Available online at www.sciencedirect.com
ScienceDirect
Journal of Hydrodynamics
2017,29(6):1067-1075
DOI: 10.1016/S1001-6058(16)60820-X
www.sciencedirect.com/
science/journal/l0016058

Water medium retarders for heavy-duty vehicles: Computational fluid dynamics and experimental analysis of filling ratio control method *

Hong-peng Zheng (郑宏鹏), Yu-long Lei (雷雨龙), Peng-xiang Song (宋鹏翔)
State Key Laboratory of Automotive Simulation and Control, College of Automotive Engineering, Jilin University, Changchun 130022, China, E-mail:zhenghp13@mails.jlu.edu.cn

(Received October 20, 2015, Revised May 12, 2016)

Abstract: The water medium (WM) retarder is an auxiliary braking device that could convert the kinetic energy of the vehicle to the thermal energy of the coolant, and it is used instead of the service brake under non-emergency braking conditions. This paper analyzes the flow distribution based on a mathematical model and analyzes the key factors that could affect the filling ratio and the braking torque of the WM retarder. Computational fluid dynamics (CFD) simulations are conducted to compute the braking torque, and theresults are verified by experiments. It is shown that the filling ratio and the braking torque can be expressed by the mathematical model proposed in this paper. Compared with the Reynolds averaged Navier-Stokes (RANS) turbulent model, the shear stress transport (SST) turbulent model can more accurately simulate the braking torque. Finally, the flow distribution and the flow character in the WM retarders are analyzed.

Key words: Heavy duty vehicle, braking system, water medium retarder, computational fluid dynamics, filling ratio control method

Introduction

With the development of the road transport industry, the load of the vehicles and the distance to the destination are increased. A heavy-duty vehicle (HDV) is a mass dominant system and a braking torque is frequentlyrequired to regulate the vehicle velocity because of the road complexity. If only theservice brake is involved under the braking conditions, high kinetic energy of the vehicle willtotally be converted to the thermal energy of the brake shoe. The brake shoe might suffer from the heat recession caused by the high temperature in its long-term usage, tosignificantly reduce the braking capacity and to threat the road safety[1-3].

In view of the braking problem stated above, abraking system is adopted by the HDVs to produce the braking torque as required. The braking system[4] includes the engine brake, the hydraulic retarder brake and the service brake. The engine brake[5] has afixed braking torque once activated and could not be regulated according to the braking requirements. However, the braking torque of the hydraulic retarder[6] could be adjusted according to the needs. When a vehicle is driven under non-emergency braking conditions, its braking system could control the engine brake and the hydraulic retarder brake to produce a braking torque to satisfy the braking requirements without using the service brake[4], thus, the time and the frequency of using the service brake are reduced. This control scheme can protect the service brake from the heat recession and to better use itsbraking capacity under emergency braking conditions[6,7].

The hydraulic retarder could produce a braking torque by converting the kinetic energy of the vehicle to the thermal energy of the working fluid[8,9]. The novel hydraulic retarder is a water medium (WM) retarder, and the working fluid is the coolant from the coolant circulation. The heat produced along with the braking torque can be dissipated by a radiator in the coolant circulation[10]. The WM retarder should produce a controllable braking torque to satisfy the braking requirement sunder complex braking conditions and then the time and the frequency of the service brake usage can be greatly reduced[11,12]. The braking torque of the WM retarder can be adjusted by the filling ratio[13] (the volume ratio between the fluid and the air) of the working chamber when the vehicle velocity is constant. The flow field of the working

* **Biography:** Hong-peng Zheng (1988-), Male, Ph. D., Researcher
Corresponding author: Yu-long Lei,
E-mail: leiyl@jlu.edu.cn

chamber was extensively studied by using the computational fluid dynamics (CFD), including the influence of the diameter of the circulation circle, the number and the angle of the blade on the braking torque of the hydraulic retarder and the corresponding flow field[14], and the flow distribution when the working chamber is partly filled with working fluid based on the two-phase flow[15]. However the mechanism of the generation of the braking torque and the key factors that could influence the filling ratio are not clearly revealed, and the control strategy of the WM retarder remains an issue to explore.

This paper introduces the coolant circulation and the construction of the WM retarder. The flow distribution is analyzed by using the fluid mechanics. The mechanism of the generation of the braking torque is expressed mathematically and the key factors that could influence the filling ratio and the braking torque are analyzed, which could be directly used in analyzing the control strategy of the WM retarder. CFD simulations are conducted to compute the braking torque by using the Reynolds averaged Navier-Stokes (RANS) and shear stress transport (SST) turbulent models, respectively. Experiments are conducted to verify the CFD simulation results and justify the key factors proposed in this study. Finally, the flow field of the working chamber is examined to analyze the character of the flow distribution.

1. Basic analysis of the hydraulic retarder

1.1 *Coolant circulation*

Figure 1(a) shows the working mode of the coolant circulation system when a WM retarder is not activated. The coolant is pumped into the engine water jacket from the pump to cool down the engine. The two-position, three-way control valve is then closed, allowing the coolant to directly flow into the thermostat and to decide whether to flow into the radiator according to the temperature setting. This circulation system is similar to a traditional engine coolant circulation system. The working mode of the coolant circulation system when a WM retarder is activated is illustrated in Fig.1(b). In this mode, the two-position, three-way control valve is opened, compelling the coolant to directly flow from the engine water jacket to the WM retarder. Subsequently, the coolant flows into the thermostat in a similar manner as when a WM retarder is not activated.

1.2 *Construction analysis*

The principal part of the WM retarder consists of the sealing component, the rotor, and the stator, as shown in Fig.2. The working chamber is formed by the rotor and the stator, and the sealing component is used to seal the working chamber. The sealing component is fixed on the stator by bolts, and the stator is fixed to the vehicle. The rotor is connected to the drive shaft by a spline. When the vehicle is being driven, the rotor rotates with the drive shaft constantly.

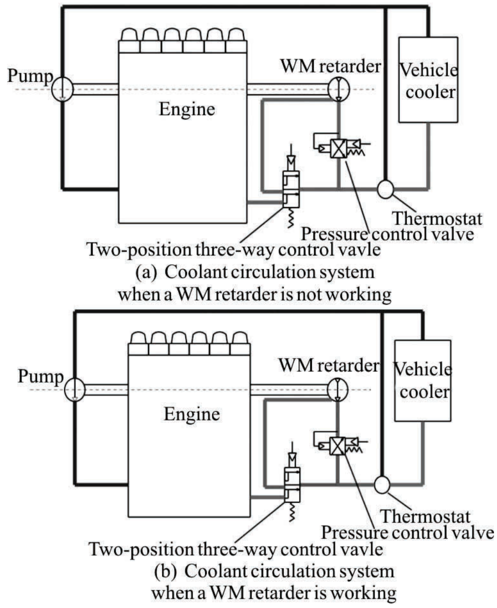

Fig.1 Sketches of the cooling circulation with WM retarder

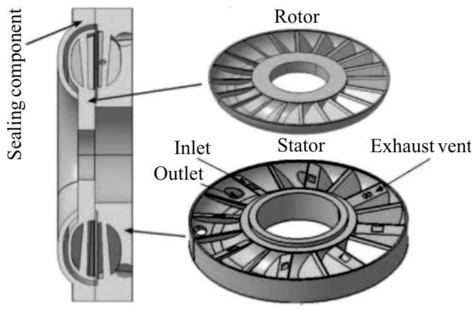

Fig.2 Sketch of the WM retarder

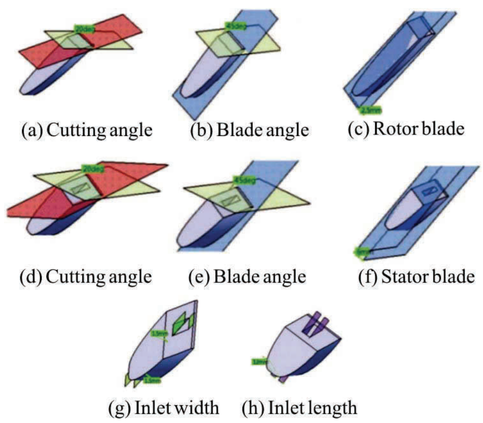

Fig.3 (Color online) Sketch of the circulation circle and the blades