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NEW TURBO COMPOUND SYSTEMS IN AUTOMOTIVE INDUSTRY FOR INTERNAL COMBUSTION ENGINE TO RECOVER ENERGY

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Abstract. The large amount of heat is scattered in the internal combustion engine through exhaust gas, coolant, convective and radiant heat transfer. Of all these residual heat sources, exhaust gases have the potential to recover using various modern heat recovery techniques. Waste heat recovery from an engine could directly reduce fuel consumption, increase available electrical power and improve overall system efficiency and if it would be used a turbochargers that can also produce energy. This solution is called turbo aggregation and has other ways to develop it in other areas of research like the electrical field. [1-3]

1. Introduction
The design of road transport engines is even more focused on reducing emissions. Recently, greenhouse gas commitments have brought new technological challenges. Exhaust gas recovery has great potential, given the amount of mechanical or electrical work that could be generated on board. The paper considers the recovery that could be obtained from exhaust gases that expand them into an additional turbine (turbo-mixing).
Over the years, the road transport sector has faced a period of strong technological change to reduce harmful emissions and, more recently, CO2 emissions, for example fuel consumption. The real technological surprise was that the emission reduction was achieved without losing the expected mechanical performance of the engine (torque, speed, driving fun, etc.). The results obtained were excellent: over the last two decades, the specific power (per unit of swept volume) increased by a factor of 1.5, while the emission level was 10 times. The EURO limits have progressively (and significantly) reduced steps, producing cleaner and more powerful engines. [4]
One of today's biggest challenges for reducing CO2 emissions is energy recovery, a key sector due to quantitative importance: the exhaust gases of an internal combustion engine have an energy content equal to about one-third of the chemical energy of the fuel. [5-6]
The first type of recovery seems to be more technologically simpler than the second one, which introduces a clear complexity when handled on board. The first recovery, which has the nature of direct recovery, is addressed in the literature as a turbo blend and has been extensively treated. Many manufacturers (John Deere, Volvo, Caterpillar), especially heavy engines, have already applied turbocharging, but have been very focused on the possibility of extra-mechanical power. Recently, in the literature, the possibility of having an energy recovery due to the turbo mix in the form of electricity has gained interest. [7]

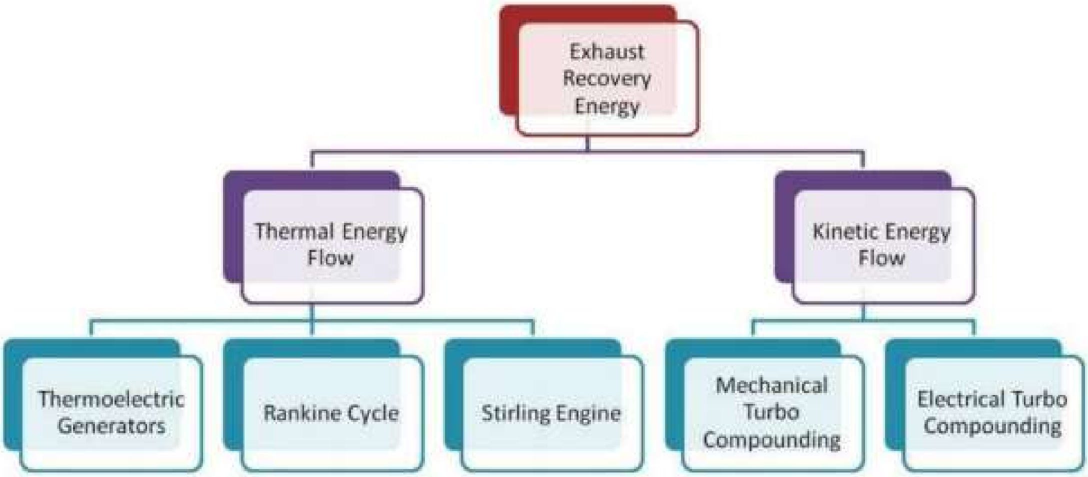

Figure 1. Main Methods of Exhaust Energy Recovery

A lot of fruitful efforts have been made to recover the energy from the exhaust gases. Figure 1 shows the main methods that have been practiced and applied to recover the energy from the exhaust gases. The most dominant technologies for the recovery of exhaust energy are the thermoelectric generators that convert heat directly into electricity, the implementation of the Rankine cycle through an expander, the Stirling engine, the mechanical combination with turbo and the blending with electric turbo compressors. [8]

Turbo compounding is the process of using an exhaust gas turbocharger to provide extra power to the crankshaft by means of a gear or hydrodynamic coupling or to power a generator that distributes power through an electronic power module. Technology is not new - the aerospace industry introduced the concept in the 1940s - but an article from the car and the driver says it could be "the next big thing in energy recovery" for automotive engines. Turbo compounding is a way to take advantage of the lost exhaust gas to provide more power to the engine. In the table above, the top right compressor (blue arrows) is fed by the turbine wheel to the left (red arrows) to send the improved intake air to the engine. However, the turbine sends exhaust gases to the left, where another turbine connected to a shaft drives a gearbox, essentially a high-speed transmission, eventually connected to the lower left crankshaft. [9]

2. Objective

Over time, it has been considered that the turbocharger has a greater potential to be developed in the field of research, such as mechanical, thermal and electric fields. But for these improvements we need to develop a constructive solution. Hybrid turbo compressors have dual purposes, such as, for example, the take-off of exhaust gas from the engine and also power generation by building the extended shaft to accommodate the alternator at the blower end to produce ecological electric power through the power Exhaust gases. The hybrid system can generate high energy efficiency, so high-speed rotation of the shaft and low weight of the parts, can produce no more than 5,50 KW without any problems. It also has an efficient construction component with a cooling system that is designed for self-cooling.

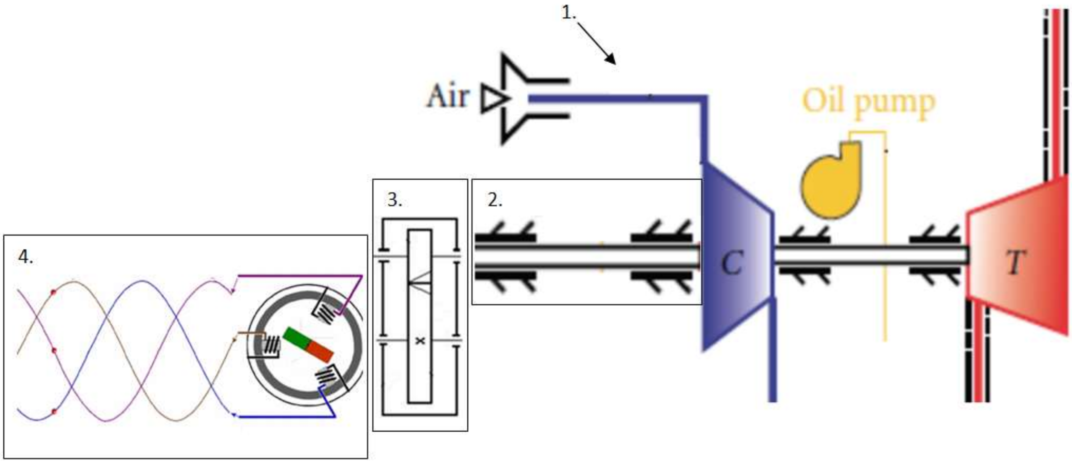

Figure 2. Schematic hybrid turbocharger solution

In figure 2- Schematic hybrid turbocharger solution, we can see that there are four groups of components which together form the proposed solution, namely: 1 - represented by the classic turbocharger (C-Compressor, T-Turbine, Oil pump), 2 - represented by external shaft, 3 – gearbox with cylindrical gear wheel, 4 - alternator / power generator. Also in the constructive schema can be seen in the marked area with 1, air inlet path labeled "Air". [10] The one-stage gear is optional but when it is used as a transmission solution is designed to reduce the generator rotational speed by a ratio 1/4 in relation with to the rotational speed which the turbocharger operates.

3. Methodology

The configurations that we are studying new turbo compound system in automotive industry for internal combustion engines to recover the energy from the engine and also a part of it to transform it into green energy for the automobile. The basics equations consist of energy, impulse and mass conservation, resolved along the average flow line. The mass and energy equations are solved for each volume and the impulse equation is resolved for each volume boundary.

Equation (1): Mass continuity equation

$$\mathbf{\frac{dm}{dt} = \sum\nolimits_{boundaries} m_{flux} \quad (1)}$$

Equation (2): Conservation of energy equation

$$\mathbf{\frac{d(me)}{dt} = p\frac{dV}{dt} + \sum\nolimits_{boundaries} m_{flux}\, H - h_{flux}\, A\left(T_{gas} - T_{wall}\right)(2)}$$

Equation (3): Engine power

$$\mathbf{P_{engine} = BME \quad {}_{D}\eta_{cycle}\ (3)}$$

The values recorded for the energy balance are:

Tabel 1. Indicative values for the thermal flows heat balance

Engine type	$\dot{Q}_e$[%]	$\dot{Q}_{ch}$[%]	$\dot{Q}_w$[%]	$\dot{Q}_n$[%]	$\dot{Q}_r$[%]
Spark ignition engine	21 . . . 29	14 . . . 28	28 . . . 48	1 . . . 40	8 . . . 19
Diesel engine	28 . . . 41	16 . . . 33	24 . . . 44	1 . . . 4	8 . . . 16

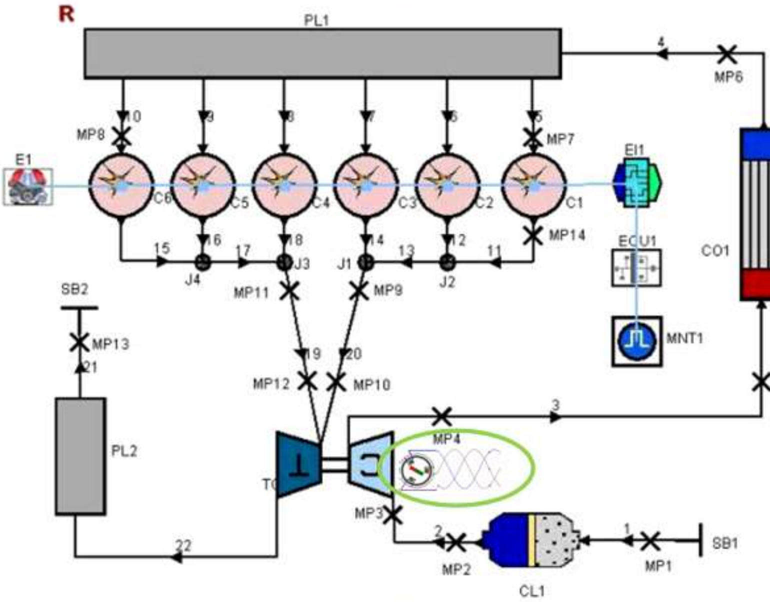

Figure 3. AVL model of the original engine

Figure 3 shows the AVL BOOST model of the original engine system that is with a turbocharger with a generator attached . The main goal of simulating the original engine is to have a reference engine performance and after that a reference of a engine simulation with a hybrid turbocharger. Which can then be compared with composite turbo engines. All the parameters set will be in accordance with the manufacturer's datasheet. [11]

4. Results

The external balance equation takes the following form:

Equation (4): Engine heat balance

$$\dot{Q} = \dot{Q}_e + \dot{Q}_{ch} + \dot{Q}_w + \dot{Q}_n + \dot{Q}_r \ (4)$$

where:
$\dot{Q}$ – the heat flow obtained by burning the fuel consumed by the engine (available energy); $\dot{Q}_e$ – useful heat; $\dot{Q}_{ch}$ – the heat flow lost through the cooling fluid; $\dot{Q}_w$ – the heat flow lost through the combustion gases along the evacuation; $\dot{Q}_n$ – the heat loss due to incomplete chemical burn; $\dot{Q}_r$ – the residue of the heat balance. [12]
Therefore the:

Equation (5): Useful heat

$$\dot{Q}_e = P_e \ (5)$$

P_e- engine power

Equation (6): Heat flow lost through the cooling fluid

$$\dot{Q}_{ch} = \dot{m}_{water} c(t_e - t_i) \ (6)$$

$\dot{m}_{wather}$- cooling water flow
c - average specific heat of water
t_e, t_i - inlet and outlet engine water temperatures

Equation (7): Heat flow lost through the combustion gases along the evacuation

$$\dot{Q}_w = \dot{m}_g c_{pmg} t_{ge} - \dot{m}_{air} c_{pma} t_a \ (7)$$

$\dot{m}_g$- the exhaust gas flow rate
$\dot{m}_{air}$ - air flow rate
c_{pmg}, c_{pma} - specific exhaust gases and air
t_{ge} - gas temperature in the outlet
t_a- inlet air temperature

Equation (8): Heat loss due to incomplete chemical burn

$$\dot{Q}_{ch} = \sum V_i Q_l \ (8)$$

V_i - the amount of uncombined components in the exhaust gas
Q_l - lower combustion heat of the gaseous components in the exhaust gas

Equation (9): Residue of the heat balance

$$\dot{Q}_r = \dot{Q} - (\dot{Q}_e + \dot{Q}_{ch} + \dot{Q}_w + \dot{Q}_n) \ (9)$$

After calculation, it can be estimated that 30% of engine exhaust gases can be recovered and from this proportion it can be produce further on green energy with the hybrid turbocharger. There are several solutions to recover some of it. A technical option is the one proposed in the paper. It is found in various other similar variants on existing engines like that for turbocompound engines but the principal of the hybrid turbocharger working is related with the electrical generators used in the marine industry. It can be seen in figure 4 an example of hybrid turbocharger used in the marine industry produced from Calnetix Company.

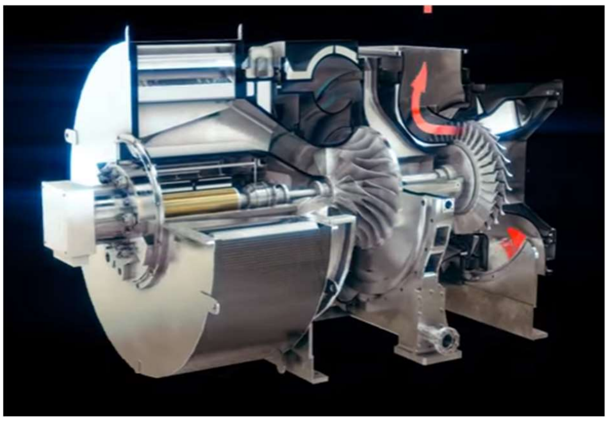

Figure 4. Hybrid Turbocharger- Calnetix product [13]

With the AVL Software it will be evaluate the energy limits of the system that it is proposed. This is partly done on the basis of the expertise, assimilated in the laboratories of the Research and Development Center - High Tech Products for Automotives – "Transilvania" University. Further results will be developed and simulated in the virtual environment and presented.

5. Limitations of the proposed study (if any)

Regarding the constructive part, the requirements for setting up hybrid turbocharger are these three basic things:
1- Conventional turbocharger with extended shaft to accommodate alternator at blower end,
2- A specially designed, very compact alternator to run at very high speed of around 100.000- 200.000 rpm.,
3- A cooling system for alternator, as heat generation will be more due to its compact size for given rpm (optional).
The rotation may vary due to the turbine's variable geometry on the turbine side with several running domains. The turbo compact has two parts: the turbine, where the flue gas is and the spiral compress with the fresh air. The two parts in turn are coupled by a shaft. The developed electric current has three possibilities:
1- Storage in the main battery of the vehicle, extending its lifetime,
2- Redirect to peripheral computer consumers,
3- Storage and redirection according to the central control computer.
Other studies will be presented. [14-15]

6. Conclusions

Turbochargers are used by Diesel engine manufacturers and a growing number of gasoline engines, especially in terms of size reduction. This component must be well understood and designed as a simulation because it is widely used at every stage of development. Indeed, cost and development time must be reduced to meet both customer wishes and stricter emissions standards. The current turbocharger simulation codes are mostly based on the search tables (airflow and air mass) provided by manufacturers. This papers aim is to present the new turbo compound system in automotive industry for internal combustion engines to recover therefore the hybrid turbocharger solution is a reliable, practical and very efficient solution in many ways: production costs, maintenance, reduced geometric geometry in terms of its applicability. From an ecological point of view: it reduces the consumption of the main battery of the vehicle and produces green electricity. From a constructive and economical point of view, production, installation and maintenance costs are very low and the product has a long life span in relation of its applicability. [15]

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