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IMPROVING THE EFFICIENCY OF A SERIAL HYBRID POWERTRAIN FOR CITY BUSSES USING AN ICE WASTED HEAT ENERGY THROUGH COMPRESSED AIR SYSTEM

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Key words: *serial hybrid powertrain, ICE-internal combustion engine, WHE-waste heat energy, CAES-compressed air energy storage, adiabatic process*

Abstract: *Improve model of the standard serial hybrid powertrain for city busses is presented. In classic topology recovered braking energy returns through the motor in the battery system. A combination of solutions with the compressed air as a dynamic reservoir for the recuperation of braking energy and the use of ICE waste heat energy as an energy booster is improved of design. The waste heat energy of ICE, that represents 65% of the consumed fossil fuels potential energy, is transferred to compressed air high-pressure vessel and by adiabatic process total energy is raised. Simulation results show that recuperated WHE can be transformed into mechanical energy up to 20% of fossil fuels potential energy. Improve design provides a rise of system efficiency to up 40%. Thus ultimately provides a total reduction of fuel consumption by over 37,5% compared to the standard topology of SHEV. The advantage of the presented system is that it reused WHE produced by ICE, so the overall efficiency of the SHEV power drive is increased and CO_2 emissions are reduced.*

INTRODUCTION

The energy efficiency of the traffic, through the process of transition to zero-emission society, set in the first place solving problems of the urban transport. As a designer's perspective solutions, the research of the hybrid drives topology of the vehicle were imposed. Namely, numerous parameters affect the efficiency of the vehicle having different physical processes, so in hybrid drives topologies of the vehicles are been combine the best particular solutions with control optimization as a necessary premise of topological complicated solutions [1,2]. Investment costs are still a significant item in this stage of the technology development of electric vehicles and slow down their implementation [1,3]. Also, it is extremely important to take into account the emissions of toxic gases, so well-to-wheel analyzes have been developed [1,4], which is a very detailed and accurate way to present influence of somewhat covert factors.

For a quality solution of urban transport, it is necessary to study the current situation and problems of transport passengers in the city and determine the capital and operating costs [5,6]. The parently greatest barrier for the faster development of electric vehicles represents the battery as a system of energy storage. Currently, the leading technology of Lithium-Ion batteries have the highest energy density and allow relatively fast charging, but still, have a number of drawbacks. [7,8].

A classic solution that is simple and requires only one source technology is Battery electric vehicle (BEV). However, the battery as the only source of BEV energy with unresolved problems (quick charging, continuous power delivery, limited source) significantly limits the range of the vehicle and increases the costs of amortization. [7,9].

Serial hybrid electric vehicle SHEV for a long time exist as a solution for heavy load vehicles[10]. As the name suggests, it is a serial connection of drive elements, or through a serial connection is made transform the energy of fossil fuels over ICE to an electric generator. In the central part of the topology, the energy is stored in the battery and ultimately transforms the electrical transformation into mechanical energy. The battery size (storage of electricity) allows the ICE to be maintained at the optimum work point, minimizing all the major disadvantages of the ICE (in the dynamic load change ICE consumes a lot of extra energy). Also, the battery takes on the dynamic load of power requirements for powering the electric motor that drives the vehicle.

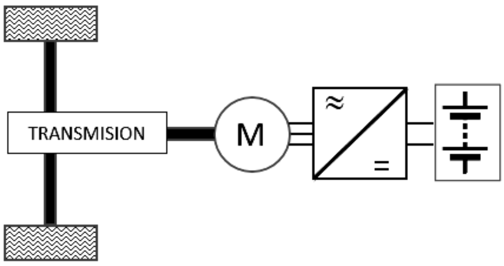

Figure 1. – Simple topology of the Battery Electric Vehicle (BEV)

Weel-to-wheel analysis [1,4,11] suggests that topology of SHEV from the 100% of the potential energy of fossil fuel in the reservoir to the vehicle wheels bring only 25%. Most of the losses (up to 65%) are waste heat energy of ICE and 10% of the energy is the losses of the control unit and battery (Fig 2.).

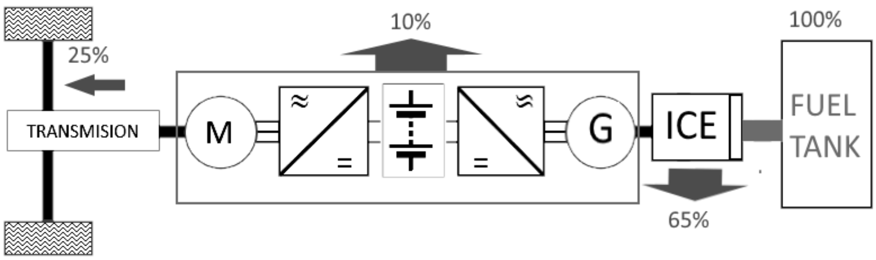

Figure 2. – Serial Hybrid Electric Vehicle (SHEV) topology and distribution of the energy

Over the past century, the car industry was trying to develop ICE improvements and today (when EV are on the doors) is the culmination of a technological development that will be reached [12]. However, despite the improvement of the efficiency of the ICE, there are present a high emission of harmful gases. Numerous researchers in the last decade have focused on the better exploitation of waste heat energy (WHE) recuperation by developing technologies that differ primarily from the domains being solved. The mechanical approach is to make the return of thermal energy back to the ICE [13].

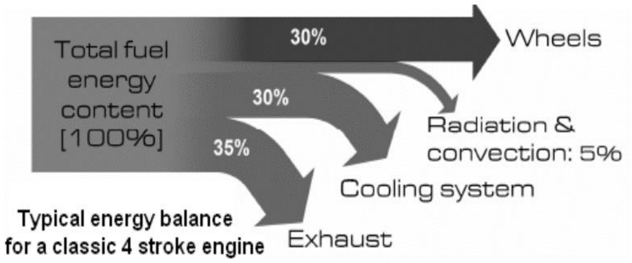

Figure 3. – Sankey diagram of the energy distribution output from ICE [1 ricardo]

Another group of solutions for WHE recuperation is used to produce hydrogen [14]. Since EV is based on the electric battery some researchers have been developed solutions with thermocouple generators [14,15]. The solutions that used compressed air appeared for the first time in 1990 with the development of a hybrid pneumatic power system HPPS [16].

RECUPERATION OF WASTE HEAT ENERGY IN SHEV

Compressed air compression technology (compress air energy storage CAES) has evolved over the last 30 years and is actually a return to 18-century technology (the first automotive drive was on the compressed air). For better energy utilization in the compression process, adiabatic volume change is required in order to reduce heat while maintaining the pressure.

In this paper, for WHER are proposed the use of a technology known for large power systems over 50MW [17,18,19]. In order to be able to use CAES systems on a micro scale, it is necessary to provide a volume-to-heat subsystem which will control the compression process in terms of energy flows [20].

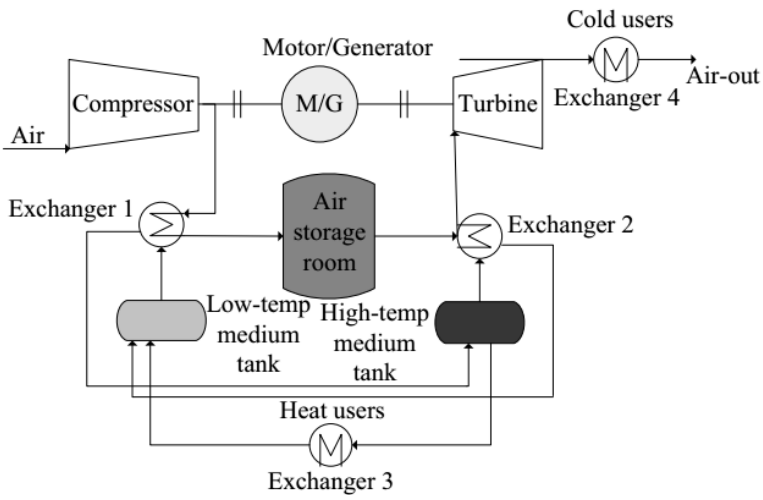

Figure 4. – Diagram of adiabatically compressed air energy storage (A-CAES) with the integrated subsystem of liquid volume regulator [20]

In the automotive industry, the biggest progress in the use of compressed air in 2004 was made by the Indian company TATA Motors (the development of a low-cost small-scale vehicle for India's market) [21]. The latest solutions come from a PSA group called HybridAir that combines ICE with a hydropneumatic engine [22].

This paper proposes a new WHE recuperation solution by combining SHEV technology with micro A-CAES technology and with the modified HybridAir technology to increase the efficiency of A-CAES on a micro scale (subsystem is shown in Fig.5).

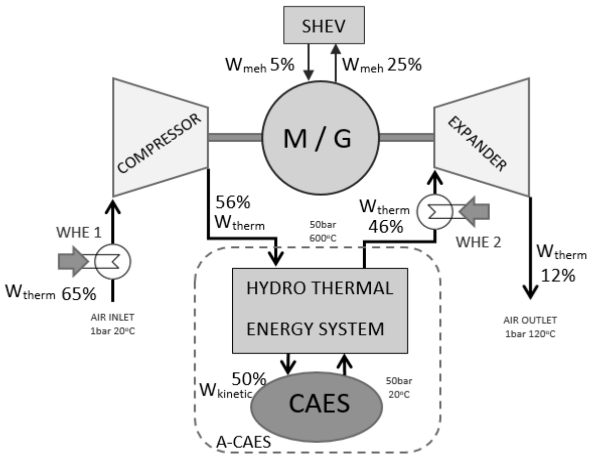

Figure 5. – Energy flow in modify A-CAES

Distribution of energy in SHEV topology (Fig. 2.) shows that the output energy of the vehicle wheels is only 25% of the potential energy of the fossil fuel in the reservoir. The modelling process assumes numerous neglecting, so realistic systems achieve even less efficiency. It is very important to notice a great loss of energy at the beginning of topology from ICE, where waste heat energy is up to 65% of potential energy. That is why today, despite numerous problems, EV technology is progressively advancing and exiting the classic ICE drive [1,4,11].

If only 20% of the output of the mechanical energy from SHEV (5% of the total fuel energy) re-conveyed to micro ACAES together with 65% of the WHE for preheating the inlet air to compressor and expander, the energy flow shown in Figure 6 is obtained.

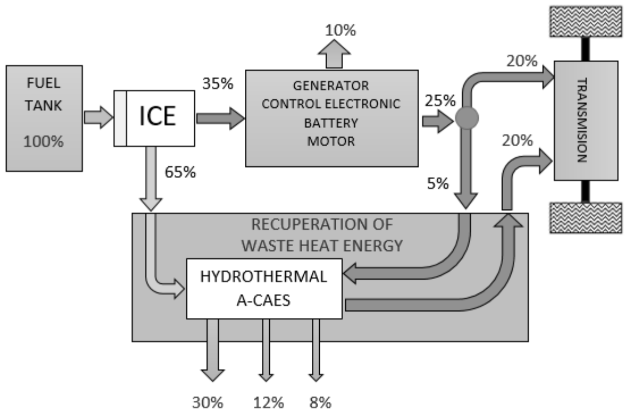

Figure 6. - Energy flow in SHEV with WHE recuperation

In a closed process of conversion of waste heat energy, mechanical energy is supplied to run the compressor and heat to preheat the air. In the first stage, the inlet air from the initial 1bar 20°C is transformed into the compressed air at 650°C and 50bar and then the adiabatic process of volume change seizes the heat while maintaining the pressure. So in compressed air reservoir in the middle stage of recuperation air have 50bar and 20°C.

In return process, the air from the reservoir is preheated again and an expansion is carried out in which the kinetic energy of the compressed air is transformed into the mechanical energy returning to the SHEV drive system. The output mechanical power supplied to the vehicle drive reaches 20%, while the output air from the system has an atmospheric pressure 1bar and a temperature of about 120°C. The level of waste heat energy remaining after the process is about 12% and further transformation is not possible because of the media low temperature. Here it should be stated that all figures were obtained by simulation, without verification on the prototype (next phase of the study).

The analysis of the energy paths shown in Fig.6 gives results that WHE (65% of the potential fuel energy in the reservoir) is transformed into 20% of the mechanical energy using 5% of SHEV mechanical exit energy. This gives a total of 40% energy to the points of the vehicle wheels, about 20% (8% to output of WHE1+WHE2 and 12% to outlet air [13]) of the heat energy is lost at the exit of the system, and 30% of the energy is lost in the micro A-CAES subsystem because of losses in energy transformation. The assumption is that the SHEV system (converters, batteries) does not waste more than the usual 10% energy [3,11].

Since the initial assumption is that the drive vehicles need only 25% of the energy management system SHEV will reduce the battery discharging (it will hold up 15% of energy) [1,3]. If ICE continues to produce energy with equal intensity at the same load cycles, it follows that after 6 driving cycles, ICE will be able to make 3 driving cycles as BEV (than ICE is not operating and energy supply is only from the battery).

CONCLUSION

This paper presents a new approach to the recuperation of the waste heat energy WHE that is lost in the work of ICE in the topology of SHEV. All aspects of the classic SHEV system are outlined and the results of compressed air usage are presented. A new drive topology is proposed in which a subsystem with micro A-CAES is added to the classical SHEV drive to convert WHE into mechanical energy. Efficiency calculation of proposed system shows an improvement from 25% to 37.5%, or nearly 50% increase in efficiency.

As the use of EV in the future of urban passenger transport is a priority that contributes to the reduction of gas emissions, further investment in system development can be expected as presented in this paper. It is clear that the analysis carried out in this paper did not include all the parameters affecting the ultimate result of the system's efficiency, but this can reduce the overall efficiency of the proposed modified drive to about 40%, which is still a great result.

In the further work, a more detailed analysis of all subsystems will be performed and simulations will be carried out based on available data from the manufacturer (all design elements are existing systems that are tested and for which detailed data are available). If those simulations confirm a match with so far obtained data (confirmation of an increase in efficiency over 40%) prototype will be made in order to verify the model.

Резюме

Abstract — Improve model of the standard serial hybrid powertrain for city busses is presented. In classic topology recovered braking energy returns through the motor in the battery system. A combination of solutions with the compressed air as a dynamic reservoir for the recuperation of braking energy and the use of ICE waste heat energy as an energy booster is improved of design. The waste heat energy of ICE, that represents 65% of the consumed fossil fuels potential energy, is transferred to compressed air high-pressure vessel and by adiabatic process total energy is raised. Simulation results show that recuperated WHE can be transformed into mechanical energy up to 20% of fossil fuels potential energy. Improve design provides a rise of system efficiency to up 40%. Thus ultimately provides a total reduction of fuel consumption by over 37,5% compared to the standard topology of SHEV. The advantage of the presented system is that it reused WHE produced by ICE, so the overall efficiency of the SHEV power drive is increased and CO_2 emissions are reduced.

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ПОДОБРЯВАНЕ ЕФЕКТИВНОСТТА НА СЕРИЙНАТА ХИБРИДНА ЗАДВИЖВАЩА СИСТЕМА НА ГРАДСКИТЕ АВТОБУСИ ЧРЕЗ ПРОЛОЖЕНИЕ НА ТОПЛИННА ЕНЕРГИЯ ПРИ СИСТЕМА ОТ СГЪСТЕН ВЪЗДУХ

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Ключови думи: *серийна хибридна задвижваща система, двигатели с вътрешно горене, енергия от отпадъчна топлина, капацитет за съхранение на енергия от сгъстен въздух, адиабатичен процес.*

Резюме: *В доклада е представен подобрен модел на стандартна серийна задвижваща система на градски автобуси. Според класическата теория енергията създадена от спирачната система се възстановява през двигателя в акумулаторната система. В доклада се разглежда комбинация от решения свързани със сгъстяването на въздух като динамичен резервоар за възстановяване на енергията от спирачната система и използването на енергията от отпадъчната топлина на ДВГ като усилвател на енергия. Отпадъчната топлина от ДВГ, която съставлява 65% от потребеното гориво, се прехвърля в съд с високо налягане и чрез адиабатични процеси, общото количество на енергията се повишава. В настоящия доклад, авторите стигат до заключението, че възстановената отпадъчна енергия може да се превърне до 20% в механична енергия от потребеното гориво. От своя страна представения подобрен модел позволява ефективността на системата да се повиши до 40%. Това от своя страна води до намаляване потреблението на гориво с до 37,5%. Предимството на тази система е, че повторното използване на отпадъчната топлинна енергия от ДВГ позволява от една страна да се повиши общата ефективност на резервоара за съхранение на сгъстен въздух, а от друга да се намалят емисиите на* CO_2.