Application Status and Developing Trend of Key technologies for self-balanced vehicle

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Abstract. This paper introduces the research status of the self-balancing car both at home and abroad and expounds the technical points of self-adjustment detection and the torque ripple as well as its suppression, compared characteristics of existing technology and methods, which provide theoretical evidences for the future research on application. Finally, the paper draws a conclusion in the research of self-balancing techniques and gives a prospect for future development.

Introduction

Currently, the environmental pollution and the traffic congestion are becoming increasingly serious, thus people are searching for a healthy, convenient and environmentally friendly conveyance. Balanceable Single-Wheel Scooter can satisfy travel of short distance needs, involving many fields of power electronics, somatosensory control, ergonomic design etc. It will become a catalyst for the improvement of public traffic network.

At present, researches of two-wheeled self-balancing robot have been rapidly developed in the United States, Japan, Switzerland and other countries. Through the establishment of experimental prototype, many new solutions have been put forward to remove the imbalance in the management system and also made the verification to its automatic balance performance and motion characteristics. Through the transformation of the two-wheeled self-balancing system, it can be easily applied to many situations, such as load bearing, conveyance and other means of transport. In 2004, Researchers at Taiwan's national central university realized the balance control of a two-wheeled by using approached of the fuzzy control. In 2005, University of Science & Technology China developed a two-wheeled self-balancing scooter vehicle. In 2002, Felix Grasser et al. from Swiss Fed Inst Tech-Zuich Switzerland industrial electronic laboratory developed a robot named JOE which is based on the principle of inverted pendulum and controlled by DSP. Segway PT developed by American inventer Dean Kamen and his research team is a mature two rounds of self-balanced robot. With the development of technology and the improvement of people's living standard, two-wheeled self-balancing E-bikes will go deeper and deeper into people's daily work and life.

Key technologies for self-balanced vehicle

With reference to the principle of inverted pendulum, a simple means of transport has been developed by using the self-balancing technology. The key point of this transport is the high-performance dynamic balance control. The key techniques are as follows:

Attitude adjustment and position detection.

The high performance of system for its dynamic control reflected in the fact that it is equipped with left and right wheels and can keep balance by itself. Its control objective is making balance state of the car body recover to the equilibrium position steadily and rapidly after disturbance, and ensuring system dynamic stability. This is the performance requirement for the balance of the control system.

Operation of the permanent magnet brushless DC motor can be achieved through the inverter power devices with the change of the positions of the rotor. Therefore, the key points of its normal operation for permanent magnet brushless DC motor are based on the accurate position detection of rotor. The existing rotor position detecting method can be divided into two types: position sensor and non-position sensor.

Control technology for position sensor. The most commonly used position sensor are photoelectric sensors and hall sensors. The hall sensor is the most widely used sensor due to its convenience and inexpensive price.

Control technology for non-position sensor. Permanent magnet brushless DC motors have been widely used due to their simple structure, high efficiency, ease of control, and low maintenance. When using three-phase six-step 120 degree commutation for traditional Permanent magnet brushless DC motors, position sensors are necessary to sense rotor position information for proper commutation. However, the drawbacks of rotor position sensors in the cost, volume and reliability limit the application of BLDCM. Therefore, researches on sensorless Permanent magnet brushless DC motors are the inevitable trend of development.

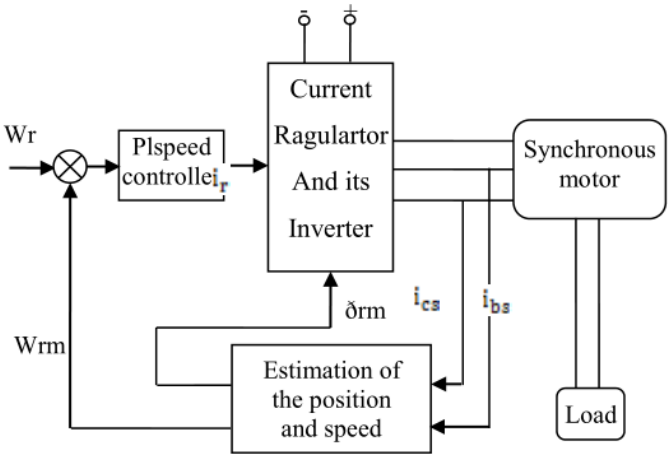

Fig. 1 controlling principle diagram of sensorless permanent magnet motor

The current detection methods for sensorless position signal have the following kinds:

(1)The method of motor model. Induction electromotive force can be obtained from the motor model by parameters of the applied current, voltage, resistance, inductance and mutual inductance. The advantage of this method is that the isolated signal can be obtained because the variables of current and voltage signals of these inputs are independent.

(2) Inductance Method. There are two forms of inductance method: sensorless saliency permanent magnet brushless DC motors and embedded magnet structure of permanent magnet brushless DC motors. In salient pole machine, winding self-inductance L can be expressed as the even cosine function of the included angle H between the winding axis and the rotor direct axis, therefore by detecting the change of L, the rough position of the rotor axis can be worked out, then the polarity can be confirmed according to the variation trend of saturation degree of the iron core, thereby obtain the right position signal. However, because of the great difficulty in realization and the limitations in application of the former method, few people use this method. The latter method has large application advantage, in an embedded permanent magnet brushless DC motor; we can obtain the rotor position signal through the detection of winding inductance with the change of rotor position and produce.

(3) Method of the back electromotive force. Suppose that the peak value of trapezoidal wave induction electromotive force is Ep when angular velocity of electric rotor is ωb, so the rise of instantaneous value of induction electromotive force is

$$e_{as}(t) = \frac{\frac{E_p}{\omega_b}\omega_s t}{\frac{\pi}{6\omega_s}} \quad (1)$$

The output voltage of the sensor is:

$$V_{vs} = \int_0^{\pi/6\omega_s} e_{as}(t)dt \ = \frac{\pi}{12}\frac{E_p}{\omega_b} \quad (2)$$

(4) Artificial intelligence method. The intelligent controller includes a neural network and fuzzy controller; it can get the information of the rotor position or commutation position from the motor variables such as the current and flux. These techniques are adaptive, so that controllers can reach continuous optimization by self-learning over a period of time. The biggest drawback is that the

neural network controller must be self-learning before operation.

(5) The State Observer Method. This method makes a coordinate transformation of the three-phase voltage and electric current of the motor, and estimates the position of the motor rotor based on the Park equation. Since the coordinate transformation only takes the fundamental component into consideration, this method is mainly applied to the brushless direct current motor with sine wave and counter electromotive force.

Interpolation function

In the ideal situation, the operation of permanent magnet brushless DC motor shall meet the following conditions, 1.Three-phase winding is completely symmetrical, and the air gap magnetic field and the stator current must be square waves. 2. Back electromotive force should also be square waves, the duration of square-wave current and the back electromotive force of trapezoidal waves were 120 electrical angle in each half cycle, ensuring strict synchronization. Under these conditions, motors can produce constant electromagnetic torque. The causes of Torque ripple and corresponding suppression methods are as follows:

Torque ripple caused by electric magnetic factor. The torque ripple of this type is produced by the interaction of the stator current and the rotor's magnetic field. Suppression methods includes: Optimization design method of motor, the optimal opening angle method, harmonic elimination method, closed-loop torque control method, etc.

Torque ripple caused by current commutation. The torque ripple of this type is produced by impediment from the instantaneous change of the motor winding inductance in the armature current, and therefore from one phase to switch to another phase will cause torque ripple. Suppression methods includes: current feedback method, overlapping commutation method, PWM chopper method, etc.

Torque ripple caused by cogging. The type of torque is the torque generated by the slot effect of magnetic field of permanent magnet and the stator core in the circumferential direction, which can also be called torque or reluctance torque. Suppression methods includes: magnetic slot wedge method and closed slot method, auxiliary slot method, the auxiliary gear method, slope method, etc.

Trend of development

Compared to other means of transport traffic, studies on self-balancing technologies were started relatively late, it seems that we still have many problems unsolved although the self-balancing car was invented as early as the beginning of the twenty-first century.

The next phase of research direction was discussed as follows, taking the strategy of energy recovery for hub motors and field weakening of motors as examples.

Strategies in energy regeneration.

It can be divided into the following three modes, (1) Emergency brake (2) slight brake (3) constant long-term braking.

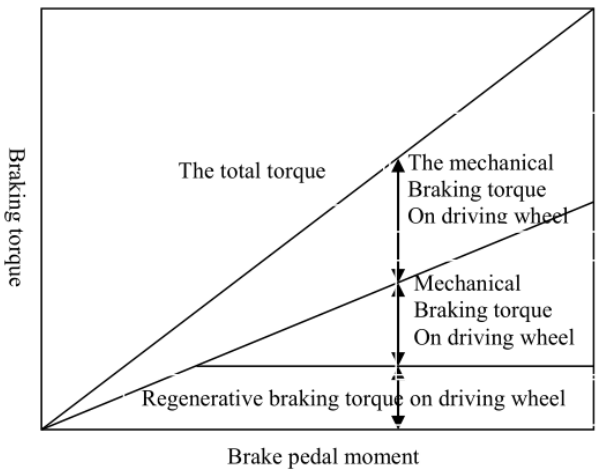

Fig.2 Distribution relationship for electric vehicle regenerative braking torque and mechanical braking torque

According to the characteristics of speed on self-balancing vehicle is relatively slow, electric braking time is the commonly used method of braking. In the field of battery energy storage, we can adopt design scheme of double energy source system. The minimum voltage of the capacitance on the C_0 is:

$$E(\min) = V_{dc} + E_p + \Delta E \quad (3)$$

In the formula, E_p is the maximum induction electromotive force at maximum speed; ΔE is designed to prevent the diode in the negative half cycle of the induced EMF conduction provided by voltage amplitude. The super capacitance has the advantages of large capacity, long life, fast charging charge and discharge, and the wide working temperature range. The super-capacitor gives full play to its function of peak load shifting, reduces the large current's impact to the battery, prolongs service life of the storage battery, increases the charge discharge efficiency of the power source and maximally recycles the braking energy of the vehicle.

Flux-weakening levels.

Since the excitation of the permanent magnet is constant, when the speed is below the base speed, the electric motor controls voltage and speed through PWM (Pulse-Width Modulation), at this moment, the motor's counter potential is in direct proportion to its revolving speed and air gap flux. When the motor operates at the base speed or above the base speed, the terminal voltage is adjusted to its maximum, as the revolving speed rises, the motor's counter potential increases and the armature current decreases. When the counter potential is equal to the terminal voltage, the armature current is zero, which is unable to generate the electromagnetic torque, and as a result, the motor will stop. In order to keep a certain armature current so as to produce electromagnetic torque, we need to implement the flux-weakening control. In the case of the square wave brushless DC motor, the traditional flux-weakening control technique cannot be used directly, thus we need to find a new controlling strategy. Various documents pointed out that we can achieve the equivalent of weak magnetic control by means of open the power device in advance. The current flux-weakening speed adjustable range of the constant power is about 2.8 times larger than the base speed.

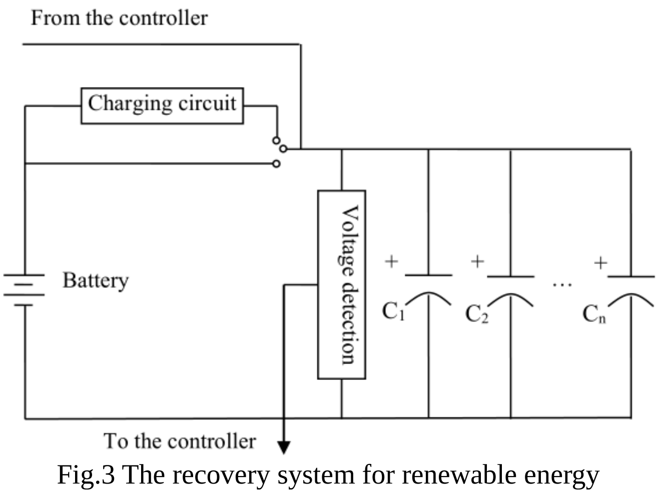

Fig.3 The recovery system for renewable energy

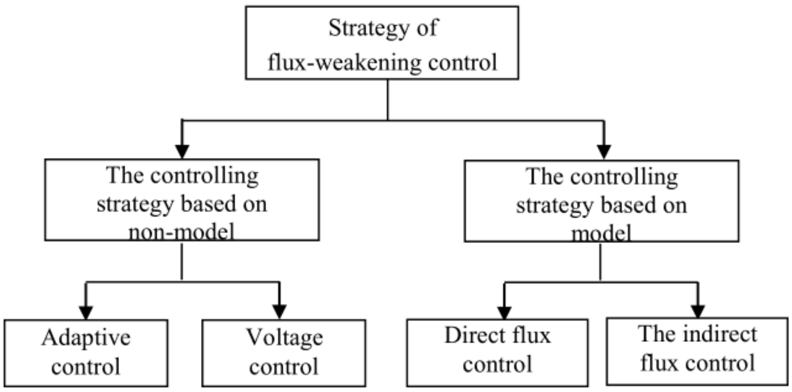

Fig. 4 Classify for Strategy of flux-weakening control

Conclusion

This paper reviewed the key technique of the self-balancing car, and discussed the trend of future research of self-balancing car. At present, the self-balancing car has not been happening on a sufficient scale in China, there is a certain gap compared to developed countries including Japan and American etc. The next step will focus on the research of energy recovery technology from the self-balancing car, providing innovative ideas for research and development

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