CARNOT PERFORMANCE COEFFICIENT AND THE EXERGETIC EFFICIENCY OF THE COMBINED THERMOACOUSTIC MACHINE (THERMOACOUSTIC ENGINE-ACOUSTIC WAVES AMPLIFIER-REFRIGERATOR)

Dan ANDREI

"DUNAREA DE JOS "University of Galati, Romania

Rezumat. Determinarea expresiei matematice a randamentului exergetic al maşinii termoacustice combinate de mare putere, care cuplează un generator de unde (motor termoacustic) cu un amplificator de unde şi un refrigerator termoacustic (pulse-tube) dă posibilitatea vizualizării parametrilor asupra cărora putem acţiona pentru mărirea acestui randament.
Cuvinte cheie: randament exergetic, motor termoacustic, amplificator termoacustic, refrigerator termoacustic (pulse-tube), maşina termoacustică combinată de mare putere.

Abstract. The exergetic efficiency of high power thermoacoustic machine, which couples a wave generator (thermoacoustic engine) with wave amplifier and thermoacoustic refrigerator (pulse-tube), shows the way we can increase the efficiency.
Keywords: exergetic efficiency, thermoacoustic engine, thermoacoustic amplifier, refrigerator thermoacoustic, high power thermoacoustic plant.

1. INTRODUCTION

The high power combined thermoacoustic machine (fig.1) consists of a couples from a thermoacoustic engine (wave generator) with wave amplifier and thermoacoustic refrigerator.

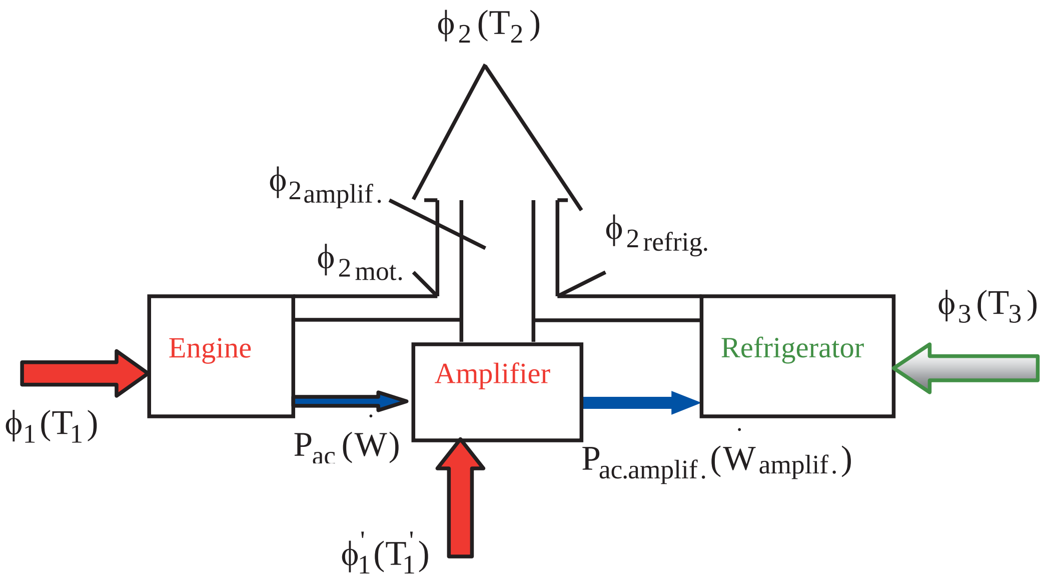

Fig. 1. Combined thermoacoustic machine.

The role of the amplifier is to amplify the power of the engine acoustic (P_{ac}), because the entry in refrigerator (pulse-tube) to have more power ($P_{ac.amplif.}$).

The equation of I Principle of Thermodynamics [1], [4], [5], [6] is:

$$\Phi_1 + \Phi_1' + \Phi_3 - |\Phi_2| = 0 \qquad (1)$$

where:

$$\Phi_2 = \Phi_{2\,mot.} + \Phi_{2\,amplif.} + \Phi_{2\,refrig.}. \qquad (2)$$

The equation of II Principle of Thermodynamics is:

$$\dot{S}_{gen.ciclu} = -\frac{\Phi_1}{T_1} - \frac{\Phi_1'}{T_1'} + \frac{|\Phi_2|}{T_2} - \frac{\Phi_3}{T_3} \geq 0 \qquad (3)$$

In the case, of the high power combined thermoacoustic machine, the engine follows the Brayton cicle (2 adiabates and 2 isobares) [1], [2], [3], [4], [5], the wave amplifier follows Ericsson cicle (2 isothermals and 2 isobares) [1], [2], [3], [4], [5], and the refrigerator (pulse-tube) follows Ericsson cicle (2 isothermals and 2 isobares) or Stirling cicle (2 isothermals and 2 isocores) [1], [2], [3], [4], [5].

2. CARNOT AND EXERGETIC EFFICIENCIES

The coefficient of performance Carnot of the combined thermoacoustic high power machine which works between the same extreme temperatures is :

$$COP_{C\_MC} = \frac{\Phi_3}{\Phi_1 + \Phi_1'} = \frac{|\Phi_2| - \left(\Phi_1 + \Phi_1'\right)}{\Phi_1 + \Phi_1'};$$

$$COP_{C\_MC} = \frac{|\Phi_2|}{\Phi_1 + \Phi_1'} - 1 = \frac{\frac{|\Phi_2|}{\Phi_1}}{\left(1 + \frac{\Phi_1'}{\Phi_1}\right)} - 1;$$

or

$$COP_{C\_MC} = \frac{\frac{T_2}{T_1} + \frac{T_2}{T_1'}\frac{\Phi_1'}{\Phi_1} + \frac{T_2}{T_3}\frac{\Phi_3}{\Phi_1}}{\left(1 + \frac{\Phi_1'}{\Phi_1}\right)} - 1$$

$$COP_{C\_MC} = \frac{\left(1 - \eta_{C.mot.}\right) + \left(1 - \eta_{C.amplif.}\right)\frac{\Phi_1'}{\Phi_1}}{\left(1 + \frac{\Phi_1'}{\Phi_1}\right)} + $$

$$+ \frac{\left(\frac{1}{COP_{C.refr.}} + 1\right)\frac{\Phi_3}{\Phi_1}}{\left(1 + \frac{\Phi_1'}{\Phi_1}\right)} - 1 \qquad (4)$$

where :

$$\eta_{Cmot.} = \frac{P_{ac.}}{\Phi_1} = 1 - \frac{T_2}{T_1} \qquad (5)$$

$$\eta_{Camplif.} = \frac{P_{ac.amplif.} - P_{ac}}{\Phi_1'} = 1 - \frac{T_2}{T_1'} \qquad (6)$$

and

$$COP_{Crefr.} = \frac{\Phi_3}{P_{ac.ampl.}} = \frac{1}{\frac{T_2}{T_3} - 1} \qquad (7)$$

are the Carnot efficiency of the engine and the amplifier and coefficient of performance of the refrigerator.

Exergetic efficiencies of the engine, the amplifier and the refrigerator and the combined thermoacoustic high power machine when environmental temperature is equal to low temperature ($T_{amb} = T_2$) is :

$$\eta_{ex.mot} = \frac{P_{ac.}}{\Phi_1\left(1 - \frac{T_{amb.}}{T_1}\right)} \qquad (8)$$

$$\eta_{ex.amplif.} = \frac{P_{ac.amplif.} - P_{ac.}}{\Phi_1^{'}\left(1 - \frac{T_{amb.}}{T_1^{'}}\right)} ; \qquad (9)$$

$$\eta_{ex.refr.} = \frac{\Phi_3\left(\frac{T_{amb.}}{T_3} - 1\right)}{P_{ac.amplif.}} \qquad (10)$$

$$\eta_{ex\_MC} = \frac{\Phi_3\left(\frac{T_{amb.}}{T_3} - 1\right)}{\Phi_1\left(1 - \frac{T_{amb.}}{T_1}\right) + \Phi_1^{'}\left(1 - \frac{T_{amb}}{T_1^{'}}\right)} =$$

$$= \frac{\frac{\Phi_3}{\Phi_1}\left(\frac{T_{amb.}}{T_3} - 1\right)}{\left(1 - \frac{T_{amb.}}{T_1}\right) + \frac{\Phi_1^{'}}{\Phi_1}\left(1 - \frac{T_{amb.}}{T_1^{'}}\right)} \qquad (11)$$

$$\eta_{ex\_MC} = \frac{\frac{\Phi_3}{\Phi_1} \cdot \frac{1}{COP_{C.refrig.}}}{\eta_{C.mot.} + \frac{\Phi_1^{'}}{\Phi_1}\eta_{C.amplif.}} \qquad (12)$$

If we name:

$$\beta = \frac{P_{ac.amplif.}}{P_{ac.}} \qquad (13)$$

the magnifier coefficient of machine and if we replace and report :

$$\frac{\Phi_3}{\Phi_1} = \eta_{C.mot.} \cdot COP_{C.refrig.} \cdot \beta \qquad (14)$$

the exergetic efficiency of combined high power machine is :

$$\eta_{ex\_MC} = \frac{\beta \cdot \eta_{C.mot.}}{\eta_{C.mot.} + \frac{\Phi_1^{'}}{\Phi_1} \cdot \eta_{C.amplif.}} \qquad (15)$$

or

$$\eta_{ex\_MC} = \frac{\beta}{1 + \frac{\Phi_1^{'}}{\Phi_1} \cdot \frac{\eta_{C.amplif.}}{\eta_{C.mot.}}} \qquad (16)$$

3. CONCLUSIONS

We notice the exergetic efficiency of combined thermoacoustic high power machine increase with the increase the oefficient β and with the decrease the reports

$$\frac{\Phi_1^{'}}{\Phi_1} \text{ and } \frac{\eta_{C.amplif.}}{\eta_{C.mot.}}.$$

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