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Prospects for the development of drivetrain systems in trucks

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The article presents the directions of development of drive systems in trucks. A database of vehicles and their technical data was developed. This data contains information about the drivetrain configuration. The external characteristics of the engines and the structure of the drivetrain were analyzed. It was found that the factors determining development are primarily economic and ecological aspects. It was noticed that, based on the configuration of the drive system, vehicles can be divided according to their purpose and type of transport. Vehicles intended for international transport are characterized by low gears and engines that achieve high torque at low engine speeds. Construction vehicles and vehicles intended for oversize transport are characterized by large gear ratios and torque amplification systems. The structure of electric vehicle drive systems is different from conventional vehicles. Gearboxes usually have two gears, and drive axles may have integrated engines located next to the main gear or in the final drive position. The study also made it possible to outline the problem of the short range of such cars and the need for further work on increasing it.

Key words: *drivetrain, truck, electrification, hybrid, e-axle*

1. Introduction

The key function of drivetrain systems is to transmit torque and rotational speed to the vehicle's drive wheels. Trucks perform specific tasks which causes these systems to be highly personalized. The purpose of customization of powertrain systems is to ensure the effectiveness, durability and efficiency of the vehicle at an appropriately high level required by the company. The essence of personalization is to adjust technical parameters and components to the specific requirements of the user. Depending on the intended use of the vehicle, deviations from standard configurations may affect elements such as: the engine, gearbox, drive axle or axles (depending on the required needs, the vehicle may be equipped with multiple drive axles), and drive support systems.

The configuration of the vehicle depends on the country, road quality and type of road surfaces, daily distance the vehicle covers, the type of cargo being transported, its weight, the topographical characteristics of the routes, and operating costs. Simultaneously work is being conducted on hydrogen technology and electric drive systems in heavy-duty trucks [20, 21]. The reduction of vehicle emissions is associated with certain challenges, including the increase in the vehicle's own weight due to the use of additional equipment [2, 13, 15, 25]. On the other hand, there is pressure from owners to reduce weight in order to increase payload capacity.

The article highlights the changes that have occurred in powertrain systems in recent years and shows the differences in the configuration of powertrain systems in trucks depending on their intended use.

1.1. Characteristics of the division of trucks

Trucks as previously mentioned are vehicles that have various applications. Therefore, these vehicles can be classified on the basis of their purpose [3]. Each group of vehicles will be characterized by specific differences in their configuration. There are many vehicles that, due to their specific features of the drivetrain, become specialized vehicles which normally are not used in different transport tasks that are intended. An example of such specialized configurations are trucks intended for long-distance transport on regular routes running through areas with gentle elevations of the ground. In this case, the drivetrain can be selected in such a way as to minimize fuel consumption, thereby reducing the company's operating costs associated with material and energy consumption as much as possible [8, 9, 14]. This is an example of a vehicle that in mountainous terrain will generate problems such as high fuel consumption, low average speed due to insufficient power, increase drivers' stress levels due to time pressure and the need for greater concentration on the road.

Another example of a specialized configuration is trucks designed for oversized loads - the priority is to efficiently transfer high torques to the ground via multiple drive axles. Another category of heavy-duty vehicles to mention is dump trucks used in the construction industry. These vehicles are characterized by a short, compact, multi-axle chassis, often with multiple drive axle systems for both steering and driving axles.

Ballast tractors, in contrast to distribution or long-haul transport vehicles, are equipped with a greater number of drive axles. Besides the increased number of wheels capable of transmitting high torque these vehicles are often featured in hub reduction gears.

Furthermore, there are cases in which vehicles also differ in the type of used clutch. Examples of this can be the aforementioned tractors used for transporting heavy, non-standard loads or construction vehicles. Examples would include the above-mentioned truck used to transport heavy, abnormal loads, or construction vehicles.

Depending on the needs, various types of gearboxes can be used in vehicles. Currently, the most popular type is the automated transmission. Among newly sold vehicles, only a small percentage feature a manual transmission. Despite the significant popularization of automated gear shifting, there is not only one possible clutch variant in vehicles. Cars can now be equipped with a traditional single-disc or double-disc dry clutch or a turbo retarder clutch, enabling more smoother transmission of high torque during uphill starts and effective vehicle braking of the vehicle when going downhill.

Truck manufacturers mostly use components from other manufacturers that specialize in the production of specific drivetrain components. Gearboxes are mostly manufactured by companies such as ZF, Eaton or Voith. In the European market, the most commonly encountered gearboxes are ZF AS-Tronic and Traxon, which have gained significant popularity in vehicles manufactured by f. ex. MAN, DAF, IVECO. There is a group of manufacturers including VOLVO, MERCEDES-BENZ and SCANIA who have chosen to develop their own designs. The use of gearboxes made by external suppliers provides economic benefits, and these vehicles are often more cost-effective to operate due to the use of components produced on a larger scale [12].

1.2. Electric drive solutions in heavy-duty vehicles

1.2.1. Hybrid module

Reducing the pollution emitted by different cars is a crucial aspect in the European Union. One of the ways to lower the emissions is to reduce the fuel consumption. To do this, hybrid modules can be used. Below (Fig. 1), a kinematic scheme of an typical module that can be installed in commercial vehicles.

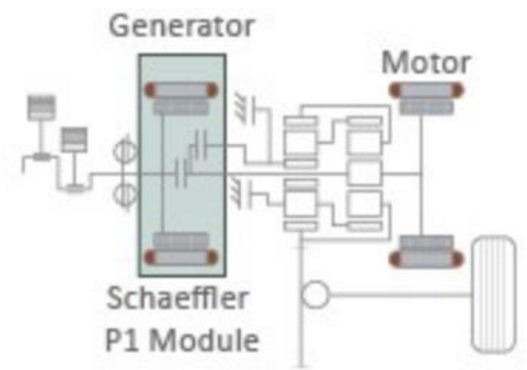

Fig. 1. Kinematic scheme of the P1 hybrid module [5]

The next photo (Fig. 2) shows the technical solution of the module mounted between the engine and the gearbox, developed by Schaeffler. The device can perform several functions. By installing an electric motor inside the flywheel, it is possible to support the operation of the drive system by generating additional torque. Depending on the version of the installed module, it also enables maneuvering at low speeds and provides propulsion in the initial phase of movement without involving a combustion engine [18].

1.2.2. Electric vehicle drive module

These modules are complete devices used in ICE vehicles. Their compact design allows for the installation of the system in the location where a traditional gearbox is usually mounted. This allows manufacturers to offer two drive versions of the vehicle on one platform. Both electric and internal combustion engine vehicles do not require any structural changes in the frame and other drivetrain components. An example of a powertrain module, such as the ZF CeTrax, incorporates an electric motor, a three-speed gearbox, gear shifting actuators, an inverter and an ECU.

Despite its small size, the engine can deliver up to 340 kW of continuous power [22, 23].

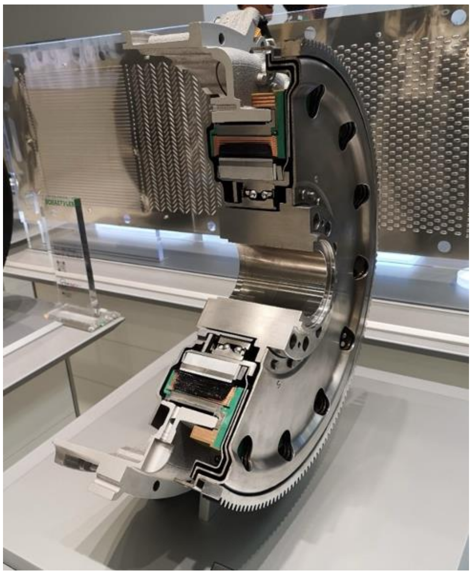

Fig. 2. A cross-sectional view of Schaeffler heavy duty hybrid module P1

Fig. 3. Combined drive module ZF CeTrax

1.2.3. Drive axles for electric vehicles

Electric vehicles come in various powertrain configurations. They can feature traditional setups similar to those in internal combustion engine vehicles designed for freight transport, using gearboxes, drive shafts and axles to transmit power. In this case, electrical modules such as the above-mentioned ZF CeTrax are used (Fig. 3). This system is primarily used in vehicles that share a common platform for different powertrain types, significantly reducing production costs.

A vehicle equipped with a drive axle with a built-in electric motor as example the Alison eGEN POWER 100s (Fig. 4) will be built in a different way. Electrified drive axles can be divided into two types depending on the place the electric motor or motors are installed:

1. With a centrally located engine – this is a solution in which an electric motor is placed at the input to the main transmission. There are designs in which two motors are mounted on both sides of the transmission and with integrated gearboxes. The advantage of this solution is that it frees up space in the vehicle between the frame rails where a gearbox is usually located In the case of emergency vehicles, this may be particularly important because the lack of a drive shaft and gearbox allows this space to be used to accommodate additional equipment (for example, in a fire truck) or by lowering the fire extinguishing water tank. This solution also enables the installation of larger traction battery packs.
2. With engines placed in the hubs of the drive axle – the axle is without a differential or final drive. The location of two independent motors in the hubs allows to differ the wheel speeds. This solution offers even greater space savings compared to a centrally located motor. Locating the engines in the hubs partially frees up space between the vehicle's wheels. This makes it possible to lower the floor level between the side members or, in the case of city buses, lower the floor level and create a low-floor vehicle with the floor at one level along the entire length of the vehicle.

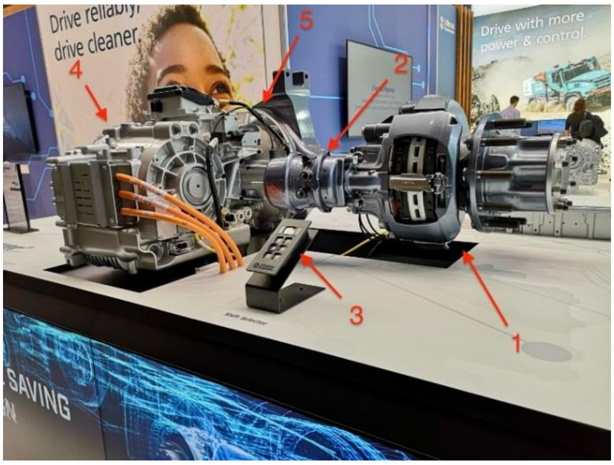

Fig. 4. Alison eGEN POWER 100s – electric drive axle with a centrally located motor; where: 1 – disc brake caliper; 2 – brake chamber; 3 – shift selector unit; 4 – electric motor; 5 – main gear with differential

1.2.4. Active trailer axles

Trailers for heavy-duty vehicles can be equipped with an energy recuperation system integrated into the axle. The low rolling resistance of the axles ensures that the vehicle rolls freely and does not affect fuel consumption. These axles can be fitted in various trailers as example reefers, walking floor trailers or curtain trailers. The trailers with these axles are equipped with battery packs which replace pallet boxes in traditional constructions. In reefer trailers the traditional refrigeration unit can be replaced by an electric one. It is already proven that these types of axles provide enough electricity for the refrigeration unit for the whole day when the trailer is used for typical local and city distribution [16].

In trailers with walking floor systems that use axles like the one shown on photo (Fig. 5), electric hydraulic pumps are installed in contrast to traditional walking floor trailers which need to be hooked up with tractors with additional hydraulic pumps. These types of axles can not only provide in electricity the mentioned above receivers but they can also assist in propelling the vehicles. SAF Holland offers an axle with an integrated motor generating 120 kW of power and 320 Nm of torque. Even though these axles are designed for trailers, they can be a good basis for developing a trailing axle for a hybrid truck. This will simplify the drivetrain's design while maintaining its conventional form, and the additional axle can function as an independent executive component controlled by a common controller. It is estimated that by implementing such an axle in a road vehicle it is possible to save up to 4,000 liters of diesel fuel per year [17].

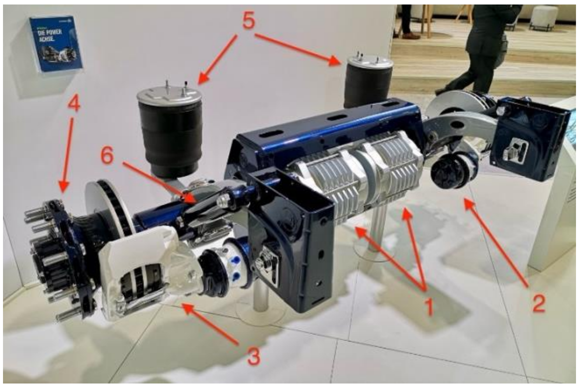

Fig. 5. Electric trailer axle with a build in electromotor for energy recuperation: 1 – electric motors; 2 – brake chamber; 3 – brake caliper and disc brake; 4 – wheel hub; 5– air suspension bellow; 6 –shock absorber

2. Methodology

In order to determine the prospects of the development of drive systems, it was necessary to create a vehicle database. Due to the variety of vehicle configurations, it was decided to assign each vehicle to a group corresponding to the type of transport performed. Each vehicle has been assigned at least one symbol graphically representing the type of transport performed (Table 1). The analysis examined the properties of elements such as engine displacement, maximum power and torque, gearbox type and its gears, drive axle ratios, the presence of differential and gearbox, and their gears.

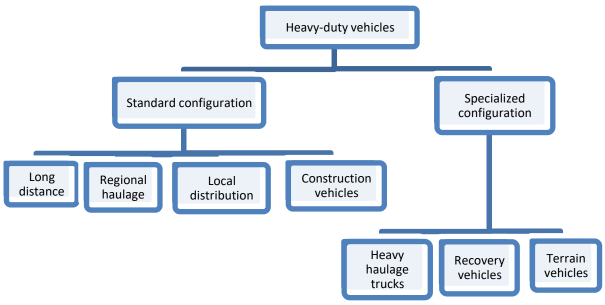

Fig. 6. Classification of HDV

In order to better illustrate the division into the specified vehicle categories, additional graphics have been developed showing the specialization of HDV (Fig. 6) and the use of electric drives (Fig. 7).

Table 1. List of trucks, their technical data and driveline parameters

	Made/ model	Purpose of use	Engine	Power [kW/RPM]	Torque [Nm/RPM]	Gearbox	Gear ratios	Type of gearbox	Drive axle ratio	Rub gear ratio
1	IVECO X-WAY 440X48 4X2 HI-TRACTION		FPT Cursor 11	353/1900	2300/970	ZF 12TX2210TD RAXON	16.69–1.00	Automated	2.85	–
2	DAF XF 480 4X2		Paccar MX13	355/1600	2350/ 900-1365	ZF 16S2300 ECO-SPLITTER	16.41–1.00	Manual	2.38	–
3	IVECO TRAKKER 4X4		FPT N67	206/1950-2500	1000/1250-1950	ZF 6S1005 ECO-LITE	6.75–0.78	Manual	6.95	0.525
4	DAF XF 480 4X2 LOW-DECK		Paccar MX13	355/1600	2350/ 900-1365	ZF 12TX2210 TD TRAXON	16.69–1.00	Automated	2.05	–
5	IVECO TRAKKER 450KM 8X8		FPT Cursor 10	331/1450-1900	2200/ 900-1450	ZF16S 2220 TO	13.8–0.84	Manual	4.67	N/A
6	SCANIA P280 6X2		Scania DC9	206/1400-1900	1400/ 1000-1400	G25CM1	20.8–0.78	Automated	3.8	–
7	SCANIA P450 4X2		Scania DC13	331/1340-1800	2350/ 900-1340	GRS905R	16,41-1,00	Automated	2.35	–
8	DAF CF 8X4		Paccar MX13	340/1450-1700	2300/N/A	ZF 16S2500	13.8–0.84	Manual	4.05	N/A
9	MERCEDES-BENZ ACTROS 3363 LS SLT 6X4		Mercedes-Benz OM473	460/1700	3000/1100	G280-16	11.7–0.69	Automated	4	1.333
10	VOLVO FE 6X2 ELECTRIC*			130/N/A		–	–	–	–	–
11	MERCEDES-BENZ UNIMOG U5023 4X4	Terrain vehicle	OM 934 LA	170/N/A	900/1400	UG 100/8	9.57–0.74	Automated	2.55	–
12	Pepper Actros MP3**		ZF CeTrax	175/0-8500	2170/–	ZF CeTrax	3.36	Automated	2.84	–
13	DAF LF		Paccar PX-5	157/2300	850/ 1200-1500	ZF 6S800	6.58–0.78	Manual	3.73	–

* Range: max. 275 km   ** Range: max. 220 km

In addition to physically existing vehicles, the list also includes vehicles proposed by configurators available on manufacturers' websites. After entering basic data such as forecasted mileage, type of transport (distribution, international transport etc.), topography of the routes on which the truck will travel and the type of vehicle frame, the application selects the parameters of the drive system. All parameters are selected in such a way that the vehicle exhibits the highest possible efficiency.

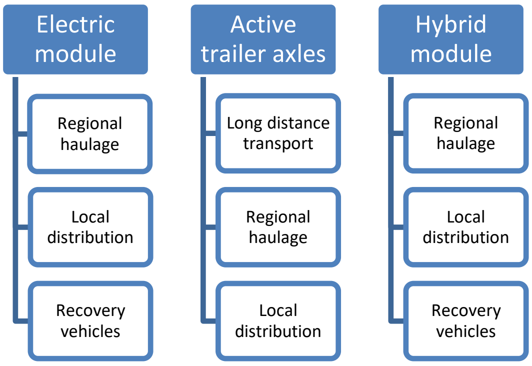

Fig. 7. Possible applications of electrical components depending on the tasks performed

The group of specialized vehicles includes cars such as a fire truck or the Mercedes-Benz Unimog, which is a heavy off-road vehicle, designed to work in difficult terrain. One vehicle that stands out significantly from the others is the Actros SLT, designed for transporting oversized cargo.

3. Results discussion

Table 1 presents a list consisting of various vehicles with different configurations. The analysis was conducted on base of technical parameters of drive systems.

3.1. Engines

Due to the key role of the drive unit in the drive system, the values of maximum torque, maximum power and displacement were analyzed. A clear observation emerges from the comparison of the parameters of the ICE used. Despite numerous solutions and different applications, the main parameters can be divided into four groups:

1. Small – power 160–170 kW; torque 0.9–1 kNm
2. Medium – power approx. 200 kW; torque 1.4–1.5 kNm
3. Large – power 330–350 kW; torque approx. 2.3 kNm
4. Extra large – power 460–500 kW; torque approx. 3 kNm.

Table 2 presents a list of engines used in the vehicles selected for analysis, taking into account the division according to engine. In the lower part of the table are shown engines used in electric vehicles included in Table 1.

Vehicles with a lower GVW are equipped with smaller engines. Reduction in performance resulting from the need to meet exhaust emission standards. Trucks equipped with them have slightly different engine characteristics. The maximum torque is achieved at higher RPMs than in mid-size and large engines. This is closely related to the combustion process and corresponds to the range of the lowest specific fuel consumption.

Electric motors installed in heavy-duty trucks generate less power, but they achieve very high torque values compared to the engine power. It should also be mentioned that these engines can operate at very high rotational speeds, providing high torque values in almost the entire revolution range.

Table 2. Values of basic operating parameters of the analyzed engines

Vehicle	Max. power [kW]	Max. torque [Nm]	Max. rpm	Engine displacement
Small engines				
11	170	900	2600	5.1
13	157	850	2500	4.5
3	206	1000	3150	6.7
Mid-size engines				
6	206	1400	2200	9.3
Large engines				
1	353	2300	2250	11.1
2; 4	355	2350	1800	12.9
5	331	2200	2150	10.3
7	331	2350	2100	13.0
8	340	2300	1700	12.9
9	460	3000	1700	15.6
Electric motors				
10	130	N/A		N/A
12	175	2170	8500	N/A

3.2. Gearboxes

Among the vehicles included in the list, 62% are equipped with automatic or automated gearboxes. The use of automatic control primarily allows to elimination the so-called human factor and achieves maximum drive transmission efficiency in all traction conditions. The predominance of automatic gearboxes proves the declining popularity of manual gearboxes.

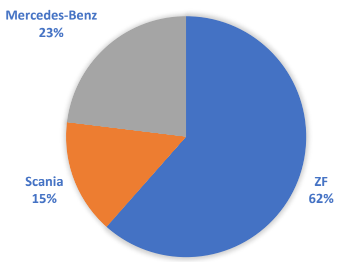

Fig. 8. Percentage share of gearbox manufacturers – based on Table 1

It can therefore be expected that in the upcoming years, the number of vehicles equipped with a manual gear shifting system will become even smaller, and the total number of vehicles with this technical solution will be only a small percentage. For many years, truck manufacturers have preferred to install proven and well-known units from well-known manufacturers (Fig. 8). Most truck brands outsource the development of mechanical transmissions to companies that supply this component. The most popular manufacturer on the European gearbox market is ZF. This company focuses on the production of ready-made technical solutions for drive systems. Their products are installed in as many as 62% of the vehicles included in the analysis.

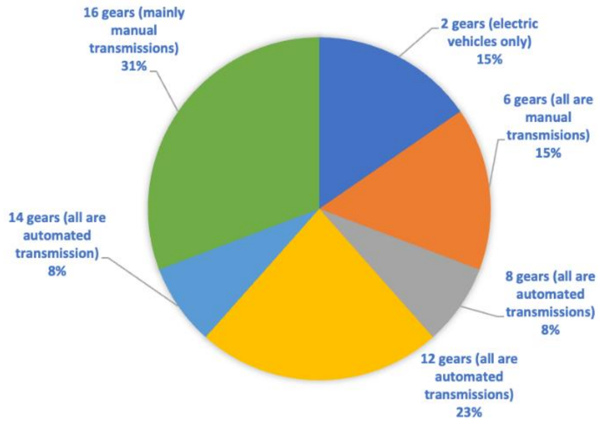

Fig. 9. Numbers of gears – based on Table 1

It can be concluded that trucks conventional use 12- and 16-speed gearboxes (Fig. 9). The number of gears is usually determined without taking into account the crawler or reverse gears. The least frequently used solutions in trucks are fourteen- and eight-speed gearboxes. The appearance of the 14-speed gearbox is due to the construction of the G25CM1 gearbox. This is a gearbox in which the first two gears take over the role of the crawler gears.

Among the gears with 16 gears, 75% are manually controlled. Considering the declining popularity of manual gearboxes, it can be concluded that transmissions with such a number of gears will become increasingly rare in the coming years. They will only be used in specialized vehicles for example in ballast tractors.

All 12-speed gearboxes are automated. Taking into account the increase in the number of vehicles equipped with twelve-speed gearboxes and the fact that 100% of them are automated, it can be expected that in the near future, mainly twelve-speed gearboxes will be installed in trucks.

Among the analyzed vehicles, 64% is equipped with an overdrive gear. Overdrive gear allows reducing engine RPM when driving at a constant speed, which combined with a wide range of maximum torque and obtaining high values at low rotational speeds, will lead to reduced fuel consumption.

3.3. Main gear

Reducing the main transmission's gear ratio results in a decrease in the engine speed at the same driving speed, which allows for reduced fuel consumption.

Each vehicle in the list has a different drive axle ratio value. In most vehicles without overdrive, gears around 2.3–2.8 are common. Trucks equipped with overdrive usually have higher final drive ratio values. If a low final drive ratio were also used in such a vehicle, a situation could arise in which the engine would not be able to generate a high enough torque to enable the vehicle to move in the highest gear.

Vehicles with very specific applications, such as ballast tractors moving with very heavy loads, are equipped with hub gears.

3.4. Devices supporting the operation of the drive system

Devices supporting drive systems, such as active axles in semi-trailers, do not currently constitute a very large population due to the fact that they are relatively new designs – they appeared in the offer of semi-trailer manufacturers a few years ago. During road tests conducted by the BMW concern, it was shown that Krone semi-trailers equipped with an active axle system reduce fuel consumption even up to 40% [1, 10]. In addition to supporting vehicle propulsion, these systems enable to power up receivers mounted in semi-trailers. For example, in a refrigerated vehicle, this allows the reefer to be powered, thus obtaining significant benefits in the form of no pollutant emissions and no unwanted sound, which is particularly desirable in urban distribution where deliveries often take place in the morning. Considering the benefits that their use can bring, they will become much more popular in the coming years [6, 19].

4. Conclusions

Climate protection will lead to more common adoptions of new solutions [7, 11]. Currently, road toll tariffs depending on the carbon dioxide emission class are being introduced in two EU countries [24]. This will undoubtedly motivate us to replace the fleet with a more fuel-efficient one, which will contribute to the increased use of micro-hybrid systems and active axles in semi-trailers.

In the context of road charges tied to CO_2 emissions, electric vehicles seem to be the best choice because they will benefit from very large discounts. may drive further efforts to extend the range of electric heavy-duty vehicles. Currently, the technology of storing electrical energy in battery packs allows a driving distance of approximately 300 km in optimal conditions. In winter, this range is reduced due to low temperatures.

A way to increase the range of electric vehicles may be to use a hydrogen cell and "Hydrozine" fuel, commonly known as formic acid. Intensive work is conducted to use hydrogen as a fuel, which also allows for increasing the range of electric vehicles [4].

Observing contemporary trends in the design of powertrains in trucks, the following conclusions can be drawn:

1. The gearbox offer is dominated by automated transmissions. 12- and 16-speed gearboxes are most often used in trucks. The aim is to lower the top gear in order to reduce fuel/energy consumption. Manual transmissions are systematically being pushed out of the market.
2. The increasing flexibility of drive units, the popularization of automated control and the use of electric motors make it possible to reduce the number of gears in gearboxes. New forms of energy storage are being developed to extend the range of electric vehicles.
3. Further development of hybrid modules makes it possible to simplify the design of drive systems. This module can be used as an electronic clutch, torsional vibration damper or starter for an internal combustion engine.
4. Additional powertrain support systems gain popularity due to increasing torque in phases of increased load and reducing overall exhaust emissions. Systems of this type use primarily electricity for propulsion. They can be seen as transitional solutions before the full implementation of electric drivetrains in this vehicle category.

Nomenclature

CNG compressed natural gas
ECU electronic control unit
GVW gross vehicle weight
HDV heavy-duty vehicles
ICE internal combustion engine

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