THEORETICAL, CALCULATING AND EXPERIMENTAL RESEARCHE OF ELECTROMECHANICAL TRANSMISSIONS OF MACHINES

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Introduction: The authors have electromechanical transmissions (EMT) with two engines driving a single shaft. Such transmissions are under ever greater efforts of development in connection with the appearance of motor vehicles having combined power installations (thermal engine (TE) + electric motor (EM) + store of energy (SE). The result of research on two layouts of EMT are given: a serial layout of TE and EM, and a parallel layout: TE and EM connected by a matching gear (MG). The second layout has been studied in detail in the case of direct closure of power flows on the driven shaft, and a conclusion has been made in favor of closure through a differential. The differential closure transmission is preferable from the viewpoint of dynamics and makes EMT automation possible. The result of theoretical studies, design and experimental research are analyzed.

Constant progress in the field of mechanical engineering and leveling-up of requirements concerning service properties of machines require to search essentially new ideas and design decisions to be used at modernization of existing machine models and at designing new models. A direction of raising machine quality is the use of combined (hybrid) power installations (CPI) consisting of thermal engine (TE), electric motor (EM) and store of energy (SE). There are no motor vehicles with such power installations, produced in quantities, because of a great amount of problems yet unsolved: experimental, as well as theoretical.

Depending on the aims set (raising economy, lowering exhaust gas toxic emissions of TE, raising traction/speed performance, etc.) various designs and components of CPI are proposed. Among them, carburetor I.C.E., diesel engines, gas turbines, etc. as TE, various of DC and AC electric motors as EM, and various types of stores, from lead-acid batteries to flywheel kinetic energy stores, as SE are proposed. Now electric energy stores are most common. That's why all the block diagrams of hybrid motor vehicles are given here for the case when electric energy stores are used as SE.

All kinds of CPI can be classified, depending on the principle of TE and EM layouts, into two categories: 1. serial layout CPI (motor vehicle wheels are driven from an electric motor), 2. parallel layout CPI (wheels can be driven simultaneously from TE and (or) EM).

The block diagram of 4×2 motor vehicle equipped with a serial TE and EM layout CPI is given in Figure 1.

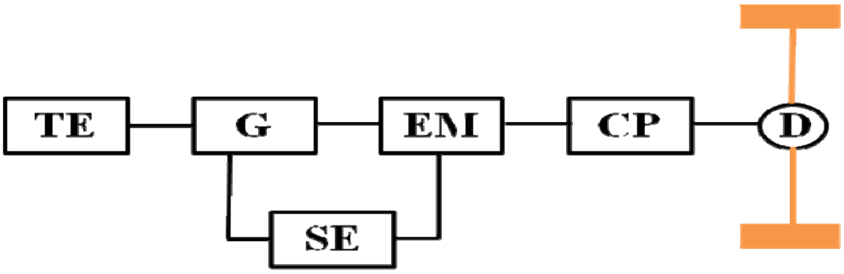

Figure 1: Block diagram of a hybrid motor vehicle with a serial CPI layout

In this case, a CPI output shaft is the EM output shaft which transmits power to the driven wheels of the motor vehicle. Behind the EM output shaft there is usually a clutch. To increase and change the torque transmitted between the output shaft and the driven wheels, as a rule, a gearbox and a reduction gear are used here, followed by an inter wheel differential (D). We shall call the section from the CPI output shaft to the differential a "converter part" (CP) of electromechanical transmissions (EMT). It must be noted that another CP design is possible, e. g. an all-wheel drive vehicle can have a transfer gearbox, a central differential, etc. Any of the said CP components possible can also be missing in the design. Generally, CP design complexity is determined by the number of vehicle drive axles. The more it is, the more complex a hybrid vehicle CP will be.

When the motor vehicle runs at stationary from TE to the driven wheels will go through the following vehicle units: TE-G(generator)-EM-CP-D. If thereby SE is discharged, then SE receives additional energy through the sequence TE-G-SE. When an additional traction force on the driven wheels is necessary (e. g. heavy road conditions, high acceleration necessary, increase of motion resistance at high vehicle speeds), energy comes from SE to the driven wheels, simultaneously with a power flow from TE, through the sequence TE-G-EM-CP-D. The vehicle can move while TE does not work, using the energy coming from SE, e. g. when it is necessary to lower toxic emissions contained in TE exhaust gases (running indoors at factories, etc., and in cities with high density of population and traffic). When braking and coasting, slowing-down and braking energy is recuperated into SE energy through the sequence D-CP-EM-SE due to EM starting to work as generator.

The CPI layout shown in Fig. 1 allows to provide TE works in a limited range corresponding to its highest fuel economy. But in this case, getting high fuel economy is a problem due to the basic limitation described in [1]. When all TE energy is transmitted to the vehicle driven wheels, it is converted three times or more. One part of TE thermal energy is connected to mechanical energy, the mechanical energy is connected by G to electric energy, and then to mechanical energy by EM. Another energy part is converted from its electric form to chemical energy and then back to electric energy by SE. It is clear that every energy conversion leads to its losses. Besides, reliability of this layout depends on EM reliability, i. e. if EM fails, the motor vehicle cannot work.

High energy losses of CPI serial layouts make them inferior to power installations whose TE and EM work in parallel. The layout of Fig. 1 may be recommended to be used when the main vehicle requirement is to lower toxic emissions. It is well known that toxicity of TE exhaust gases grows many times as high at TE transient regimes. The majority of these transient regimes can be excluded by using CPI layout considered. TE work at stationary regimens cannot be reached in full because of high torque's on the driven wheels necessary in the process of acceleration or at road resistance growing.

As it was said, in the development of a hybrid motor vehicle it is preferable to use parallel CPI layouts which allow to increase vehicle fuel economy by 30 to 50 %, as well as to better emission control. A 4×2 vehicle layout, now most common, with such CPI, is shown in Fig. 2. To match the rpm of TE and EM shafts, they are interconnected by a matching gear (MG).

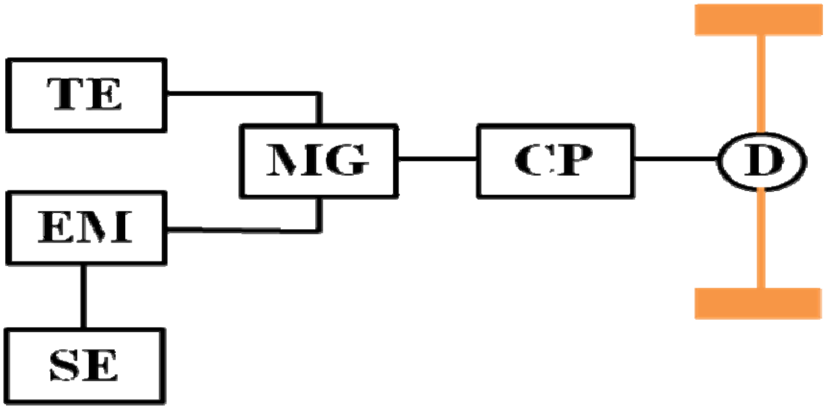

Figure 2: Block diagram of a hybrid motor vehicle with a parallel CPI layout

In this case vehicle motion at constant and nearly so speeds is provided by the power transmitted to the driven wheels through the sequence TE-MG-CP-D. At a high acceleration, the driven wheels receive additional power through the sequence SE-EM-MG-CP-D. When it is necessary to charge SE while the vehicle moves at stationary and nearly so speeds, SE is charged through the sequence TE-MG-EM-SE, i. e. EM starts to work as a generator. Coasting and braking is accompanied by energy recuperation into SE energy through the sequence D-CP-MG-EM-SE.

Various gear types can be used as MG, e. q. chain, toothed wheel, and belt types. Theoretic studies and design research are carried out for these MG types, which are described in [2, 3, 4, etc.]. Prototype of hybrid electric vehicles are developed, which are based on the estate car Izh-21261 and have three types of MG. Laboratory and road tests are carried out [5].

A combined power installation is consists of: carburetor I. C. E. "VAZ - 1111" (rated power 22 kW, max torque 44.1 N×m, displacement 0.649 l); EM "PT-125-12" (armature supply voltage 120V, armature current max 120 A, torque 49 N×m); MG; CPI frame; clutch; gearbox; SE.

To carry out full-scale comparative experimental research, prototypes with various MG were developed. The first MG version was a chain unit. This version proved to be not reliable enough and was replaced with a toothed wheel MG. The latter structure consisted of four pairs of wheels capable of not only to transmit torques from both, TE and EM, but also transmit torques from/to each other. These MG capacities were used to realize the process of recuperation and to use EM as a starter.

In the third version, to lower energy losses in MG, the torque was transferred directly to the transmission, and the EM torque was transmitted through a belt drive. It was decided to use a belt drive in connection with a number of reasons: large distance between TE and EM axes, rather low torque transmitted, no tight coupling of the shafts, low noise level.

Road test results showed that hybrid power unit vehicles with a parallel layout are comparable with ordinary motor vehicles equipped only with TE in connection with traction/speed performance. And the cruising range of these vehicles is limited only by the quantity of fuel in the tank. Their fuel economy can be raised by up to 30 % practically without changing design parameters of the car "Izh-21261" equipped with CPI.

Thereby, some limitations of this layout have been found out.

Firstly, increased power losses in the transmission of EMT because of MG inclusion into CPI structure. According to the general theory of power [6], MG is a generalized node which converts simultaneously power and speed factors of power flows from TE and EM. There are no losses in the transmission of EMT due to power circulation because in the design considered (Fig. 2) there are no closed power flows. Increased power losses in EMT are caused by the complex dynamic processes in MG, i. e. there are high dissipate losses which are hard to eliminate by means of design.

Secondly, it is a problem of matching TE and EM work because of transient TE regimes in various service conditions of the vehicle which also influences energy losses and increased dynamic loads in MG in the final analysis. This problem is solved with a starting/regulating apparatus and an electronic controller, the main index of perfection of which is their capability to match TE and EM work at transmitting torques according to a given program modeling real conditions of vehicle motion.

Another parallel CPI layout is possible, which is preferable from the viewpoint of TE and EM work matching and allows to lower dynamic loads in MG and dissipate power losses in the transmission. A block diagram of a hybrid vehicle with such CPI is shown in Fig. 3.

In this case, CPI is a closed-circuit differential gear allowing to transmit TE power to the driven wheels in two flows after a splitter (S). TE and EM power flow closure is provided with a differential MG (DMG) inserted into the structure, and that gives additional possibility for EMT automation. Most TE power is transmitted to DMG through a sequence with a constant gear ratio TE-S-DMG. Another power part is transmitted to DMG from EM which works as a variable-speed drive with electronic control. Thus we have an automatic EMT.

The hybrid vehicle whose layout is shown in Fig. 3 can have the following power flows. At stationary and nearly so speeds, is transmitted to the driven wheels through the sequences TE-S-DMG-CP-D, and TE-S-G-EM-DMG-CP-D. SE being discharged, an additional energy is transmitted to SE through the sequence TE-S-G-SE. When high torques on the driven wheels are necessary, an additional, third power flow is created in CPI through the sequence SE-EM-DMG-CP-D, i. e. SE gives additional power. At braking and coasting, energy recuperation is realized through the sequence D-CP-DMG-EM-SE, and EM works as a generator. When it is necessary to move using only EM, with TE switched off, power flow to the driven wheels is provided through the sequence SE-EM-DMG-CP-D.

Now theoretic studies and design research of the hybrid vehicle whose block diagram is shown in Fig. 3 are carried out in order to decide on the prospects of this CPI layout and the possibility to embody it in a prototype.

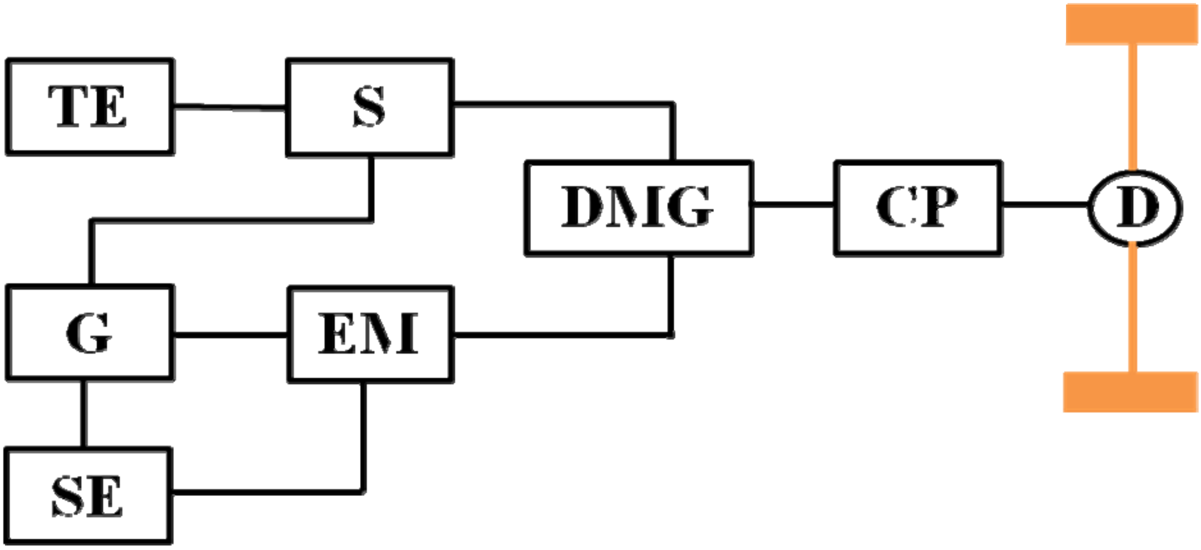

Figure 3: Block diagram of a hybrid vehicle with TE and EM power flow closure through a differential

Conclusion

Research results have proved prospectiveness and necessity to go on with creating machines with CPI, and that will allow to essentially enhance fuel economy and ecological properties of motor vehicles without detrimental influence on their traction and speed performance.

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