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Lepeshko I.I., Ivanov V.G., Matar Sukheil, Hassan Abdulkadir Baba

ANALYSIS OF VEHICLE BRAKE SYSTEMS

Minsk 1993

I, Mikhail S. Shpakouski, sworn translator, do hereby certify that I am fluent in the English and Russian languages, and that the above document is an accurate and complete translation of the document entitled "Analysis of vehicle brake systems" made this 27th day of September 2012.

Pr. Masherova 1-134, Minsk 220005 Belarus
Tel/fax: (375 17) 202-11-11, e-mail: 2021111@lan.by
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The growth of the traffic intensiveness imposes stricter requirements to the active road safety; main participants of such traffic are motor vehicles and road-trains. The increase in active safety is accompanied by the complication of the structure of brake systems with a simultaneous increase of expenses for their production, operation and repair. For example, the prices for the manufacture of the brake system with hydraulic drive for a ZiL type truck not taking into account the anti-lock braking system equal up to 15% of the total expenses on the truck production.

In relation to the growth of complexity and price of brake systems the choice of the brake system type and brake mechanisms structure for the designed vehicle satisfying the modern requirements to the active safety at the minimal expenses on the production, operation and repair become crucial.

In order to solve the stated problem it is necessary to perform an analysis of the modern status and ways of development of the brake systems on the basis of the existing structures, patent solutions and scientific publications.

In order to perform the analysis of the brake drives let's create their classification based on the relation between the pressure on the control pedal, its movement and the braking torques of the brake mechanisms (3).

All the brake drives used in the vehicles can be divided by the abovementioned criteria into three groups (see Fig. 1):

- direct action drives;
- parallel action drives;
- indirect action drives.

The direct action drives are used in the passenger cars of the compact car and small car class, light trucks and buses with gross weight up to 4 tons. The typical representatives of such drives are hydraulic and mechanical drives. The mechanical brake drive due to special properties concerning the duration of action is used as a parking brake in all types of vehicles.

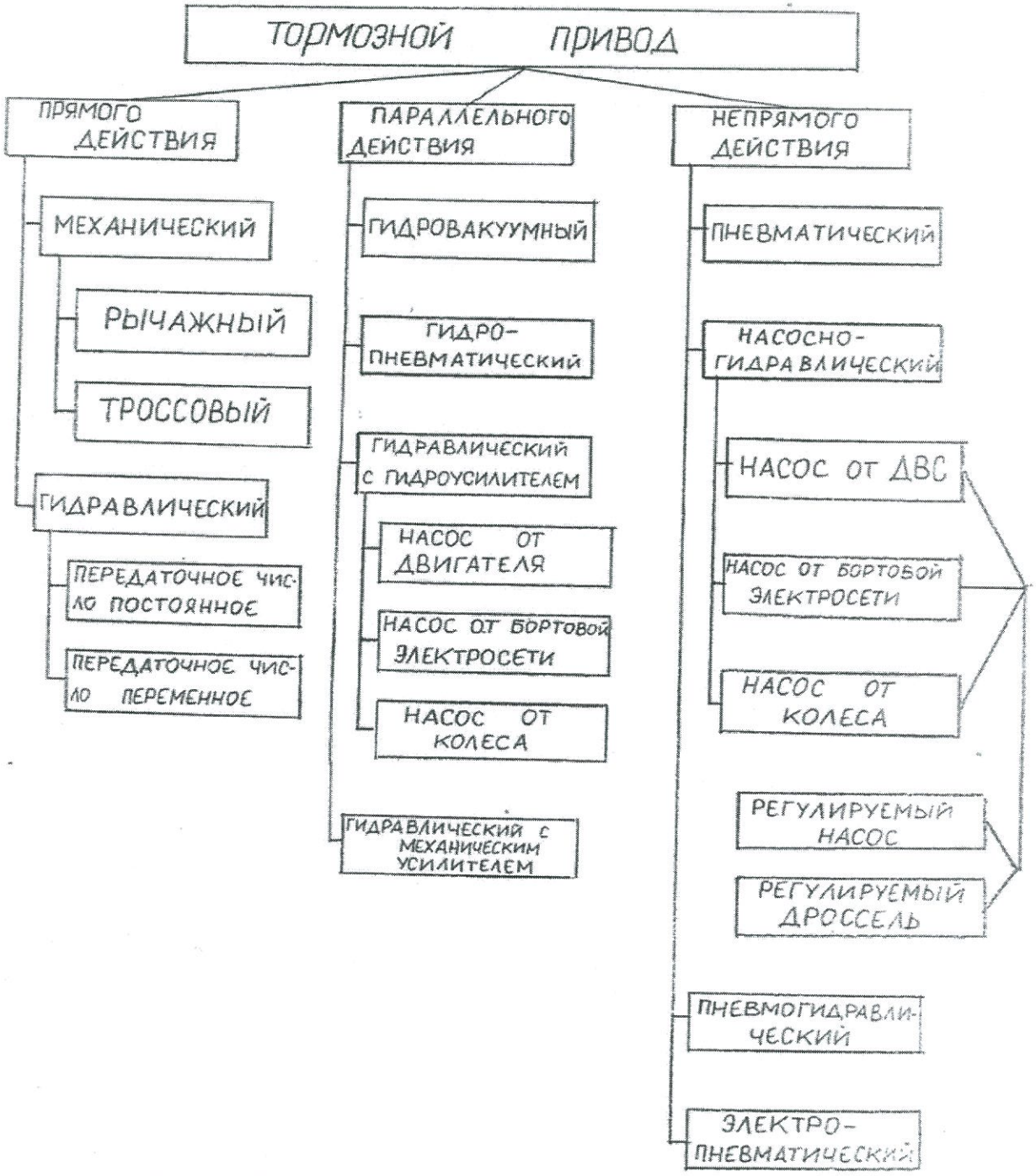

Fig. 1. Classification of brake drives

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The attempts to expand the sphere of application of the hydraulic drives to heavier vehicles by the means of introduction of the variable-gear ratio were not successful due to the unsatisfactory results of operation of such drives in the dynamic mode.

The main advantages of the direct action drives are:

- their readiness to work at any moment independently of the vehicle condition;
- the possibility of keeping the vehicle immovable for a long time (mainly regards the mechanical drives);
- simple structure and minimal expenses for the production, operation and repair;
- the high response of the drive.

The main disadvantage of the direct action drives is their limited application conditioned by the physical abilities of the driver that are subjected to the sanitary norms in respect to the pressure on and movement of the brake pedal or control arm (3).

The mentioned disadvantage can be eliminated by the application of various types of boosters using different types of energy.

The parallel action drives are used in single-unit trucks operated without trailers.

In order to establish the potential abilities of such drives let's make a more detailed analysis of them.

1. HYDRAULIC BRAKE DRIVE WITH A VACUUM BOOSTER.

Such drives became broadly spread in many types of passenger cars and trucks with carburetor engines and regulation of air-fuel mixture by throttling of intake manifold.

The efficiency of operation and the response of the vacuum booster are determined by the grade of manifold vacuum and receiver volume.

The intake manifold vacuum influences the engine's fuel efficiency and the toxicity of exhaust gases. At the same time the increase of manifold vacuum leads to the increase of fuel consumption and worsening of toxicity values. In order to improve the mentioned values in the sphere of engine-building they try to minimize the losses in the intake manifold by the means of the reduction of the manifold vacuum grade even up to the injection of fuel, i.e. the refusal of carburetor usage and regulation of engine speed by throttling.

The mentioned circumstances lead to the increasing of the dimensions and the delay in the vacuum booster response. If the grade of manifold vacuum is too law, for example, in the case of fuel injection, than the application of the vacuum problem becomes a serious challenge.

In addition to the peculiarities mentioned above the vacuum booster ceases to work after the stopping (stalling) of the engine and the depletion of vacuum in the receiver or the vacuum unit itself. Thus, such drive becomes a direct drive unit with all that it implies. Thus, the transfer to the direct action drive leads to a significant increase of the required pressure on the control pedal and the reduction of braking efficiency; very often it is the reason of breakdowns, especially in the case of passenger cars.

2. HYDRAULIC BRAKE DRIVE WITH A HYDRAULIC BOOSTER.

Such drives have no significant differences from the drives with vacuum boosters but they allow the significant expansion of the sphere of their application at the account of larger power capacity, the possibility of the creation of the larger air reserves in case of engine stop and higher response.

In the absence of the compressed air such drives get the properties of the direct action drives.

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The hydraulic brake drives with a pneumatic drive are rather difficult and require higher, in comparison to vacuum boosters, expenses on their production, operation and repair. It is conditioned by the installation of the compressor and the systems for its control and the system of the compressed air preparation (cleaner, moisture/ oil separators, coolers, accumulators, pressure control, etc.).

It shall be noted that the presence of the compressed air allows usage of such vehicles to road-trains with trailers equipped with a pneumatic brake drive.

3. HYDRAULIC BRAKE DRIVE WITH A HYDRAULIC BOOSTER.

The drives with hydraulic boosters compare favorably with the mentioned above due to the possibility of provision of higher efficiency and response on the background of small dimensions as a result of working medium high efficiency and the possibility of power take-off from various sources. Depending on the place for installation of the pump station drive three trends can be distinguished:

- power take-off from the main engine;
- power take-off from the vehicle-mounted electric network;
- power take-off from vehicle wheels.

Let's make an analysis of the peculiarities of brake drives belonging to the specified trends.

3a. Hydraulic brake drive with a hydraulic booster and a pump station actuated by the engine – is the most widespread scheme (1). This drive has a significant disadvantage – after the engine stop the fluid supply for the booster operation ceases, thus leading to the direct action drive.

In order to eliminate the abovementioned disadvantage the energy accumulator (hydraulic accumulator) is included into the brake drive. The application of the hydraulic accumulator leads to the introduction of the automatic feeding system thus complicating the system and making it more labor-consuming in the process of its production, operation and repair, and on the other hand – allows reduction of the generating capacity and, correspondingly, the size of the pump station.

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Moreover, the presence of the hydraulic accumulator allows increasing of the brake drive response, but the operation of the brake drive on the background of the switched-off pump (stopped engine) is very limited due to the leakage through the gaps in the valves and due to the limited capacity of hydraulic accumulators.

3b. Hydraulic brake drive with a hydraulic booster and pump station actuation from the vehicle-mounted electric network eliminates the disadvantage of the previous drive, i.e. increases the durability of the brake drive as the energy reserve in the electric battery is quite big and the pump station can have minimal dimensions. At the same time it is necessary to install a hydraulic accumulator into the brake drive as a device securing the necessary response of the brake drive.

At present such brake drives become more widespread in passenger vehicles and start to expand to cargo trucks.

The main disadvantage of such drive is the discharge of the vehicle-mounted battery due to the prolonged usage of the brake system and non-operating engine. It shall be noted that the abovementioned brake drives become more popular as a part of antilock brake systems and traction-control systems.

3c. Hydraulic brake drive with a hydraulic booster and pump station with actuation from vehicle's wheel.]

The main antecedent for the application of this drive is the usage of the kinetic energy of the moving vehicle for the activation of the brake system.

The broad range of the speed change from the maximum value to zero imposes certain limitation on the work of the brake drive represented by the provision of the pressure at low engine speed and "stop" modes. With this purpose such drives are equipped by hydraulic accumulators, thus the system obtains no significant advantages and preserves the common disadvantage peculiar of all drives with a hydraulic accumulator – the limitation of application by the energy reserve in hydraulic accumulators.

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4. HYDRAULIC BRAKE DRIVE WITH A MECHANICAL BOOSTER

The main peculiarity of the brake system with a hydraulic drive and a mechanical booster is the application of two-step brake mechanisms located in one brake drum or on a one brake disc. The first step of such mechanism is actuated by the direct action drive and the second – by the brake mechanism of the first step by the means of their mechanical interaction.

The abovementioned drive has no disadvantages characteristic of other brake drives with boosters. These drives have all the features of the direct action drives and the usage of the mechanical booster using the braking torque of the first step mechanism significantly expands the sphere of application of such drives up to heavy vehicles and outsized vehicles.

Some complication of the brake mechanisms can be compensated by the significant simplification of the brake drive, thus allowing reduction of expenses on the production, operation and repair of such systems up to 50% in comparison with the system used nowadays.

The main disadvantage of such drives is the limitation of their usage by heavy road-trains with a big number of brake mechanisms. This limitation is conditioned by the driver's physical abilities.

The analytical check of the brake drive with a mechanical booster and a direct action hydraulic drive on the first step control demonstrated the possibility of their installation on individual vehicles and road-trains with up to 12 braking wheels.

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The common peculiarity of the parallel action brake drive operation is the inclusion of the booster into operation after the appearance of the pressure in the drive to the driver's force, i.e. after the backlash elimination and application of the brake pads to the brake drum or disc. This peculiarity implies a limitation on the selection of the gear ratio, thus preventing it spreading to the heavy vehicles with many axles and road-trains.

The expert's evaluation of the parallel action brake drives demonstrates us that the most prospective is the hydraulic brake drive with a mechanical booster.

Taking into account the specificity of such drive and the absence of publications in the native and foreign scientific literature, the conduction of research and experimental development in this direction shall be considered prospective.

INDIRECT ACTION DRIVES

Such drives became widespread in the practice of automotive industry mainly in the vehicles and road-trains of heavy and very heavy payload capacity. The main peculiarity of these drives is the absence of the direct firm connection between the driver and the brake mechanisms. At the same time the driver controls the energy flow performing the work on the actuation of the brake mechanisms (2).

In order to specify the peculiarities of the brake drives of the mentioned group, let's examine their types provided in the classification table (Fig. 1).

1. PNEUMATIC BRAKE DRIVE.

This drive is widespread nowadays due to several advantages, namely:
- the cheapness and unlimitedness of the working medium (compressed air);

- the insensibility of the brake drive to small leakages;
- the insensibility of the working medium to the change of the temperature in a broad range;
- the relative simplicity of the organization of the control of the trailer brakes.

In addition to the advantages mentioned above there are several disadvantages, the main of which are:

- the delayed response of the brake drive, especially for the vehicles and road-trains with long pipelines connecting the brake devices to the distributing devices;
- the high sensibility of the drive to the moisture, especially at low temperatures, leading to the formation of ice blockages resulting in the inoperability of the pipelines;
- the time limitation of the brake drive action on the background of the switched-off compressor.

The elimination of the abovementioned disadvantages of such systems leads to the significant complication of the structure (4) and, as a rule, to the increase of expenses on production, operation and repair. These expenses, first of all, are stipulated by the introduction of various boosting devices, devices increasing system survivability in case of line breakaway, installation of compression air tanks close to the actuating mechanisms, preparation of the working medium (moisture and oil removal, cooling, compressor operation control, etc.), installation of additional systems operating independently from the main brake system, installation of the significant number of compressed air tanks, especially for the drives with antilock and anti-traction brake systems, etc.

In addition to the disadvantages mentioned above these drives consume a significant amount of energy taken off the engine, thus leading to the non-productive fuel consumption.

It shall be noted that the pneumatic brake drive by its structure and functional purpose, including the complexity and price, is almost not related to the vehicle's payload capacity, that's why the brake drive share in the expenses on the production of the vehicle varies a lot, with the tendency for its increase for cheaper vehicles. For example, the brake system share for MAZ type trucks is 9-11% and for ZIL type trucks – up to 15%.

2. PNEUMOHYDRAULIC BRAKE DRIVE.

It is widely used in the vehicles and road-trains with a heavy or a very heavy payload capacity. The application of the pneumohydraulic drive complicates the structure of the brake drive, thus increasing the expenses on the production, operation and repair. Despite the mentioned complication such drives are spreading due to the faster response in comparison with the pneumatic drive and due to the reduction of the compressed air consumption. Moreover, the brake mechanism becomes more compact.

3. ELECTROPNEUMATIC BRAKE DRIVES.

These drives become more widespread in long-wheelbase road-trains with long pneumatic lines.

The Main purpose of the application of the abovementioned drives is the increase of the brake drive response, i.e. the elimination of the main disadvantage of the pneumatic brake drive. Still, during the realization of such drives there arise some additional problems concerning the organization of the drive's tracer action thus leading to the complication of the drive electrical part up to the application of the electronic systems. The introduction of the electronic systems is accompanied by the drive complication, i.e. the introduction of the necessary gauges and systems providing the stabile operation of the electronic part with actuating pneumatic mechanisms.

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As a result, the electropneumatic drive increases the expenses in comparison with the pneumatic and pneumohydraulic drives.

4. PUMP-HYDRAULIC BRAKE DRIVE.

The pump-hydraulic brake drives have some significant advantages before the pneumatic and pneumohydraulic drives; that's why they are used in heavy and outsized vehicles. Among the main advantages are:

- the drive's high response;
- the ability to create high drive force;
- small dimensions and weight.

In addition to the positive features there are some disadvantages, namely:

- the complexity in the organization of the trailer brake system;
- the fluctuations and pulsations of the pressure leading to the pipeline vibration;
- the ceasing of the drive operation after the stop of the pump station;
- the sensibility of the working medium to the change of the temperature.

The results of the statistical analysis of the national innovations can be applied to this group of drives. In Fig. 2. you can see the fitted distribution curve. In that case the mean-square deviation equals 3.32. From the diagram you can see that at present there is an increase in the number of research in this field.

The pump-hydraulic brake systems can be organized independently from the pump station drive type in accordance with one of two basic diagrams of pressure regulation:

- the pressure regulation in the brake drive by the means of the change of the throttle resistance (spool-type pressure regulators);

- the pressure regulation by the means of the change of the pump station productivity, at the same time the throttle resistance can be permanent (the orifice size is permanent).

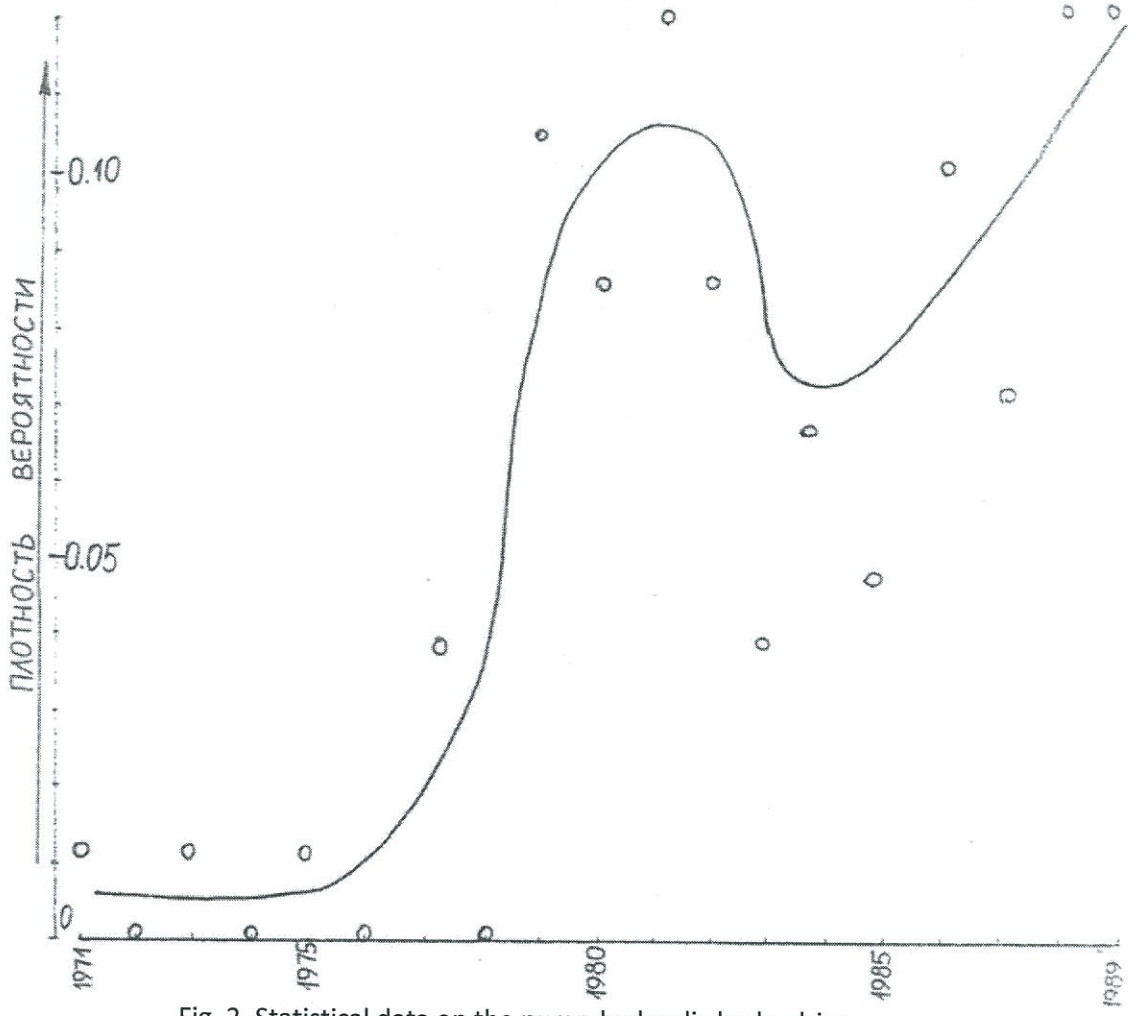

Fig. 2. Statistical data on the pump-hydraulic brake drive

Any of the abovementioned schemes has its advantages and disadvantages. Thus, in the scheme with an adjustable orifice the pump station uses the constant displacement pump (gear-type, vane-type, piston-type, etc.) that are quite simple and have small dimensions. At the same time the system of automatic pressure control gets more complicated.

What concerns the drive with the variable displacement pump, it is, as a rule, more complicated and, correspondingly, the expenses on its application are higher; still, such a brake drive does not use the controlled pressure valves.

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The decision on the usage of one of the abovementioned schemes can be taken only after the thorough technical and economic analysis in regard to the designed vehicle and the production facilities.

The pump-hydraulic drives can be divided into three groups by the method of power take-off:

- the drives with the power take-off from the engine;
- the drives with the power take-off from the vehicle-mounted electric network;
- the drives with the power take-off from a wheel or wheels of the vehicle.

In addition to the groups mentioned above the combined power take-off can take place – from the engine and the transmission.

Let's make a more detailed analysis of the abovementioned groups of the brake drives.

4.1. THE DRIVES WITH THE POWER TAKE-OFF FROM THE VEHICLE ENGINE.

These drives are equipped by a pump station actuated by the engine, a controlled pressure valve, a hydraulic accumulator and an automatic pressure valve controlling the operation of the pump and the filling of the hydraulic accumulator. The hydraulic accumulator in this system has two functions: it provides the necessary response of the brake drive on the background of the limited productivity of the pump; it guarantees the operation of the brake system in the case of engine stop.

The main disadvantage of such drive is the limited operating time of the brake drive in the context of the engine stop due to the limited energy reserve in the hydraulic accumulators.

4.2. THE DRIVES WITH THE POWER TAKE-OFF FROM THE VEHICLE-MOUNTED ELECTRIC NETWORK

These drives become more widespread, even in the passenger cars. The drive, as in the previous case, is equipped by a hydraulic accumulator. The application of the hydraulic accumulator for such type of drive follows the goal of the decrease of the pump station productivity in order to reduce the consumed power and simultaneous increase of the response of the brake drive.

The main disadvantage of such drive, as in the previous case, is the limitation of the drive operating time due to the capacity of the hydraulic accumulators and vehicle-mounted batteries. It shall be noted that the drive with the power take-off from the vehicle-mounted electric system has a significantly higher power capacity than the drives with the power take-off from the engine.

4.3. THE DRIVES WITH THE POWER TAKE-OFF FROM THE WHEEL (WHEELS).

The main peculiarity of such drive is the possibility of the usage of kinetic energy of the moving vehicle for the actuation of the brake mechanism. At the same time there appears the possibility to refuse from the application of hydraulic accumulators and to simplify the brake drive. The necessary response of the brake drive in this case is provided by the selection of the pump station parameters. The possibility of the pump displacement increase is conditioned by the fact that the power consumed by the pumps facilitates the vehicle's deacceleration and has no influence on the fuel values, as in the case of the power take-off from the vehicle-mounted electric network.

This drive includes the pump with protection devices and controlled valve.

The main disadvantage of this drive is the impossibility to use the "stop" mode, as the vehicle receives the mode of the "creeping" speed that is the result of the fluid leakage in the valve and the pump itself in the form of volumetric loss. This phenomenon requires the introduction of additional devices for the elimination of this disadvantage.

It shall be noted that the present of the "creeping" speed along with its negative sides has a positive effect, too. It is represented by the automatic fulfillment of anti-lock brake system functions by the brake drive.

The performed functional analysis demonstrates that among all the variety of the used and prospective brake gears one can distinguish the following trends that require further in-depth theoretical development and technical and economic analysis and development work.

1. The hydraulic brake drive with a mechanical booster. The main trend of research is the two-step brake mechanism.

2. The pump-hydraulic brake system with the pump actuation from a vehicle wheel. The main trend of research is the development of the calculation methods, dynamics of the brake drive operation and the research of the possibility of the combination of the functions of the anti-traction system with the main braking mode.

In addition to the abovementioned trends it shall be noted the necessity of research directed at the usage of such drives in road-trains of the schemes "hauler-semitrailer" and "hauler-trailer". It is conditioned that in the case of the trailer the power take-off can be performed from the wheels and there is the possibility of the braking control of the trailer wheels.

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