Piezoelectric Thermo-Acoustic Refrigeration System with Peltier Module Energy Regeneration

Alex Jayaprakash Thomas[1], Ambady S[2] Abhiram KK[3], Merit Kurian[4]
Assi.Prof.Santhu Varghese Thomas[5]

[1,2,3,4]Btech students,Department of Mechanical Engineering,Mangalam College of Engineering,Kottayam,Kerala,India
[5]Professor, Department of Mechanical Engineering, Mangalam College of Engineering, Kottayam, Kerala,India

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Abstract - *Thermoacoustic refrigeration is a technology that operates without the use of any moving parts or hazardous refrigerants. Acoustic waves are used in this technology to transport heat across a temperature gradient. The acoustic input in this project is generated by a piezoelectric speaker. One of the safest types of refrigeration systems is thermoacoustic refrigeration. Furthermore, the potential of piezoelectric actuation as an effective means of driving thermoacoustic refrigerators is demonstrated in comparison to conventional electromagnetic loudspeakers, which are heavy and require a large amount of actuation energy. The theoretical and experimental tools developed can be used to design and test other piezoelectrically-driven thermoacoustic refrigerator configurations. The proposed model is based on the Peltier effect and employs the Peltier module, a thermoelectric device that converts electricity into temperature and vice versa. In our project, we're using it to generate electricity from waste heat. The primary goal of this paper is to provide a detailed overview of the configuration and operation of the refrigeration system using high intensity sound waves.*

Key Words: **Thermo acoustic , Piezoelectric, Peltier module, Aluminium stack.**

1. INTRODUCTION

According to Rott, who built the majority of the theoretical framework for the topic, the term thermoacoustics has a fairly self-explanatory definition. As the name implies, thermoacoustics is concerned with the interaction of heat (thermo) and pressure oscillations in gases (acoustics). This field is divided into two subcategories. The first is the forward effect, which is concerned with the development of pressure oscillations caused by heat. This effect is widely used to create thermoacoustic engines, which are frequently mentioned in the literature. The second subcategory, or reverse effect, is the use of acoustic waves to pump heat. This reversal effect is commonly used in thermoacoustic refrigerators. However, on this study, we can give attention to thermoacoustic gadgets that leverage thermoacoustic standards to create beneficial refrigeration. Lord Rayleigh's landmark work "The Theory of Sound" posted in 1887 supplied the primary qualitative rationalization of acoustic effects. " If warmth is supplied to the air for the time being of most compression or taken from it for the time being of most rarefaction (expansion), the vibration is promoted," he explains how acoustic oscillations are created. The thermoacoustic impact may be understood via way of means of following a given parcel of fluid because it actions via the stack or regenerator. Fig. 1 shows the (idealized) cycles a normal fluid parcel is going via because it oscillates along the plate.

2.OBJECTIVE AND SCOPE

The purpose of this study is a comprehensive study of thermoacoustic refrigerators with piezoelectric and Peltier modules. These thermoacoustic energy collector prototypes, as well as piezo-driven thermoacoustic refrigerators, are designed, modeled, built, and operated. This work also aims to show how to combine the developed mathematical model with the widely used DeltaEC thermoacoustic modeling software. Electromagnetic speakers power almost every thermoacoustic refrigerator on the market. These refrigerators, which provide engineers with excellent design tools, have many excellent numerical models. However, at high frequencies, the performance of the electromagnetic speaker will be significantly reduced. Piezoelectric drivers have thus been used in high frequency thermoacoustic cooling applications. Electromagnetic drivers may be required in applications that use magnetically sensitive devices. In contrast to their electromagnetically driven counterparts, there is no numerical model of a piezoelectrically driven thermoacoustic refrigerator. In this task, we will build a thermoacoustic refrigerator powered by piezoelectrics. The overall efficiency of thermoacoustic energy is determined by the efficiency of heat-to-acoustic and acoustic-to-electrical energy conversions. From this perspective, both approaches to improving the output power of a particular sound energy or transducer need to represent higher overall efficiency for improving the performance of different systems. Efforts to improve the acoustic performance of the stack are primarily related to stack optimization. Various stacking configurations such as materials, porosity, spacing, and parallel plates, pin arrays, circular pores, and changes in tube shape and aspect ratio.

3. COMPONENTS

Table -1: Components and their materials

Components	Materials
Acoustic Driver	Piezoelectric
Stack	Aluminium
Heat exchanger	Water cooler
Resonator Tube	Acrylic Tube
Working gas	Air
Electronic Device (Amplifier)	-
Peltier module	TEC1-12706

Table -2: Components and their specifications

Components	Specifications
Acoustic Driver	Frequency (50-500 Hz)
Stack	Thermal Conductivity (aluminium-0.038W/(m•K) Diameter: 50-100mm Length: 50-160mm
Heat exchanger	Length:100mm
Resonator Tube	Large dia.: 103mm Small dia.:56mm Resonator length: 700-1400mm
Working gas	Prandtl Number (20 C) = (Air=0.72)
Electronic Device (Amplifier)	Power output: 20 watts

4. DESIGN

4.1 DESIGN STRATERGY

There are five basic components to design, with the stack being the most important. It is the most important component for the operation of the thermo acoustic refrigerator, as well as having a significant impact on the design and orientation of all other components. Before beginning to design the stack, all of the parameter values must be obtained and finalised. Direct values for some parameters are not always available. Specific temperature values are precisely available, and operating temperature values can be estimated using relevant equations.

4.2 PELTIER MODULE DESIGN

Copper is used in this model due to its excellent heat conduction properties. Peltier cooling and heating are produced as a result of the built-in electric process and charge recombination in the space charger region. We are using a Thermoelectric cooler 6A Peltier Module in this project.

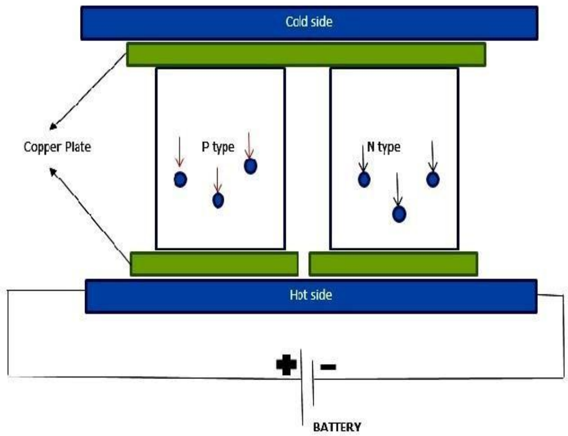


Fig -1: working principle of Peltier Module

4.2 FREQUENCY

A high resonance frequency is an obvious choice because the power in the thermoacoustic device is a linear function of the acoustic resonance frequency. In contrast, K is inversely proportional to the square root of the frequency, implying that stack plates have relatively close plate spacing. The frequency of 267Hz was chosen as a compromise between these two effects, as well as the fact that the driver resonance must be kept close to the resonator resonance for maximum driver efficiency.

4.2 STACK DESIGN

The stack spiral was made out of 35 mm aluminium foil. As shown in Figure 4.12, a 0.37 mm diameter nylon line was bonded over the sheet to enforce the spacing between the layers. The sheet was rolled up and glued at the very end after the adhesive had dried, as shown in Figure 4.13. The rolled-up stack measures 0.890" (2.47 cm) in diameter and 1.58 in height (3.7 cm). The strip of sheet measures approximately 22 in before being wrapped (53.8 cm).

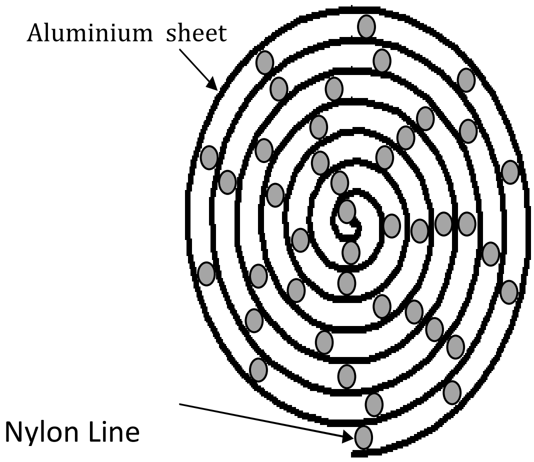


Fig-2: Crossectional view of stack

4.3. MODEL(DELTAEC MODEL)

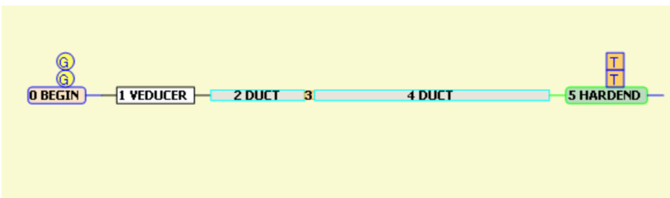


Fig-3: DeltaEc model

5. ANALYSIS AND RESULTS

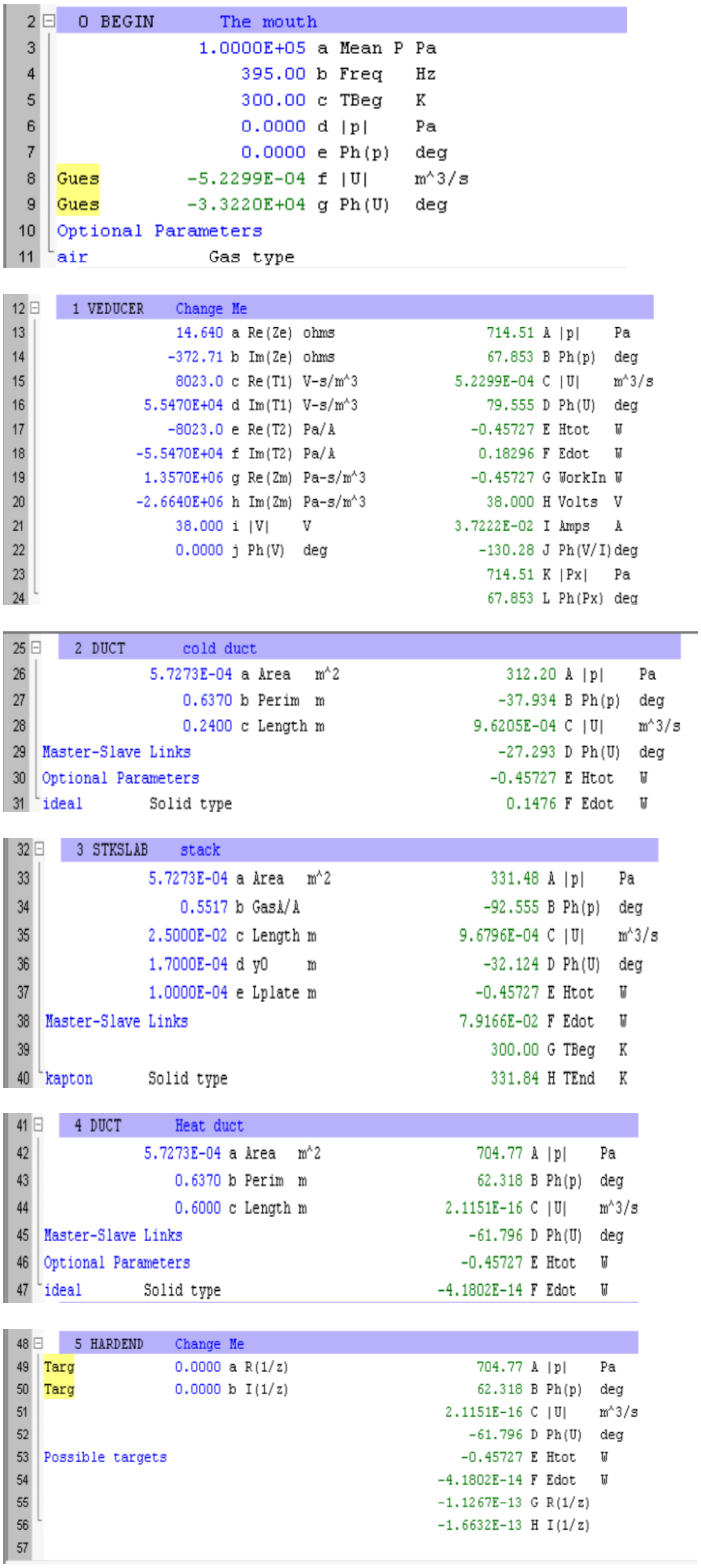
5.1 THEORETICAL ANALYSIS

DeltaEC integrates momentum, continuity, and energy equations numerically. In DeltaEC software, we iterated a few geometric and thermophysical parameters that affected thermoacoustics, which are as follows:

The following parameters must be entered into DeltaEC:

- **Mean P:** It indicates the charging pressure inside the resonating tube.
- **Frequency:** It is the frequency of our acoustic source. It is measured in Hertz.
- **T_{Beg}:** T_{Beg} is short form for Temperature at beginning. Its value generally is equal to the value of surrounding.
- **|p|:** It is the dynamic pressure which is a function of amplitude of acoustic source.
- **Ph |p|:** It shows the phase of dynamic pressure.
- **|U|:** Flow rate in (m^3/s).
- **Ph |U|:** It shows the phase of flow rate. Flow rate and its phase both are kept as guesses in DeltaEC

  s we cannot determine its value practically or theoretically.



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 0 BEGIN      The mouth
          1.0000E+05 a Mean P Pa
              395.00 b Freq   Hz
              300.00 c TBeg   K
              0.0000 d |p|    Pa
              0.0000 e Ph(p)  deg
Gues     -5.2299E-04 f |U|    m^3/s
Gues     -3.3220E+04 g Ph(U)  deg
Optional Parameters
air            Gas type

 1 VEDUCER    Change Me
          14.640 a Re(Ze) ohms          714.51 A |p|     Pa
         -372.71 b Im(Ze) ohms          67.853 B Ph(p)   deg
          8023.0 c Re(T1) V-s/m^3    5.2299E-04 C |U|    m^3/s
      5.5470E+04 d Im(T1) V-s/m^3       79.555 D Ph(U)   deg
         -8023.0 e Re(T2) Pa/A        -0.45727 E Htot    W
     -5.5470E+04 f Im(T2) Pa/A         0.18296 F Edot    W
      1.3570E+06 g Re(Zm) Pa-s/m^3    -0.45727 G WorkIn  W
     -2.6640E+06 h Im(Zm) Pa-s/m^3      38.000 H Volts   V
          38.000 i |V|    V          3.7222E-02 I Amps   A
          0.0000 j Ph(V)  deg          -130.28 J Ph(V/I)deg
                                        714.51 K |Px|    Pa
                                        67.853 L Ph(Px)  deg

 2 DUCT       cold duct
      5.7273E-04 a Area   m^2           312.20 A |p|     Pa
          0.6370 b Perim  m            -37.934 B Ph(p)   deg
          0.2400 c Length m          9.6205E-04 C |U|    m^3/s
Master-Slave Links                     -27.293 D Ph(U)   deg
Optional Parameters                   -0.45727 E Htot    W
ideal          Solid type               0.1476 F Edot    W

 3 STKSLAB    stack
      5.7273E-04 a Area   m^2           331.48 A |p|     Pa
          0.5517 b GasA/A              -92.555 B Ph(p)   deg
      2.5000E-02 c Length m          9.6796E-04 C |U|    m^3/s
      1.7000E-04 d y0     m            -32.124 D Ph(U)   deg
      1.0000E-04 e Lplate m           -0.45727 E Htot    W
Master-Slave Links                   7.9166E-02 F Edot   W
                                        300.00 G TBeg    K
kapton         Solid type               331.84 H TEnd    K

 4 DUCT       Heat duct
      5.7273E-04 a Area   m^2           704.77 A |p|     Pa
          0.6370 b Perim  m             62.318 B Ph(p)   deg
          0.6000 c Length m          2.1151E-16 C |U|    m^3/s
Master-Slave Links                     -61.796 D Ph(U)   deg
Optional Parameters                   -0.45727 E Htot    W
ideal          Solid type           -4.1802E-14 F Edot   W

 5 HARDEND    Change Me
Targ      0.0000 a R(1/z)               704.77 A |p|     Pa
Targ      0.0000 b I(1/z)               62.318 B Ph(p)   deg
                                     2.1151E-16 C |U|    m^3/s
                                       -61.796 D Ph(U)   deg
Possible targets                      -0.45727 E Htot    W
                                    -4.1802E-14 F Edot   W
                                    -1.1267E-13 G R(1/z)
                                    -1.6632E-13 H I(1/z)
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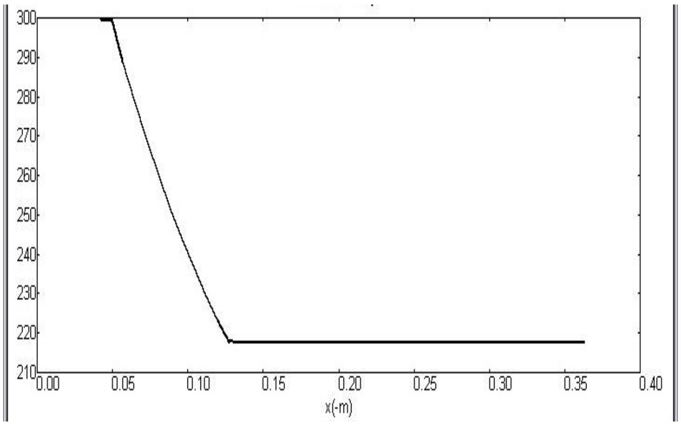

Fig -4: Result obtained in form of temperature drop

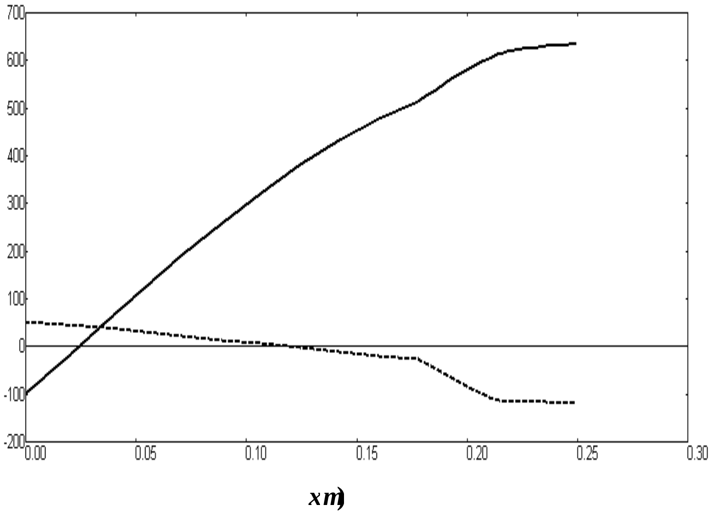

Fig -5: Real (Solid line) and imaginary (Dotted line) parts of the pressure in the refrigerator.

6. CONCLUSION

To obtain lower temperatures, the highest temperature gradient across the stack region, the least input power for producing a cooling effect, and finally the system's coefficient of performance, various numerical and experimental optimization methods were used. Based on previous investigations in the field of thermoacoustic refrigeration, some conclusions have been formed. 1. For stack shape, thermal penetration depth and stack spacing are key factors. A compromise between manufacturing compatibility and thermal penetration depth will be made in the end. 2. The stack position from the driver end should be critically optimised in order to get the required output; it should be placed near the driver end but not exactly at the driver end; the results are severe when it is placed exactly at the driver end. In comparison to previous studies, this one is notable for using materials that are both inexpensive and widely available. This is an excellent choice for a low-cost thermoacoustic refrigerator used to demonstrate the fundamental physical principles of thermoacoustic phenomena.

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