Transient Thermal Behaviour of Engine Components During Cold Start

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Abstract: **Cold start operation represents one of the most critical phases in internal combustion engine performance. During this period, engine components experience rapid temperature variations that significantly influence efficiency, emissions, lubrication, and mechanical wear. This study investigates the transient thermal behavior of key engine components during cold start conditions. The analysis focuses on temperature evolution, heat transfer mechanisms, and thermal gradients affecting engine durability and performance. A transient thermal model is employed to evaluate temperature rise characteristics of major components, highlighting the impact of heat generation and thermal inertia. The findings indicate that non-uniform temperature distribution and delayed oil warming play a vital role in friction losses and component stress. The study provides insights into improving thermal management strategies during engine cold start.**

Keywords: **Cold start operation, emissions, lubrication, temperature evolution, heat transfer mechanisms.**

1. INTRODUCTION

The cold start phase of an internal combustion engine is characterised by unstable thermal conditions, incomplete combustion, elevated emissions, and increased mechanical losses. Unlike steady-state engine operation, cold start involves rapid temperature transitions that influence combustion efficiency, lubrication effectiveness, and material stresses.

At engine start-up, most components are at ambient temperature. Combustion heat generation initiates thermal energy transfer throughout the engine structure. However, due to thermal inertia, components respond at different rates, leading to temperature gradients and transient heat flow phenomena.

Understanding transient thermal behavior is crucial for:

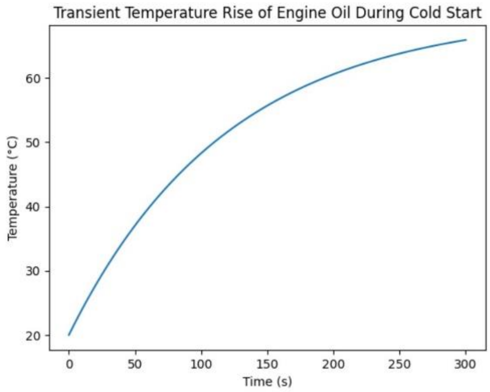
• Reducing fuel consumption

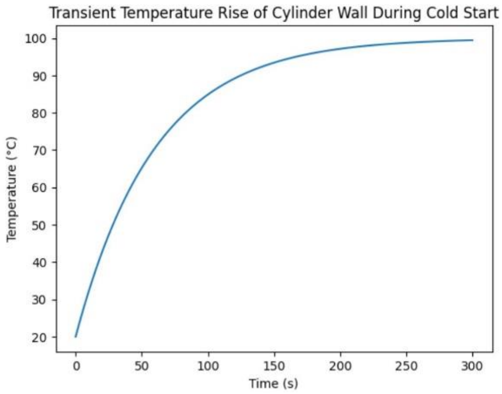
• Minimising harmful emissions

• Preventing excessive mechanical wear

• Improving engine durability

This study aims to analyse the temperature evolution of engine components during cold start and evaluate the associated thermal effects.





2. LITERATURE REVIEW

Previous studies have emphasised the importance of thermal conditions during cold start:

Heywood (1988) highlighted that cold engines suffer from poor vaporisation and incomplete combustion, leading to efficiency losses. Stone (2012) noted that thermal imbalance significantly affects lubrication regimes and frictional behaviour.

Research by Rakopoulos & Giakoumis (2006) demonstrated that transient heat transfer strongly influences combustion chamber temperatures. Studies on engine friction (Taylor, 1993) revealed that low oil temperatures increase viscous resistance, contributing to mechanical losses.

More recent investigations using numerical simulations (CFD/FEA) show that:

• Cylinder walls heat rapidly

• Engine oil warms slowly

• Thermal stresses peak during early start-up

Despite extensive research, transient thermal effects remain a critical area for optimisation.

3. METHODOLOGY AND SYSTEM FRAMEWORK

This study employs a transient thermal analysis approach.

3.1 Assumptions

To simplify modelling:

• Initial engine temperature = Ambient (20°C)

• Heat generation begins at ignition

• Heat transfer modes: conduction + convection

• Material properties assumed constant

3.2 Heat Transfer Mechanisms

During cold start:

1. Combustion Heat Generation
2. Conduction through Engine Structure
3. Convection to Coolant & Oil

Energy balance:

$$Q_{generated} = Q_{stored} + Q_{lost}$$

Where:

• Q_{stored}→ Raises component temperature

• Q_{lost}→ Dissipated via cooling systems

4. TRANSIENT THERMAL ANALYSIS

Temperature variation follows exponential heating behaviour:

$$T(t) = T_{initial} + (T_{steady} - T_{initial})(1 - e^{-t/\tau})$$

Where:

• τ→ Thermal time constant

• Depends on mass & heat capacity

5. RESULTS & DISCUSSION

Two representative component behaviours are observed:

Cylinder Wall Response

• Rapid temperature rise

• Direct exposure to combustion heat

• High thermal gradients

Engine Oil Response

• Slower temperature increase

• High thermal inertia

• Critical for lubrication regime

Key observations:

• Thermal mismatch between components

• Increased friction during early start

• Elevated thermal stresses

Engineering implications:

✓ Poor lubrication → Higher wear

✓ Thermal gradients → Material fatigue

✓ Slow oil heating → Efficiency loss

6. ENGINEERING INTERPRETATION

Cold start penalties arise from:

• Heat absorption by cold metal surfaces

• Increased oil viscosity

• Non-uniform temperature distribution

Potential solutions:

• Pre-heating systems

• Improved coolant flow design

• Advanced thermal coatings

7. CONCLUSION

The transient thermal behaviour of engine components during cold start significantly affects engine performance, efficiency, and durability. Rapid heating of combustion-exposed components combined with delayed oil warming leads to thermal imbalance, increased friction, and mechanical stress.

Optimising engine thermal management during cold start can substantially improve:

• Fuel economy

• Emission reduction

• Component lifespan

Future work may involve CFD/FEA simulations or experimental validation.

REFERENCES

[1] Heywood, J.B., 1988. *Internal Combustion Engine Fundamentals.* McGraw-Hill.

[2] Stone, R., 2012. *Introduction to Internal Combustion Engines.* Palgrave Macmillan.

[3] Rakopoulos, C.D. & Giakoumis, E.G., 2006. *Diesel Engine Transient Operation.* Springer.

[4] Taylor, C.F., 1993. *The Internal Combustion Engine in Theory and Practice.* MIT Press.

[5] Ferguson, C.R. & Kirkpatrick, A.T., 2015. *Internal Combustion Engines.* Wiley.