

Power transfer box for experimental hybrid-electric vehicle

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Abstract. This paper presents design proposal for power transfer box intended for experimental light hybrid-electric vehicle. This vehicle is originally configured as parallel hybrid with mechanical power at the rear axle and two electric hub-motors at the front axle. Vehicle should subsequently be also equipped with additional electric generator enabling charging of traction batteries for front axle drive, enabling also configuration of series hybrid or range extender. Task of the transfer box described in this paper is to connect IC engine with either rear driving axle or PTO for electric generator, or both. The goal of design process is to design the transfer box by minimizing the mass and power losses.

1. Introduction

Following actual trends of vehicle drivetrain electrification and hybridization, light experimental hybrid-electric vehicle was developed in the Laboratory for engines and vehicles, Faculty of technical sciences at the University of Novi Sad. This vehicle represents platform for education and research and was realized as a student project. This project is mainly foreseen as an opportunity for students to gain some hands-on experience in solving real engineering problems, as well as to study contemporary engineering solutions through practical application of theoretical knowledge gained during study. Current appearance of the vehicle is shown in Figure 1. Vehicle design process was carried out taking into account general rules of automotive engineering (e.g. [4]), and considering main features and requirements for hybrid-electric vehicles, e.g. [1, 2].

Main feature of the vehicle is hybrid-electric drivetrain. It is arranged in parallel configuration, with two in-wheel electric motors driving front wheels, and IC engine driving rear axle through the gearbox, chain drive and conventional passenger car final drive. The front and the rear axle are shown in Figures 2 and 3 respectively. Parallel hybrid configuration means that the front and the rear axle can be driven either independently of each other or simultaneously, according to chosen driving mode. These functions are yet to be realized through design of appropriate electronic control system which is one of the following steps in project development.

In order to increase educational value and research-work capabilities of this project, it was subsequently decided to retrofit additional transfer box enabling the powertrain arrangement to be also configured as in-series hybrid, without losing the possibility to be used in parallel mode, as foreseen originally. User should be able to choose between available configuration options. Series hybrid configuration means that IC engine is only used to power electric generator which charges batteries when necessary, while vehicle is driven only by electric powertrain. Such usage of IC engine in hybrid-electric vehicle is also known as "range extender".





Figure 1. The hybrid vehicle in development stage.



Figure 2. Front axle with in-wheel electric motors and batteries.



Figure 3. Rear axle with conventional passenger-car final drive, driven by IC engine.

Goal of this paper is to describe development of appropriate transfer box which has to fulfill following main requirements:

- minimal dimensions, mass and rotational inertia,
- minimal sources of energy loss,
- minimal required modifications of existing vehicle due to retrofitting,
- convenient for application of control elements,
- convenient for production, assembly and maintenance.

2. Transfer box layout choice

According to required functions and tasks, transfer box should couple (and also decouple) output shaft of vehicle gearbox with both final drive and generator input shaft. Thereby following operational regimes should be enabled:

1. Generator off, IC engine driving rear axle - for purely mechanical or parallel hybrid mode (as provided by original vehicle layout)
2. Rear axle off, IC engine driving generator - for the range extender or series hybrid mode
3. Both rear axle and generator driven by IC engine - mixed parallel/series hybrid
4. IC engine disconnected, generator coupled to the rear axle - enabling regenerative braking on the rear wheels.

Several layouts fulfilling functional requirements were defined as shown in Figure 4. All proposed layouts fulfil functional requirements in view of coupling and decoupling drivetrain components. Comparing these layouts on the base of complexity, mass and dimensions, convenience for production, design and maintenance easily leads to conclusion that layout "A" represents optimal choice.

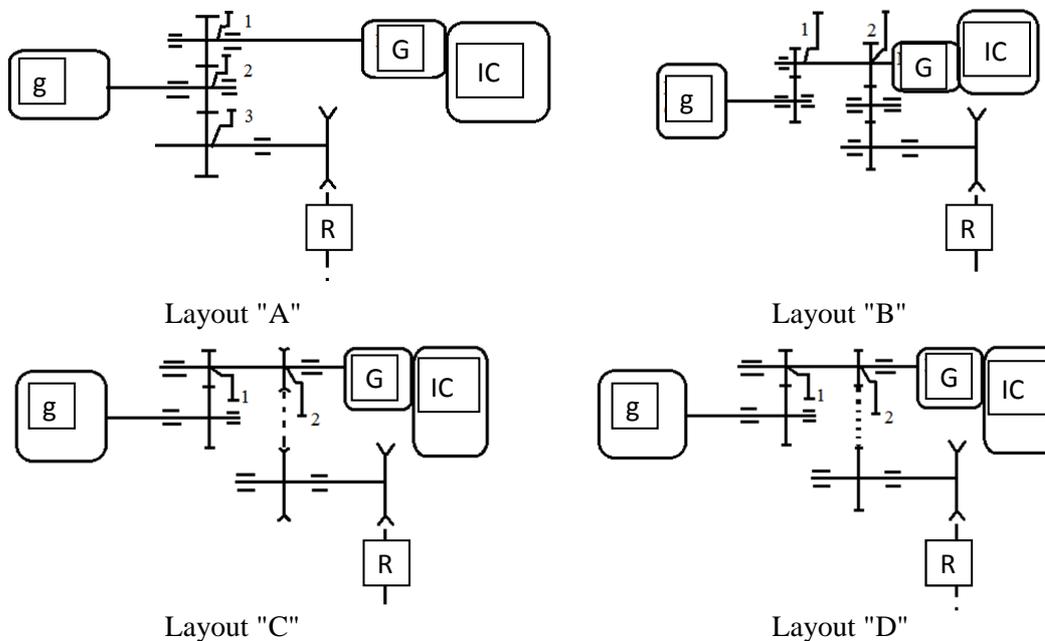


Figure 4. Some proposed transfer box layouts fulfilling functional requirements: IC - IC engine, G - gearbox, g - generator, R - rear axle chain drive; 1, 2, 3 - clutches.

Therefore starting from layout "A" in Figure 4, further simplification was introduced taking into account possibility of purely electrical decoupling of generator so that it may remain permanently mechanically connected to the gearbox output shaft. This way though the generator rotational inertia is unnecessarily driven all the time, but it was assessed that overall benefit of design simplification and mass reduction justify this shortcoming. More thorough analysis of those opposed criteria lies out of the scope of this work. Layout that was finally adopted is shown in Figure 5. It can be noticed that there is only one mechanical clutch necessary for different operational modes as required by the project task. When this clutch is engaged, torque is transmitted from the gearbox output shaft to the sprocket wheel of the rear-axle chain drive in direct manner, i.e. as if there were no changes to the original configuration. Disengagement of this clutch breaks this torque transmission path and rear axle

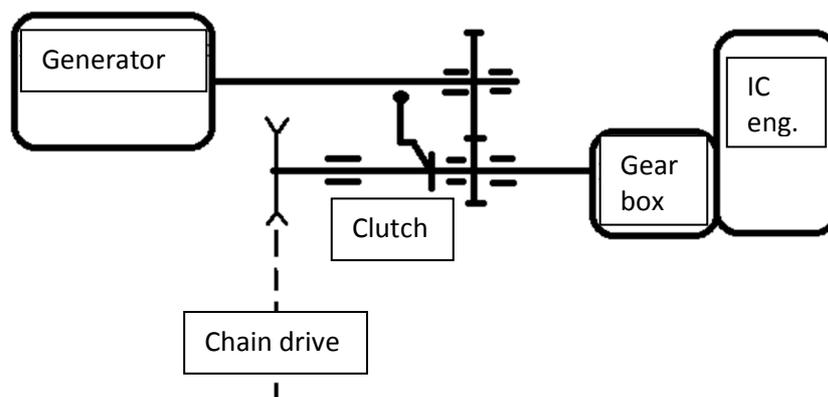


Figure 5. Adopted layout of power distribution.

is no longer connected to the IC engine. The generator input shaft is driven permanently via gear pair whereby torque drawn off by the generator depends on its own operational regime. It should also be noted that in general it is also possible for the generator to operate in electric motor mode, thus being able to provide additional driving torque to the rear axle. Power flow in different operating modes is depicted in the Figure 6.

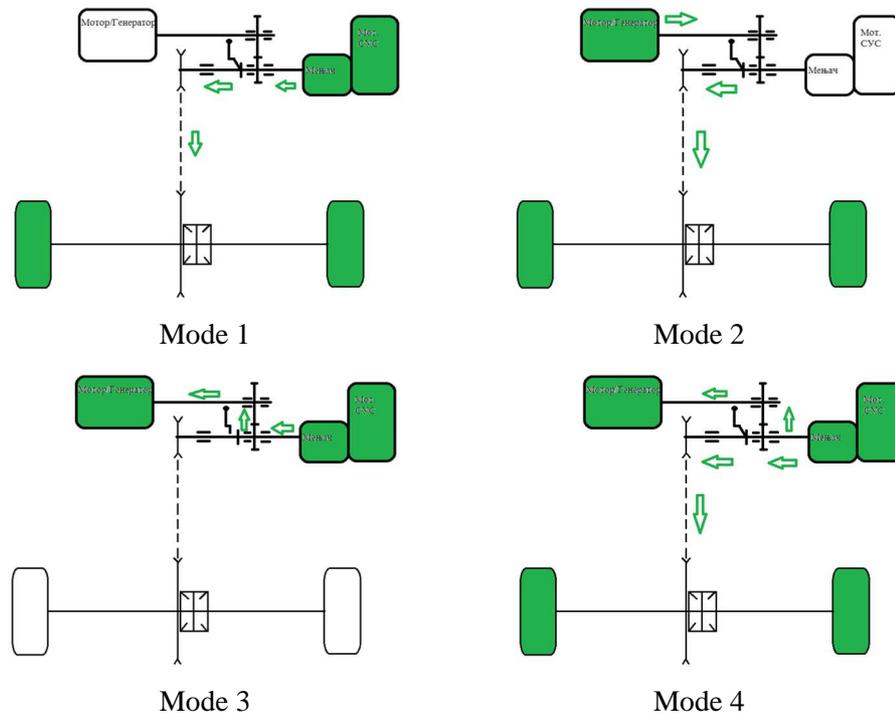


Figure 6. Power flow in different operating modes.

Operating modes shown in Figure 6 are as follows:

- Mode 1: the generator is turned off, the IC engine drives rear axle;
- Mode 2: rear axle is coupled with the generator, regenerative braking is enabled (depicted in the Figure is the case with the power flow opposite to regenerative braking, when the generator is working in the motor mode thus providing additional drive torque to the rear axle);
- Mode 3: the IC engine provides drive only to the generator;
- Mode 4: both rear axle and generator are driven by the IC engine.

Cases depicted in Figure 6 give confirmation that all operating modes as required by project task are enabled.

3. Calculation and choice of transfer box design parameters

After final adoption of the transfer box layout and functionality check, final designing steps were carried out in order to fully determine geometry, shape and choice of standard elements such as bearings. General rules of mechanical engineering calculations were adhered to (e.g. [3]). Calculations and drawings were made by using software "Autodesk Inventor 2016 – Student version".

3.1. Gears

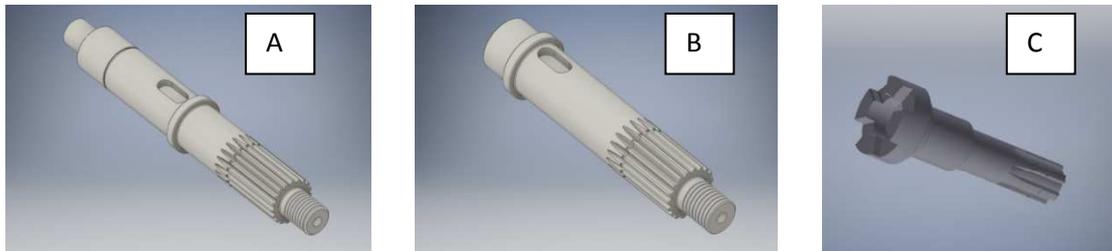
Gear pair calculation was carried out according to standard ISO 6336:1996. It was assumed that the generator operates at 1500 rpm and that input power coming from the IC engine reaches 10kW. In range-extender mode engine rpm can be best matched by selecting appropriate gearbox ratio so that main criteria for selecting gear ratio were compact design and strength of elements. Basic gear data are summarized in the Table 1.

Table 1. Summary of gear data.

	Input gear	Output gear
Number of teeth	40	48
Width [mm]	22	20
Diameter [mm]	59.690	71.078
Module [mm]	1.375	
Helix angle [deg]	15	
Material	37Cr4	

3.2. Shafts

Choice of material for the shafts was the same as for gears. Input shaft and first output shaft (providing drive to the generator) are loaded, besides by torque, by both axial and radial force due to the bevel gear pair. Second output shaft (the one providing drive to the sprocket wheel and thus to the rear axle final drive), carrying only torque, is not loaded by neither axial nor radial forces. Calculations were made by taking into account these conditions. Appearance of all three shafts is shown in the Figure 7.

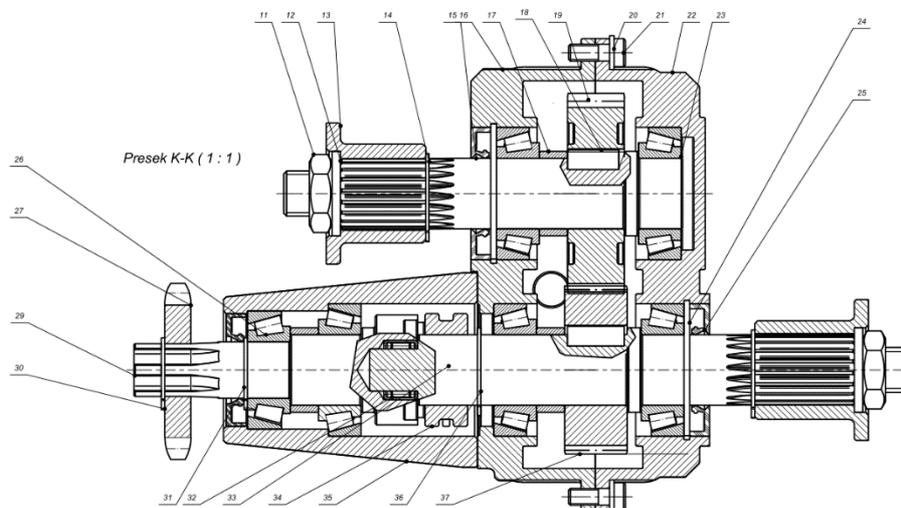
**Figure 7.** Appearance of input (A) and both output shafts (B, C).

3.3. Bearings

All shafts are pivoted by using pair of tapered roller bearings due to their ability to support both axial and radial loads. Selection and calculations were carried out according to the method proposed by bearing-producing company SKF.

3.4. Final design and shape of the transfer box

Final design and shape of the transfer box is depicted in Figures 8-11.

**Figure 8.** Longitudinal section of the transfer box.

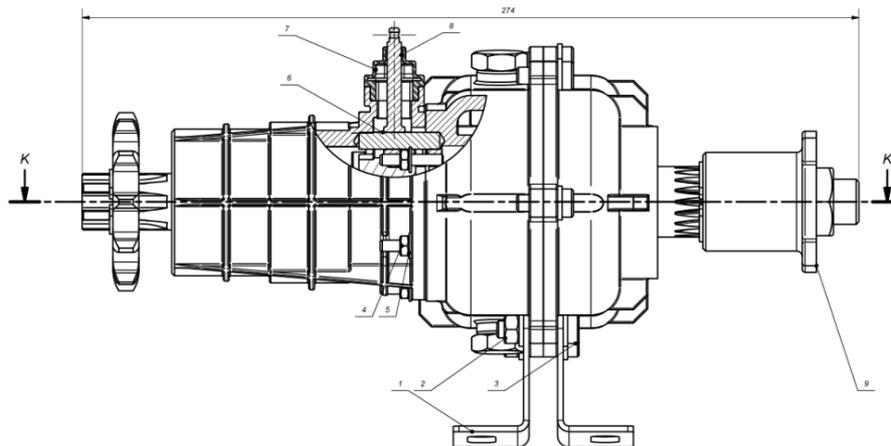


Figure 9. Partial section through clutch-operating lever for operating mode choice.

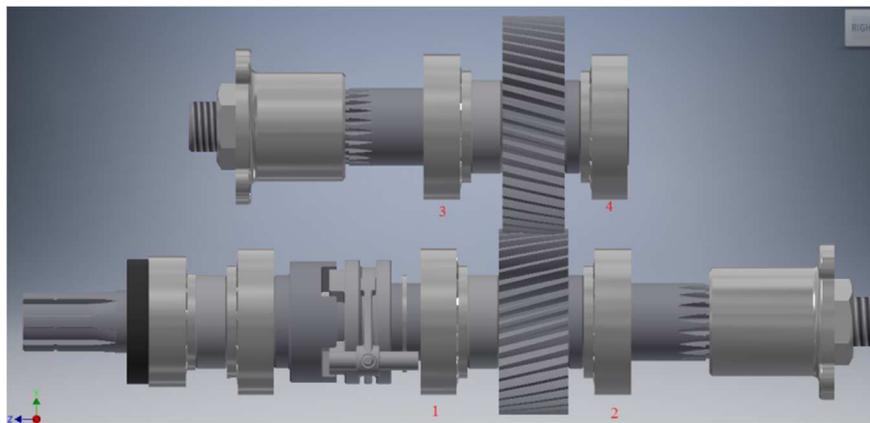


Figure 10. Appearance of the transfer box internal elements.

4. Final remarks and conclusions

In this paper development of multi-purpose power transfer box for usage in hybrid-electric vehicle is described. Basic functions of transfer box are coupling and decoupling different powertrain elements to enable different operating modes of hybrid vehicle. Multiple layout choices enabling all required functions were proposed and optimal solution was adopted. Calculations of gear pair, shafts and bearings were carried out according to general rules of mechanical engineering by using the software "Autodesk Inventor 2016 – Student version". Final design decisions were made adhering to main design goals which were to develop compact, light and efficient transfer box not requiring complex modifications of the existing vehicle.

Engineering calculations of all mechanical parts and elements shown that all safety factor values lay in the range of required values. Minimal dimensions of gears were attained through optimization of material properties, gear width and number of teeth. Helix angle of helical gears had to be adapted so as to enable minimum required axial force in view of bearing safety factor and lifetime. Idea of using chain or belt drive inside transfer box was inappropriate due to size of required components for required torque. Joining between gears and shafts are realized by using wedges, though it should be noted that it is also possible to use rigid joining with interference fit. Such approach reduces number of elements needed, but on the other hand it requires greater manufacturing accuracy. Convenience for maintenance can also be compromised this way should it be required to disassemble gear from the shaft. Finally, shape of the transfer box housing was formed based on the conventional shape form of similar existing devices.

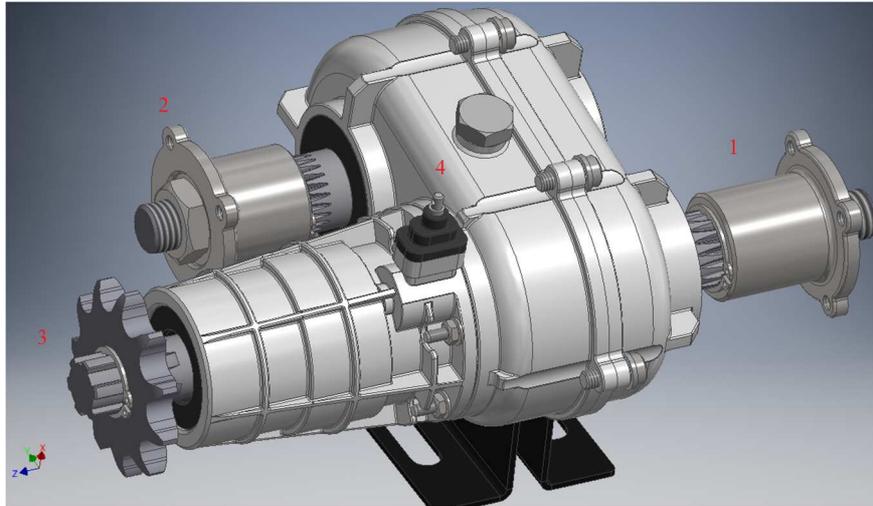


Figure 11. External appearance of the transfer box.

References

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