_{ac} = P_{ac} - P_{loses}$  – useful acoustic power;  $P_{hot}, P_{cold}$  – powers extracted by cold and hot heat exchangers;  
 $P_{heat} = P'_{ac} - P_{hot} - P_{cold}$  – thermoacoustic effect power.

Thermoacoustic refrigerator with an electromechanical generator is a complex energy transforming system (Fig. 2) in which the sound wave energy  $P_{ac}$  in the resonator is formed by the supplied to the oscillator electric power  $P_{el}$ , and thermoacoustic heat energy is the result of useful acoustic power  $P'_{ac}$  conversion into heat  $P_{heat}$  through the stack. Therefore, TAR can be divided into two subsystems: electroacoustic ( $P_{el} \Rightarrow P_{ac}$ ) and thermoacoustic ( $P'_{ac} \Rightarrow P_{heat}$ ).

The high dependence of TAR's thermoacoustic subsystem ( $P_{ac} \Rightarrow P_{heat}$ ) efficiency on a number of uncontrolled parameters [2, 3, 5], which are almost impossible to consider on the design stage (the exact value of resonator components roughness, heat exchangers and the stack manufacturing defects, environmental conditions etc.) leads to the need for additional settings during the TAR working process in order to drive it to the optimal regime. From other hand, in loudspeaker driven devices,

electroacoustic parameters are the main subject for future adjustments at the stages of testing and working process.

For a high power thermoacoustic systems the sound pressure level (SPL) of 150-170 dB must be maintained in the resonator cavity during the work process, which leads to the emergence of parasitic nonlinear effects [3, 9].

Thus, the task of creating a system for automated acquisition and data analysis of TAR's acoustic and electromechanical components is important. It should be noted that large number of different nature parameters (acoustic pressure, electric current, temperature fluctuations, etc.) lead to the need of specialized microprocessor system implementation [5, 10] for solving the tasks of registration and processing large amounts of data in real time.

The aim of the article is to analyze the dependency of loudspeaker driven standing wave thermoacoustic refrigerator efficiency on the parameters of electroacoustic subsystem.

## 2. TAR Electroacoustic Subsystem Efficiency Criteria's Overview

### 2.1. Sound Wave Frequency Impact on Acoustic Pressure Magnitude

Traditionally, the sound wave is considered as a set of working environment pressure (1) and velocity (2) fluctuations [11], whose values depends on the structural features of the specific thermoacoustic plant and external influences. The frequency of a sound signal, formed by the electromechanical generator, significantly affects the magnitude of the acoustic pressure and particle displacement in the resonator [6, 7], and is an important parameter in the design and functioning of the TAR.

$$P(x,t) = P_S \cos kx \sin \omega t, \quad (1)$$

where  $P_S$  is the pressure magnitude,  $\omega=2\pi f$  is the sound wave angular frequency,  $\chi$  is the longitudinal coordinate,  $t$  is the time,  $k$  is the wave number.

$$v(x,t) = \frac{P_S}{\rho_0 C} \sin kx \cos \omega t, \quad (2)$$

where  $\rho_0$  is the gas density,  $C$  is the gas heat capacity.

It is known that the most effective mode for thermoacoustic systems working process is the functioning at the resonant frequency [3, 6]. In general, the resonant frequency (3) of the acoustic pressure oscillations (1) for the empty resonator TAR can be calculated [11] as

$$f_{res} = \frac{a}{\lambda} = \frac{\sqrt{\gamma kT/m}}{4L}, \quad (3)$$

where  $f_{res}$  is the sound wave resonant frequency,  $a$  is the speed of sound,  $\lambda$  is the sound wave length,  $\gamma$  is the adiabatic index,  $k$  is the Boltzmann constant,  $T$  is the absolute temperature,  $m$  is the single molecule mass,  $L$  is the resonator length.

It should be noted that the sound frequency calculated according to (3) is only approximate value [3, 10], because its calculation does not consider the specific design features of TAD and external environment basic physical parameters. Therefore, authors conducted the experimental research [10] to determine the exact value of resonant frequency. The result of experiment shows (Fig. 2) that acoustic pressure has nonlinear extreme dependency on sound wave frequency with the maximum pressure value at the resonant frequency  $f_{res} \approx 229\text{Hz}$  [3]. Considered given results all further experiments were held on this frequency.

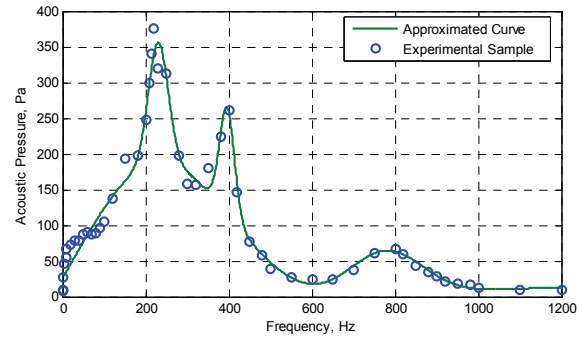


Fig. 2. Acoustic pressure magnitude dependency on sound wave frequency at 15 % of maximum power.

### 2.2. Electroacoustic Subsystem Energy Performance Index

The main parameters of sound waves [2, 3] that determine the efficiency of thermoacoustic devices includes:

- The sound wave frequency;
- The shape of the sound wave front;
- Acoustic pressure level;
- Acoustic wave power ( $P_{ak}$ ).

These characteristics directly depend on the properties of the acoustic oscillations electromechanical generator and its productivity. Therefore the value of electromechanical generator efficiency will directly impact on the overall productivity of refrigerator and can be considered as the main electroacoustic subsystem efficiency criteria.

Bearing in mind the fact that loudspeaker is an electromechanical device that transforms electric energy into acoustic, its performance index  $\eta_{e/a}$  (4) can be found as generated acoustic  $P_{ac}$  (5) and supplied electric  $P_{el}$  (6) powers ratio

$$\eta_{e/a} = \frac{P_{ac}}{P_{el}} \cdot 100\%, \quad (4)$$

$$P_{ac} = \frac{S}{T} \int_0^T p(t)v(t)dt = IS, \quad (5)$$

where  $S$  is the cross-sectional area of the resonator,  $T$  is the time period,  $p(t)$ ,  $v(t)$  is the instant acoustic pressure and velocity values,  $I$  is the acoustic wave intensity.

$$P_{el} = \frac{1}{T} \int_0^T u(t)i(t)dt, \quad (6)$$

where  $u(t)$ ,  $i(t)$  are the instant values of electromechanical generator voltage and current.

The electric power  $P_{el}$  calculation can be done by simultaneous multiplication of loudspeaker current and voltage values that could be simply measured by current sensor and voltage divider. Acoustic power

measurements require additional equipment and are followed by more complicated calculations as it will be shown in next section.

### 2.3. Two-Sensor Method for Acoustic Power Measurements

The traditional way of acoustic power registration [12] is a simultaneous pressure  $p(t)$  and velocity  $v(t)$  measurement using the pressure sensor or microphone and the laser Doppler velocity meter. This approach allows determining the value of acoustic pressure and oscillations velocity with high accuracy, but requires expensive equipment and the availability of transparent duct for laser beams passage. These shortcomings limit the possibility of the direct method usage and make it impractical for automated control systems implementation.

An alternative method of acoustic parameters registration is known as two-sensor method [1, 12], where pressure  $p(t)$  and velocity  $v(t)$  values are calculated using the parameters of the two pressure sensors located on a fixed distance  $\Delta x$  from each other (Fig. 3, [12]).

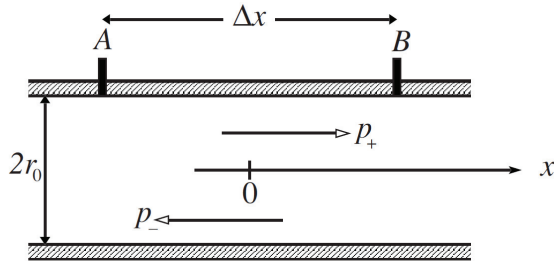


Fig. 3. Cylindrical duct of radius  $r_0$  with two pressure sensors A and B [12].

Two-sensor method proposed by Fusco et al. [1] stays that based on the values of pressure sensors A and B the acoustic pressure  $p(0)$  (7) and axial velocity  $v(0)$  (9) in the middle point 0 (Fig. 3) can be calculated as

$$p(0) = \frac{p_A + p_B}{2 \cos(k\Delta x / 2)}, \quad (7)$$

$$k = k_0 \left\{ 1 + \frac{1-j}{2} \frac{\delta_v}{r_0} \left( 1 + \frac{\gamma-1}{\sqrt{\sigma}} \right) \right\}, \quad (8)$$

$$v(0) = \frac{kF}{\omega \rho} \frac{p_A - p_B}{2j \sin(k\Delta x / 2)}, \quad (9)$$

$$F = 1 - \frac{1-j}{r_0 / \delta_v}, \quad (10)$$

where  $k$  is the complex wave number,  $\Delta x$  is the distance between pressure sensors A and B,  $p_A, p_B$  are the A and B pressure sensors values,  $k_0 = \omega/a$  is the

wave number in free space,  $\sigma$  is the Prandtl number,  $\delta_v$  is the viscous boundary layer thickness,  $r_0$  is the duct radius,  $\rho$  is the average gas density,  $j = \sqrt{-1}$  is the imaginary unit.

Based on the equations (7) and (9) and taking into account that acoustic intensity can be calculated by equation (11), the acoustic power  $P_{ac}$  in the TAR resonator can be determined by equations (12) and (13).

$$I = \frac{1}{2} \text{Re}(\tilde{p}v), \quad (11)$$

where  $\tilde{p}$  is the complex conjugate of  $p$ ,  $\text{Re}$  is the real part of a complex number.

$$P_{ac} = \frac{S}{8\omega\rho} \left[ \text{Im}(H) \left( |p_A|^2 - |p_B|^2 \right) + 2 \text{Re}(H) |p_A| |p_B| \sin \theta \right], \quad (12)$$

$$H = \frac{kF}{\cos(\tilde{k}\Delta x / 2) \sin(k\Delta x / 2)}, \quad (13)$$

where  $\text{Im}(H), \text{Re}(H)$  are the imaginary and real parts of complex value,  $\theta$  is the phase difference between signals  $p_A$  and  $p_B$ ,  $\tilde{k}$  is the complex conjugate of  $k$ .

## 3. Experimental Setup for Thermoacoustic Plants Electroacoustic Efficiency

### 3.1. Description of the Experimental Setup for Electroacoustic Efficiency Analysis

Experimental verification of the electroacoustic efficiency analysis model was held on created experimental plant (Fig. 4) which consist of: standing wave thermoacoustic refrigerator, 100 W loudspeaker, microprocessor data acquisition system that is based on the STM32 CortexM4 ARM microcontroller (MCU) and includes Freescale MPXV7007DP (170 dB SPL,  $\Delta P = \pm 7$  KPa) acoustic pressure sensors (Ps1, Ps2), Allegro current sensor ACS712ELCTR-05B-T ( $\Delta i = \pm 5$  A), personal computer with its soundcard output connected to MCU analog to digital converter (ADC) input and to MMF LV103 acoustic amplifier.

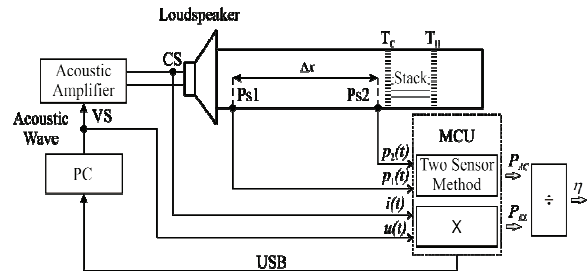


Fig. 4. Schematic of the microprocessor system for thermoacoustic plants efficiency analysis.

STM32F4DISCOVERY with its STM32F407VGT6 MCU was selected as the main executive unit of the acquisition system. It combines 32-bit high speed (up to 168 MHz) CortexM4 ARM CPU with three 12-bit, 2.4 MSPS ADC and hardware implemented floating point unit and therefore is suitable for digital signal processing tasks. Its main functions are: collect data from the sensors; process collected data and results send via USB to PC software.

Developed for microprocessor system software allows the acoustic signals generation of different shapes and magnitudes [5] at the output of the electromechanical generator and can store and display data received from the MCU in real time.

### 3.2. Noise Cancellation by the Means of Designed FIR Filter

In modern digital signal processing systems the analysis of acoustic data is often carried out under the conditions of uncertain system characteristics. In particular, during the operation of data acquisition and processing systems, the parameters of their objects and operation environment may change unpredictably due to the presence of random noise sources, poor interchange of the various components and power circuits, etc.

To overcome such influence on the designed system calculation results authors implemented digital finite impulse response (FIR) band pass filter [13], which output is a weighted sum of the current and a finite number ( $N$ ) of input previous values. This operation is described by equation (14), which defines the output value  $y[n]$  in terms of its input sequence  $x[n]$ :

$$y[n] = \sum_{i=0}^N b_i x[n-i], \quad (14)$$

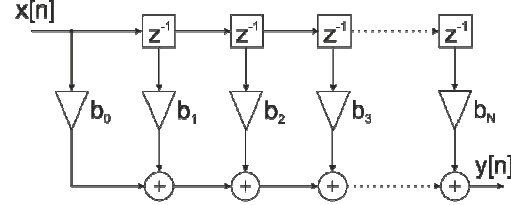
where  $N$  is the number of filter coefficients or filter order,  $b_i$  is the  $i$ -th filter coefficient value.

Fig. 5 shows the schematic and magnitude-frequency response of the implemented filter with pass band  $f_{pass}=[180..250]$  Hz 40 dB noise suppression level and order  $N=560$  and sampling rate  $F_s=5$  kHz.

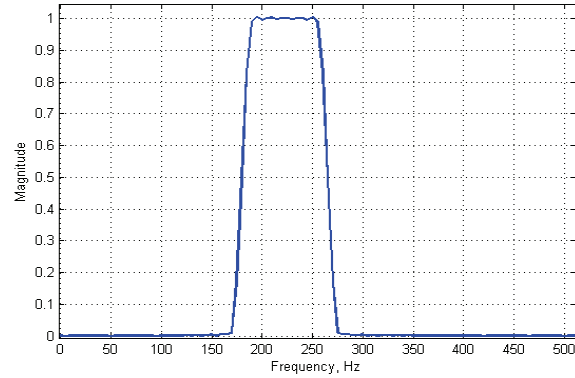
Filter working process is shown on Fig. 6, where input signal  $U_s$  is the experimental data of PC soundcard voltage level. It should be noted that selected MCU has unipolar ADC and therefore can measure only positive half of sound signal  $U_s$  (Fig. 6b). As the result the spectrum of measured signal (Fig. 6a upper diagram) has additional parasitic harmonics.

Filter modeling results shows (Fig. 6a lower diagram) that the output signal  $U_f$  is the sine wave (Fig. 6b) with twice lower magnitude that the measured one

and PC soundcard voltage level can be found as the filter output signal  $U_f$  multiplied by 2.

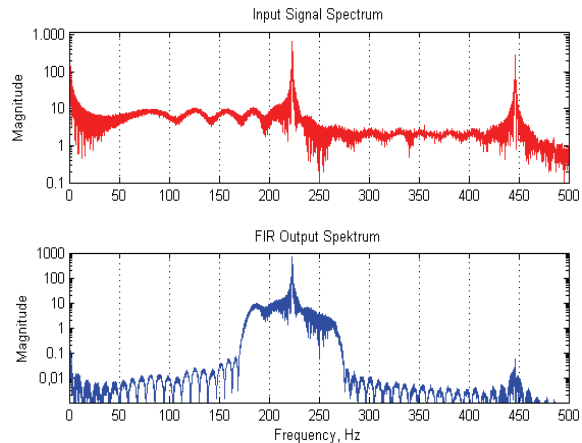


(a) FIR filter schematic.

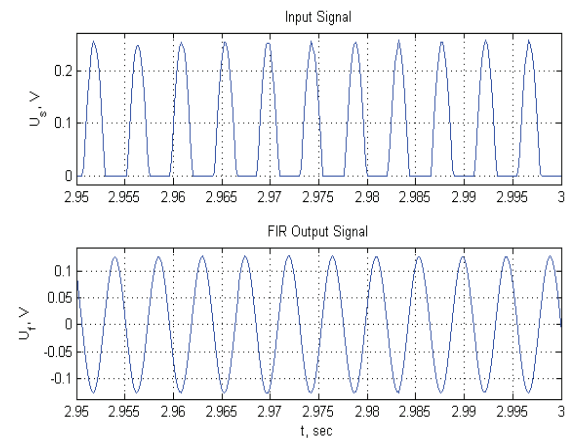


(b) Magnitude-frequency response.

Fig. 5. Band pass FIR filter design magnitude-frequency response.



(a) Spectrum diagram.



(b) Time graph.

**Fig. 6.** Band pass FIR filter modeling.

The supplied to loudspeaker voltage finally can be calculated as soundcard voltage multiplied by experimentally defined acoustic amplifier gain  $K_{amp}=90.2724$ . The resulting equation for loudspeaker voltage (15) can be defined as

$$u_{lsp}(t) = 2K_{amp}u_{pc}^{filt}(t), \quad (15)$$

where  $u_{lsp}(t)$  is the voltage supplied for loudspeaker,  $K_{amp}$  is the acoustic amplifier gain,  $u_{pc}^{filt}(t)$  is the PC soundcard filtered signal.

#### 4. Experimental Verification of the Proposed Microprocessor System and Discussion of the Results Obtained

The verification of proposed microprocessor system for electroacoustic efficiency analysis was held on the experimental plant (Fig. 7) that includes PC, designed microprocessor system and loudspeaker driven quarter wavelength thermoacoustic refrigerator.

During the experiment loudspeaker generated sine sound wave [14] with frequency  $f_{res} \approx 229 \text{ Hz}$  at 40 % of maximum power. Fig. 8a shows the pressure variations at the starting moment of acoustic wave generation. It should be noted that the different pressure magnitudes ( $P_{s2} > P_{s1}$ ) are the result of standing acoustic wave inside the resonator [15] and the phase shift  $\theta = 0.1366 \text{ rad}$  between two pressure signals (Fig. 8b) is the result of  $\Delta x = 140 \text{ mm}$  distance between pressure sensors Ps1 and Ps2 (Fig. 4).

Using described in sec. 2.3 two-sensor method [1, 12] we obtain the time dependencies of pressure (7) and velocity (9) in the middle between the sensors Ps1 and Ps2 (Fig. 4). The resulting graphs are illustrated on Fig. 9. Calculation of the power

characteristics of electroacoustic part was carried out using the equations (12) and (6) for acoustic and electric powers respectively. After power calculations the resulting electroacoustic performance index value was obtained using the equation (4). Acquired values are summarized in Table 1.

The calculated electroacoustic subsystem performance index of loudspeaker driven thermoacoustic refrigerator is less than 4 % (Table 1). This value corresponds to the theoretical data on the loudspeaker efficiency [16] and therefore it can be concluded that the proposed system can be used for real-time electroacoustic efficiency calculations.

**Table 1.** Thermoacoustic refrigerator electroacoustic subsystem performance index.

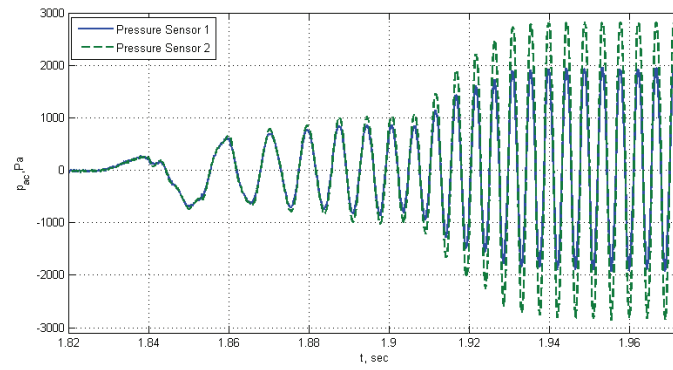
Parameter	Notation	Value	Unit
Acoustic power	$P_{ac}$	1.69	W
Electric power	$P_{el}$	51.19	W
Performance index	$\eta_{e/a}$	3.3	%

#### 5. Conclusions

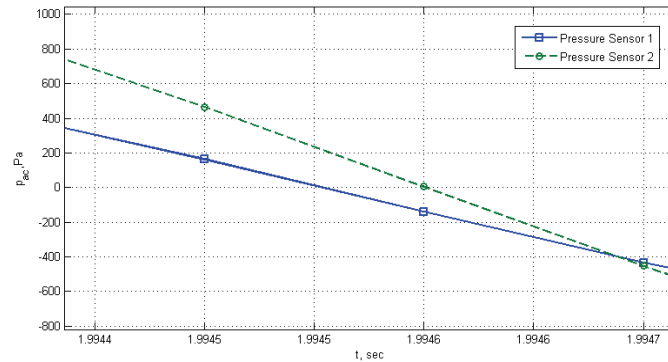
Given analysis show that thermoacoustic systems efficiency is highly dependent on the sound wave parameters, especially the wave frequency and pressure values. Also the number of uncontrolled structural defects (resonator inner walls roughness, heat exchanger efficiency, etc.) lead to the necessity of after construction tuning procedures. In loudspeaker driven thermoacoustic systems the electric driver is the source of acoustic waves and therefore is the primary object for control and tuning algorithms.

Authors implemented the real-time electroacoustic efficiency calculation system using the 32-bit ARM microcontroller that uses the two-sensor method for acoustic power determination and direct current and voltage measurements for electric power calculations.

**Fig. 7.** Experimental plant for standing wave thermoacoustic refrigerator overall efficiency calculation.

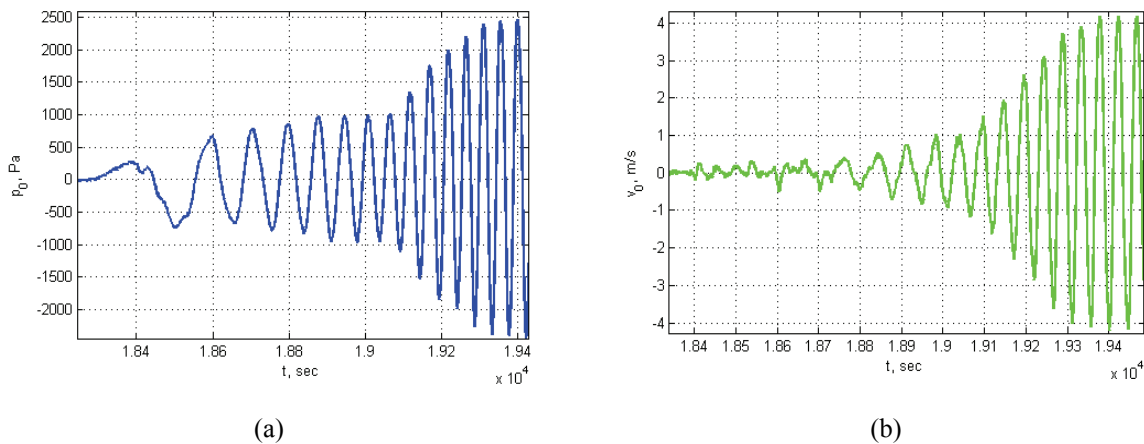


(a) Pressure measurements at the starting moment of acoustic wave generation



(b) Phase shift between two pressure signals

**Fig. 8.** Experimental investigation of pressure fluctuations during the TAR working process.



**Fig. 9.** Experimental investigation of pressure fluctuations during the TAR working process.

Proposed system was tested on the loudspeaker driven quarter wavelength thermoacoustic refrigerator and it results show that the designed microprocessor system with implemented data processing algorithm can be used for real-time calculation of thermoacoustic plants overall efficiency.

Measured performance index of thermoacoustic refrigerator electroacoustic subsystem is 3.3 %. Therefore it can be concluded that the loudspeaker driven devices has low efficiency due to the driver limitations and all further research should be held on

thermoacoustic engine driven devices. Designed microprocessor system can be easily adopted for such device class with implementation of temperature data acquisition hardware.

### Acknowledgements

The work presented in this paper was supported by Grant of Ministry of Education, Youth and Sports of Ukraine under Grant No. 0111U002311.

## References

- [1]. A. M. Fusco, W. C. Ward, G. W. Swift, Two-sensor power measurements in lossy ducts, *Journal Acoustic Society of America*, Vol. 91, 1992, pp. 2229-2235.
- [2]. J. C. Wheatley, G. W. Swift, A. Migliori, The natural heat engines, *Los Alamos Science*, Vol. 14, Issue 2, 1986, pp. 2-33.
- [3]. N. Rott, Thermoacoustics – a unifying perspective for some engines and refrigerators, *Acoustical Society of America*, 2002.
- [4]. T. Tomonaga, Fundamental Thermoacoustics, *Uchida Rokakuno Publishing*, Tokyo, 1998.
- [5]. Y. Kondratenko, V. Korobko, O. Korobko, Multisensor data acquisition system for thermoacoustic processes analysis, in *Proceedings of the 6<sup>th</sup> IEEE International Conference (IDAACS' 2011)*, Vol. 1, 15-17 September 2011, Prague, Czech Republic, pp. 54-58.
- [6]. R. S. Wakeland, Use of electrodynamic drivers in thermoacoustic refrigerators, *Journal Acoustic Society of America*, Vol. 107, Issue 2, 2000, pp. 827-832.
- [7]. M. E. H. Tijani, J. C. H. Zeegers, A. T. A. M. de Waele, Construction and performance of a thermoacoustic refrigerator, *Cryogenics*, Vol. 42, 2002, pp. 59-66.
- [8]. Tariq M. Younes, Mohammad A. K. Alia, Shebel Al-Sabbah, Acoustic Temperature Transducer, *Sensors & Transducers*, Vol. 119, Issue 8, August 2010, pp. 46-57.
- [9]. T. D. Rossing, Springer handbook of acoustics, *Springer Science Business Media*, LLC New York, 2007.
- [10]. Y. Kondratenko, O. Korobko, O. Kozlov, Frequency tuning algorithm for loudspeaker driven thermoacoustic refrigerator optimization, *Lecture Notes in Business Information Processing*, Vol. 115, 2012, pp. 270-279.
- [11]. Lord Rayleigh, The theory of sound, 2nd edition, Vol. 2, *Dover*, New York, 1945.
- [12]. T. Biwa, Y. Tashiro, H. Nomura, Y. Ueda, Experimental verification of a two-sensor acoustic intensity measurement in lossy ducts, *Journal Acoustic Society of America*, Vol. 124, Issue 3, 2008, pp. 1584-1590.
- [13]. A. B. Sergienko, Digital signal processing, St. Petersburg, *Peter*, 2006.
- [14]. Mohammad A. Alia, Mohammad Al-Khedher, Mazouz Salahat, Practical investigation of an acoustic encoder, *Sensors & Transducers*, Vol. 126, Issue 3, March 2011, pp. 85-91.
- [15]. H. R. Pota, A. G. Kelkar, Modeling and control of acoustic ducts, *Transactions of the ASME*, January 2001.
- [16]. G. Ballou, Electroacoustic Devices, Microphones and Loudspeakers, *Focal Press*, 2009.

2013 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.  
(<http://www.sensorsportal.com>)



**Easy and quick  
sensors systems development**

**Evaluation Kit CD  
EVAL UFDC-1/UFDC-1M-16**

International Frequency  
Sensor Association  
**IFSA**

OPTYS Corporation  
**OPTYS  
CORPORATION**

- 16 measuring modes
- Frequency range from 0.05 Hz up to 7.5 MHz (120 MHz)
- Programmable accuracy from 1 % up to 0.001 %
- RS232 (USB optional)

[sales@sensorsportal.com](mailto:sales@sensorsportal.com)  
[http://www.sensorsportal.com/HTML/E-SHOP/PRODUCTS\\_4/Evaluation\\_board.htm](http://www.sensorsportal.com/HTML/E-SHOP/PRODUCTS_4/Evaluation_board.htm)