Matching Design of Power Coupling for Two-Motor-Drive Electric Vehicle

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Abstract. In order to solve the problem of no power coupling in independent driven vehicle, liquid viscous coupling (LVC) has been chosen from several power couplings. The performance characteristic of LVC and vehicle steering performance have been analyzed, and LVC for target vehicle has been designed. Then the lateral simulation for vehicle with LVC has been conducted. The results show that LVC used as power coupling has no bad effect on vehicle steering performance, and the handling and stability performance has been improved.

Introduction

Based on driving mode, electric vehicle can be divided into two categories: central drive and independent drive. Independent driven vehicle has compact structure, and the chassis is easier to control. Therefore, more and more experts in the world have started to do related research, such as Tokyo University of Agriculture in Japan [1], Tongji University and Beijing Institute of Technology in China [2].

The performance of independent driven electric vehicle can be improved by controlling each driving wheel. In order to improve vehicle passing ability and active safety, it is necessary to develop a power coupling for those vehicles which are often running on bad road. The power coupling is used to combine the left power and the right power and it can also help reduce dependence on the precise control of driving motors. It should not work when vehicle is running normally. This paper designs a proper power coupling for two-motor-drive electric vehicle, which is developed by National Engineering Laboratory of Electric Vehicle, Beijing Institute of Technology.

Selection of Power Coupling

The performance characteristic of power coupling is very important, for it not only is able to combine bilateral power, but also can meet the requirement of vehicle normal steering. In consideration of structure, couplings like electric clutch, liquid viscous coupling (LVC) and electronically controlled hydraulic multi-plate clutch can all be chosen. Compared with others, torque transferred by LVC is changed automatically depending on bilateral rotational speed difference, that is, there is no need to impose any control on LVC, which can automatically adjust the torque transferred into bilateral axles. The effect of other couplings is obtained by controlling current or voltage, which needs to coordinate with the control strategy of two-motor-drive vehicle. So this paper chooses LVC as power coupling to do research. The position of LVC in vehicle is shown in Fig. 1.
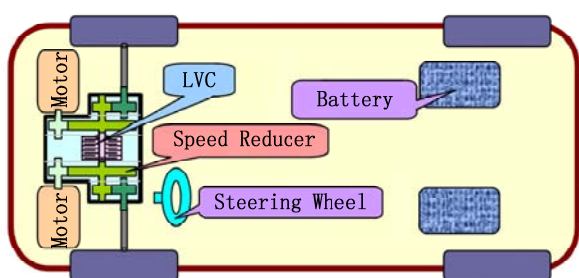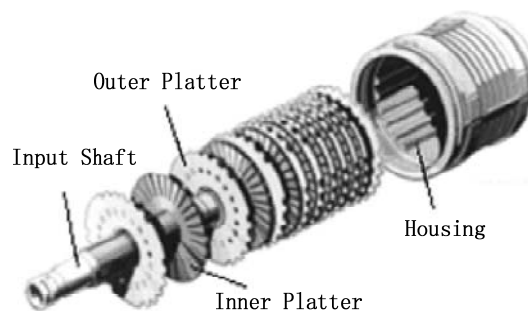

Fig. 1. Position of LVC

Fig. 2. Structure of LVC

The structure of LVC is shown in Fig. 2. It consists of an input shaft, an output shaft, the housing, the inner platters, the outer platters, etc. Isolating rings are used to fix the outer platters to maintain equal distances between the outer platters. The inner platters can move axially along the spine [3].

Performance Characteristic of LVC

LVC has two working conditions: shear and hump. When bilateral rotational speed difference is low, LVC transfers torque by shearing the inner silicone oil. When bilateral rotational speed difference is high enough, inner platters are pressed against the outer ones by high pressure. At that time, torque is transferred depending on the friction between the inner and outer platters, and this is the hump phenomenon.

Sheer Characteristic of LVC

According to Newton's law of internal friction, the shear torque can be obtained [4]:

$$T = \frac{1}{2}\frac{(n_1+n_2-1)\pi\rho\nu}{s}(\omega_2 - \omega_1)(r_2^4 - r_1^4) \qquad (1)$$

Where n_1 and n_2 are the numbers of inner platters and outer platters, respectively; ρ and ν is the density and kinematic viscosity of silicone oil, respectively; s is the oil film thickness; ω_1 and ω_2 are the angular velocity of the inner platters and outer platters, respectively; and r_1 is the inside radius of outer platter, r_2 is the outside radius of inner platter.

Hump Phenomenon of LVC

Fill rate of Silicone oil for LVC is around 90%. When hump phenomenon occurs, it turns to nearly 100%. According to that, the triggered temperature can be obtained [5]:

$$T_h = T_0 + \frac{1-\eta_0}{\beta_s\eta_0} \qquad (2)$$

Where T_h represents the temperature when the Hump phenomenon is triggered, T_0 is the initial temperature; η_0 is the filling ratio of the silicone oil, β_s represents the coefficient of thermal expansion of the Silicone oil.

Referring friction principle and Eq. 2, the hump torque can be obtained:

$$T_h = \frac{2\pi\varepsilon kfmP_0}{3}\frac{T_h}{T_0}\frac{(1-\eta_0)(r_2^3-r_1^3)}{1-\eta_0-\eta_0\beta_s(T_h-T_0)} \qquad (3)$$

Where ε is the influenced coefficient of the holes and grooves, k is the contact coefficient of the platters, f is the coefficient of friction, m is the group number of platters, and P_0 represents the initial pressure of LVC.

Matching Design of LVC

Triggered Rotational Speed Difference of Hump Phenomenon

When vehicle is turning and one wheel is about to off the ground, bilateral rotational speed difference reaches maximum of all normally driving conditions. The hump phenomenon must not be triggered under this condition. That is, vehicle can run normally with LVC as power coupling. The maximum rotational speed difference under different turning radius can be obtained:

$$\Delta N = [60B\sqrt{gBR/2h}/(2\pi Rr)]_{max} \qquad (4)$$

Where ΔN is bilateral rotational speed difference, B is wheel tread, R and h is the turning radius and height of the vehicle's center of mass, respectively, r is the wheel radius.

Referring Eq. 4 and vehicle parameters, maximum rotational speed difference can be obtained, when vehicle is running in different turning radius.
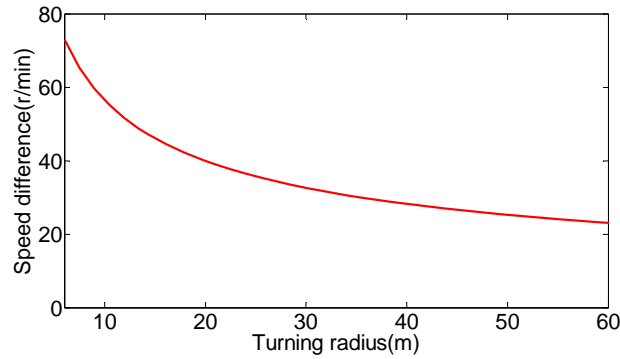
Fig. 3. Maximum rotational speed difference
under normally driving conditions

Design of LVC and Torque-Speed Characteristic Curve

Referring Fig. 3, maximum rotational speed difference is about 70r/min when vehicle is turning at higher speed. Therefore, triggered rotational speed difference of hump phenomenon should be higher than 70r/min. At the same time, in order to avoid seal failure due to high inner temperature of LVC, the designed maximum working temperature should be below 433K. From the above, LVC aimed for the target vehicle has been designed. The values of its main parameters are listed in Table 1.

Table 1. Values of designed LVC parameters

Parameter[Symbol]	Value[Unit]
Number of inner platters[n_1]	10
Number of outer platters[n2]	11
Inside radius of outer platter[r1]	0.0325[m]
Outside radius of inner platter[r2]	0.06[m]
Oil film thickness[s]	0.0004[m]
Kinematic viscosity of silicone oil[ν_0]	$6\times10^4[mm^2 \cdot s^{-1}]$
Fill rate of silicone oil[η_0]	90%
Triggered temperature of hump phenomenon[Ts]	415[K]
Triggered rotational speed difference[ΔN_h]	196[r/min]

According to LVC parameters and Eq. 1, 2, 3, torque-speed characteristic can be obtained through simulation in Matlab. The curve is shown in Fig. 4.
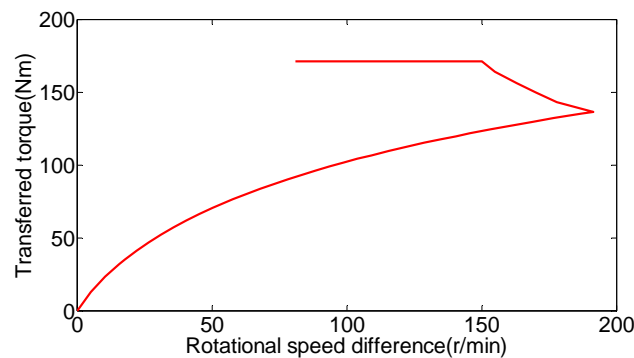

Fig. 4. Torque-speed characteristic curve

From Fig. 4 we can see that the transferred torque is increasing with the growing speed difference. When wheel slips on bad road, LVC will transfer greater torque, even trigger the hump phenomenon. Then vehicle will be able to get away from adverse road.

Impacts of LVC on Vehicle

The rotational speed difference between both sides is very low when vehicle goes straight, so LVC does not work under this condition. Therefore, only the lateral motion of target vehicle has been simulated [6].

Steady-State Steering

Vehicle accelerates from 0m/s to 10m/s on good road, and then keeps running straight at constant speed of 10m/s. After 12 seconds, input a steering angle of 9°. Simulation continues for 40s. The results are shown in Fig. 5-8.
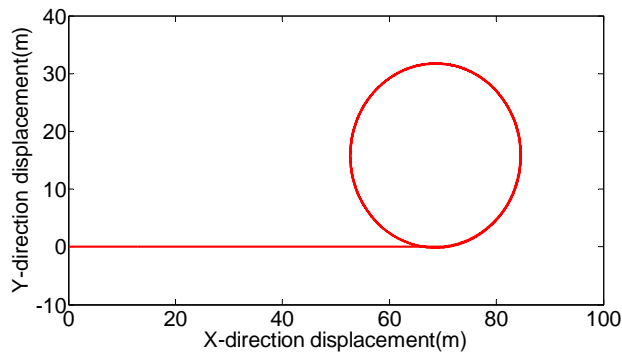
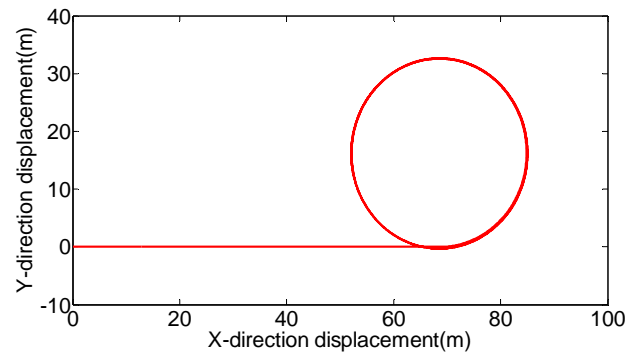Fig. 5. Vehicle running track without LVC
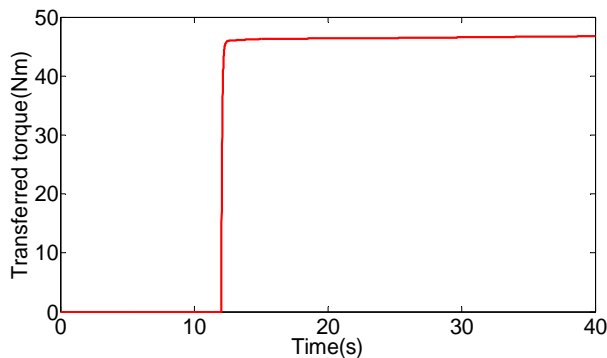
Fig. 6. Vehicle running track with LVC
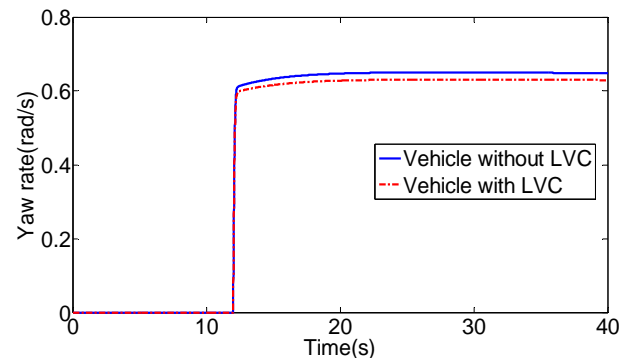
Fig. 7. Torque transferred by LVC

Fig. 8. Comparison of yaw rate

From those figures we can see that LVC has transferred lower torque, which has no bad effect on normal steering. Moreover, vehicle with LVC has lower yaw rate and insufficient steering trend.

Snaking Motion

Assume that the vehicle is driving on good road at constant speed of 10m/s, then at the eighth second, the steering angle is changed and it starts doing snaking motion. Simulation continues for 20s. The results are shown in Fig. 9, 10.
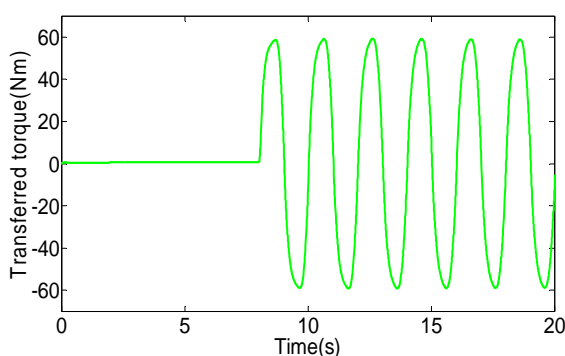
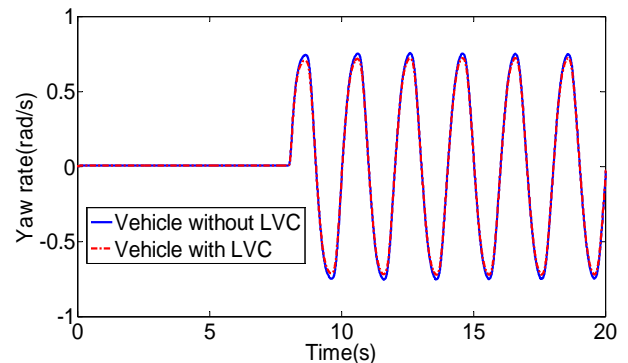Fig. 9. Transferred torque by LVC

Fig. 10. Comparison of yaw rate

The sign of torque in Fig. 9 reflects the transferred direction of torque, and it fluctuates in sine law. It can be seen from Fig. 10 that the yaw rate of vehicle with LVC is lower than that of vehicle without one. Therefore vehicle handling and stability performance has been improved.

Summary

Based on analysis of performance characteristic of LVC, this paper has designed a LVC for target vehicle as power Coupling. LVC can adjust transferred torque depending on the rotational speed difference between both sides. When bilateral rotational speed difference is higher, the coupling effect is strengthened and even the hump phenomenon will probably be triggered. At that time, the transferred torque reaches the highest to help vehicle get away from bad conditions. The simulation results show that torque transferred by LVC is rather low when vehicle is steering normally, that is, LVC has no bad effect on normal steering. Moreover it can improve vehicle handling and stability performance. This paper proposes a project to solve the problem that there is no power coupling in existing independent driven electric vehicle.

References

[1] Masao Nagai, Motoki Shino and Feng Gao: submitted to JSAE Review (2002)

[2] Zhang Lipeng: Dynamic Simulation and control of Two-Motor-Drive Electric Vehicle (Beijing Institute of Technology Publication, China 2011).

[3] Mohan S K, Ramarao B V: Viscous Coupling in 4WD Vehicles: Application of Computational Modeling (SAE Publication, America 2002).

[4] Wei Chenguan, Zhao Jiaxiang, in: Principle of Viscous Transmission, edited by Zhao jiaxiang, chapter 3, National Defence Industry Publisher (1996).

[5] Joji Takemura, Yasuhiro Niikura: An Analysis of Viscous Coupling Torque Transmission Characteristics and Hump Phenomenon (SAE Publication, America 2000).

[6] Wang Huiyi, Xu Chunyu: submitted to Journal of System Simulation (2004)