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DRIVE AND CONTROL SYSTEM OF ENERGY RECUPERATION

1. Introduction

The progress in the field of variable-speed drives is going on, and two trends can be observed:

- the first one consists in improving the properties of existing transmissions by introducing new constructional solutions, using materials of higher strength, and improving the quality of conformance.
- the other aims at attenuating the drawbacks of existing variable-speed transmissions by connecting them to toothed constant ratio gears or with multi-speed ones. The former are to ensure better operating conditions of a variable-speed transmission, which leads to an increase in their efficiency. The latter are to increase the range - insufficient for a given use - of the dynamic ratio of a variable-speed transmission itself. There are two methods of connecting transmissions to form complex drive systems: series and parallel.

In a series connection the same power flows through all the elements of the system, while the efficiency and the range of ratios of the whole drive system is equal to the product of the efficiency or the range, respectively, of particular elements. In this connection it is possible to increase the range by means of adding a reducer, whereas an increase in the efficiency can be obtained in the same way only in the case of shifting the operating parameters of a variable-speed transmission to a more favourable area.

In the parallel connection, where the power transmitted branches off, a variable-speed transmission transmits part of the power and has a different range of ratio than the whole drive system. Besides, the transmission transmits smaller power but has smaller dimensions and weight. Consequently, the drive system obtained can have better properties in every respect than the variable-speed transmission constituting its element, if it were to transmit the whole power. In many cases it is the only acceptable solution, e.g. for a city bus. In addition, parallel systems allow a variable-speed transmission to be combined into systems of a variable structure, which will yield properties satisfying the requirements resulting from their use in vehicles.

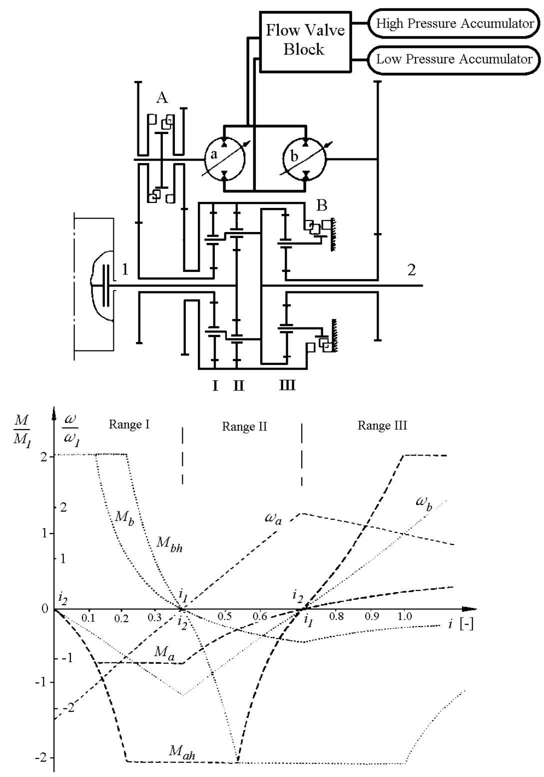

Fig. 1. A schematic diagram of the power transmission system and curre's course of the basic parameters of the hydrostatic transmission

The work on the construction of the hybrid drive in a city bus has led to the solution shown in Fig. 1. The main units are: hydropneumatic energy accumulators and a three-range variable-speed transmission with a parallel power flow. The latter consists of: a planetary transmission with three simple series I, II, III, two clutches A and B which change over the ranges of ratio, a hydrostatic transmission with two machines a and b, and several toothed gears of constant axes. A change in the ratio in the hydromechanical variable-speed transmission is brought about by a change in the ratio in the hydrostatic transmission. The following configurations are possible: in range I - the connection of the hydrostatic transmission to the remaining part of the parallel system by means of a constant transmission at the output, and in ranges II and III - with the internal connection [1,2]. The method of connection of the hydrostatic branch to the mechanical one affects curves of the basic parameters, Fig.1, and the algorithm of operation of the control system.

The construction of the variable-speed transmission gear-box and the type of the energy accumulator have an effect on the realisation of the control of the transmission through the control of the hydrostatic transmission. The introduction of a variable-speed transmission will reduce fuel consumption by approx. 12÷16%, and supplementing the transmission with a set of energy accumulators will result in a further decrease by 14÷18%. In view of the functioning of a hybrid drive, an essential problem is the manner of cooperation of energy sources: the primary - from the combustion engine, and the secondary - from the energy accumulator. The conception of such cooperation, verified experimentally, allowing the realisation of any cycle of driving in the city bus has been presented. In principle, the combustion engine performs the function of the unit equalising the energy balance.

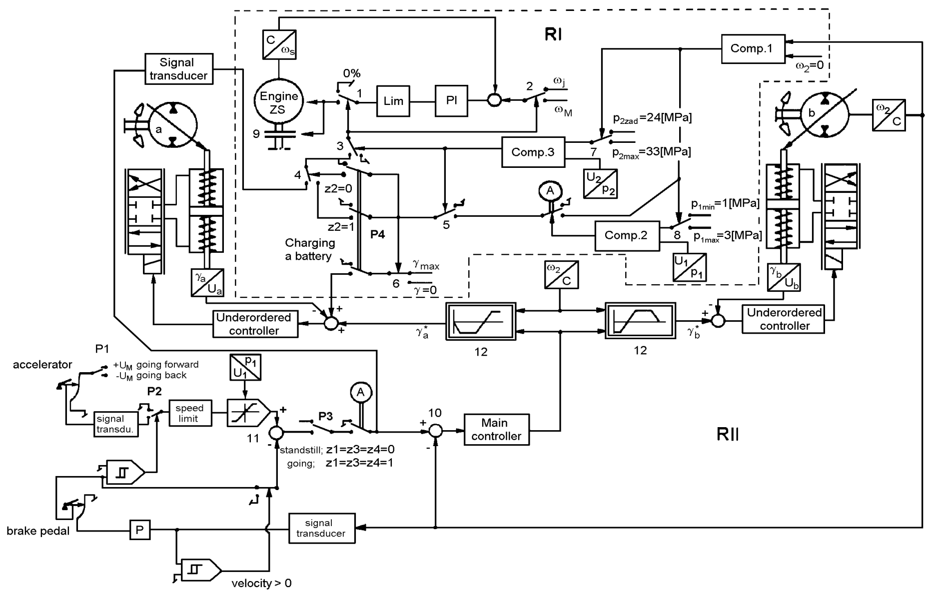

Fig. 2. A schematic diagram of the controll system for the prototype variable-speed transmission and hydropneumatic energy accumulators

The microprocessor control system, Fig.2, for the following operating conditions to be obtained:

I. Standstill

1. The control system switched off. No tasks are performed in the system. The bus is parked in a bus depot or at a terminus.

2. The control system switched on. Direct current is supplied to the functional switches and governors. The valves controlling the oil flow are closed; z1=z2=z3=z4=0.
3. Charging the accumulators while parking. The charging pump connected to the combustion engine by means of a constant-ratio transmission, always pumps the oil to the low-pressure accumulators through non-return valve (z1), when the engine is running. In the comparator, comp (1) the selection of the maximum pressure values in the accumulators is made. During the vehicle standstill (ω_2=0) these values are p_l=3 MPa and p_2=33 MPa; while driving: p_l=1 MPa and p_2=24 MPa, respectively. Until the pressure in the low-pressure accumulator reaches a value of 3 MPa, the comparator, comp (2) will not switch on switch A, thereby the control system is disconnected. The charging of the high-pressure accumulator can take place when switch P4 is in the position z2=1. Then, a signal from the comparator, comp (1), through the switches: A, 5, P4, 4 and 3 engages clutch (9) and sets the angular velocity ω_s=ω_M in the combustion engine governor and switches on switch (6), while the deflection angle of the disk γ_{max}=18^o is given to the secondary governor of hydrostatic machine 'a'. When the value of p_{2max}=33 MPa is reached in the high-pressure accumulator, the comparator, comp (3), disconnects the system. In the combustion engine governor the signal controlling switch (1) is turned off, and the angular velocity ω_s=ω_j is set, whereas the value of γ=0 is conveyed through switch (6) to the deflection circuit of the disk.
4. During a standstill, when switch (P4) of governor RI is switched over from the 'accumulator charging' position, the system charges only the low-pressure accumulators. When the value of 3 MPa is reached, switch A is turned on and a signal from the comparator, comp (1) is sent to switch (P4), and a signal from the set signal processing system in governor RII can be given to adder (10).

II. Driving

1. The vehicle is powered by a combustion engine only ('conventional drive'). Switch (P3) is in the z1=z3=z4=1position, while switch (P4) in z2=0. When valve (z1) is turned-on, it is possible to make up leakage in the hydrostatic circuit by means of the low-pressure accumulators and the charging pump, to the value p_{1min}=1 MPa. A signal of the set speed of the vehicle is worked out in the unit of control of signals, where a signal from the accelerator is sent to the matching element in which it is changed into a standard internal signal of the governor. The value of this signal depends on the degree of the accelerator pedal and switch (P1) position. It can assume positive values with

the ‘driving forwards’ position or negative values with the ‘driving backwards’ position. The signal of the set speed is then sent through switch (P2) to the acceleration speed limiting block. The position of (P2) depends on the value of the signal from the system: the sensor of the speed ω_2, the matching element, the reversing amplifier, the brake pedal potentiometer. The signal thus shaped is sent to adder (11), in which it is added to the signal from the brake pedal potentiometer. One of these signals is always equal to zero. The first of these governors, on the basis of the set and actual speed, works out the signal of the set position of the servovalves that deflect the disk in hydrostatic machine ‘a’ or ‘b’, whereas the second one works out the signal controlling the servovalve. The signal of the set speed, through the matching system and switch (4), is also conveyed to the combustion engine governor, in which the angular velocity $\omega_s=\omega_M$ is set. In this way, it is possible to transfer the energy from the ZS engine, through the hydrostatic transmission a, b, to the vehicle wheels without the participation of the energy accumulated in the high-pressure accumulator.

2. Hybrid drive. The connections in the control systems are the same as described above, and switch (P4) is turned on. The phases of operations proceed here as in sections I.3 and II.1; if the pressure in the high-pressure accumulator is $p_2>24$ MPa, only secondary, accumulated energy will be used for the motion of the vehicle. Below the set value of the pressure, the comparator, comp (3) will turn on switches (3) and (5) and send the signal to the engine governor, thereby allowing the interaction of two sources of energy: primary - the combustion engine, and secondary - the high-pressure accumulator. While braking there will be a reverse flow of energy - from the vehicle wheels, through hydrostatic machine ‘b’, which then starts functioning as a pump, to the high-pressure accumulator; the energy will accumulate in the accumulator as a result of the operation of governor RII.

References

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