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# Optimization of a phase adjuster in a thermo-acoustic stirling engine using response surface methodology

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**Abstract**

In this study, we carried out the optimization of the structure of phase adjuster (PA) using response surface methodology (RSM). The influences of the PA position, its inner diameter and length on the resonance frequency, pressure amplitude and the onset temperature difference had been investigated. To improve the performance of the engine, the optimal parameters group was selected and also simulated by DeltaEC. The similar results verified the accuracy of the RSM. In addition, the performance of the thermo-acoustic Stirling engine without/with PA was compared. Results showed that optimized PA decreased the onset temperature difference and increased pressure amplitude.


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*Key words*: thermo-acoustic Stirling engine; phase adjuster; response surface methodology; pressure amplitude; onset temperature difference.

## 1. Introduction

The thermo-acoustic engine is a new type engine based on the interaction between the thermodynamic and acoustic phenomena. They shows great advantage and proposing prospect because of no moving parts, high reliability and environmental friendliness compared with the traditional heat engine. However, the efficiency of the thermo-acoustic engine is generally low, especially for the standing wave thermo-acoustic engine. Although the traveling wave thermo-acoustic engine realizes the reversible cycle, the efficiency of heat-to-sound energy conversion is still low because of miscellaneous dissipations and some nonlinear effects. To improve the efficiency of thermo-acoustic conversion is crucial to extend commercial application of thermo-acoustic engines.

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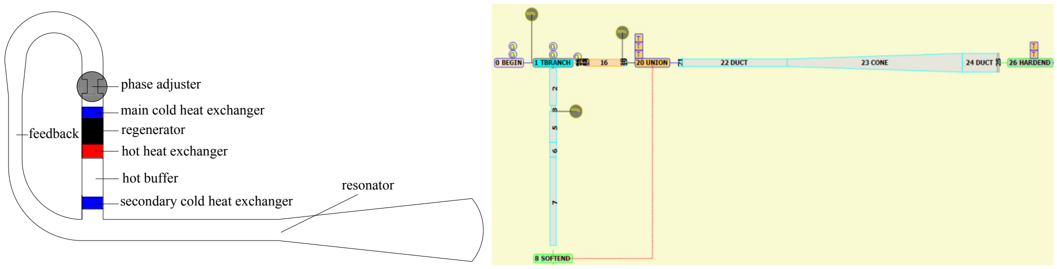
For this purpose, many strategies were proposed. Swift first presented the jet pump to suppress the sound direct current in the loop in a thermo-acoustic engine [1]. The working fluid would make an abrupt transition from large cross-sectional area to small one when flowing through the jet pump, which generated additional pressure drop to supress the sound direct current, thus improving the efficiency. Subsequently, Petculescu et.al investigated the nonlinear effect and minor loss of the jet pump and discussed the influence of different cone half-angles [2]. The jet pump acted as the rudiment of phase adjuster (PA). Recently, Sakamoto et.al introduced a PA in the Loop-Tube-Type thermo-acoustic system [3]. They found PA decreased the onset temperature difference and increased the acoutic intensity.

Inspired by Swift and Sakamoto, we introduced a PA in the loop of a thermo-acoustic Stirling engine. Referring to the RMS introduced by Hariharan [4], we carried out the optimization of PA geometry. The major parameters of PA influencing the performance of the engine includes the position of PA, its inner diameter and length. Optimal parameters were also simulated by DeltaEC [5] and the performance with two different methods was compared.

## 2. Mathematical modeling of the thermo-acoustic Stirling engine with a PA




(a) (b)

Figure 1 (a) The schematic illustration of the thermo-acoustic Stirling engine with a PA and (b) its DeltaEC's schematic view

A PA was introduced in the loop of thermo-acoustic Stirling engine to improve the heat-to-sound energy conversion efficiency. The Stirling engine with the PA is illustrated in Figure 1(a). PA narrows the cross-sectional area of the part of the loop tube presented by a grey round. DeltaEC was used to simulate the performance of the Stirling engine with PA. Figure 1(b) presents the DeltaEC's model of the Stirling engine with PA. The shadow zone in Figure 1(a) and the part 2 in Figure 1(b) with sudden change of cross section both represent PA. The position of PA was measured by the distance away from the main ambient heat exchanger represented by the length of the tube 2 in Figure 1(b).

Helium gas was used as the working gas and charge pressure was 3.0 MPa. Three factors of PA (the position of PA, inner diameter of PA and the length of PA) were used and coded by A, B and C varying between -1 and 1. The range of variables was carefully chosen to include all parameters spaces to obtain good fitting formulas. The selected range and variables are listed in Table 1.

Table 1. Levels of variables in Box-Behnken Design (BBD)

| Variables | Ranges and levels | | |
|---|---|---|---|
| (m) | -1 | 0 | 1 |
| A: Position of PA | 0.02 | 0.42 | 0.82 |
| B: Inner diameter of PA | 0.03 | 0.06 | 0.09 |
| C: Length of PA | 0.02 | 0.07 | 0.12 |

## 3. Results and discussions

The RSM is an empirical approach used for modeling and optimization of processes in which a response of interest is influenced by several variables. The RSM combines mathematical and statistical techniques, which is suitable to identify the correlation between various design parameters and responses and their coupled impacts.

As Table 1 shown, the variables are designated as -1, 0 and 1, with being lowest, middle and largest. According to the arrangement of test point in BBD, the results were grouped into the matrix form with the factors and the responses. The experimental design matrix and corresponding results are presented in Table 2.

Table 2. Design of experimental martix

| Run | Factors | | | Responses | | |
|---|---|---|---|---|---|---|
| | Position of PA (m) | Inner diameter of PA (m) | Length of PA (m) | Resonant frequency (Hz) | Pressure amplitude (KPa) | Onset temperature difference (K) |
| 1 | 0.02 | 0.03 | 0.07 | 62.457 | 238.290 | 357 |
| 2 | 0.82 | 0.03 | 0.07 | 61.463 | 227.530 | 442 |
| 3 | 0.02 | 0.09 | 0.07 | 61.911 | 236.000 | 361 |
| 4 | 0.82 | 0.09 | 0.07 | 61.871 | 235.660 | 363 |
| 5 | 0.02 | 0.06 | 0.02 | 61.885 | 235.930 | 362 |
| 6 | 0.82 | 0.06 | 0.02 | 61.829 | 235.430 | 365 |
| 7 | 0.02 | 0.06 | 0.12 | 62.637 | 238.520 | 350 |
| 8 | 0.82 | 0.06 | 0.12 | 62.268 | 235.180 | 369 |
| 9 | 0.42 | 0.03 | 0.02 | 61.869 | 235.190 | 368.5 |
| 10 | 0.42 | 0.09 | 0.02 | 61.783 | 235.560 | 363.5 |
| 11 | 0.42 | 0.03 | 0.12 | 62.487 | 233.610 | 398 |
| 12 | 0.42 | 0.09 | 0.12 | 62.014 | 236.160 | 360.5 |
| 13 | 0.42 | 0.06 | 0.07 | 62.199 | 236.450 | 360 |
| 14 | 0.42 | 0.06 | 0.07 | 62.199 | 236.450 | 360 |
| 15 | 0.42 | 0.06 | 0.07 | 62.199 | 236.450 | 360 |

In order to use the low grade energy and improve the heat-to-sound energy conversion efficiency, the onset temperature difference should be low and the pressure amplitude should be high. According to this principle, we optimize the PA geometry by the RSM. To verify the accuracy of the RSM, the optimal parameters group was obtained and simulated by DeltaEC. The comparison of results by the RSM and DeltaEC is shown in Table 3.

Table 3. Comparison of the RSM and DeltaEC

| Optimal parameters (m) | Responses | RSM | DeltaEC | Without PA |
|---|---|---|---|---|
| A:Position of PA=0.02 | Resonant frequency (Hz) | 62.64 | 62.78 | 61.74 |
| B:Inner diameter of PA=0.05 | Pressure amplitude (KPa) | 239.157 | 239.130 | 235.430 |
| C:Length of PA=0.12 | Onset temperature difference (K) | 350 | 349 | 364 |

By comparing the RSM with DeltaEC, we could conclude that the responses are similar under the condition of the optimal parameters group. The errors of the resonant frequency, pressure amplitude and onset temperature difference were 1.6%, 0.09%, and 0.3%, which indicated the validity of the RSM. The thermo-acoustic Stirling engine without PA was also simulated by DeltaEC and presented in the far right column of Table. Compared the results of the engine without/with PA, resonant frequency has a slight change. Pressure amplitude increases to 239.157KPa from 235.430KPa, and onset temperature difference decreases from 364K to 349K. This indicated that PA decreased the onset temperature difference and increased pressure amplitude.

## 4. Conclusions

To investigate the impact of PA on the performance of a thermo-acoustic engine, a successful mathematical model has been developed by RSM. The optimal parameters group of PA were selected and also simulated by DeltaEC. Compared the results of two methods, the accuracy of the RSM was verified. In addition, Performance of the thermo-acoustic Stirling engine without and with PA was compared. Results showed that PA decreased the onset temperature difference and increased pressure amplitude, which was helpful to use low-grade energy and improve the efficiency of thermo-acoustic conversion.

## Acknowledgements

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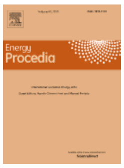


**Biography**

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