ANALYSIS AND OPTIMIZATION OF SOME OSCILLATION PARAMETERS OF THE THERMAL EXHAUST VALVE SYSTEM MODEL IN INTERNAL COMBUSTION ENGINES

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DOI: http://doi.org/ 10.57001/huih5804.2025.253

ABSTRACT

The article analyzes the oscillation characteristics of the exhaust valve system in internal combustion engines. By using dynamic analysis methods, the authors established differential equations that describe the system's oscillations. At the same time, the paper proposes an optimization problem aimed at reducing the decay time of the oscillations and controlling the oscillation amplitude within allowable limits. An optimization algorithm employing a Genetic Algorithm (GA) is used to optimize the system's parameters, thereby minimizing the coupling between different oscillatory components. The results indicate that the optimized parameters can significantly reduce the interactions among individual oscillations, which in turn enhances the overall stability of the system.

Keywords: *Heat exhaust valves; internal combustion engines; oscillation model; Optimal; Genetic Algorithm -GA.*

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Received: 14/3/2025
Revised: 10/5/2025
Accepted: 25/7/2025

1. INTRODUCTION

Mechanical oscillation is one of the important problems in the fields of mechanics and dynamics. Controlling oscillations to achieve optimal performance such as reducing decay time, maintaining oscillation amplitudes within safe limits, or adjusting parameters to minimize mode coupling is a highly applicable issue in the design of engineering systems.

The exhaust valve system in internal combustion engines is one of the components that induce oscillations affecting the overall system quality. In some previous studies [1-3], only the oscillation characteristics were described, without providing the optimal design parameters to reduce oscillations. Therefore, the main objective of this paper is to optimize parameters such as spring stiffness and mass to significantly reduce the interaction between the individual oscillations.

2. SYSTEM DESCRIPTION

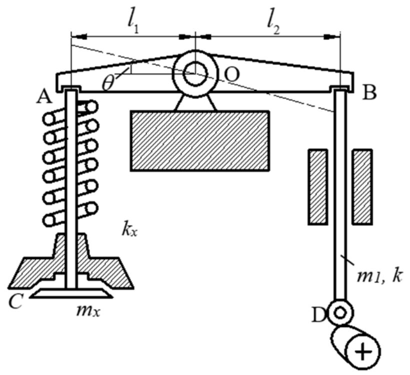

Fig. 1. Diagram of thermal exhaust valve system

The schematic diagram of the exhaust valve system of an internal combustion engine is shown in Fig. 1. The lever AB rotates about the axis O and has a moment of inertia J. The mass of the poppet valve AC and spring is m_x, with the spring having a stiffness k_x. The weight of the spring itself, calculated on the basis of the Rayleigh method, can be approximated as $m_x/3$ concentrated at point A. The push rod BD has a mass of m_1 and a stiffness k, and θ is the rotation angle of the lever AB.

3. SET UP THE OSCILLATION MODEL

3.1. Building a mathematical model

The system's differential equation of motion has the form:

$$M\ddot{X} + KX = 0 \quad (1)$$

with:

$X = [x_A, \theta, x_D]^T$ is the state vector.

M is the mass matrix.

K is the stiffness matrix.

The own oscillation solution is defined as:

$$x_A = X_A e^{i\omega t}; x_D = X_D e^{i\omega t}; \theta = \Theta e^{i\omega t} \quad (2)$$

In which: ω is the own oscillation frequency.

Substituting these solutions into the equations of motion, we obtain an algebraic system related to X_A, X_D, Θ and ω.

$$\begin{cases} (k_x - m_x\omega^2)X_A = 0 \\ -I_O\omega^2\Theta + l_1k_xX_A + l_2kX_D = 0 \\ (k - m_1\omega^2)X_D = 0 \end{cases} \quad (3)$$

Rewrite in matrix form:

$$\begin{bmatrix} k_x - m_x\omega^2 & 0 & 0 \\ l_1k_x & -I_O\omega^2 & l_1k_x \\ 0 & 0 & k - m_1\omega^2 \end{bmatrix} \begin{bmatrix} X_A \\ \Theta \\ X_D \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

Condition for own oscillations: In order for the system to exhibit nontrivial own oscillations (i.e., not all simultaneously equal to zero), the determinant of the matrix must be equal to 0.

$$\det \begin{bmatrix} k_x - m_x\omega^2 & 0 & 0 \\ l_1k_x & -I_O\omega^2 & l_1k_x \\ 0 & 0 & k - m_1\omega^2 \end{bmatrix} = 0 \quad (5)$$

Because in reality there is an interaction between x_A, x_D and θ, the system can produce coupled oscillations.

The general solution of coupled oscillation has the form:

$$x(t) = C_1X_1e^{i\omega_1 t} + C_2X_2e^{i\omega_2 t} + C_3X_3e^{i\omega_3 t} \quad (6)$$

In there: C_1, C_2, C_3 are constants calculated from initial conditions; ω_1, ω_2, ω_3 are the corresponding own oscillation frequencies.

The first oscillation, X_1, is the oscillation ratio between x_A, x_D and θ. This is the primary oscillation, with C_1 controlling the amplitude and phase.

The second oscillation, X_2, describes the coupled oscillation between the rotational angle θ and the x_D displacement, with its amplitude regulated by C_2.

The third oscillation, X_3, is an independent vector that primarily plays a role in stabilizing the state.

3.2. Calculations with specific data.

Table 1. Actual calculation data

m_x (kg)	m_1 (kg)	k_x (N/mm)	k (N/mm)	l_1 (mm)	l_2 (mm)
0.092	0.2	26.68	40	40	64

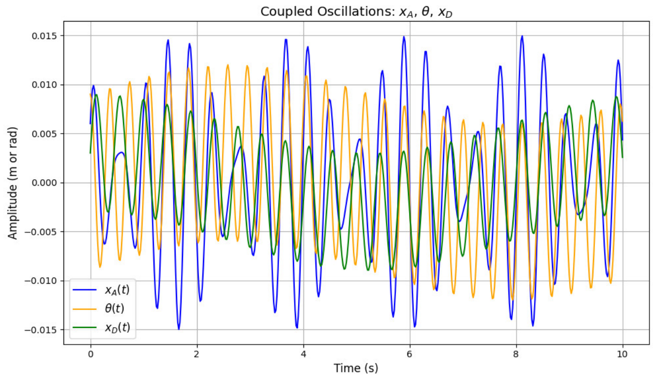

Fig. 2. Coupled oscillation graphs of $x_A(t)$, θ(t) and $x_D(t)$

4. OPTIMIZATION PROBLEM OF OSCILLATION COUPLING REDUCTION USING GENETIC ALGORITHM

+ *Objective function:*

To reduce coupling, we minimize the integral of the squared deviation between the oscillations.

$$\text{Minimize}: J = \int_0^T \left(\begin{aligned} &(x_A(t) - \theta(t))^2 + (x_A(t) - x_D(t))^2 \\ &+ (\theta(t) - x_D(t))^2 \end{aligned} \right) dt \quad (7)$$

+ *Parameters to be optimized:* *k_x, k, m_x, m_1*

k_x: Stiffness of the poppet valve; k: Stiffness of the pushrod BD; m_x: Mass of the poppet valve; m_1: Mass of the pushrod BD.

+ *Constraints:*

Parameters must be greater than 0: $k_x > 0$, $k > 0$, $m_x > 0$, $m_1 > 0$

Parameters are within reasonable physical ranges

Table 2. Physical parameter table

Design variables	Lower limit	Upper limit
k_x (N/mm)	20	50
k (N/mm)	20	50
m_x (kg)	0.1	0.3
m_l (kg)	0.1	0.5

+ *How to implement genetic algorithm (GA)* [4]

- Encoding individuals: Each individual is a sequence of real numbers $[k_x, k, m_x, m_1]$

- Maximize fitness function: $\text{Fitness} = \frac{1}{J}$ (8)

- Population Initialization: Randomly generate a set of initial individuals with 50 initial individuals.

- Selection: Based on fitness function to select the best individual.

- Mating: Combining any two individuals to create a new individual, with the probability of 0.7.

- Mutation: Random change of some genes in an individual, with a mutation probability of 0.2.

- Iterate: Continue until the number of generations or fitness function reaches a threshold.

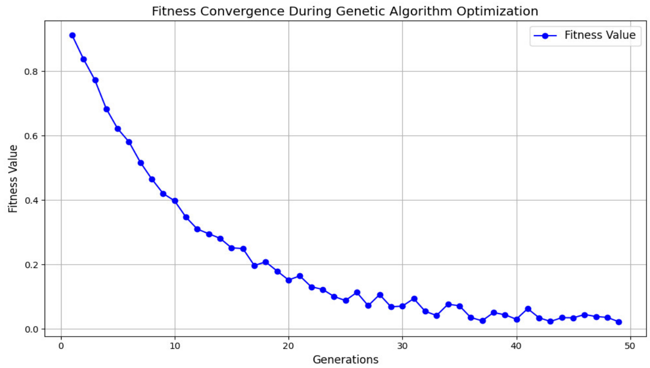

Fig. 3. Process chart of fitness value convergence in genetic algorithm optimization

The optimal result to reduce the coupling between x_A, θ and x_D is:

k_x = 20N/mm; k = 24.897363051060433N/mm;

m_x = 0.059997241745876 53kg;

m_1 = 0.25631928128696624kg.

With the initial set of parameters, the objective function J = 0.22488638200390657; with the set of parameters after optimization, the objective function J = 0.1293223617878742.

Substituting the optimal results into the problem, we obtain the optimal oscillation graph of $x_A(t)$, θ(t), and $x_D(t)$ as shown in Fig. 4. It can be observed that the oscillations have reduced their interdependence, the oscillation amplitude has decreased, and the system has become more stable with less interaction compared to the initial non-optimized case shown in Fig. 2. This allows designers to select appropriate material parameters for the thermal exhaust valve system model in internal combustion engines, thereby reducing the impact of vibrations on the system during operation.

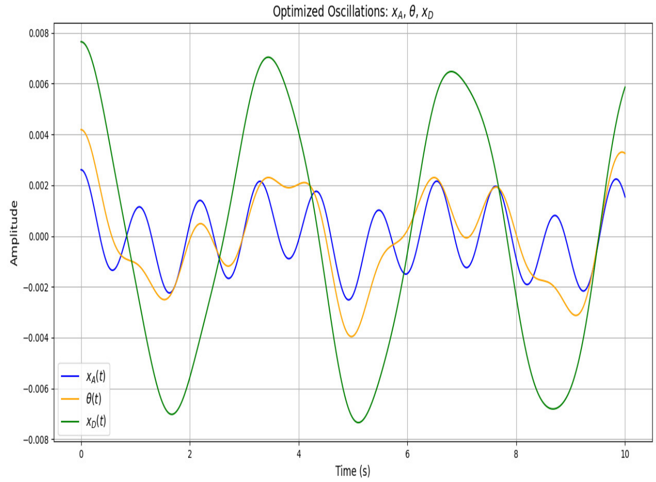

Fig. 4. Optimal oscillation graph of xA(t), θ(t) và xD(t)

5. CONCLUSION

This paper employs the genetic algorithm to reduce oscillatory coupling in the mechanical system of the thermal release valve model in an internal combustion engine. The objective function J decreases by 1.74 times compared to the initial value after optimization. This demonstrates the effectiveness of the genetic algorithm in optimizing nonlinear vibration parameters. The method also proves to be efficient in improving the stability of mechanical vibration systems and can be applied for design enhancements in engineering fields.

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