

New Generation Hydraulic-Mechanical Transmission with Lock-up Mechanisms and Automatic Start Clutch

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ABSTRACT

New Generation Advanced Hydraulic-Mechanical Transmission (A-HMT) with the Lock-Up mechanism and the automatic start clutch mechanism was developed. In the lock-up mechanism, an electronic control in conjunction with transmission control was adopted using oil temperature, throttle opening, and input / output rotation ratio as parameter to reduce a rotational energy change of input and output axis caused by the volumetric efficiency of A-HMT. In the automatic start clutch, the load sensing function, damper function, and cooling function by replacing the simple hydraulic mechanism are equipped. By these solutions, the transmission efficiency has enhanced approximately 10% compared with former A-HMT, and excellent starting performance and smooth transmission performance have achieved.

INTRODUCTION

In these years, even with straddle-type motorcycles, simplification of driving operations by automatic transmission has been required. In applying a V belt-type continuously variable transmission that is popular in scooter-type motorcycle, however, it is necessary to change the location on the engine or the power transmission structure to the driving wheel. The Advanced Hydraulic Mechanical Transmission (A-HMT) adopted for All Terrain Vehicle (ATV) in 2000 has a merit of easy accommodation inside the engine of straddle-type motorcycle by its unique uniaxial structure and can be defined as continuously variable transmission (CVT) suited for straddle-type motorcycle with its excellent transmission performance. Details of the structure and the performance have been reported in the past ⁽¹⁾⁽²⁾. The A-HMT is composed of a pair of fixed displacement axial piston pump and variable displacement axial piston motor and features a uniaxial structure with the cylinders of hydraulic pump and

hydraulic motor connected together and integrated with the output axis. This characteristic is noticeable in power transmission as shown in Figure 1 and Table 1. General parallel axial-type hydro-static transmission (HST) allows the input mechanical power to be converted to fluid power by means of the hydraulic pump and then output after being converted to mechanical power again by means of the hydraulic motor. Theoretical formulae in HST are shown below.

$$T_{out} = \frac{D_{motor}}{D_{pump}} T_{in} \quad (1)$$

$$\frac{N_{in}}{N_{out}} = \frac{D_{motor}}{D_{pump}} \quad (2)$$

T_{in} : Input torque

T_{out} : Output torque

N_{in} : Input rotational speed

N_{out} : Output rotational speed

D_{pump} : Pump displacement

D_{motor} : Motor displacement

The A-HMT is a kind of power split drive. The output power from hydraulic motor is similar to that of HST. The output power from hydraulic pump depends on the hydraulic reaction force generated in it. They are synthesized and output finally. Theoretical formulae in A-HMT are shown here.

$$T_{out} = T_{in} + \frac{D_{motor}}{D_{pump}} T_{in} \quad (3)$$

$$\frac{N_{in}}{N_{out}} = 1 + \frac{D_{motor}}{D_{pump}} \quad (4)$$

Output power delivery is executed by the hydraulic motor. The hydraulic pump has a swash plate of a fixed angle

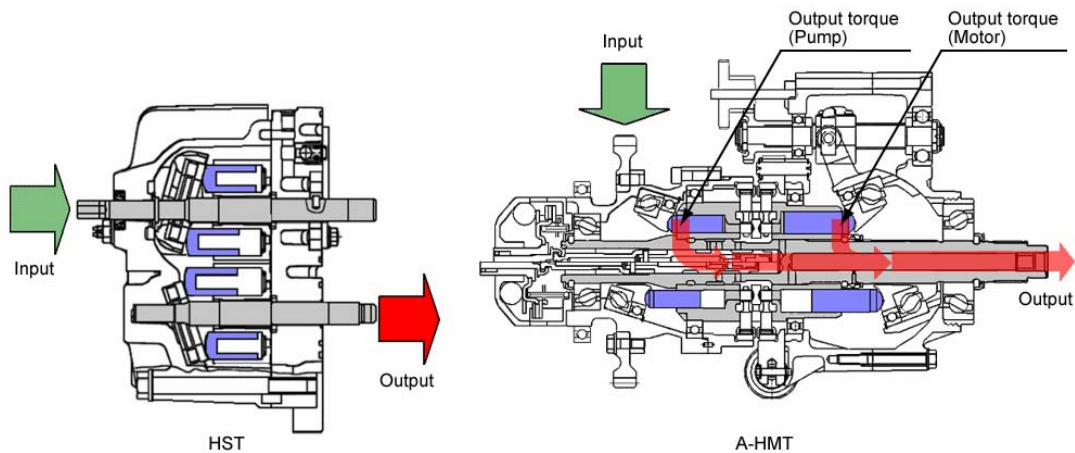


Fig.1 Difference of power flow between HST and A-HMT

Table 1 Specifications of A-HMT

		Pump	Motor
Cylinder	Outer diameter [mm]	73	70
	Piston pitch diameter [mm]	46.5	48.5
Piston	Diameter [mm]	11	14
	Number	9	9
Swash plate	Inclined angle [deg]	17	*-1.7 - 20
Distributor valve	Diameter [mm]	7	7
	Number	9	9
Cam ring	Center offset [mm]	3.0	0 - 3.0
Others	Displacement [cm ³ /rev]	12.08	24.24
	Theoretical ratio	1.00 - 3.00	
	Maximum pressure [MPa]	35.21	

* -1.7 - 0 deg angle for lock-up

and transmits the torque equal with the input torque. The transmission torque and the output rotational speed of hydraulic motor are changed by the variable control of the swash plate. Especially, when the motor swash plate is in the position perpendicular to the rotation axis, conversion to mechanical power is not carried out but driving power transmission is carried out by the hydraulic pump. In this case, the hydraulic motor is only to get leakage loss and mechanical loss caused by the high-pressure operating oil sent from the hydraulic pump. To avoid these losses, a mechanism to block the high pressure inflow to the hydraulic motor was provided to improve transmission efficiency. This mechanism is called the lock-up of A-HMT.

The A-HMT is a transmission utilizing fluid power. The clutch mechanism to be installed before or behind of the transmission can be eliminated by having built-in a mechanism to control fluid power in the main body. However, the driving power variable mechanism by the variable control of pump swash plate as in HST is hard to realize in the structure of the A-HMT where parts other than motor swash plate are rotational. Accordingly, oil passage to connect high-pressure chamber and low-pressure chamber together inside the cylinder and axis is provided and a clutch mechanism to control the A-HMT inside hydraulic pressure by the on and off of the oil passage was adopted. For these two mechanisms, structure, issue, and effect are detailed in the following section.

LOCK-UP MECHANISM OF A-HMT

LOCK-UP STRUCTURE

Blocking of high pressure inflow to the hydraulic motor is carried out by the distributor spool valves on the hydraulic motor side radial arranged in the cylinder as shown in Figure 2. The distributor spool valves are controlled with an outside cam ring. Normally, the center of cam ring and the center of the cylinder are eccentric. This controls the flow of the operating fluid to and from the piston chamber while the distributor spool valves are operating in reciprocating motion in the cylinder. At the time of lock-up operation, the cylinder center and the cam ring center match with each other to block the high pressure oil path to the piston chamber at all times. As a result, the flow of high-pressure oil into the piston chamber is stopped and lock-up effect can be achieved. The point to be noted is occurrence of a rapid change in driving force by the operation of discharging oil of the motor piston when lock-up is functioned when the motor swash plate inclined is declined greatly from the perpendicular position. Therefore, lock-up must be operated near the perpendicular position.

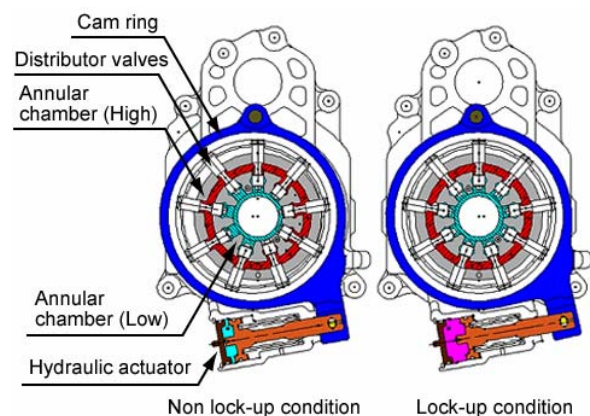


Fig.2 Structure of Lock-up mechanism

LOCK-UP HYDRAULIC CIRCUIT

Figure 3 shows the lock-up hydraulic circuit. The cam ring is operated with the hydraulic actuator. The on and off of operational oil to the actuator is carried out by the electronic solenoid valve. As the centrifugal force of the distributor spool valves and the hydraulic force from the bottom are applied to the cam ring, quick operation and stable retention require cancellation of these forces. The actuator spring load and the actuator piston diameter required for operation and retention of the cam ring are specified as shown in Table 2. The oil circuit has a relief oil passage formed in the motor anchor body for retaining the motor swash plate and the edge can be opened or shut by the motor swash plate. Even if oil flow is present in the oil circuit with the motor swash declined greatly, the relief oil passage is open and no pressure necessary to operate the actuator will occur.

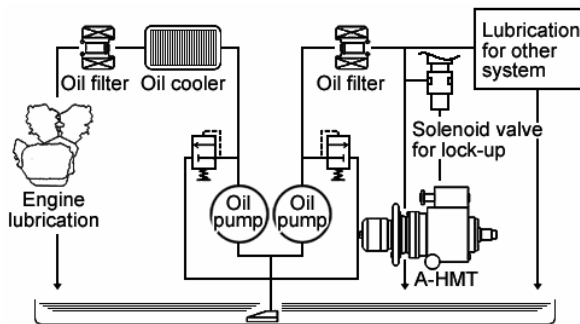


Fig.3 Hydraulic circuit

Table 2 Specifications of Lock-up mechanism

Piston	Diameter [mm]	25
	Stroke [mm]	6.5
Spring	Force / set [N]	156.8
	Force / operation [N]	218
Fluid controls	Solenoid valve	DC12V, 2 WAYS
	Maximum pressure [kPa]	780

EFFECT OF LOCK-UP EFFICIENCY IMPROVEMENT

The overall efficiency of the A-HMT is expressed by the volumetric efficiency and mechanical efficiency of hydraulic pump and hydraulic motor, respectively. This is similar to a general hydrostatic transmission. Figures 4(a)-(c) show the transmission efficiency at the time of the lock-up operation and the lock-up non-operation.

$$\eta_{overall} = \eta_{pump} \times \eta_{motor} = \frac{N_{out}}{N_{in}} \times \frac{T_{out}}{T_{in}} \quad (5)$$

$\eta_{overall}$: Overall efficiency

η_{pump} : Pump efficiency

η_{motor} : Motor efficiency

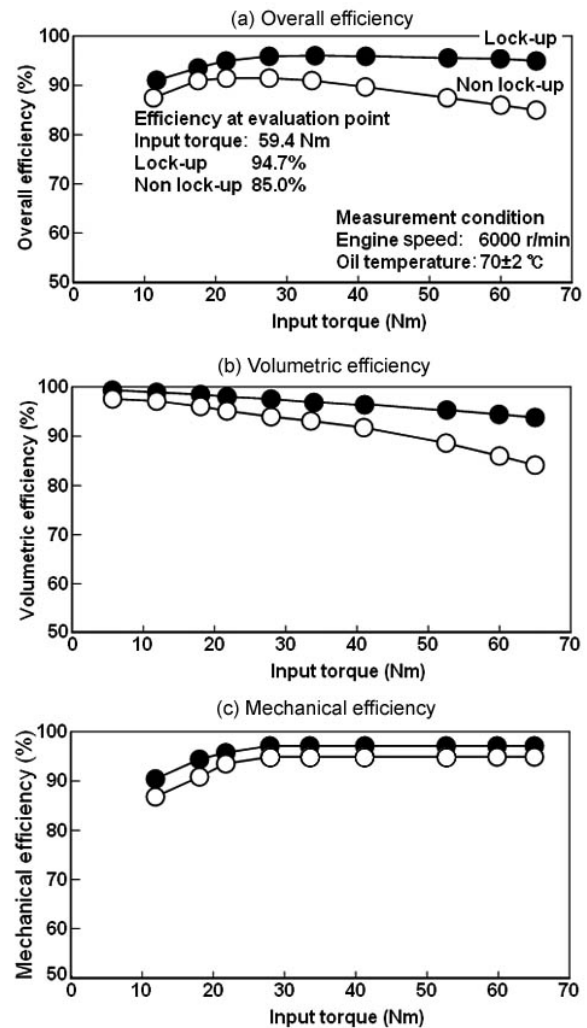


Fig.4 Transmission efficiency of A-HMT

It can be understood that as flow of high pressure into the hydraulic motor is not present when lock-up is operating, the friction of the hydraulic motor and the loss by the leak of operational oil decrease and both volumetric efficiency and mechanical efficiency are improved.

CHANGE IN DRIVING FORCE AFTER EFFICIENCY CHANGE

The issue on lock-up mechanism is occurrence of a change in driving force caused by the efficiency change before and after operation. The volumetric efficiency has effect on the change in rotational speed and the mechanical efficiency on the change in transmission torque. As lock-up operation is limited to the proximity of top ratio, the change in mechanical efficiency has little effect on the driving wheel but the change in volumetric efficiency appears as the operational energy change of each rotational axis in the engine, and the effect is great. Therefore, we put the focus of solving this issue on the reduction of change in rotational energy.