APPLICATION AND DESIGN OF HYDRO TRANSMISSION FOR TRACTORS

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1. INTRODUCTION

The production of tractors/ in the world began around 1858, and since then the evolution of the tractor significantly progressed. In Serbia, the first tractor was produced in 1949, which means 100 year after the first production of tractors in the world [1]. The development of transmissions for agricultural tractors has caused manual gearbox to change to hydrostatic, continuous, and eventually the electrical transmission. All these solutions have the aim to improve traction - dynamic characteristics optimize the agro-technical conditions and increase the degree of rationalization of production. In this way we are trying to find the most optimal solution, i.e. approach ideal pulling hyperbola.

In today's development trend of tractor transmissions there is an increasing application of so-called continuously variable transmissions which provides continuous power transfer depending on the operating conditions [2].

Tractors were initially made with small power motors and a small number of gears, but with the development of agriculture and the development of large farms, there was a need for larger and more powerful machines that are in possession of a larger number of gears and transmissions with more engine power. By observing the stage of development of tractor transmissions it can be seen that the mid-eighties of the twentieth century tractors had maximum speed beyond the standard 30 km/h, while the speed of tractors in nineties was around 40 km/h, which has become later a standard for higher power tractors. At the beginning of 21st century tractors with a maximum speed of 50 km/h appeared which set the new standards. Today, some manufacturers even offer special models of tractors with a maximum speed of over 60 km/h. Increasing the overall speed range, as well as number of requests for higher speed in the main operating range (4-12 km/h) and crawling speed (below 1 km/h), has led to a drastic increase in the number of gears from 4-5 in the sixties, to over 40 gears at the end of the twentieth century. In addition to the increased number of gears, the transmission had to become fully synchronized like the ability to change gears at full load. The purpose of a tractor defines his traction characteristics. The basic requirement is that in the exploitation range there is a number of gears that will provide different traction forces at different speeds, and that these speeds are in the context of technological speed for certain operations. In fact, sliding coefficient and the efficiency of the tractor must be within the limits laid down for the particular type of tractor.

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2. HYDROSTATIC TRANSMISSION

Hydrostatic transmissions have been around for a long time. A hydrostatic transmission consists of a pump hydraulically coupled to a hydraulic motor. It uses oil (hydraulic fluid medium) to transmit power from the power source to the driven mechanism. If the displacement of regulation pump and regulation engine is constant, hydrostatic transmission simply acts as a transmission that transmits power from the primary actuator to load. The main advantage of hydrostatic power transmission is the use of a variable displacement pump, regulating motors or both devices together, so that the speed, torque or power can be regulated.

Hydrostatic transmissions offer a number of advantages over other types of power transmission. Depending on their construction, hydrostatic transmissions:

- can transmit high power,
- exposed to low inertia,
- work effectively in a wide range of relations torque - speed,
- maintain a controlled speed regardless of the load within the structural limits,
- maintain the current speed exact opposite driving or braking loads,
- capable of transmitting one of the primary drivers of up to several locations, even if the position and orientation of the location change,
- can remain fixed and undamaged under full load at low power losses,
- do not slide at speed 0,
- provide a faster response in relation to the mechanical and electro-mechanical transmission,
- can provide dynamic braking.

Disadvantages of the hydrostatic system are the compressibility of fluids and fluid's viscosity that changes with temperature and pressure.

Figure 1 Hydrostatic transmission [3]

Wheel drive vehicles with hydrostatic transmission design can be performed in several ways. The first way, and also the simplest, is through construction pumps and motors in the same housing (Figure 2a) where the drive torque is applied to the wheels through a differential with an additional reduction in the wheels. Another way is with pump that drives two hydraulic motors attached to the gear wheels (powered two-wheel vehicles) (Figure 2b), and the third way is the one that is used to drive the vehicle on all four wheels being driven where pump supplies hydraulic motors with energy (the pump is built into the wheels of the vehicle with planetary gear unit) (Figure 2c) [4].

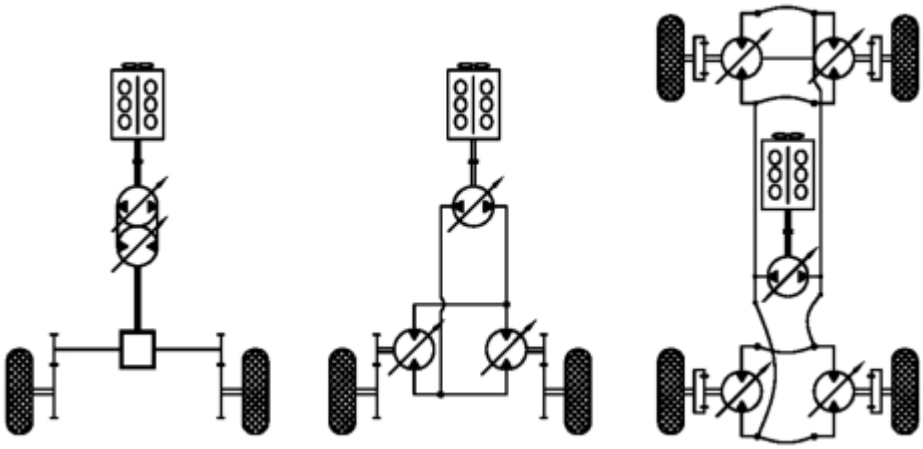


Figure 2 Variants of the vehicle wheel drive with a hydrostatic transmission: a) construction of pumps and motors in the same housing, b) two wheel drive, c) four wheel drive [4]

The tractor mainly uses pumps and motors axial piston-type with tilting plate. Further development of continuously variable transmissions can be achieved with the use of friction and electrical continuously power transmissions, but also of a hybrid drive, with diesel engine and an electric motor powered by electric batteries and a generator.

In the last years, modern efficient tractors have been distinguished by continuous variable transmissions (CVT) which enabled infinite number of tractor speeds. A split power (hybrid transmission or CVT) improves the efficiency of a hydrostatic transmission while retaining the advantage of continuous variability. In the hybrid transmission presented by Figure 3, power is partially transmitted mechanically and partially - hydrostatically. For example, the Fendt Vario transmission is a hydrostatic-mechanical power split drive. With the speed increase, the share of the mechanical power transmitted through the planetary set increases. The hydrostatic motor, which can be swung 45 degrees, and a high operating pressure of max. 550 bars ensure exceptional efficiency.

Varying the displacement of the pump provides a continuously variable speed ratio. At the startup and with low output speeds, most of the power is transmitted via the hydrostatic drive. As the output speed continues to increase, an increasingly large percentage of the power is transmitted mechanically and a smaller percentage is transmitted hydrostatically. Thus, as power demand rises, an increasing portion of the power is transmitted via the more efficient mechanical drive. The range transmission permits efficient operation at low field speeds and also at high transport speeds. The low range of this transmission provides speeds of 0.03 to 21 km/h, while the high range provides speeds of 0.03 to 50 km/h and reverse speeds of 0.03 to 38 km/h [6].

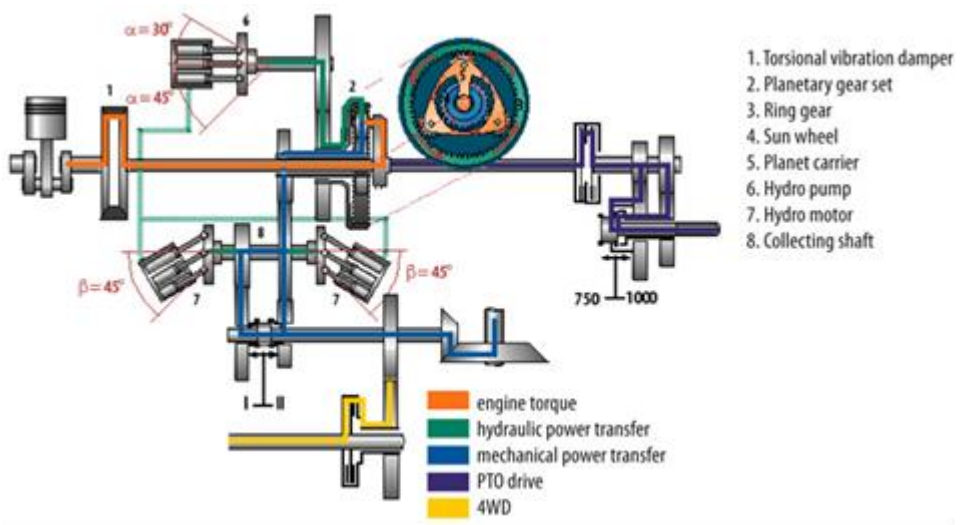


Figure 3 The Fendt Vario transmission [5]

In addition to previously mentioned Fendt Vario transmission, today there are two construction solutions for standard agricultural tractors on the market. These are „S- Matic“ CVT/CVX gear from factory „Steyr“ and „Eccom“ producer „ZF“. These transmissions are currently installed in tractors „Case –IH“ and „Case- Steyr“, and the tractor „John Deere“ and „Deutz – Fahr“.

2.1 Calculation of hydrostatic transmission

The calculation was done for the hydrostatic transmission which is applied to wheeled tractors Fendt 313 Vario.

The initial data were:

- the total mass of the tractor: $m_0 = 10000\ kg$
- load weight: $m_t = 3500\ kg$
- dynamic weel radius: $r_d = 0{,}685\ m$
- engine power: $N = 90\ kW$
- pump speed: $n_p = 4500\ \min^{-1}$
- maximum operating speed: $v_{R\max} = 11\,km/h$
- maximum transport speed: $v_{T\max} = 45\,km/h$
- the adhesion coefficient: $\phi = 0{,}8$
- the resistance coefficient: $f = 0{,}03$
- ratio: $i_G = 18{,}79$

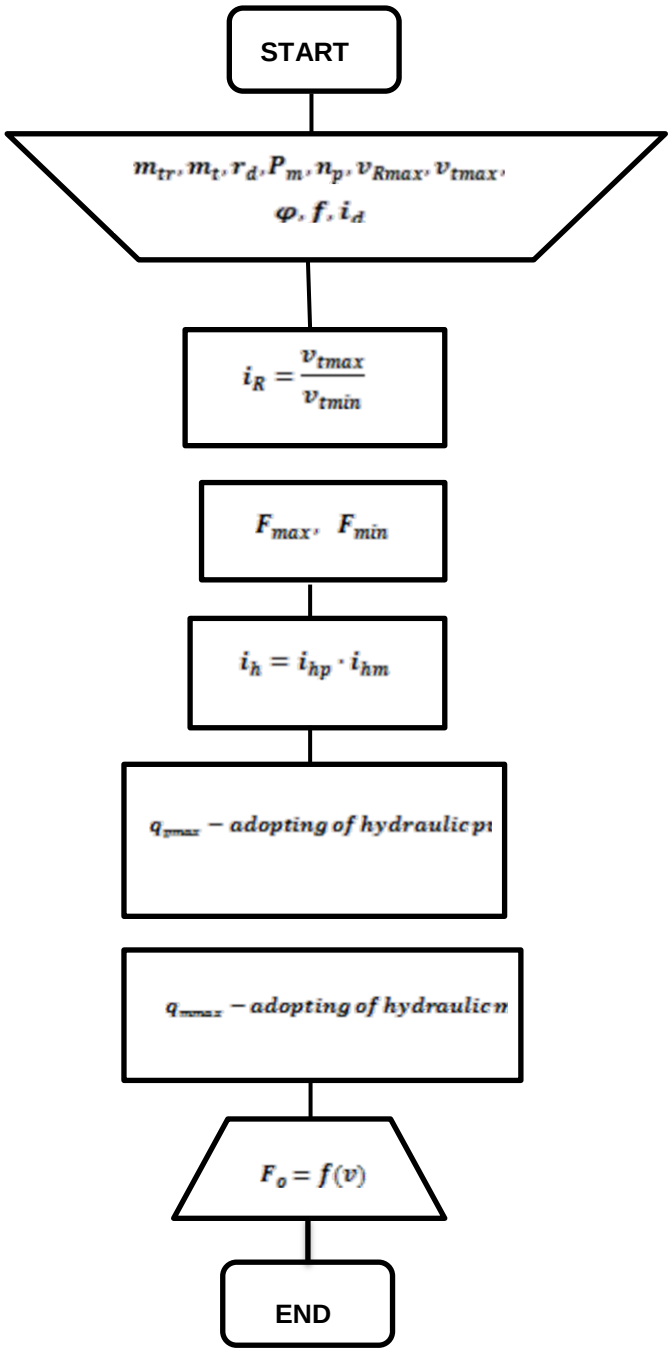


Figure 4 Algorithm for calculation of hydrostatic transmission

The figure 4 shows an algorithm for calculation of hydrostatic transmission. The calculation consists of determining the traction (Figure 5), according to the maximum specific flow rate of the hydraulic pump and hydraulic motor.

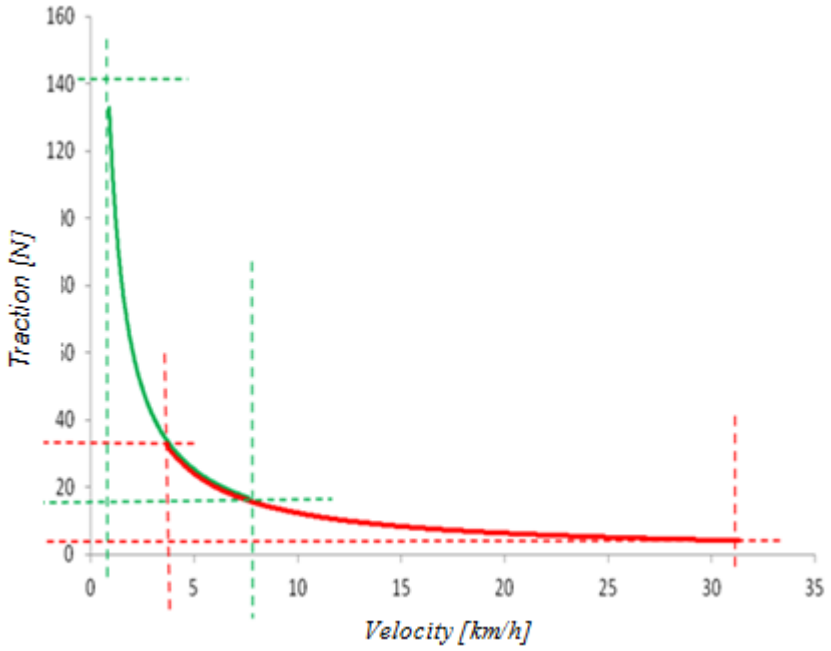


Figure 5 Chart of depending on the velocity-traction

3. HYDRODYNAMIC TRANSMISSION

Hydrodynamic power transmission for tractors occurs only in combination with mechanical or hydrostatic components. The basis of hydrodynamic transmission consists of a hydrodynamic coupling (Figure 6) or hydrodynamic torque converter.

Although it was shown that tractors with a hydrodynamic coupling have higher productivity of 12 to 20% comparing to the tractor without it, while the hydrodynamic torque converter on tractors have no greater application due to high prices, the complexity of the structure and relatively poor output parameters. Most frequently use can be found on the US market, comparing to Europe where it can be rarely found.

Due to fundamental differences in principle of action and properties, hydrostatic and hydrodynamic transmissions are separately examined. However, it is possible to make some basic comparisons:

a) The fact that the hydrostatic power transmission is based on pressure fluids, causes complete tightness of these transmission, which requires a good sealing and high quality processing. Bearing in mind that the transfer of high power hydrostatic gear can only be done effectively at high pressure (250-300 bar), the problem of sealing the required quality of processing represents major drawback of hydrostatic transmission. In the hydrodynamic transmission, quality of processing is not the most important condition of quality power transmission, and considering the pressures in these transmission is low, sealing is easily solved. The power that can be transmitted by hydrodynamic transmission is practically only limited by durability of materials (considering the present centrifugal forces acting on the rotating parts of these transmission).

b) Comparison based on dimensions give favors to hydrostatic transmission, particularly in the transfer of small forces.

c) As regards the level of efficiency, its change is favorable with the hydrostatic transmission, or on the side of the hydrodynamic transmission, the advantage is that the moment and the speed automatically adjust operating conditions (load output shaft). When hydrostatic transmission regulation is made outside impulses.

d) Elements of hydrodynamic transmission does not require special maintenance, whereas for hydrostatic it is essential [7].

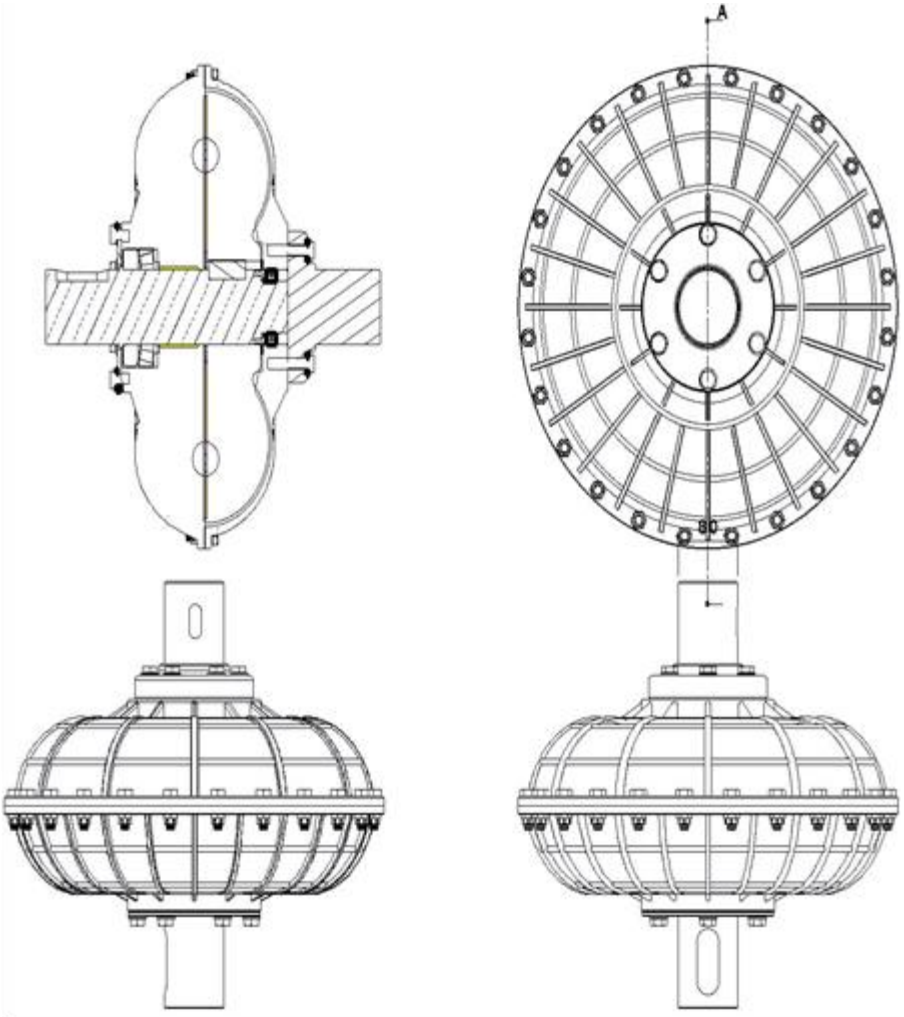
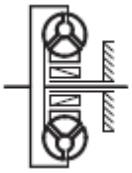
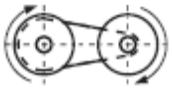
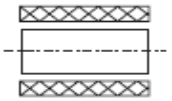


Figure 6 Hydrodynamic coupling

In table 1 shows the basic differences, advantages and disadvantages of transmissions used in tractors.

Table 1 Important physical principles of continuously variable transmissions for vehicle drives [8]

Type of CVT		Principle of energy Transmi-ssion	Ratio control	Application	Efficiency
1.	Hydrodynamic 	Mass forces at pump and turbine	Usually automatically by load	Important for pass. cars and construction machinery	poor
2.	Mechanical 	Traction forces within friction contacts	Radius of traction force	Important for passenger cars	excellent
3.	Hydrostatic 	Hydrostatic forces at pumps and motors	Displacement of the units	Important for mobile machinery	moderate
4.	Electrical 	Electro-magnetic forces at generators and motors	Frequency of current or electric flux or load	Upcoming	moderate

3.1 Calculation of hydrodynamic transmission

Calculation of hydrodynamic transmissions is done by tractor John Deere 7310R [9]. The input data are:

- Power: P_p= 250,8 kW
- Speed drive: n= 1900 min^{-1}
- Impeller speed: n_p=1900 min^{-1}
- Hydraulic oil: 850 kg/m^3, at t=20 ℃, working temperature t =55 ℃

The figure 7 shows an algorithm for calculation of hydrodynamic transmission, and in the figure 8 3D model of this transmission is shown.

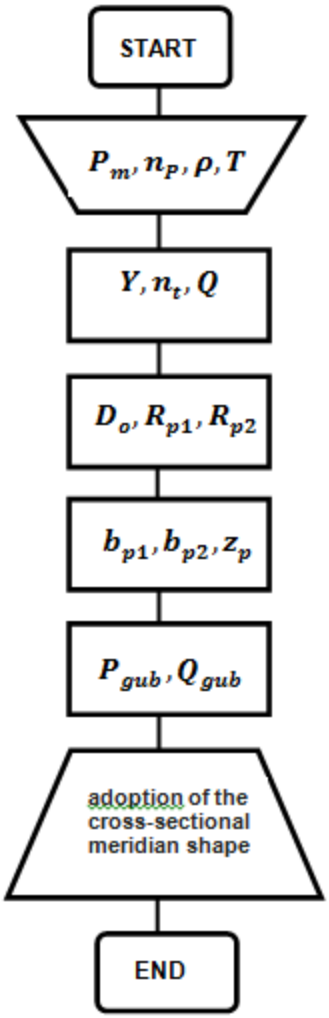


Figure 7 Algorithm for calculation of hydrodynamic transmission

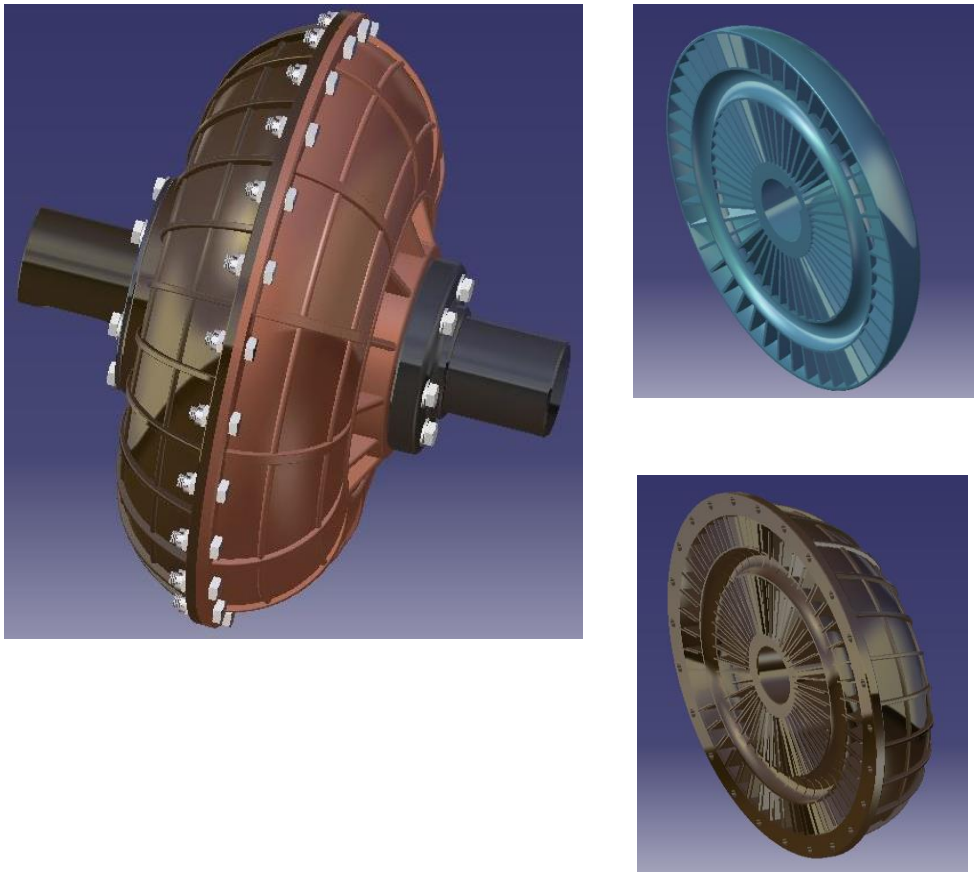


Figure 8 3D model of hydrodynamic coupling

4. CONCLUSION

In many countries, about 40 to 50 % of the total investment in agricultural mechanization is invested in tractors. Constructional features of tractors used in high-income countries in the last 30 years have changed significantly. Western European and North American farmers require modern, so-called , "high - tech" tractors, equipped with the latest technical advances that enable high productivity and efficiency. More and more attention is paid to the ergonomics of the tractor, and the tractor impact on the environment.

The use of hydrostatic and hydrodynamic transmissions will always find application in the transfer of rotary motion which requires safe, accurate and reliable operation of the power transmission system. Construction, energy, agriculture, transport and other branches already know how to use the benefits of such widely used power transmission. Daily improvement and increasing the overall efficiency level, as well as combining with other power transmission, open up a wide field of application of such power transmission systems with emphasis on application of composite materials with high resistance, and also it reduction the weight of these transmission.

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