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PROCEEDINGS

The Third International Symposium on Agricultural Engineering

ISAE-2017

October, 20-21, 2017.
Belgrade - Serbia

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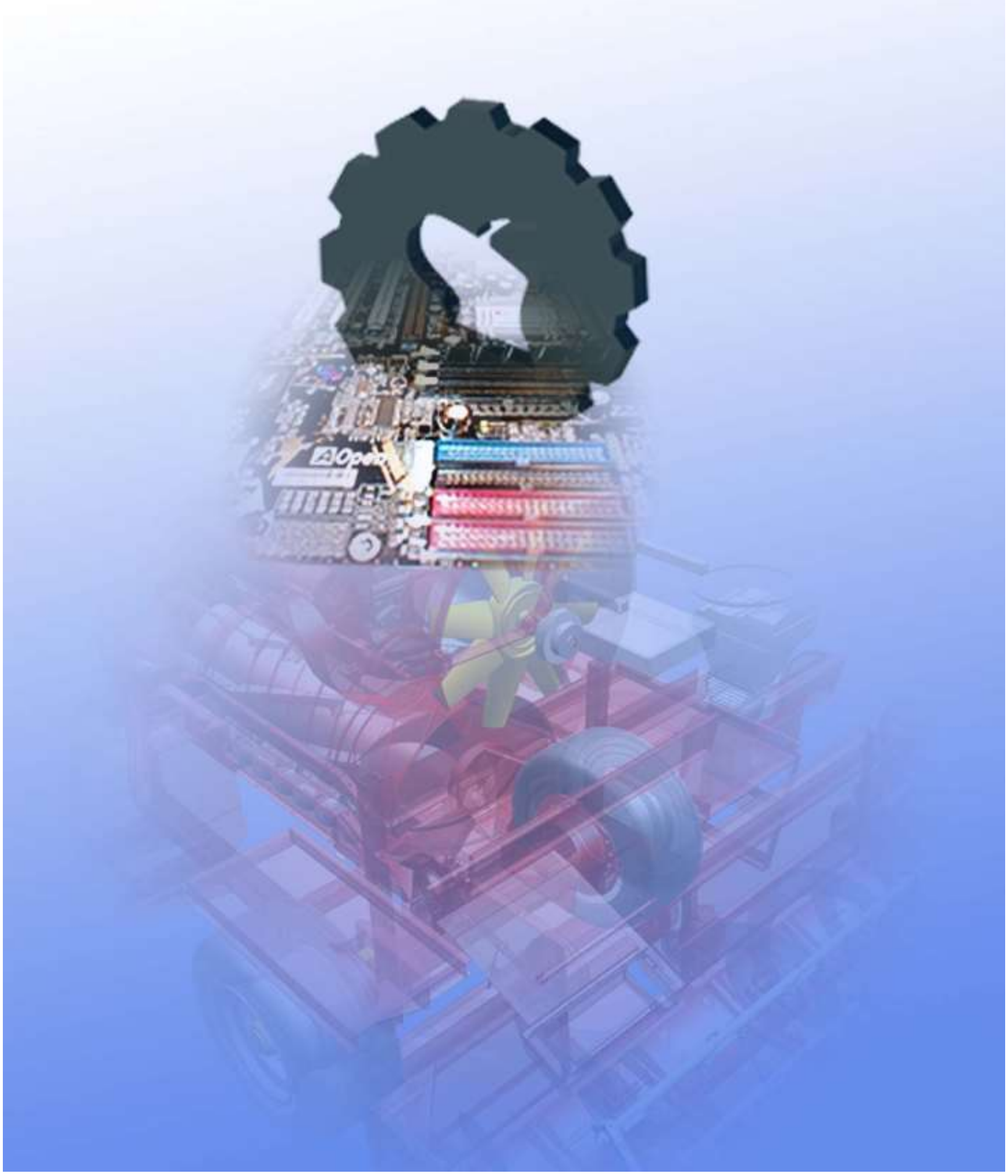

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ISAE-2017

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PREFACE

After the successful First and Second International Symposium on Agricultural Engineering ISAE 2013 and ISAE 2015, that were held in Belgrade at the Faculty of Agriculture, thanks to our colleagues we are organizing The Third International Symposium on Agricultural Engineering – ISAE 2017. Together with the University of Basilicata, School for Agricultural, Forestry, Food and Environmental, Sciences (Potenza, Italy), University of Sarajevo, Faculty of Agricultural and Food Sciences (Sarajevo, Bosnia and Herzegovina), Aristotle University of Thessaloniki Faculty of Agriculture, Thessaloniki (Greece), University of Belgrade, Faculty of Mechanical Engineering, Belgrade (Serbia), Vinča Institute for Nuclear Science, Belgrade, Serbia and thanks to the Ministry of Education, Science and Technological Development, Republic of Serbia, support of the EurAgEng and the AMAPSEEC, and sponsor and donors, we have managed to organize the presentations of the 34 papers that were submitted to the Scientific Committee of the ISAE 2017 Symposium. We have arranged them in to eight sections and categorized them as Original scientific papers, Scientific review papers, Firs (short) communications, Case studies, Professional (Expert paper) and Popular papers. All papers within the Proceedings of the ISAE 2017 were reviewed by the members of the Scientific Committee and kind assistance of some members of other Conference bodies.

Book of Proceedings of the ISAE 2017 International Symposium has 324 pages and it is organized in eight thematic sections. Section I – Crop, Fruit and Vegetable Production Systems (13 papers); Section II – Livestock Farming Systems and Equipment (1 paper); Section III – Power and Machinery; Diagnostics and Maintenance of the Agricultural Machinery (4 papers); Section IV – Post Harvest Technology, Processing and Logistics; measuring, Sensing and Data Acquisition in Agriculture (6 papers); Section V – Information Systems and Precision Farming; Modelling, Predicting and Optimal Control in Agricultural Engineering (2 papers); Section VI – Soil and Water Use and Environment (1 paper); Section VII – Energy, biomass and bio recourses in Agriculture (2 papers); Section VIII – Agricultural Policies, Sustainable Agriculture, ergonomics and Safety in Agricultural Machinery Exploitation (5 papers).

We wish to thank to all the authors for their contribution to the ISAE 2017 Symposium and to the all the Institutions, Associations, Universities, Sponsors and Donors for the contribution in ISAE 2017 Symposium organization.

ISAE-2017 Proceedings

CONTENTS

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DESIGN OF HYDROSTATIC TRANSMISSION OF AGRICULTURE MACHINES

Dimitrov S. Sasko, Dimitrovski Zoran, Milev Sasko

Goce Delcev University, Stip, Faculty of Mechanical ingineering
Republic of Macedonia

E-mail: sasko.dimitrov@ugd.edu.mk

Abstract. *This paper focuses on the use of hydrostatic transmissions for an agriculture machine. A hydrostatic transmission modifies and transmits power from the engine to the final drive, or directly to the wheels or tracks. An entire text could be devoted to the analysis required to properly match prime mover and load characteristics to achieve optimal productivity and efficiency. The objective in this paper is to understand the characteristics of a hydrostatic transmission so that it can be compared with mechanical transmissions.*

Key words: *servo pump, hydromotor, hydrostatic transmission.*

1. INTRODUCTION

The hydrostatic transmission is used in heavy vehicles such as earth moving machines, agriculture machines, forest machines, industrial and mining lifters. Nowadays, the demand of that kind of transmissions is increasing because of hydraulic drives have many advantages over other technologies. That is because of hydrostatic transmission has a high output capacity combined with high overall efficiency over a wide velocity range, and all that, with a low weight and volume.

Hydrostatic transmission is the conversion of mechanical energy to hydraulic energy using pump driven by a prime mover, supplies pressurized fluid to a utilization point, and its conversion back to mechanical energy to drive a hydraulic motor (fig.1) which in turn, drives a load connected to its shaft. Two parameters, torque (T) and speed (n), are converted to two different parameters, pressure (P) and flow (Q), using a pump. The two new parameters, P and Q are converted back to torque (T) and speed (n) using a hydraulic motor. The principal reason for converting to fluid power is the convenience in transferring energy to a new location. The pressurized fluid, defined by the P and Q parameters, easily flows around corners and along irregular pathways before reaching the point where it is reconverted to T and n. The product of T and n is called mechanical energy and the product of P and Q is called hydraulic energy. The HST system can provide smooth change of output speed, output torque and hence output power according to the design requirements. If the displacement of the pump and the motor are fixed, the HST system simply acts as a gearbox to transmit power from the prime mover to the load. The majority of HST systems, however, use a variable-displacement pump and a fixed displacement motor or both pump and motor may be of variable displacement type so that, speed, torque or power can be suitably regulated [1], [2], [3].

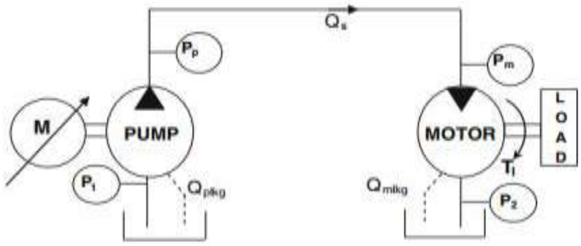

Fig. 1 Schematic diagram of the hydrostatic transmission

A general view of the system that is going to be designed can be observed in the fig.2 with a diesel engine which sends the power to the hydrostatic transmission. This hydrostatic transmission is made up of one variable pump and one variable motor. It sends a different shaft speed and torque depending on the displacement settings of both hydrostatic units to the machinery wheels but to have different possibilities it has a gearbox with at least two gear relations [4].

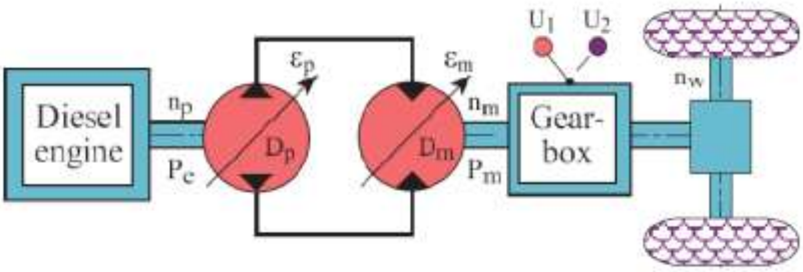

Fig. 2 The hydrostatic transmission of an agriculture machine

2. Comparison of Hydrostatic and Mechanical Drives

A vehicle with rear-wheel drive with mechanical transmission has the components shown in fig.3. The power from the engine through the clutch is transmitted to the mechanical transmission. In the mechanical transmission the revolution per minute is decreased and the torque is increased. Then, through the universal joint and differential the torque is transferred to the wheels. The mechanical transmission can be thought of as a black box with gears inside. The engine can deliver torque over a given range. A gear mesh is selected to match required output torque to available input torque. The clutch disconnects output shaft from driveline so that the gears in the transmission can be shifted to a new mesh. With a manual clutch, the operator manually engages the clutch and manually shifts the transmission to a new gear mesh [5], [6].

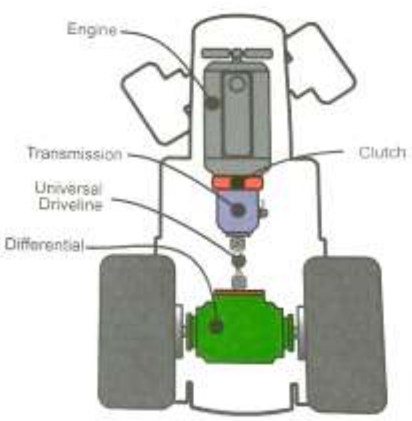

Fig. 3 Diagram of the rear-wheel drive vehicle with mechanical transmission

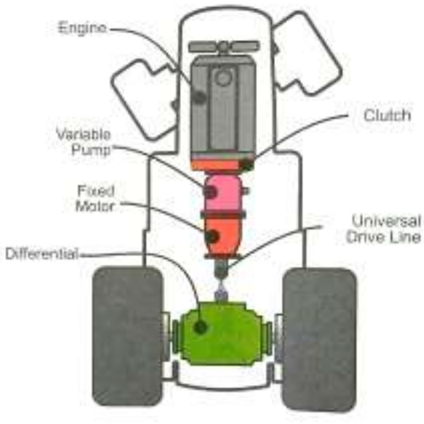

Fig. 4 Diagram of the rear-wheel drive vehicle with hydrostatic transmission

The same vehicle shown in Fig. 3 is shown in Fig. 4 with the mechanical transmission replaced with a hydrostatic transmission; all other components remain the same [5], [6].

To provide a specific example, we will begin by specifying a variable displacement axial piston pump and a fixed displacement axial piston motor, fig.5. Pump output is increased by stroking the pump, thereby increasing the speed of the motor. The vehicle can be speeded up and slowed down by moving the hand control that strokes the pump.

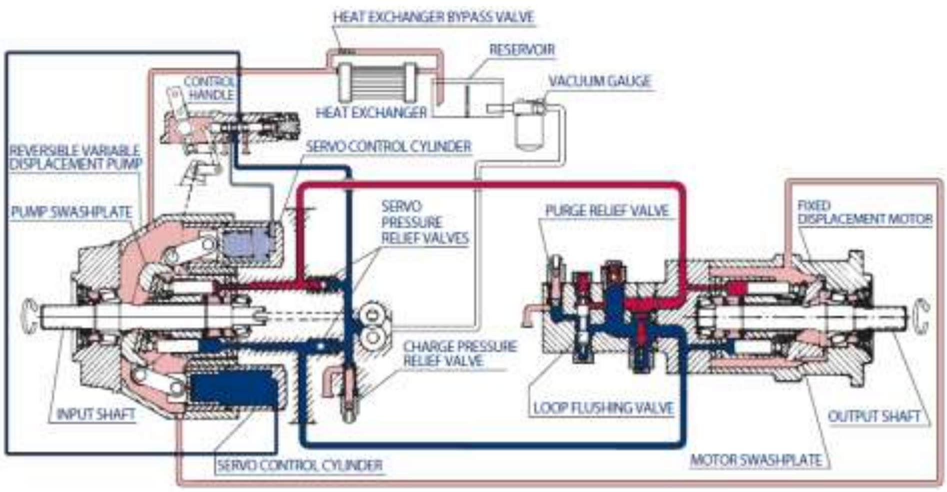

Fig. 5 The principle of operation of hydrostatic transmission systems

The rotation of the motor shaft can be reversed by moving the swashplate control through the neutral position and displacing it in the opposite direction. The reverse position of the swashplate causes fluid to flow in the opposite direction, which causes the motor to turn in the opposite direction, thus reversing the vehicle. Vehicle motion can be changed from forward to reverse with a simple hand movement. This maneuverability is often the justification for installing a hydrostatic drive on a vehicle. It is tiring and time-consuming when an operator has to shift a mechanical transmission each time the direction of motion is changed. Vehicle productivity is increased with a hydrostatic transmission. A hydrostatic transmission, like an automatic shift transmission, connects the engine and load with a fluid connection. The key disadvantage, as with all fluid devices, is some decrease in efficiency [7].

This type of hydrostatic transmission is called closed-circuit hydrostatic transmission. It consists of a reversible variable displacement servo pump, fixed displacement hydro motor and additional accessories like filter, heat exchanger and reservoir.

In the hydrostatic circuit there is a charge pump. A charge pump (generally a small, fixed displacement pump) is built into the housing with the main pump and operates off the same input shaft as the main pump. The purpose of the charge pump is:

- It replaces the fluid that leaks past the pistons into the pump housing. The same leakage flow occurs in the motor. This flow is essential, because it provides lubrication and seals clearances.
- It provides a flow of cooling fluid through the pump and motor housings. When the high-pressure fluid in the main circuit leaks into the housing, mechanical energy is converted into heat energy. In addition, heat results from friction between the moving parts. A flow of cooling fluid is required to remove this heat.

3. SERVO-CONTROLLED PUMP

The variable displacement servo pump is of axial piston design. When the control piston extends, it moves the swashplate to increase the amount of fluid pumped by the pistons. (Displacement of the pump is increased.) Flow of fluid to the control piston, and thus its position, is controlled with a servo valve. A pump with these features is called a servo-controlled pump.

A servo valve operates like a directional control valve. The spool shifts in one direction to direct pressurized fluid to Port A, and in the other direction to direct pressurized fluid to Port B. The spool in a servo valve is precisely machined; consequently, the cost is higher than the cost of a standard directional control valve. It is helpful to first consider a manually controlled servo pump (fig.6.). Suppose the manual control lever is moved to the left (rotated in the counter-clockwise direction). The spool of the servo valve is shifted to the left. High-pressure fluid is directed to the bottom control piston, causing it to extend. The top control piston is connected to the case drain; thus it retracts when the bottom control piston extends. As the two control pistons move, the swashplate is rotated clockwise, thus increasing the amount of fluid pumped. When the swash plate moves, it pushes the yoke feedback link to the right. The link pivots and pushes the spool of the servo valve to the right. This spool movement closes the two ports of the servo valve, thus locking the control piston in a position that corresponds to the new position of the manual control lever. This position of the swash plate is held until the manual control lever is moved to e new position [5].

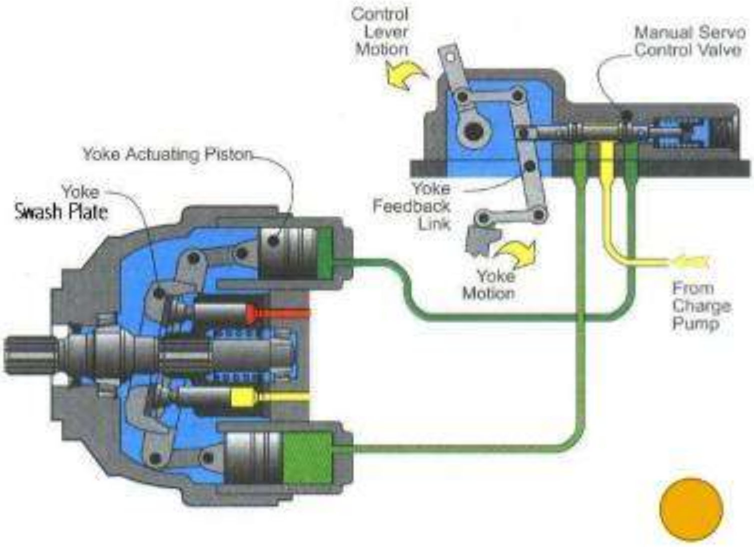

Fig. 6 Manually operated servo pump

The servo pump on fig.7 operates like the one presented on fig.6 except the control lever is shifted hydraulically, using a pilot hydraulic circuit and a remote control valve. The feedback mechanism works in the same way.

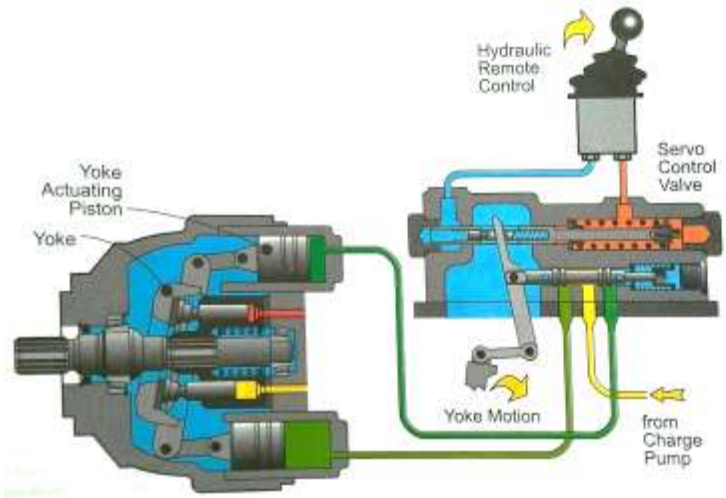

Fig. 7 Hydraulically operated servo pump

The servo pump shown in fig.8 is like that shown in fig.7, except a torque motor is used to position the spool of the servo valve. A torque motor rotates through several degrees of rotation, when a current is passed through the winding. The torque motor shown has a flapper attached to the armature. This flapper is centered in the nozzle such that the pressure drop on both sides is equal. Pressure on both ends of the servo valve spool is equal. This design is called a flapper nozzle servo valve.

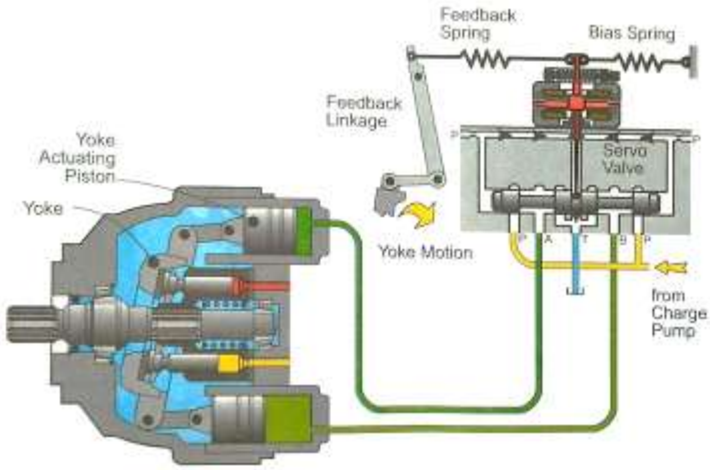

Fig. 8 Servo pump operated with flapper-nozzle torque motor

4. SERVO-VALVE CIRCUIT

The key features of the electrical circuit for a closed-circuit, closed-loop hydrostatic transmission are shown in fig.9.

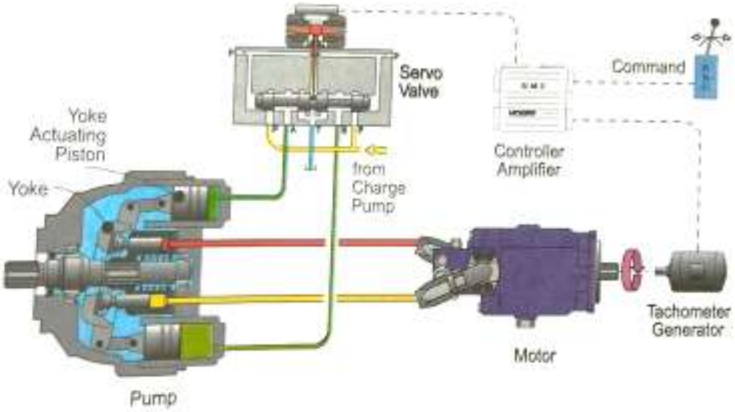

Fig. 9 Servo speed control

The motor output shaft drives a transducer, typically a tachometer generator. Voltage output from the tachometer generator is directly proportional to shaft speed. As shaft speed increases, voltage increases, and vice versa. The controller compares the tachometer generator voltage with the command voltage. The difference between the two is the error voltage. If the tachometer generator voltage is equal to the command voltage, meaning that the motor is turning at the desired speed, then the error voltage is zero.

The error voltage is fed to a servo amplifier. The servo amplifier produces an output current proportional to the input voltage. This current is fed directly to the coil of the torque motor. The armature rotates, initiating the sequence of events described in the previous figure.

5. Advantages of the Hydrostatic Transmissions

A hydrostatic transmission provides improved maneuverability, but at a cost. The efficiency of a hydrostatic transmission is always lower than a discrete-gear transmission. A discrete-gear transmission will typically have an efficiency of 95% or greater, meaning that 95% of the input energy is delivered to the load (wheels). A hydrostatic transmission has an efficiency of around 80%. Some well-designed units will have an efficiency slightly above 85%, but none can approach the efficiency of a discrete-gear transmission. A designer always poses the question: Does the gain in vehicle productivity offset the loss in efficiency and resultant higher fuel cost? In addition to increased maneuverability, a hydrostatic drive vehicle offers several other advantages:

1. It operates over a wide range of torque/speed ratios. Once a gear ratio is selected with a direct-drive transmission, the only speed variation available is that achieved by controlling engine speed. Once the engine speed reaches a maximum, the transmission must be shifted to a lower ratio to increase vehicle speed. With a hydrostatic transmission, vehicle speed is continuously variable from a slow creep up to a maximum.
2. It can transmit high power with low inertia. When a large mass is rotated at a given speed, it takes an interval of time to change this speed. A hydrostatic transmission adds little inertia to the total rotating mass associated with vehicle operation; consequently, a hydrostatic transmission vehicle tends to change speed more quickly (have less inertia) than a direct-drive or automatic shift transmission vehicle.
3. It provides dynamic braking. A hydrostatic drive vehicle can be stopped by destroking the pump. Imagine that you are traveling forward and you suddenly move the swashplate control to the neutral position. What will happen? A pressure spike will develop, and fluid will flow across the relief valve. The vehicle’s mechanical energy will be converted to heat energy, and the vehicle quickly slows (probably sliding the wheels).
4. It remains stalled and undamaged under full load. Vehicle hydrostatic transmissions are almost always designed for wheel slip to occur before a relief valve is actuated. The relief valve’s role is to clip off peaks and attenuate shocks. If the vehicle loses traction and bogs down, the pressure increases until the relief valve opens. Stalling the vehicle in this manner does not damage the transmission. Holding

it in a stalled condition causes the fluid temperature to rise, and this is undesirable. Most HST pumps today are available with a pressure limiter function that provides the "stall and undamaged" feature with little heat generation. The pressure limiter destrokes the pump by shifting the swashplate much like a pressure compensator.

5. There is no interruption of power to wheels during shifting. Anyone who has watched the driver of a direct-drive vehicle with discretegear transmission shift gears while climbing a hill can appreciate the advantage of continuous power flow over a speed range.

6. CONCLUSION

A hydrostatic transmission is simply a pump and motor connected in a circuit. Other components are included in the circuit design to ensure that the functional objective is achieved. The pump and motor can either be included in the same housing or separate components connected with hoses or tubing.

Typically, mechanical transmissions have efficiencies of 95% or greater, whereas hydrostatic transmissions have an efficiency of around 80%. Some well-designed units have an efficiency of 85% over a certain operating range.

Hydrostatic transmissions are used to increase vehicle maneuverability. They also provide continuous speed control from a slow creep up to maximum speed. Before a hydrostatic transmission is chosen over a mechanical transmission, a study is done to ensure that the advantages yield an increase in vehicle productivity to offset the lower efficiency.

A variable displacement axial piston pump can have a control piston mounted in the pump housing. This control piston is used to control the position of the swashplate and thus the displacement of the pump. A servo valve controls the flow, which extends (or retracts) the control piston. The servo valve shifts when current is delivered to a torque motor mounted on the valve. A typical closed-loop transmission operates as it is presented. The voltage signal from the transducer that senses motor speed is fed to a servo amplifier to obtain a current. This current causes the torque motor to rotate, which opens the servo valve and ultimately increases (or decreases) the pump displacement. Using a feedback design of this type, transmission output speed can be held constant as load varies.

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