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Measurement & Control of Slip in A Continuously Variable Transmission

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Abstract: *There's been proven that a Continuously Variable Transmission (CVT) has the same efficiency as a manual transmission. To capture the market the CVT has to be improve and be better than a manual transmission. Therefore the aim of research is to get a better robustness and improve of the efficiency. In the macro slip region the push belt will slip more than normally allowed. To create this more slip, the pulley clamping forces has to be decreased. This decrease in clamping forces, results in a decrease in the needed power for the clamping forces, which results in a better efficiency and an improving in fuel consumption.A model describing slip in a CVT is verified using measurements with a belt with increased play. It is found that small amounts of slip can be controlled in a stable way on the setup. Efficiency is found to be highest for 1 to 2% slip depending on the ratio. The model is in reasonable agreement with the measurements.*

Keywords : *CVT, Slip control,Set point of slip control*

I. INTRODUCTION

The quest for vehicle efficiency improvement in the field of automotive power trains has led to many innovations. One of them, the Continuously Variable Transmission (CVT) can be seen as the optimal transmission due to its infinite number of gears. Within certain limits the engine speed can be chosen independent from the vehicle speed, which would lead to faster acceleration and lower fuel consumption. However, due to inefficiencies in the CVT these improvements are not achieved. In a CVT the main losses occur in the hydraulic actuation system, in the pushbelt itself and in the friction contact between the belt and the pulleys.

Due to the construction of a CVT the problem of slip is always present. Traditionally this is solved by adjusting a constant minimum clamping pressure, which in normal operation leads to overclamping. This lowers the efficiency because of the energy dissipated by the hydraulics, the bearings and the belt. Other clamping force strategies have been developed to cope with this problem, for example the safety factor principle from VDT and the slip control from LuK (Faust et al., 2002). As in most cases there is a trade-off between performance and durability, high slip percentages caused by low clamping forces lead to high efficiency but can cause wear. Low slip percentages can be reached by high clamping forces which leads to lower efficiency, less wear, but more fatigue. Between these two regions an optimal can be found where wear and fatigue are low, but efficiency is high. If it is possible to keep the CVT in the optimal slip region efficiency can be improved without significant durability loss (van Drogen and van der Laan, 2004).In this case an axial position sensor is used to measure the secondary pulley position, from which the geometrical ratio can be derived, which in turn enables us to compute the amount of slip. With an online clamping force controller it is possible to control the amount of slip, which leads to lower pressures and therefore a higher efficiency. In this paper the control principle will be discussed. The system is tested for critical situations and efficiency.

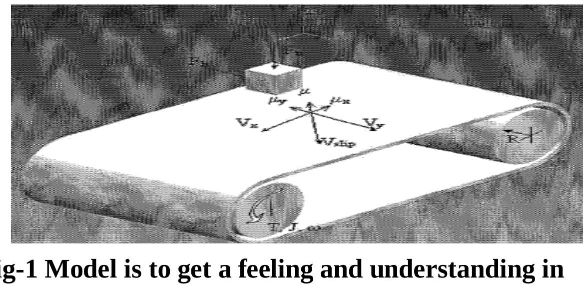

Fig-1 Model is to get a feeling and understanding in the relevant dynamical equations.

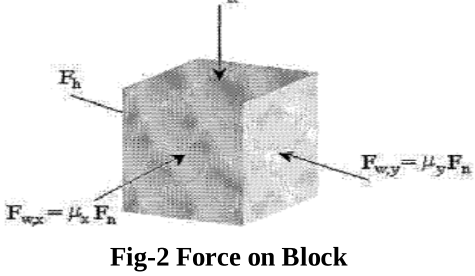

Fig-2 Force on Block

II. INDENTATIONS AND EQUATIONS

In this model, figure 1, the belt will be simulated as one block fixed on top of the belt This mode! is to get a feeling and understanding in the relevant dynamical equations. Setpoints will be give in to create a slip in x-direction and y-direction (the shift-direction). These setpoints will in Matlab/Simulink be respectively coupled to horizontal (Fh)s,h ift force, and vertical force (F_n,), clamping force. These forces will control the slip in both directions, see figure 2.

Dynamic equation in x-direction

$$m\ddot{x} = F_{w,x}$$

:

$$F_{w,x} = \mu_x F_n$$

Dynamic equation in y-direction

$$m\ddot{y} = F_h - F_{w,y}$$

:

$$F_{w,y} = \mu_y F_n$$

Slip-speed

The slip-speed in x-direction of the block is defined as:

$$V_{slip,x} = V_{pulley} - V_{block,x}$$

within

$$V_{pulley} = r\omega$$

The V_{slip}, x to V_{pulley} is equal to can be calculated through the input variables of the pull-belt see table 1

$$\dot{\omega} J = \Delta T$$

Cause the friction force acts in negative direction on the pullbelt,action reaction, the torque difference is equal to:

$$\Delta T = T - F_{w,x} r$$

Input	Value	Si
m	1	[kg]
T	10	[Nm]
J	0.5	[kgm^2]
v0	0.1	[m/s]
r	0.1	[m]
ω	v0/r	[1/s]
k	2000	[N/m]

Table 1- Input Variable

$$\Delta T = T - \mu_x F_n r$$

$$\dot{\omega} = \frac{T - \mu_x F_n r}{J}$$

V_{pulley}, $V_{slip,x}$ can now be calculated $V_{pulley} = V_{slip,x}$

The slip-speed in y-direction of the block follows from the dynamic equation in y-direction:

$$V_{slip,y} = \int \frac{F_h - \mu_y F_n}{m}$$

- **Slip Control**

To create a slip between the belt and the pulley, the needed forces has to be controlled. As discussed before, the control forces in the simulation are the shift force *(Fh)* and the claping force (F_n,). These control the slip in x- and y-direction. In figures 3 and 4 the visualization of the control in both direction are shown

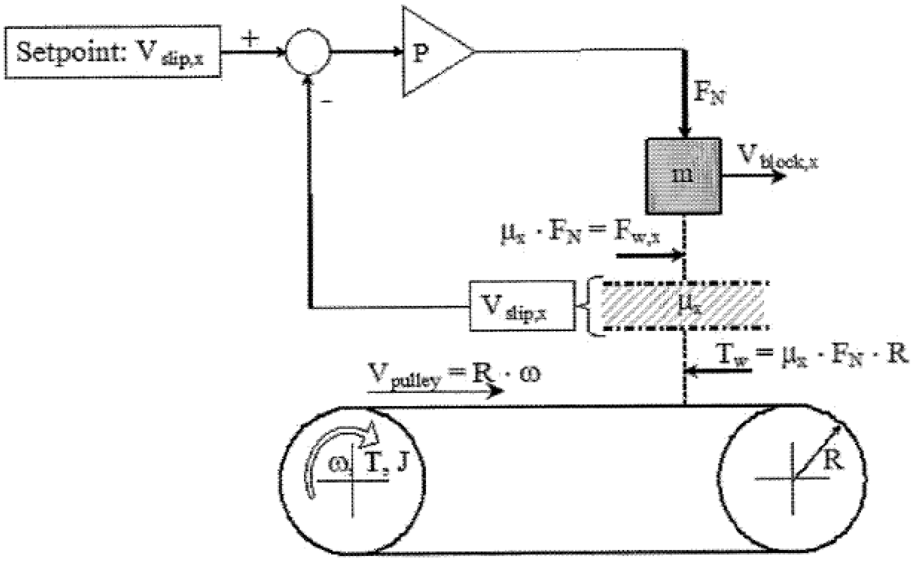

Fig.3-Slip Control In X-direction

The setpoint for the slip in x-direction will be keep constant, for a constant pulley speed. The setpoint for the slip in y-direction will increase and decrease in a iixed time period. This has to be done, to similate a shifting movement of a CVT.

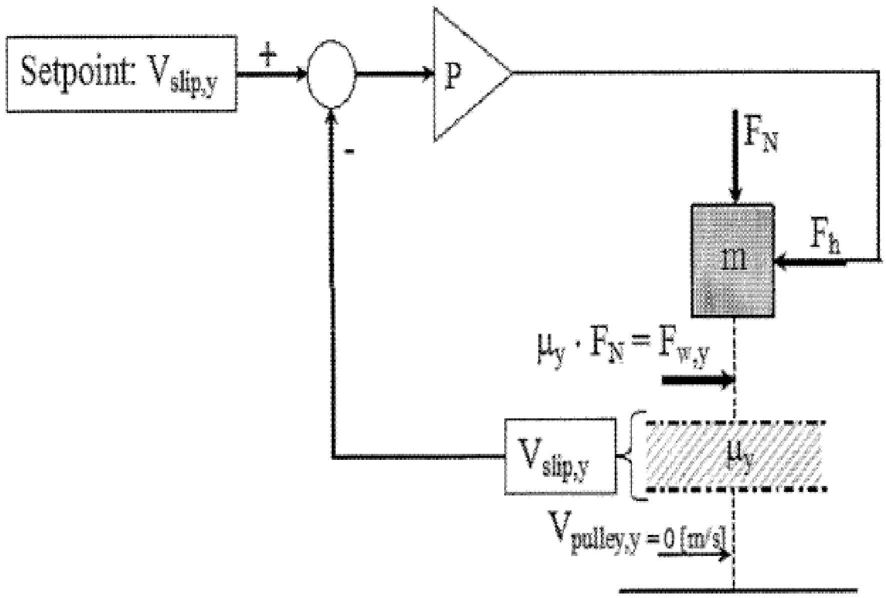

Fig.4- Slip control in Y-direction

Friction coefficients ***(),*** friction torques (T_w***)*** ***a***nd pulley-speed (V_{pulley}) can be determined.

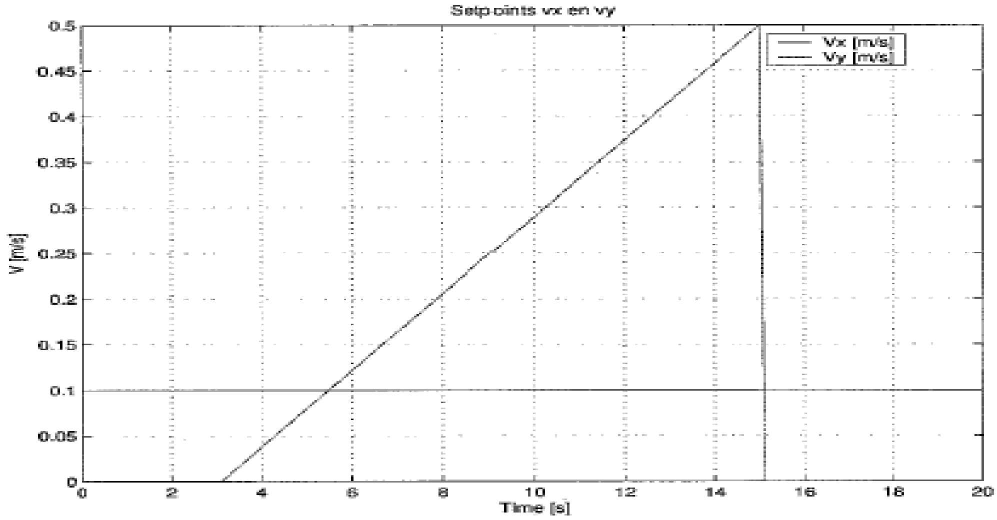

Fig.5- Set point for slip control

III. CONCLUSION

Therefor a slip model implementation, dynamic equations, determination of friction and slip control have been made. The assumption increasing slip speed in x-direction, &y,z, results in decreasing of the needed forces. Increase in Vslip,z results in a decrease in needed clamping force and a reduction in needed shifting force. These both reductions will result in decrease of needed power and so in reduction of fuel consumption.
The slip-simulation is very simplistic,therefore some improvements can be made to cut more realistic push-belt slip-simulation:Real push-belt simulation.The infinitesimal part between the push belt and pulley is based on **3** blocks. A more realistic push belt can be made to simulate all segments of the push belt. Ratio difference during shift During shifting not all segments has slip with the pulley. During shifting there's a ratio difference, so only the segments on the wrapped angle has slip.**e** Material influence Friction between push belt and segments.In this simulation there's only friction between push belt and pulley. In reality there's also friction between segments and belt in the van Doorne push belt.

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