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Gasoline hybrid pneumatic engine for efficient vehicle powertrain hybridization

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HIGHLIGHTS

- The hybrid pneumatic powertrain is an alternative solution for hybridization.
- The main advantages are the low cost and the direct transmission of the torque.
- The hybrid pneumatic powertrain suits for urban driving and mild hybridization.
- An efficiency improvement of 50% is reached for urban driving and C Segment vehicle.
- The CO_2 emissions on the urban cycle are very low – only 51 g CO_2/km.

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ABSTRACT

The largest applied convertors in passenger cars are the internal combustion engines – gasoline, diesel, adapted also for operating on alternative fuels and hybrid modes. The number of components that are necessary to realize modern future propulsion system is inexorably increasing. The need for efficiency improvement of the vehicle energy system induces the search for an innovative methodology during the design process.

In this article the compressed air is investigated as an innovative solution for hybridization of small gasoline engine. The combination of a conventional IC engine and a pneumatic short-term storage system is an interesting approach to achieve lower fuel consumption. Instead of using a battery, a hybrid pneumatic vehicle uses a robust and inexpensive air pressure tank for energy storage. The fuel consumption benefit of the hybrid air system is assessed and the vehicle usages leading to the maximal fuel consumption benefits of the hybrid pneumatic powertrain are investigated.

The hybrid pneumatic concept is applied on a largely deployed C Segment commercial vehicle with 3 cylinder gasoline engine. The lowest fuel consumption results are investigated on the usage of this vehicle.

1. Introduction

With the increasing trend of mobility of the human population, vehicles have to face the problem of primary energy resources scarcity. The vehicles need higher efficiency and better adaptation to the alternative energy sources [1]. The need to improve the efficiency of the vehicle energy system motivates the search for innovative solutions during the design process [2].

The main way for vehicle efficiency improvement that the automotive industry takes in the moment is the electrification of the vehicle powertrains [3,4]. The hybrid electric vehicles, with different degree of electrification of the powertrain proliferate. The introduction of the electric components in the powertrain leads to increased cost and mass of the vehicles. This is especially due to the relatively low energy density capacity of the high voltage battery. The best storage potential available in serial production is the Li-Ion battery with energy density of 90 W h/kg [5]. The efficiency/cost balance of the thermal and hybrid electric vehicles is represented in Fig. 1. One can see that there is a technological gap in the zone of high powertrain efficiency (50–70 g CO_2/km) and vehicle cost between 15,000 and 25,000 euros.

This zone in the cost/efficiency balance can be reached with an alternative way of hybridization – the pneumatic hybridization. This concept uses the combustion engine as pneumatic motor and pump and stores the energy in the tank under pressure. The main mode for propulsion stays still the internal combustion engine.

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Nomenclature

CV	charge valve
CVT	continuously variable transmission
HPE	hybrid pneumatic engine
HPP	hybrid pneumatic powertrain
ICE	internal combustion engine
MGB	manual gear box
NA	natural aspirated
NEDC	new european driving cycle

This article proposes a modellization methodology, based on energy balance calculation, for design of the hybrid pneumatic powertrain. Also the best fuel consumption reduction is researched as alternative of the power boost of turbocharged four cylinder engines, highlighted by several researchers [7]. Other researchers [8] propose a hybrid pneumatic engine concept on 4 cylinders engine, with two air tanks and show experimental results with at least 70% of fuel improvement on stationary test bench conditions.

The novelty of this article is that the efficiency concept is developed on a small 1.2 l 3 cylinders natural aspirated gasoline engine, with just one compact air tank, and after the vehicle integration, the best customers' usages are researched under dynamic conditions. The major contribution of the article is to bring a model that is used to estimate the fuel consumption benefit on a C-Segment Vehicle, which is one on the most popular categories of vehicles and targets the price zone.

2. Pneumatic hybrid engine systems

The combination of a conventional IC engine and a pneumatic short-term storage system is an interesting approach to achieve lower fuel consumption. Instead of using a battery, a hybrid pneumatic vehicle uses a robust and inexpensive air pressure tank for energy storage. The internal combustion engine is able to run in purely pneumatic modes, acting as a pneumatic pump or motor without fuel injection. The resulting concept is called Hybrid Pneumatic Engine (HPE) [5]. The concept appears in 1999 studied as new cycle opportunities for automotive engine [9]. Firstly, its efficiency estimations are done by simulations [10] and then the concept is realized for fuel reduction potential estimation [11]. Also different operations modes and possibilities to exploit the HPE for engine downsizing and "maximum torque at low rotation speed" are highlighted in [7]. An architecture using two air tanks is presented and explored on test bench in [8].

The concept allows recuperating some of the energy that is otherwise lost when braking and the elimination of the most inefficient engine operating point is possible. Moreover, it is an ideally complements for a downsized or supercharged engine. Since the air is provided to the cylinder by a fully variable charge valve, the torque can be raised from idling to full load, from one engine cycle to the next i.e. in the shortest possible time. The hardware configuration necessary for a directly connected HPE includes an additional valve in the cylinder head, which is connected to the pressure tank. A fully variable actuation of the valve is mandatory (Fig. 2). This valve is called charge valve (CV) and is the link between the cylinder and the air tank.

The precision and the dynamic performances of this charge valve are extremely important for the concept viability. The pneumatic energy needs to be conserved in the tank. So the number of parameters for accurate system modeling is increasing and an appropriated methodology is needed.

This article is investigating the hybrid pneumatic engine as alternative solution for mild hybridization of the vehicle powertrain. The price vs CO_2 emission balance of the standard way to reach mild hybridization by electrification is situated in Fig. 1. The study presents the hybrid pneumatic concept and the simulation results of the efficiency improvement of a small gasoline engine, operating in hybrid pneumatic modes. The guide line of the study is to research the maximal efficiency improvement. The hybrid pneumatic gasoline powertrain is investigated on C-Segment commercial vehicle. The article proposes a modeling methodology, which considers all parameters for vehicle

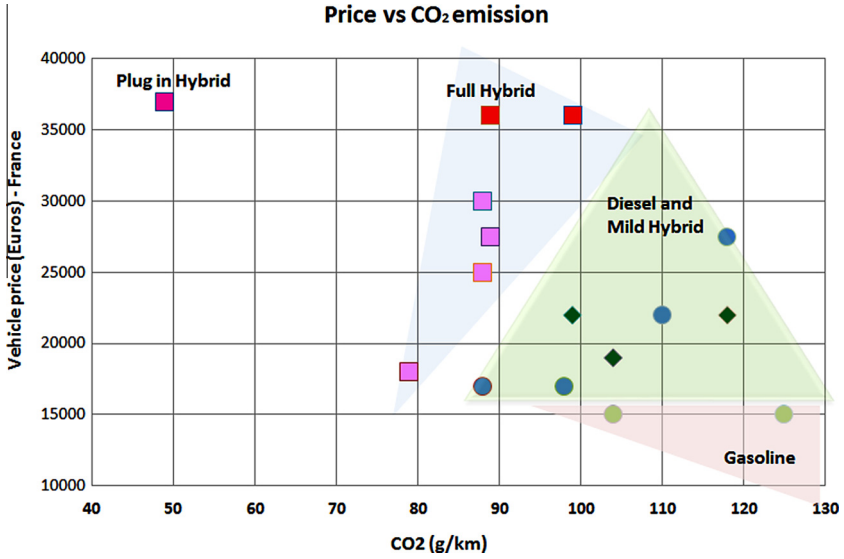

Fig. 1. Price vs CO_2 emission of different hybridizations [6].