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Gearshift Control for Transmission-By-Wire Based on Position Sensorless

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Abstract—**In order to simplify the design structure of Transmission-By-Wire, a new position sensorless gearshift control is proposed using electromotive force detection instead of real-time displacement estimation or displacement sensor. Based on the principle of back EMF, the change of electromotive force produce by electromagnetic coil and armature under the current is switched on. According to the working principle of electromagnetic clutch. Using GUI toolbox of MATLAB to analyse the electromagnetic coil and armature, the dynamic response mathematical model of armature is established. Through the simulation analysis, the armature position of the position sensorless transmission-by-wire can be accurate obtained by simulation. The movement state of the armature is divided into three stages, the axial displacement is 1.2 mm, the maximum force is 62 N, its dynamic response characteristics meet the requirements of position sensorless gearshift control.**

***Index Terms*— EMF, Transmission-By-Wire, Armature, Electromagnetic Induction.**

I. Introduction

With the rapid development of automotive electronic technology and control theory, the level of automotive automation is constantly improving. Automatic transmission improves the power, economy, comfort and safety of the vehicle [1]. Sensor should have enough defect quantitative differentiation and high signal noise ratio. However, sensor in practice are usually worked in dreadful conditions, it has been less than satisfactory. Sensorless control technology refers to the technology that the actuator uses its own self sensing ability or electrical parameters to indirectly obtain physical information such as position or speed by detecting sensor signals such as the voltage and current of the actuator coil [2]. Based on the dry dual clutch automatic transmission, the position sensorless brushless DC motor drive mode is proposed for the hydraulic oil supply system, and the feedback signal of the controller is used as the driving signal of the DC motor [3]. In the research of timing overlapping gearshift technology, the position and speed of the mover are controlled by back EMF without position sensor [4].

This paper takes the transmission-by-wire as the research object and the electromagnetic clutch as the shift actuator. Transmission-by-wire is a new type of automatic transmission, which cancels the hydraulic transmission device and drives the actuator to shift through the electromagnetic force generated by the electromagnetic coil. As a moving part, the armature of the electromagnetic clutch has the characteristics of small mass and fast speed. A slight position change can produce a measurable back EMF signal change in the electromagnetic coil. Based on the self sensor ability of the shift actuator controlled-by-wire, the speed and position sensorless is adopted, it is great significance to improve the reliability of the gearshift system.

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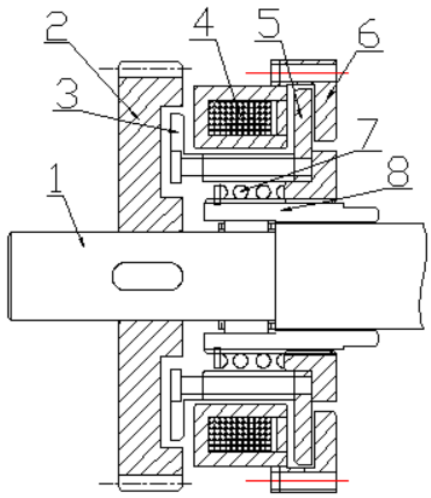
II. STRUCTURE AND WORKING PRINCIPLE OF TRANSMISSION-BY-WIRE

The electromagnetic gearshift structure of transmission-by-wire is shown in Figure 1. When the electromagnetic coil is electrified, the armature moves towards the electromagnet against the force of the preloading spring under the action of the electromagnetic force generated by the electromagnetic coil, which drives the transmission copper sleeve to combine with the input gear to complete the rotation synchronization of the input gear and the transmission copper sleeve. The transmission copper sleeve and spline shaft are driven by spline teeth to realize the synchronous rotation of spline hub and input shaft, so as to realize the power transmission of clutch engagement state. When the electromagnetic coil is not powered on, under the force of the preloading spring, the armature and the locking disc are engaged and stopped, and the input gear, the transmission copper sleeve and the spline shaft are disconnected and in a separated state, and the power transmission is disconnected.



1.input shaft 2.input gear 3. transmission copper sleeve 4. electromagnetic coil 5. armature 6. locking disc 7. preloading spring 8. spline shaft

Fig.1 The structural sketch of transmission-by-wire

Under the action of magnetic force, the armature overcomes the pressing force of the preloading spring and produces axial movement [5]. In the process of movement, in order to ensure the armature to follow the expected trajectory and motion parameters, the position and moving speed of the armature must be monitored in real time. In the conventional actuator control system, in order to realize the motion control of the actuator, mechanical sensors such as position or speed are usually added to convert the digital signal into electrical signal and feedback to the electronic control unit [6]. According to the value of voltage and current, can be decide the position of armature. In the position sensorless control system as shown in Figure 2. The electric signal of driving coil is detected by electronic control unit, and the position or speed of actuator is estimated by corresponding signal processing and numerical calculation. The position sensorless control technology makes the actuator achieve the unity in structure and function, and the motion control system has more compact structure and stronger robustness [7].

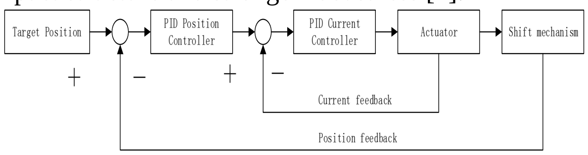


Fig.2 sensorless control system

III. MATHEMATICAL MODEL

A. Electrical Model

By making use of Faraday's law of electromagnetic induction and Kirchhoff's law of voltage, a differential equation relating the control coil voltage (u), the coil current(I), the coil resistance(R), and the armature displacement(x) may be expressed as:

$$U(t) = RI(t) + L\frac{dI(t)}{d(t)} + k_E\frac{dx}{dt} \quad (1)$$

$$L = \frac{u_0 N^2 d}{l}\left[\pi dk - t_0\left(0.693 + C\right)\right] \quad (2)$$

Where u_0 is relative permeability of coil, k_E is back-EMF, k is Nagaoka coefficient, C is decided by I/t.

Therefore, the speed of the armature can be calculated by the following formula:

$$v(t) = \frac{dx}{dt} = \frac{U(t) - RI(t) + L\frac{dI(t)}{d(t)}}{k_E} \quad (3)$$

Where R is Coil internal resistance; I is Coil current; L is coil inductance.

B. Dynamic Model

Automatic transmission-by-wire adopts the concept of static electromagnetic coil and permanent magnet to armature interaction [8]. The resistance and friction force of the preloading spring are overcome by the action of armature in the magnetic force. According to Newton's second law, the movement mechanical model can be expressed as:

$$m\frac{d^2x}{dt^2} = F_m - k_s x - F_f \quad (4)$$

Where m is quality of armature, F_m is electromagnetic force, F_f is friction.

$$F_m = \frac{B^2}{2\mu}S \quad (5)$$

Where B is magnetic induction intensity of working air gap, μ is permeability of vacuum, S is cross section area of magnetic circuit.

C. Noise Optimization

In addition, due to the noise in the current measurement, the differential operation is easy to produce serious burr. In order to avoid the influence of measurement noise on the estimation results, it is necessary to eliminate the current differential term. The optimization method is defined as follows:

$$\eta(t) = v(t) + N\left(I(t)\right) = v(t) + \lambda I(t) \quad (6)$$

By deriving the above formula:

$$\frac{d\eta(t)}{dt} = \frac{dv(t)}{dt} + \frac{dN\left(I(t)\right)}{dt} = \frac{dv(t)}{dt} + \lambda\frac{dI(t)}{dt} \quad (7)$$

The position estimation is obtained by integrating the accurately estimated velocity signal. The formula is expressed as follows:

$$x(t) = x(0) + \sum_{1}^{i} v(t)h(t) \quad (8)$$

The implementation of the optimization estimation algorithm requires the use of three electrical parameters of the actuator: the inductance, resistance and characteristic parameters of the actuator. According to the measurement results of the actuator parameters, the inductance value is only related to the duration of the current, basically does not change with the position, and the value is small. Due to the short shift time, it can be approximately considered that the resistance of the actuator coil does not change during the shifting process. According to the characteristic parameters of the actuator, the actuator parameters are proportional to the current and nonlinear to the displacement.

IV. SIMULATION ANALYSIS

A. Parameters and Performance Requirements

In order to verify the feasibility of the designed position and speed algorithm, feedback control is adopted for the motion control of gearshift by wire actuator [9]. In the GUI toolbox of MATLAB software, the model of electromagnetic coil and armature is established. The control system is divided into inner and outer loop control system and actuator control system, can be seen from Firgue3. The input current and voltage of electromagnetic coil are input in the form of simulation signal. Set the feedback output signal of voltage and current to detect the voltage and current. The voltage is calculated by duty cycle and current is measured by current sensor. The position of the armature can be observed by calculating the current and voltage by the state observer. In the actuator control system, there are three parts: current system, magnetic circuit system and mechanical system. The signals between the three subsystems have the function of signal transmission and feedback, which can detect and output signals from each other.

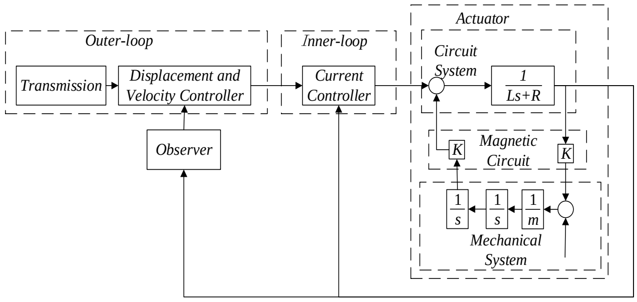


Fig3 position sensorless control system

In this paper, based on the working characteristics and requirements of the transmission-by-wire. Based on the design of transmission structure, the parameters of main components of electromagnetic are designed. Basic parameters of the electromagnetic clutch as shown in table 1.

Table 1. The basic parameters of transmission-by-wire

Parameter	Numerical	Unit
u_0	$4\pi\times10^{-7}$	Wb/A▪m
I	4	A
R	2.1	Ω
S	0.8×10^{-3}	m^2
N	250	
l	300	mm
d	0.9	mm

B. Simulation and Analysis s

The current is measured by the current sensor, and the signal filtering and phase advance are realized by the phase advance module. The input voltage is calculated by duty cycle and constant voltage source. It can be seen from the Figure 4 that the induction electromotive force and inductance will be generated when the electromagnetic coil is switch on, which will hinder the increase of current. With the increase of power on time, the current increases with the increase of time, and finally tends to be stable. The stable current is 4 A. The induced electromotive force decreases gradually from 12 V at power on. When the current increases gradually, the induced electromotive force decreases to 0. The inductance rises to 135 mH immediately after power on, and then decreases by 18 mH with the increase of current.

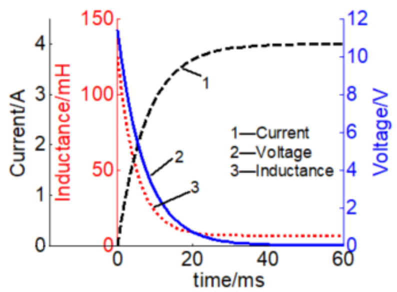


Fig4 current, inductance, voltage curve

The Figure 5 shows the electromagnetic force curve. It can be seen that with the increase of the current, the magnetic flux passing through the air gap of the armature gradually increases, the magnetic induction strength increases, and the electromagnetic force tends to increase. When the current reaches the maximum value in 40 ms, the electromagnetic force reaches the maximum value of 62 N. At this time, the magnetic force generated by the electromagnetic coil of the armature is enough to overcome the compression force of the preloading spring and friction resistance to meet the normal operation.

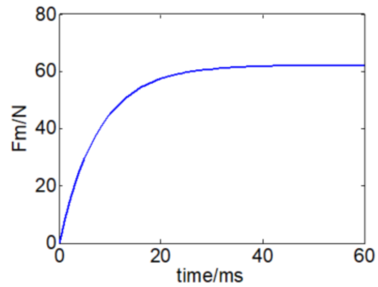


Fig5 electromagnetic force curve

The position estimation results are obtained by integrating the speed estimation results, which are substituted into the fitting function expression of actuator characteristic parameters, and the actuator characteristic parameters in the speed estimation algorithm are corrected in real time. According to the curve of the relationship between current, time and the speed formula of the actuator, the three-dimensional diagram of time-current-position can be obtained, as show in Figure 6. The armature response of automatic transmission by wire is divided into three stages. In the first stage, with the rapid increase of the current, the electromagnetic force gradually increases, which overcomes the preloading spring and friction force, and the armature does not move in this stage. In the second stage, as the current continues to increase, the generated electromagnetic force is enough to overcome the preloading spring and friction force, and the armature begins to move. In the third stage, when the current increases to 4 A, the armature moves 1.2 mm axially and remains stationary. At this time, the armature reaches stable working state.

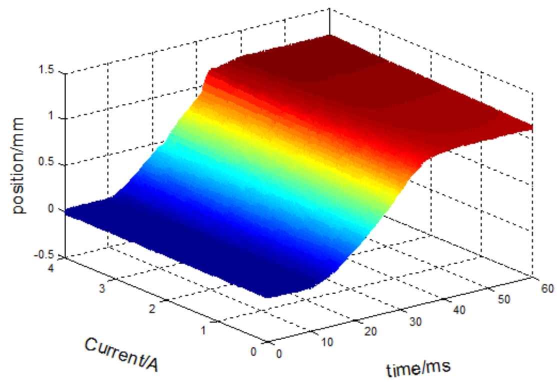


Fig6 three-dimensional diagram of time-current-position

V. CONCLUTION

Based on the principle of back EMF of electromagnetic coil, the position of armature is calculated in this paper. Through the back EMF generated by the electromagnetic coil in the process of electrification, not only the electromagnetic force generated by the electromagnetic coil on the armature can be calculated, but also the armature displacement can be calculated based on the back EMF. According to the simulation analysis, the dynamic response process of transmission-by-wire position sensorless can meet the requirements of electromagnetic coil work and armature position calculation.

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