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EXPERIMENTAL INVETIGATION OF HYBRID VEHICLE

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Abstract

For energy saving, many attempts were tried in off-highway, highway vehicle and tram .First, we studied SATV vehicle of breakthrough and rescue purpose which is composed of hybrid power line CPS for low speed and MMT for high speed running.

Second, we studied CPS vehicle composed of variable P/M and energy recovery of flywheel.

In the last, we introduced flywheel driven FST tram prototype performance recently developed . This system is controlled by switching valve using fixed P/M.

KEY WORDS

HST HMT CPS Switching System

NOMENCLATURE

HST Hydrostatic Transmission
HMT Hydro-mechanical Transmission
CPS Constant Pressure System
FST Fluid Switching Transmission

INTRODUCTION

At present, to prevent global earth warming problem, automobile exhaust gas reduction and saving energy are becoming very important problem .

Roughly speaking, there are two methods to solve this problem.

1) First is of course, improvement of prime mover engine itself and many attempts are tried such as digital engine technology and operation of engine always at good fuel consumption point .

2) Second way is improvement of power transmission line efficiency. This is especially important in hydraulic operated off-highway vehicle. In this field, HST is a fundamental element where large starting torque generation , wide speed ratio and transmission efficiency are three important parameters to consider .

To obtain wide required speed ratio of vehicle, one considers simple combination of variable P/M at first . But, partial efficiency

of P/M is not sufficient and limitation of usable capacity is 1/3-1/5 of rated capacity .

To avoid this problem , gear change or driving motor switching appling 2 motor driving system .

Importance of transmission efficiency is dependent on vehicle running duty cycle . For example, in wheel loader , running duty is not so frequent and above mentioned HST is applied .

But in tractor, running performance is important. Therefore, hydro mechanical transmission (HMT) is applied which combines hydraulic machine and planetary gear . To achieve required speed range , many kind of complicated system was developed combining speed and torque summation mechanism as fundamental element .

Third way is to construct hybrid system to absorb vehicle kinetic energy at braking by combining auxiliary power source.1),2)

Energy accumulation system is classified as follows

1) Engine +Electric Generator

Energy accumulation device is, such as battery, capacitor and flywheel

2) Engine+Hydraulic Pump/Motor

Energy accumulation device is accumulator and flywheel.

Here, according to the selection of hydraulic machine,pump/motor type ,different hydraulic system is created .

If we choose conventional variable P/M, constant pressure system (CPS) or secondary regulating system is possible to apply.

If we wish to choose combination of constant volume P/M, switching valve system will be one candidate .

1 CPS and HMT COMBINED SUPER ALL VEHICLE DEVELOPMENT

Crawler vehicle is recently gaining attention by its good snow driving performance . At the same time , it has the potential application as rescue vehicle . In this kind of purpose , necessary function is to reach disaster area as fast as possible from city center . Therefore high speed running performance inside city and break through performance of deserted area are demanded .3)

For this purpose , we studied SATV (SUPER ALL TERRAIN VEHICLE) using CPS and HMT combined power line as shown in Fig.1.

In SATV, low speed drive is by 4 hydraulic motor in front and rear and high speed drive is by rear HMT .Power flow of CPS and HMT is shown in Fig.2 .

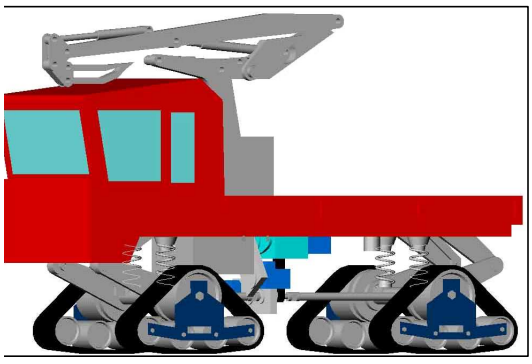

Fig.1 SATV Concept

1.1 CPS DRIVE

Power line from engine is composed of two lines CPS and HMT . At CPS drive, engine is connected to CPS gear box and HMT line is disconnected . Drive unit motor is connected to front and rear axle through clutch. By selecting clutch operation, it is possible to realize independent front or rear drive .

In CPS drive, flywheel is adopted . Detailed discussion of this system is omitted here , because another CPS was introduced in next chapter .

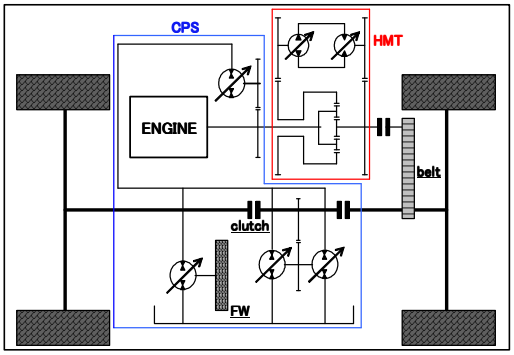

Fig.2 Power line of SATV

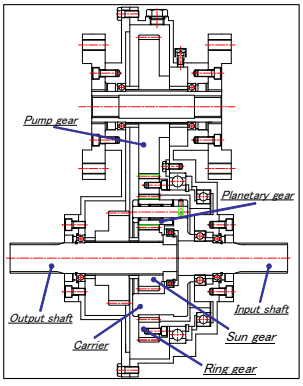

Fig.3 Developed input split HMT

1.2 HMT DRIVE

Power from HMT is transferred to drive shaft and crawler through output pulley. HMT is a combination of HST and planetary gear with CVT performance by HST and high efficiency by planetary gear.

There are two type of single HMT of input and output split type .

Hydraulic power ratio is compared with input split and output split. When hydraulic power ratio is zero, power transmission is made by planetary gear train only, without hydraulic power loss .

Therefore, at this speed ratio, transmission efficiency becomes best .In this time, we selected input split from control purpose. Manufactured HMT is shown in Fig.3. We confirmed fundamental performance of it by bench and experimental SATV vehicle.

2 CPS DRIVEN NEW CAR DEVELOPMENT

2.1 FUNDAMENTAL CONFIGURATION OF CPS WITH FOUR VARIABLE HYDRAULIC P/M

As shown in above, conventional drive method frequently applied for heavy vehicle is HST . This method has good transmission performance. But, braking energy storage is not possible and combination with hydraulic actuator or consumer is also difficult. In a word, HST application is limited only traction without energy recovery.

On the contrary, CPS is more flexible hydraulic system which is capable to coexist

with drive line and actuating system.4),5)

In the following, new CPS system is explained ,shown in Fig.4.

There are four variable hydraulic machines, that is, 1) engine coupled variable pump/motor, 2) flywheel coupled variable pump/motor 3) two driving variable pump/motors.

For energy storage , it is common to use hydraulic Acc (accumulator) . But, this system is assumed not fitted for light vehicle because Acc weight is heavy.

The system of FFC P/M (fluid force couple type pump/motor) connected to flywheel is shown in Fig.5. Let explain principle of energy storage by flywheel unit.

A) Deceleration

By pressing brake, capacity(eccentricity ratio) of drive unit FFC-P/M is set to the pump side in proportional to brake pedal displacement .

By this action, FFC discharges high pressure oil to the CPS high pressure line and vehicle is decelerated by braking torque . In this state , discharged oil makes rise the pressure of high pressure line and flywheel side FFC is regulated to act as hydraulic

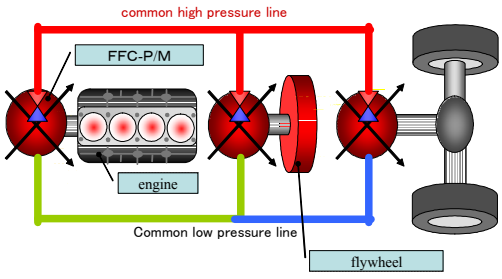

Fig.4 Car drive system by CPS

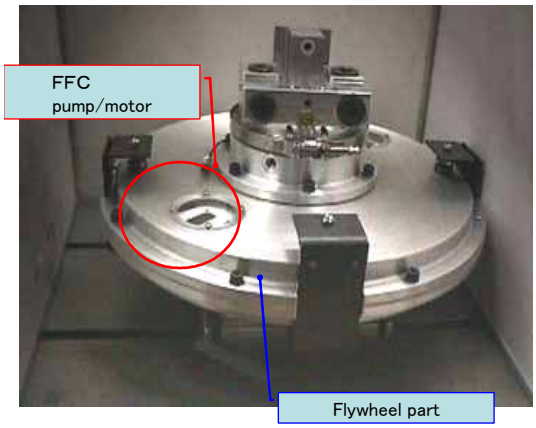

Fig.5 Flywheel driven by FFC

motor to absorb discharged oil . Then, flywheel begins to rotate . That is, braking energy is converted to flywheel rotation .

B) Acceleration

When operator pushes acceleration pedal , capacity of drive unit FFC is set to the value of pedal displacement . As the result, pressure of high pressure line decreases and flywheel FFC acts as pump to discharge oil to compensate for pressure decrease. Revolution speed of flywheel decreases due to energy discharge. That is, flywheel rotational energy is converted to the vehicle acceleration.

In the case where flywheel accumulating energy is sufficient in the process of flywheel discharge and absorbing energy, engine is possible to stop to enhance fuel economy.

In the case of engine restart, engine drive FFC is set to the motoring action with simultaneous firing of injector .

In this state, as engine FFC absorbs high pressure oil, pressure of CPS line decreases . Therefore, flywheel rotation is required to be higher than certain limit.

2.2 STATIONARY TEST OF FLYWHEEL ENERG Y STORAGE AND DISCHARGE

Measurement of flywheel energy storage efficiency was attempted by the process " engine start –flywheel acceleration(energy storage)-engine stop-flywheel deceleration (energy reuse)-engine-restart-flywheel acceleration-flywheel deceleration " without vehicle running .

By this test, efficiency of the hydraulic system is possible to evaluate . Control parameters are selected for each test condition .From this, system pressure is confirmed regulated nearly constant , by engine and flywheel action .

2.3 FLYWHEEL ENERGY STORAGE TEST OF RUNNING CONDITION

After stationary test, we conducted running test by using vehicle as shown in Fig.6 . After engine stops and flywheel reaches maximum speed , FFC coupled to flywheel starts to discharge oil to the high pressure line and vehicle accelerates by the energy of flywheel .

When the flywheel speed reduces to the lower limit ,then braking command is given to the driving FFC .

By this action, flywheel speed is once more increased to absorb braking energy .

Let calculate regenerative braking energy efficiency .

Ratio of energy stored in flywheel and energy restored in flywheel in the process of vehicle start and stop is energy accumulation efficiency .

Efficiency of acceleration of vehicle by flywheel η_A and regenerative or braking energy η_B are defined as follows ;

$$\eta_A = J_V N_V^2 / J_{FW}(N_{F1}^2 - N_{F2}^2) \quad (1)$$

$$\eta_B = J_{FW}(N_{F3}^2 - N_{F2}^2) / J_V N_V^2 \quad (2)$$

Where, N_{F1}; flywheel maximum revolution

N_{F2} ; flywheel minimum revolution

N_{F3};flywheel revolution at regeneration

N_V; driving unit maximum revolution

J_V; vehicle equivalent moment of inertia of driving unit shaft

J_{FW}; flywheel moment of inertia

Total efficiency η is product of η_A and η_B , thus ,

$$\eta = (N_{F3}^2 - N_{F2}^2) / (N_{F1}^2 - N_{F2}^2) \quad (3)$$

These calculation includes CPS hydraulic system and vehicle driving efficiency .

So that , efficiency is total vehicle driving and energy storage efficiency .

By experiment , driving efficiency $\eta_A = 70\%$,braking energy recovery efficiency $\eta_B = 40\%$ and total efficiency $\eta = 30\%$ are obtained .

The reason why η_A, η_B different is not clear ,just now .

At acceleration of vehicle , flywheel rotational energy is converted to vehicle velocity through two FFC units .Also at braking, vehicle braking energy is transferred to flywheel through two FFC .

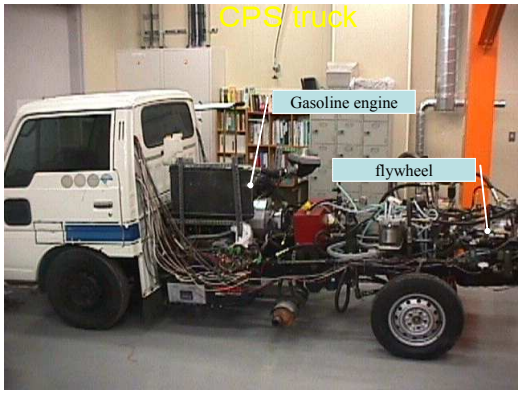

Fig.6 Test truck driven by CPS

3 FLUID SWITCHING TRANSMISSION

Contrary to using variable P/M, new approach to use constant P/M with switching valve named FST was developed recently .6)

Developed 3 axis 6 wheel automatic steering bogie machine is prototype for tram application ,equipped with small engine and large flywheel for energy storage as shown in Fig. 7 .

Fig.7 Tram model driven by FST

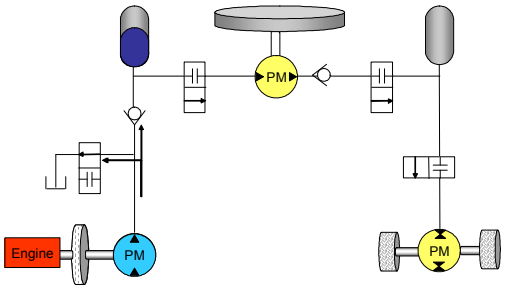

Fig.8 FST hydraulic diagram

Flywheel is specially designed to minimize rotational loss and capacity is 13.0 Kgm2 ,about 6 times larger than CPS car .

. Basic hydraulic diagram is shown in Fig.8. Switching circuit is constructed in engine –flywheel and flywheel-driving motor .

Driving command is inputted by mono lever and on-off valve is controlled by FST algorithm. Flywheel is accelerated to the top speed by engine. Then, by this flywheel energy, tram is accelerated to the desired speed . Braking energy is also recuperated to the flywheel .

FST hydraulic circuit is simple because only using switching valve and gear P/M instead of complicated variable P/M. Tram acceleration and deceleration are confirmed fundamentally same as of above mentioned CPS.

System total efficiency at running is estimated high due to using fixed P/M and switching valve. In this system, surge phenomena takes place due to rapid switching of fluid line. If we have effective measures to this problem , FST is also applicable to hybrid vehicle.

CONCLUSION

Experimental investigation of hybrid vehicle was conducted including SATV composed of CPS and HMT and flywheel car driven by CPS.

Further, FST was reviewed which was driven by switching principle .

1) **CPS and HMT combined power transmission system was proposed for SATV.**
2) **By actual running test, braking energy was possible to recuperate in CPS car.**
3) **By switching valve system FST , simple and effective driving system for tram is possible to realize.**

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