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Review Report on Cooling System and Control Model for Improved Engine Thermal Management

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ABSTRACT

Advanced thermal management systems for combustion engines will improve fluid temperature regulation and servo–motor power consumption to positively impact the pipage emissions, fuel economy, and parasitic losses by better regulating the combustion method with multiple computer-controlled parts. Advanced automotive thermal management systems integrate electro-mechanical components for improved fluid flow and thermodynamic control action. Progressively, the design of ground vehicle heating and cooling management systems require analytical and empirical models to establish a basis for real time control algorithms. One of the key elements in this computer controlled system is the smart thermostat valve which replaces the traditional wax-based unit. This paper gives a review of the cooling system and control model for improved engine thermal management and related work.

KEYWORDS: *Intelligent cooling system, Thermal management Engine efficiency, Heated thermostat, Electrical water pump, Variable speed fan*

I. INTRODUCTION

Advanced thermal management systems for internal combustion engines can better regulate the combustion process by harmoniously controlling the cooling system's actuators to obtain desired thermal conditions in a power-efficient manner. Advanced automotive thermal management systems can effectively maintain the desired temperature in internal combustion engines for enhanced performance [1]. Internal combustion engine active thermal management systems offer enhanced coolant temperature tracking during transient and steady–state operation.

The main cooling loop ensures that the engine block does not overheat, thus leading to coolant boiling. Similarly, the transmission oil is cooled by pumping the fluid through an auxiliary heat exchanger typically located inside the radiator. The charge air cooler loop can improve combustion and fuel economy by decreasing the compressed inlet air temperature [5]. Advanced automotive cooling systems replace the conventional wax thermostat valve with a variable position smart valve, and replace the mechanical coolant pump and radiator fan with electric and/or hydraulic driven actuators. The thermostat regulates the coolant flow through the radiator and/or engine bypass to control the heat exchange between the radiator's coolant fluid and the ambient air. The electric water pump improves upon this concept by prescribing the coolant flow rate based on the engine's overall operation and the driver commands rather than solely on the crankshaft speed. The traditional radiator fan is belt driven and equipped with a clutch to limit parasitic loads during operating conditions that provide sufficient radiator heat rejection. It is designed to just guarantee a sufficient heat removal at maximum engine output conditions at the worst vehicle operating conditions (low vehicle speed and high ambient temperature) However, these operational conditions only represent approximately 5% of the conditions that the vehicle will encounter during its life [2]. It also facilitates transitional calculations of the mode drive, which are difficult with three-dimensional analysis [3]. Similarly, a solenoid controlled three-way valve offers similar functionality to traditional thermostats but could be electrically controlled by the engine control module (ECM). The concepts of vehicle thermal management (VTM) were firstly applied in the aviation and space industries, then in the 1970s researchers advocated employing it in the vehicle industry too [7,8]. The modern vehicle integrated thermal management (VITM) system can realize rational and comprehensive control over thermodynamic processes in terms of power system integration [9]. The objects of VITM are various, depending on the different power systems. Hence, for an internal combustion engine vehicle (ICEV), the ITM contains internal combustion engine (ICE) cooling, turbocharged cooling, exhaust gas recirculation (EGR) cooling, lubrication cooling and air conditioning (AC) or heat pump (HP). As for electric vehicles (EVs), these can be classified into pure electric vehicles (PEVs) and hybrid electric vehicles (HEVs) according to the different configuration mechanisms. For PEVs, the ITM mainly includes battery cooling/preheating, electrical motor, direct current to direct current converters (DC-DC) cooling and heat pump or air conditioning. Besides, the ITM of HEVs, considering the series, parallel and series-parallel mechanisms, combines ICE cooling and electric power system (EPS) cooling [11]. The classification of VITM is shown in Figure 1. Although the power source differs between ICEVs and EVs, the essences of their VITM systems is identical, which can realize fuel economy, emission reduction and energy efficiency promotion via rational, effective and synergetic control over the interrelated thermodynamic system. To create an efficient automotive thermal management system, the vehicle's cooling system behavior and transient response must be analyzed. In [8] pursued a lumped parameter modeling approach and presented multi-node thermal models which estimated internal engine temperature. In [7] created a mathematical model to analytically predict the dynamic behavior of a 4.6L spark-ignition engine. To accompany the mathematical model, analytical/empirical descriptions were developed to describe the smart cooling system components.

II. Literature Survey

Arya K. Haghighat et. al. [1] "An intelligent cooling system and control model for improved engine thermal management" Engine performance was improved over all parts of the NEDC cycle, including engine warm-up and both high and low engine load conditions. A controlling model for the cooling system of an engine was developed in order to reduce fuel consumption and engine emissions through the use of controllable engine cooling components including an electrical water pump, an electrical fan, and a heater thermostat. This model was based on engine characteristics that were derived from several experiments on a 1.4 L engine. In this model, a control program is suggested that can control the different active intelligent components. The results of simulations using the derived engine model showed that fuel consumption decreases 1.1% for the intelligent cooling system under NEDC cycle operation compared to a conventional cooling system.

Soheil Jafari et. al. [2] "A review of evaporative cooling system concepts for engine thermal management in motor vehicles" The purposes of this review are to establish the evident system shortcomings and to identify the remaining research questions that need to be addressed to enable this important technology to be adopted by vehicle manufacturers. The evaporative cooling system concepts proposed over the past century for engine thermal management in automotive applications are examined and critically reviewed. EC systems proposed over the past century were examined. Initially, the physical principles and the benefits of EC were expounded together with the state-of-the-art capability for modeling and numerical simulations. If these research challenges are overcome, it will then be possible to establish the control variables that achieve peak heat flux levels comparable with those of state-of-the-art sub-cooled systems.

Kevin Bennion et. al. [3] "Integrated Vehicle Thermal Management for Advanced Vehicle Propulsion Technologies" A critical element to the success of new propulsion technologies that enable reductions in fuel use is the integration of component thermal management technologies within a viable vehicle package. Integrated vehicle thermal management is one pathway to address the cost, weight, and size challenges. The integration of the power electronics and electric machine (PEEM) thermal management with other existing vehicle systems is one path for reducing the cost of electric drive systems. This work demonstrates techniques for evaluating and quantifying the integrated transient and continuous heat loads of combined systems incorporating electric drive systems that operate primarily under transient duty cycles, but the approach can be extended to include additional steady-state duty cycles typical for designing vehicle thermal management systems of conventional vehicles. The proposed method of using the generated heat load curve provided a method for evaluating the transient and continuous heat loads of individual components and integrated thermal management systems over actual in-use conditions for components that experience significant transient use.

Yan Wang et. al. [4] "Advances in Integrated Vehicle Thermal Management and Numerical Simulation" This article reviews relevant researching work and current advances in the ever-broadening field of modern vehicle thermal management (VTM). Based on the systematic summaries of the design methods and applications of ITM, future tasks and proposals are presented. This article aims to promote innovation of ITM, strengthen the precise control and the performance predictable ability, furthermore, to enhance the level of research and development (R&D). To pursue high efficiency and lightweight in automobile design, the power system and its vehicle integrated thermal management (VITM) system have attracted widespread attention as the major components of modern vehicle technology. According to the different power sources, the research objects of VITM are quite different to some extent. Regarding ICEVs, their thermal management systems contain ICE cooling, turbo-charged cooling, exhaust gas recirculation cooling, lubrication cooling, and air conditioning or heat pump.

H H Pang et. al. [5] "Review of engine cooling technologies for modern engines" The performance of the conventional engine-cooling system has always been constrained by the passive nature of the system and the need to provide the required heat-rejection capability at high-power conditions. This leads to considerable losses in the cooling system at part-load conditions where vehicles operate most of the time. A set of design and operating features from advanced engine cooling systems is reviewed and evaluated for their potential to provide improved engine protection while improving fuel efficiency and emissions output. The controllable element can also be employed to maintain oil and block temperature within its design-operating range for low frictional losses and emissions impact. Though this is an ideal arrangement for the engine cooling structure itself, the design and requirement of external circuits have considerable influence on the performance of the whole ECS.

Pradeep Setlur et. al. [6] "An Advanced Engine Thermal Management System: Nonlinear Control and Test" Internal combustion engine thermal management system functionality can be enhanced through the introduction of smart thermostat valves and variable speed electric pumps and fans. To study these cooling system actuators, with accompanying nonlinear control strategy, a scale experimental system has been fabricated which features a smart valve, electric coolant pump, radiator with electric fan, and immersion heater. In this paper, mathematical models will be presented to describe the system's behavior. The thermal management system for gasoline and diesel engines can benefit from the introduction of mechatronic system components that provide greater control over the heating/cooling process.

III. THERMAL MANAGEMENT

The term "thermal management" describes the efficient control of thermal energy flows in the vehicle in accordance with the specific requirements and the prevailing operating and load conditions. As a result, vehicle emissions can be reduced; also the thermal state, friction torque and mechanical engine efficiency can be improved. This leads to lower fuel consumption, longer engine life, and the upswing in thermal comfort. The key benefits of thermal management systems can be

Summarized as follow:

- Reduce parasitic power losses.
- Improve cooling system control.
- Quicker engine warm-up during cold start.
- Reduce engine wear and friction.
- Increase lubricant life.
- Increase the average combustion temperature.
- Enhance fuel economy.
- Decrease exhaust emissions.
- Eliminating hot soak after an engine stop.

IV. Overview of Advancements in Engine and Power train Technology

After Advancements in propulsion technology, those implemented as well as those under development, may be classified into two basic categories: 1) those that entail modifications of existing hardware leading to improvement via design optimization, and 2) those that entail the addition of newly developed hardware (mechanical as well as electrical components). Also, another significant advancement in modern automobiles, in the form of a non-propulsion technology, is the capability to formulate more sophisticated control architectures for controlling complex systems that have a high level of interdependency. Typically, a combination of all these three approaches is today applied in the design of vehicles. Modifications to existing engine and power train related technological practices imply replacing the hardware with more robust and capable components, implementation of more involved control strategies as well as a combination of the two. Modifications made to power trains at present include improvements to combustion processes, start-stop technology reduction of weight using lighter materials. Engineering more efficient auxiliary components such as coolant pumps, air-conditioning systems, cooling fans etc., The advancements mentioned above may also be classified based on system-level improvements, via modification or new development, made to one of the following vehicular systems:

- Improvement to engine combustion and air-path systems;
- Improved transmission and driveline technologies;
- Vehicle system optimization (reduction of vehicle mass, use of lighter and stronger materials, engine thermal management, ancillary load reduction);

A. Improvement to engine combustion and air-path systems

Improvements to combustion events are generally oriented towards increasing combustion efficiency and reduce its duration. Fast-burn combustion systems are used to increase the efficiency of SI engines by increasing the fuel burn-rate to attain higher peak pressures and temperatures [2.8]. This is possible by developing more turbulence in the air-fuel mixing process and obtaining a more uniform charge formation. This is the concept, for example, behind Homogenous-Charge Compression Ignition (HCCI). Engines, which has received much attention recently. HCCI combustion involves a premixed, homogeneous charge of air, fuel and residual gases that is combusted by auto-ignition. The main feature of HCCI combustion is the self-ignition process that results from tight control of the pressure and temperature conditions within the cylinder. HCCI combustion has the potential of lower emissions than in traditional SI and CI engines. Fuel economy benefits of over 16% over an EPA City Drive Cycle with HCCI implementation on a baseline. L direct-injected engine with twin-independent VVT and EGR have been demonstrated. Several other studies provide insight into the fuel economy benefits of implementing HCCI technology. As HCCI combustion is based on self-ignition, it leads to problems with engine knocking and durability of the engine. With the development of better techniques of Controlled Auto-Ignition (CAI), to harness the full potential of HCCI technology by avoiding problems related to pre-ignition and engine knock, HCCI combustion promises to be an integral part of future engines.

B. Automotive Cooling Systems

To introduce the work in the field of automotive cooling systems, a list of references is presented which offers insight to the past and current work. In [13] considered an advanced thermal management system capable of fuel efficiency benefits of up to 5%. The electric water pump introduced a 1.9 kW reduction in parasitic losses. In [12] introduced the need for an electrical water valve for the thermal management intelligent system as an alternative to the passive wax thermostat operating as a water bypass valve. In [14] presented a smart thermostat and coolant pump to control engine thermal management. The presented valve was a linearly actuated three-way valve to control the bypass and radiator coolant flow. In [11] introduced a smart thermal management system that reduced warm-up time, temperature tracking errors and power consumption of the electrically actuated cooling components. In [12] presented an enhanced vehicle and engine cooling system simulation through the coupling of advanced engine and cooling system computer-based simulation tool. This active cooling simulation was applied to a Detroit Diesel series 60 engine where power consumption and engine warm-up time reduction was studied.

Rigorous models have been used in the development of the simulation system. A classical PID controller, with combinations of feedback and feed-forward control, was used as well as special transport delays. In [16] presented a light-duty diesel.

Conclusion

In this paper study is oriented on an intelligent cooling system and control model for improved engine thermal management and related work. In [1] controlling model for the cooling system of an engine was developed in order to reduce fuel consumption and engine emissions through the use of controllable engine cooling components including an electrical water pump, an electrical fan, and a heater thermostat. In [2] EC systems proposed over the past century were examined. Initially, the physical principles and the benefits of EC were expounded together with the state-of-the-art capability for modeling and numerical simulations.

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