

A Controllable Engine Cooling Pump Based on a Magnetorheological Fluid Clutch

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ABSTRACT

The activity described in this paper has been carried out in the framework of a funded project aimed at evaluating the feasibility of a controllable water pump based on an integrated magnetorheological fluid clutch. The advantages consist of an improvement of the overall vehicle performance and efficiency, in the possibility of disengaging the water pump when its action is not required, and in the control of the cooling fluid temperature. So, the design constraints have been defined with reference to the available space, required torque, and electrical power. After an iterative procedure, in which both mechanical design and magnetic field analyses have been considered, the most promising solution has been defined and a first physical prototype has been realized and tested. A preliminary experimental characterization of the developed prototype has been presented.

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INTRODUCTION

Recently, strict emission regulations have become the most important issues in the automotive industry [1]. For solving these problems, considerable research on various technologies, such as hybrid electric vehicles and super clean diesel engines, is being conducted. It is important to improve fuel economy by adopting new technologies, but it is also important to analyse and reduce the energy losses in the engine. The chemical energy of fossil fuel is converted into heat energy in the engine during the combustion process, but all the heat energy is not used to generate mechanical energy. A portion of the heat energy is used to overcome friction, or is transferred to coolant and lubricating oil through the auxiliary devices such as the water pump and the oil pump. The auxiliary devices are, in the more common configuration, kinematically linked to the engine shaft and their operation is not strictly given by the needs, with the consequence that the energy absorption is not finalized to effective benefits for the engine. Starting from an approach focused on the intelligent managing of the auxiliaries, their control represents a valid tool for the reduction of fuel consumption and emissions. Indeed, the possibility to disengage the devices, such as the oil pump or the cooling pump, allows to reduce the energy absorption in all the conditions in which the intervention is not necessary [1]. In the recent years, some researchers have been working on the possibility to use smart materials, such as magnetorheological fluids (MRFs) for the vehicle performance optimization [2, 3, 4]. As an example, MRFs have been adopted in [5, 6] to drive the engine cooling fan by means of a controllable clutch. The use of smart materials permits the regulation of the speed and, consequently, of the power

absorbed by the cooling fan, optimizing its operation on the basis of temperature control (e.g. the cooling fan could be disengaged during engine warm-up).

This paper describes an activity concerning the design and the development of a new controllable cooling pump based on an MRF clutch. The idea consists of a multidisc clutch filled with MRF and integrated with the cooling pump with the aim of regulating the transmitted torque and of moving the device only when it is necessary.

THE CONTROLLABLE COOLING PUMP

The proposed idea is based on the employment of the MR fluid in order to control the torque that is transmitted to the pump impeller. A brief description of the MR fluids is made in the following subsection.

Magnetorheological Fluids

Magnetorheological (MR) fluids are suspensions of micron-sized and magnetisable particles in a carrier fluid. Normally, MR fluids are free-flowing liquids, having a consistency similar to that of lubricant oil. However, when a magnetic field is applied, their rheology changes to more a solid-like gel. MR fluid rheology is modelled in pre-yield and post-yield regimes. In the pre-yield regime, MR fluids demonstrate a visco-elastic behaviour. For visco-elastic materials, while some of the applied energy is recovered (elastic behaviour), some is dissipated in the form of heat. The visco-elastic behaviour of the MR fluids in the pre-yield regime is analyzed by linear visco-

elastic theories. On the other hand, the MR fluid post-yield behaviour in presence of a magnetic field is approximated by the Bingham plastic model:

$$\tau = \tau_{yd}(H) + \eta \frac{d\gamma}{dt} \quad (1)$$

where, τ is the shear stress, τ_{yd} is the dynamic yield stress due to applied magnetic field (H), η is the no- field fluid viscosity, and $d\gamma/dt$ is the shear rate. When the magnetic field intensity rises, the ferromagnetic particles find an orientation and the yield stress increases. This property makes the MR fluids functional for the employment in controllable devices [7].

The Concept

The proposed idea of controllable cooling pump is illustrated in [Figure 1](#).

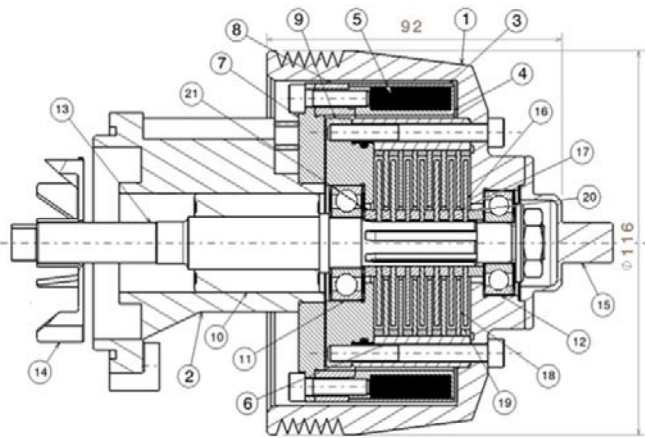


Figure 1. Controllable cooling pump cross section

The several components of the controllable pump are listed in [Table 1](#).

Table 1. Components of the controllable cooling pump

S/No	Description	Material
1	Pulley	ARMCO Pure Iron
2	Body	Stainless Steel
3	Outer Coil Surface	Ertalon
4	Coil Housing	Ertalon
5	Coil	Copper
6	Disk Housing	AISI 304
7	External Disk	AISI 304
8	Ring	ARMCO Pure Iron
9	Disk Housing Element	ARMCO Pure Iron
10	Bearing	-
11	Bearing	-
12	Bearing	-
13	Shaft	18NiCr
14	Impeller	-
15	Input Shaft	LL 7075
16	Inner Disk	ARMCO Pure Iron
17	Spacer Element	AISI 304
18	Outer Disk	ARMCO Pure Iron
19	Spacer Element	AISI 304
20	External Spacer Element	AISI 304
21	External Spacer Element	AISI 304

Differently from a common cooling pump, the proposed device is characterized by the presence of an integrated magnetorheological fluid clutch that is constituted by the inner and outer disks and the coil. An MR fluid is contained in the gap located among the several disks. As a consequence, changing the coil current, it is possible to modify the torque transmitted from the pulley shaft (15) to the impeller (14). In this way, the impeller can be disconnected from the engine when its action is not required and, moreover, it can be regulated taking into account the real needs in terms of cooling, with advantages concerning fuel consumption and emissions. Starting from a commercial cooling pump driven by belt, a suitable pulley has been designed with the aim to contain the MRF based clutch. The external diameter of the pulley has been retained in order to make the device characterized by the same gear ratio of the original pump. The space necessary for locating the integrated clutch has been obtained along with the axial direction, maintaining unchanged the position where the belt is in contact with the pulley. [Figure 2](#) shows the typical cooling pump while [Figure 3](#) shows the controllable cooling pump with the new pulley well visible.



Figure 2. Traditional cooling pump

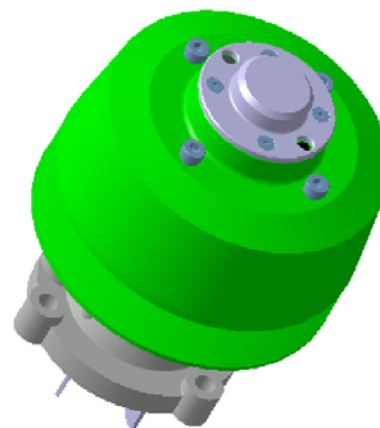


Figure 3. Controllable cooling pump

An exploded view of the controllable cooling pump is illustrated in [Figure 4](#).