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Hydrostatic Transmission for Compact Tractors for India market

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Background— Indian ractor industry is world's largest tractor manufacturing hub, close to 1 million tractors are produced on annual basis. This industry is witnessing three major market drivers in agriculture sector:

1) Mechanization of farm equipment

2) Demand on operator comfort

3) Productivity improvement

To address these trends, the tractor industry is poised to transition from mechanical manual transmission to automatic transmission. The usage of compact tractors in European market is on vegetable and fruit plantations; and North America are for landscaping purposes. As the demand for tractors with comfortable and high efficient transmissions—similar to those used in the higher horsepower ranges—was increasing, the transition from mechanical to hydrostatic transmission was started since last two decades in compact tractor segment. Currently, there are multiple options available in global tractor market for automatic transmission. However, they are not very popular in Indian tractor market today due to higher initial price as well as higher cost of ownership.

However, automatic transmissions provide multiple benefits over the traditional mechanical transmissions which we will discuss in next sections. For Indian tractor market, the hydrostatic transmissions are suitable for tractors from 15 hp to 40 hp due to its ease of adaptation. There are mainly 3 key requirements;

1) Dynamic Braking

2) Neutral dead band which are safety critical for customers

3) Volumetric Efficiency to gain more fuel saving for end users.

I. INTRODUCTION

The function of any form of transmission is to match a power source, also called a prime mover, to a driven device. Transmissions typically serve several purposes, but the major purposes are to allow physical separation between the motor and the driven device, to scale the torque, and to scale the speed. Obviously,

the transmission torque and speed cannot be scaled independently. Transmissions may also be characterized in terms of the steps of speed ratio between the motor and the driven device. The speed ratio for drives using gears is usually fixed by geometry and will consist of one or more fixed ratios. In some applications, it is important that the speed ratio can be varied continuously over some desired range during operation. This can be achieved by a step less transmission. In the hydrostatic transmission, the prime mover drives a variable displacement pump. In turn, the high-pressure oil is passed to a motor. Motors with fixed displacement are most common for a hydrostatic transmission. The pump section of a hydrostatic transmission is an axial piston pump with direct manual or servo control for swash plate actuation. Obviously, cost is a factor. Adding a pilot valve adds to cost, but also gives the designer much more flexibility in terms of the link between the operator and the pump. Axial piston pumps are paired with axial piston motor.

Hydrostatic transmissions are very popular in off road and agricultural equipment because they provide a satisfactory combination of compactness, cost, and location flexibility. Like the electric generator/electric motor combination they allow the designer a considerable flexibility in locating the prime mover with the pump coupled to it and the motor.

Figure-1: Typical Compact HST Unit

II. PROBLEM STATEMENT

Today's tractors are with mechanical transmission has more mechanical control, need more force to operate pedals and lever and results into un-comfortable braking. To operate the pedals for accelerations or braking, it takes high force and also not very comfortable for the operators. Pressing clutch and changing the gears also takes lot of manual efforts.

Figure-2: Key Market Drivers

With hydrostatic transmission we can solve above problems and get below benefits: No gear shifting, smooth operation, excellent braking, gender neutral transmission design (less force to operate pedals).

With hydrostatic transmission, operator get the dynamic braking as a best feature but with that the system designer need to focus on few important considerations during the system design and optimize those by working on system level fine tuning.

Dynamic braking & neutral dead band which are safety critical for customers and achieving good Volumetric Efficiency to gain more fuel saving for end users are some of the key considerations.

III. PACKAGED TRANSMISSION CONSTRUCTION

This packaged HST unit is the combination of the close circuit variable axial piston pump and fixed displacement motor connected directly through the passages given in the center section. Both pump and motor are assembled in single housing casing and on common center section. Closed circuit piston pumps convert rotational power into hydraulic power. The input shaft transmits torque and rotational direction to the cylinder block via splines. The shaft is supported by bearings at the front and rear of the pump. Leakage between the shaft and housing is prevented by a shaft lip-seal.

There are typically nine piston-shoe subassemblies that reciprocate inside the spinning cylinder block. Each piston shoe subassembly is connected by a ball joint. The shoes are held down on the swashplate via a retainer plate, ball guide and springs. The reciprocating movement of the piston-shoe subassemblies occurs as the shoes slide against the inclined swashplate during rotation. Pressure in the cylinder block is broken into a high and low-pressure side by the valve plate which ports oil to the center section. The pressure of the oil flowing out of the center section is regulated within a maximum pressure by a high-pressure relief valve. Oil flows into the circuit to replace leakages in the low-pressure side of the center section. These leakages, which provide lubrication and cooling, occur at the valve plate/bearing plate interface, the cylinder block/piston interface and the shoe-swashplate interface. The leakages return to the reservoir via case drain ports in the housing. The volume and direction of the pumped fluid is controlled by the swashplate angle. In direct manual control, the swash plate angle is controlled by an external force on the swash control shaft. The pump displacement command is maintained by a means of the swashplate position

manually. This maintains the stability of the system. Charge pump serves as replenishing source for closed circuit system of pump & motor by supplying oil to low pressure loop of the closed-circuit system. The Pump side kit is connected to motor side kit. The flow from pump side kit is input to the motor which convert hydraulic power into mechanical power output. The output shaft transmits torque and rotational motion to the wheels.

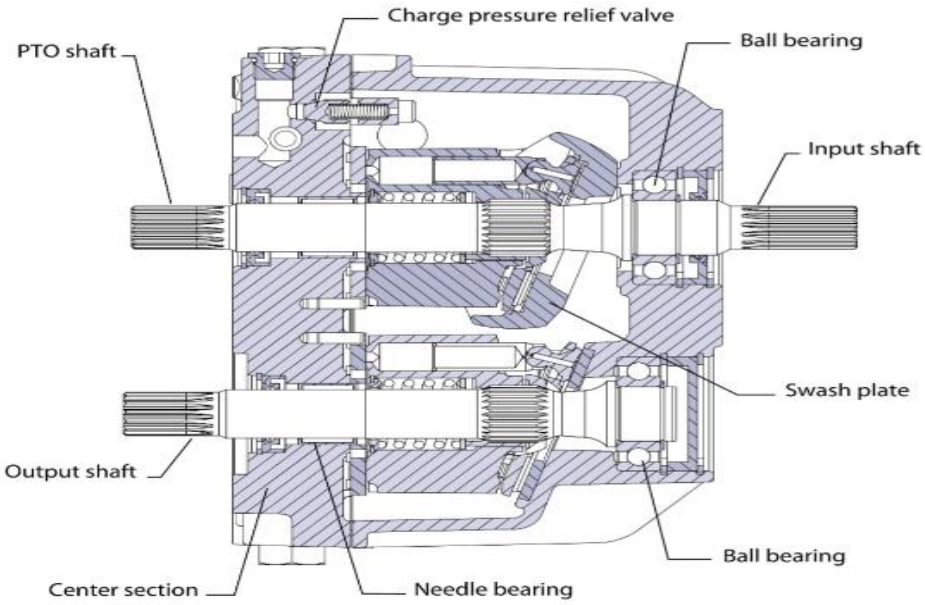

Figure-3: Cross-section of Hydrostatic Transmission

The speed of motor is controlled by varying the flow of the pump. The pump swash is connected to tractor pedal by linkage mechanism. Typically, there are two pedals, separated for forward and reverse operation of the tractor.

IV. METHODOLOGY

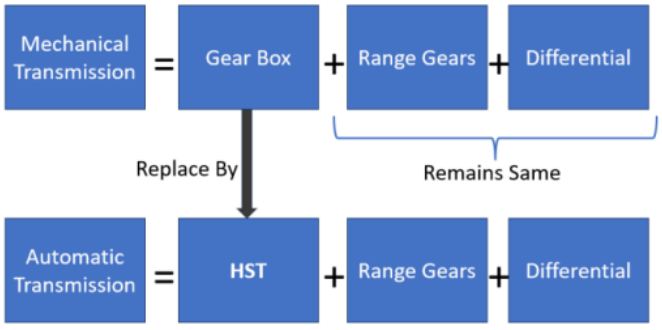

Figure-4: Mechanical Vs HST-System level changes

In a typical tractor transmission system, above are the key building blocks.

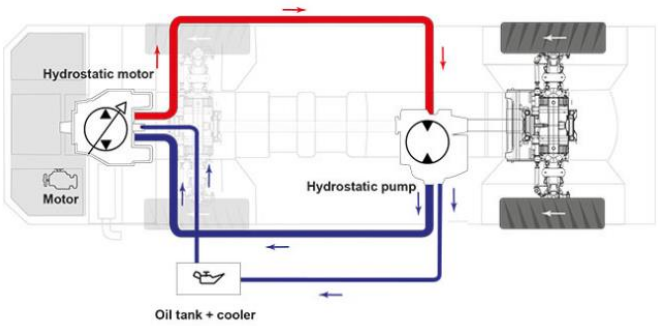

Figure-5 Typical Hydrostatic Transmission layout

In the mechanical transmission, the gear box with gear lever is replaced with Hydrostatic Transmission (HST) unit, which is a packaged transmission and eliminates the use of gear lever. Only the reverse and forward foot pedals are operated for the desired movement of tractor. The light duty hydrostatic transmissions consist of single integrated housing & center section design for both pump and motor rotating kits. The single housing and center section for pump and motor gives significant advantages in compactness and cost of the unit. Analyzing the rotating kit and valve plate geometry, using digital tools becomes critical. Through this analysis, the valve plate cross porting and swash moments are optimized such that the unit requires swash plate moments in pumping as well as motoring mode. These moments are critical for the tractor performance in uphill and downhill conditions. The valve plate geometry affects the volumetric efficiency and neutral dead band as those are critical requirements for the customers. With these the noise of the hydraulic unit also becomes critical as the unit noise should not go beyond the engine noise. As HSTs offer infinitely variable speeds as compared with the fixed gear ratio in mechanical transmissions, it provides an overall smooth torque curve across all the speed ranges as shown in below graph. It helps to cover the 'Power holes' which gets created due to the fixed gear ratios. It is also important to set right linkage mechanism which connects the swash plate to tractor operating pedal. By analyzing maximum force the operator can apply and linking to swash plate moments at all different speed and pressure conditions becomes critical.

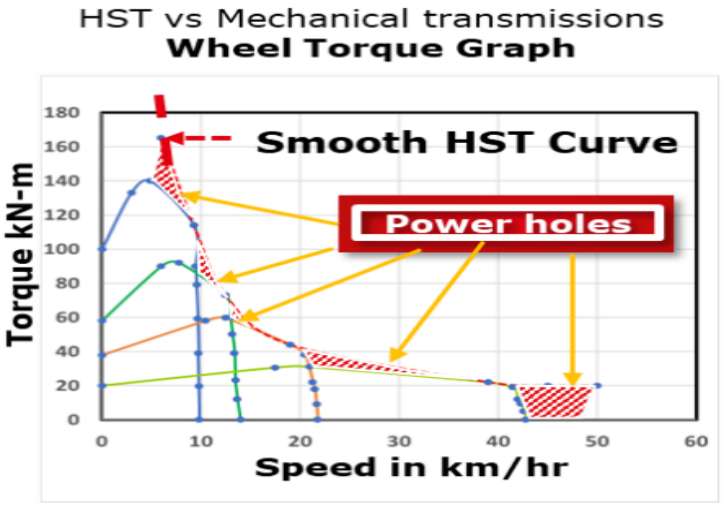

Figure-6: Wheel Torque Graph

The linkage mechanism also has the springs to make sure the HST unit comes to neutral when pedal force is removed. The right stiffness and forces at different swash inclination are analyzed and optimized through this process with is very in-different for each tractor. The dampener is also added in linkage mechanism for smooth pedal movement in forward and reverse tractor operation. Both tractor and HST manufacturer's needs to work together in this linkage analysis to get overall success. Small backlash and play can cause the issues in neutral setting and jerk on tractor.

Figure-7: A tractor application in field

The hydrostatic transmissions brings-in multiple advantages to overall tractor operations. As the tractor operation requires frequent reverse and forward movements in the field, the automatic transmission helps to improve the productivity in the field as no stoppage or gear change is required. Operator comfort is improved greatly by elimination of manual gear shifting mechanism. This also makes the tractor application gender neutral as the tractor operating becomes easy. This transmission helps to eliminate the component

wear caused due to frequent breaking and clutching in specific operations like front loader, this is achieved because of elimination of clutch and gear box assembly.

As this is an automatic transmission, the operator need not to worry about changing the gear when hill starts, so this adds in safety in the operation by eliminating motion loss or tire slip.

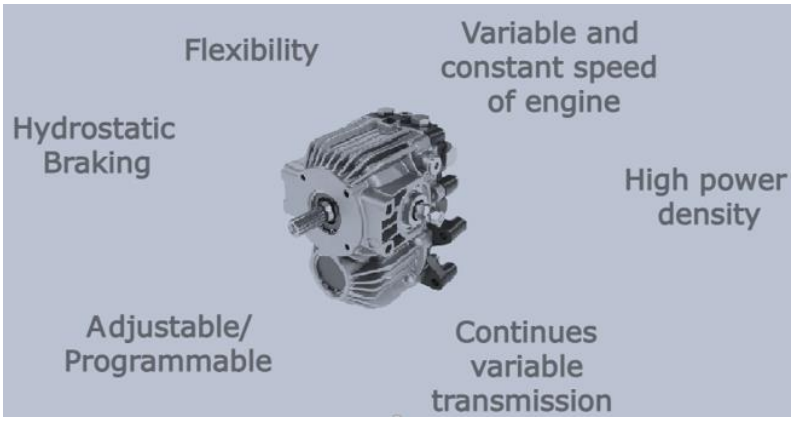

Figure-9: Benefits of Hydrostatic Transmissions

To operate hydrostatic transmissions, no special skills are required to find sweet spot for productivity and fuel efficiency. HST helps to operate the tractor at different conditions while keeping constant engine rpm so overall helps to optimize the fuel consumption. Overall, automatic transmission comes with no clutch concerns, no early tire wear and no abuse load spikes, thus helps in overall improved system reliability and lower service costs.

V. RESULTS AND DISCUSSIONS

In Europe and US regions, the tractors with HST transmissions are widely used for smaller HP (<35 HP) compact tractors since more than a decade. The typical applications are hobby farming including front loader attachments. In such application areas, these transmissions are proved to be successful due to the various advantages discussed earlier. There are multiple global tractor OEM manufacturers who offers HST tractors in these application areas.

The study showed below comparative differences in the speeds observed using the gearbox Vs Hydrostatic transmission. The Hydrostatic transmission clearly has advantages due to the inherent capability to achieve infinitely variable speed characteristics. The closer look of the below graph shows comparison about how the speed varies with respect to the gear shifting. One important aspect to note here is that while changing the gear, the speed of the tractor has to be reduced significantly while it's not required for the automatic transmission. This change in speed in manual transmission leads to jerky movement of the tractor. However, such jerky movement is not expected in hydrostatic transmission even with the unskilled operators using the machine first time.

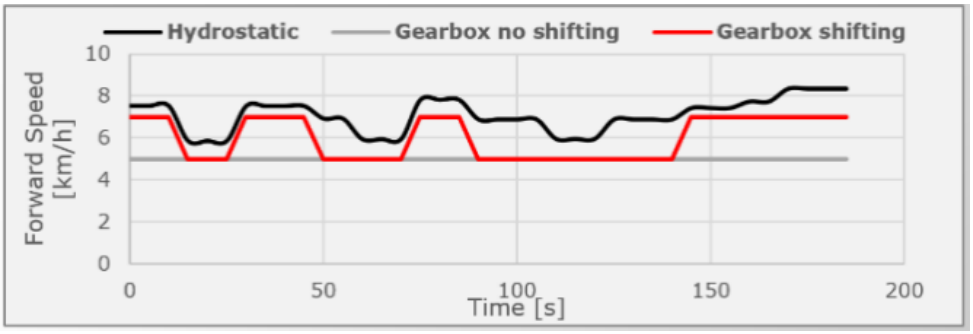

Figure-10: Speed variation comparison

So, overall, we have a good potential to adopt the automatic transmission with HST for Indian tractors as well. With less force to operate the pedal, no clutch and gear arrangement and no frequent braking; overall it becomes gender neutral and provides higher productivity. However, there are few areas which needs to evaluate further to prove its potential: • The Indian duty cycles, severity of usage and possible application overloading need to evaluate for HST application, as the application may not be hobby only. • The reliability expectations from Indian customers and end users are different than that of US & Europe market. • Whether the cost impact will be acceptable to Indian market as compared with the advantages it offers. • The maintenance and serviceability aspects are different in US/Europe and India markets.

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