Original Article

Research to Improve the Quality of the TD3000 Speedometer Testing Device Applying Vector Control Algorithm

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Abstract - *Nowadays, vector control is being researched and applied in many industries to replace traditional PID control thanks to its advantages, such as easy adjustment, quick response, and high stability. Therefore, this article proposes the application of a vector control algorithm in motor speed control in order to improve the accuracy of TD3000 rotation speed meter testing equipment. The simulation results show that this method has been effective in finding the optimal coefficient for the system to achieve control quality criteria such as small setting errors, fast response times and high stability when loading changes.*

Keywords - Vector control, Power electronics, Electrical measurement, Turn round speed, Device TD3000.

1. Introduction

The TD3000 tachometer testing device is a device used to test tachometers on military vehicles. This device uses a non-contact DC motor to create rotation with a standard number of revolutions connected to the meter to be checked through a mechanical transmission system such as a belt or speedometer wire. The core part of the device is a motor controller made of a 3-phase inverter circuit, controlled by a microprocessor programmed according to the traditional PID control algorithm (PID controller). PID controller has been used very commonly [1-3]. However, this method makes it difficult to optimize the parameters Kp, Ki, and Kd due to the influence of measurement equipment errors and system noise [4]. This method has no basis for determining the optimal value and requires the designer to have experience.

Currently, vector control is being researched and applied a lot in the industry to replace traditional PID control thanks to advantages such as easy adjustment, fast response and high stability. Therefore, the application of a vector control algorithm in engine speed control to improve the accuracy of the TD3000 speedometer testing device is completely close to practical requirements [5-10].

2. Principle of Space Vector Modulation Method

Inheriting the principle of pulse width modulation and applying space vector theory, the vector modulation method was born to organize the switching states of semiconductor valves so that the modulated voltage vector value is calculated.

The calculation is an approximation to the desired voltage vector.

Figure 2 shows the schematic of a three-phase voltage source inverter with three pairs of IGBT semiconductor valves. Corresponding to these three pairs of valves, we have $2^3 = 8$ on and off states of the valves. Corresponding to each valve's on/off state, we obtain a fixed voltage vector (both direction and magnitude). Therefore, we will obtain a total of 8 fixed voltage vectors called 8 standard boundary vectors [6, 7].
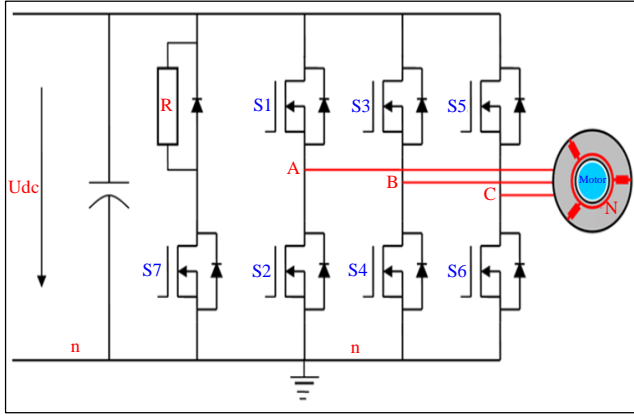

Fig. 1 TD3000 speedometer testing device

Fig. 2 Three-phase inverter diagram

The basis and basic problems of vector control have been presented in detail in [6, 7]. The basic idea of vector control is to convert, according to the motor parameters, a three-phase motor to a two-phase motor, from which the desired control amounts can be calculated. Those results are then converted into three actual phases to affect the instantaneous value of the current, corresponding to the motor's magnetic flux vector.
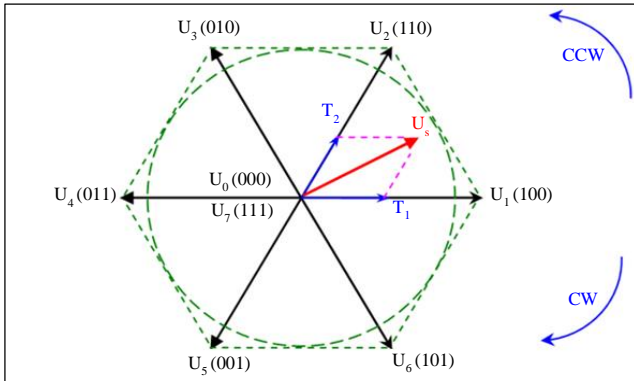

Fig. 3 Synthesize the voltage space vector

On the other hand, vector control allows independent control of the axial and transverse flux components, where the axial component is considered as the armature reaction. This component has the same effect as the armature reaction, and adjusting it will have the same effect as adjusting the excitation in a classic DC machine, thereby expanding the speed range for the motor [5-7]. If controlled by traditional methods, the current and voltage of the motor are in the form of rectangular pulses.

However, if using vector control, the width of the pulses in each pulse beam of the half-cycles is not equal but changes according to the rule. Sine law, by controlling the switching state of the inverter's switches, easily controls the magnitude and rotation speed of the voltage space vector. Then, the inverter output voltage has a sinusoidal PWM form, leading to the electromotive force of the motor having a sinusoidal form, and the current will also have a sinusoidal form.
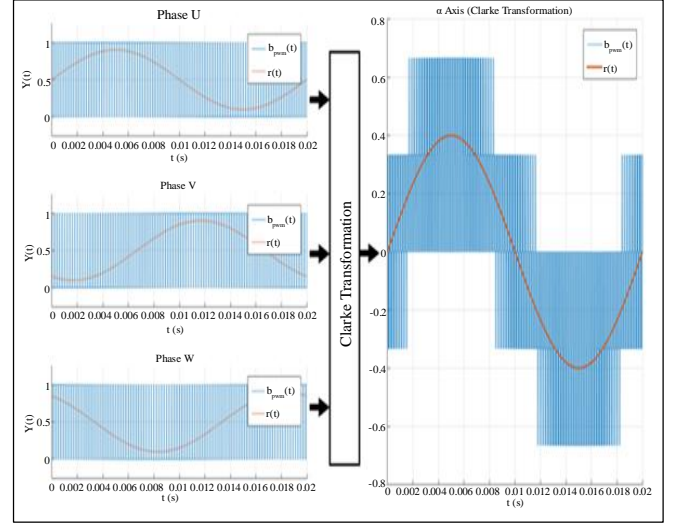

Fig. 4 Control pulse beam and voltage shape on each phase

The representation of the three-phase system is done using the Clarke transform. The result of the Clarke transformation is a rotation vector similar to the flux vector in a generator, which represents a 3-phase power system. The Clarke transformation is a vector synthesis of three instantaneous values, ua, ub, and uc, with rotation angles $2\pi/3$ to create a total vector representing the three-phase system. The vector synthesis formula is as follows.

$$\overrightarrow{u_s} = \frac{2}{3}(u_a + \alpha u_b + \alpha^2 u_c) \qquad (1)$$

Recovering the three single-phase components in the Clarke inverse transform formula is simply a phase shift of the space vector by angles $2\pi/3$.

3. Synthesis of Vector Controllers

As stated in the principle section, the space vector modulation method is a method of creating the desired voltage vector from standard boundary vectors. In this part of the article, details will be presented on the calculation of timing and modulation of boundary vectors to create the desired output voltage vector.

The purpose of modulation is to provide a switching order of semiconductor valves so that the output voltage of the inverter block approximates the applied voltage. Therefore, the information that we are interested in is the time and duration for the valves to perform conduction or locking. The functional block diagram of the electric drive system using vector control is shown in Figure 5.

In calculating the specific modulation time, knowing which sector the applied voltage vector is currently in is extremely important information. Because it decides which pair of standard edge vectors will be modulated. Moreover, the formulas for calculating the modulation time for each sector are also different.
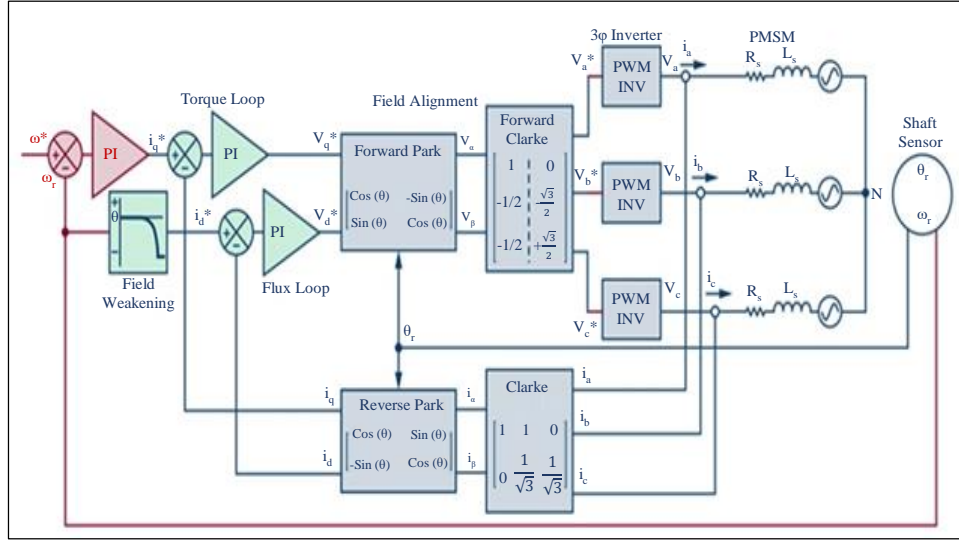
Fig. 5 Block diagram of vector controller

Therefore, first, we must determine the sector containing the vector to be modulated based on the applied voltage vector information. After knowing which two standard boundary vectors the applied voltage vector lies between, we proceed to calculate the component vectors on that standard boundary vector to synthesize the applied voltage vector based on the geometric vector addition method.

At the end of this step, we obtain the ratio of the length of the component vector compared to the standard profile vector.

This is the ratio of boundary vector modulation time in one modulation cycle. From the boundary vector modulation time information, we go to the final step, determining the time and duration of the corresponding valves. Therefore, the sequence of implementing the space vector modulation algorithm will have to perform the following 3 steps in turn:

- Step One: Determine the sector containing the vector to be modulated.
- Step Two: Determine the modulation time of the boundary vectors.
- Step Three: Determine the switching time on each semiconductor valve.

4. Simulation Verifies Research Results

After completing the technical work of the spatial vector modulation algorithm, before turning this algorithm from a theoretical idea into a mathematical formula that can be implemented on a microprocessor, we will use the software Matlab - Simulink simulation to verify the theory as well as the formulas built above [5-7].

The simulation program is written according to the algorithm construction sequence [11, 12], and the functional blocks are simulated in the following order:

- Sector selection block: Calculate the location of the sector containing the vector to be modulated.
- SVPWM switching time determination block: calculates boundary vector modulation time, and block calculates pulse generation time Ta Tb Tc.
- PWM Hardware pulse control block.
- Hardware simulation block of inverter circuit and RL load.
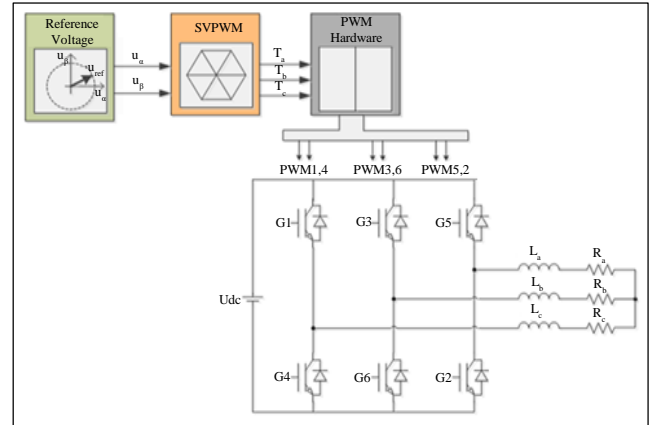

Fig. 6 Block diagram of the open-loop inverter model simulation

The simulation results show the correlation between the load current response in the real circuit and the load current response in the mathematical model. We can observe that these two current responses almost coincide with each other. This shows that the mathematical model has correctly simulated the dynamic characteristics of the vector control algorithm with RL load. The coincidence of the two load lines reflects the accuracy and almost instantaneous application speed of the SVPWM algorithm. From here, we can reaffirm the conclusion that the SVPWM block, along with the inverter circuit, acts as a voltage source that can be controlled in both phase and magnitude.
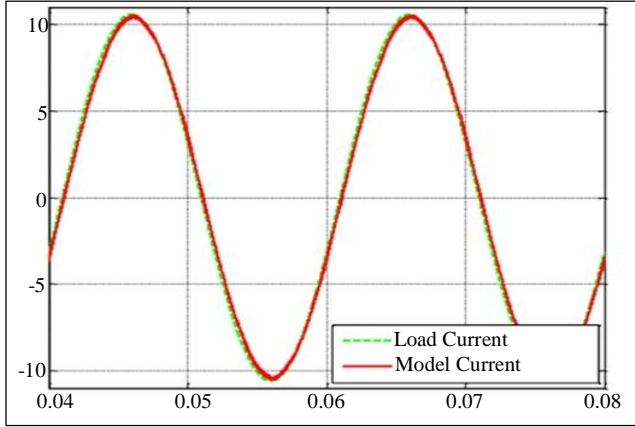
Fig. 7 Meets load current and model current

5. Applying Research Results on TD3000

The TD3000 speedometer testing device has a very ideal structure. The device includes all necessary functional blocks, such as central processing blocks and peripheral blocks, to ensure all research conditions.
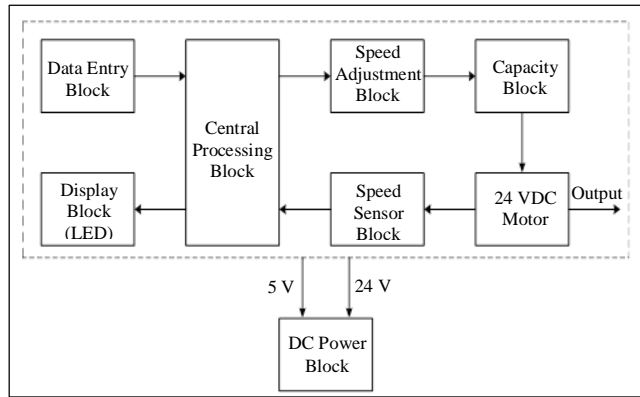

Fig. 8 Block diagram of TD3000 device

In Figure 8, the hardware circuits will execute control signals or measure and convert the necessary quantities into appropriate voltages and send them to the central processing block. The central processing unit controls all operations of the TD3000 device. In Section 3, we have synthesized the order of modulation of boundary vectors for each sector as well as the order of switching on and off the corresponding valves. The modulation pulse sample table allows us to visualize the results of the method.

Basically, current microprocessors all support hardware modulation pulse generation; users only need to load the calculation result values of the vector algorithm into the microprocessor's function registers accordingly. From there, there will be output modulation pulses of the microprocessor. Writing control software for microprocessors is also simplified by exploiting high-level programming tools using the C++ language, combined with the supplier's code compilation tool, so calculations follow the algorithm. Optimized vector control algorithm ensures real-time factor.

Finally, when the TD3000 operates, check and measure the output speed with the PLT200 speed-measuring device with a high accuracy level of $\pm$ 0.01%. Measurement results show that TD3000 has achieved higher quality criteria, small setup error, fast response time and good stability; it achieves high results when the load changes.
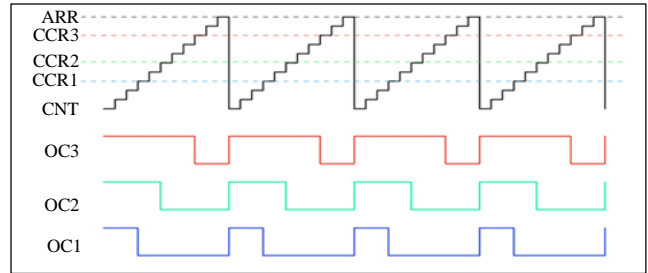

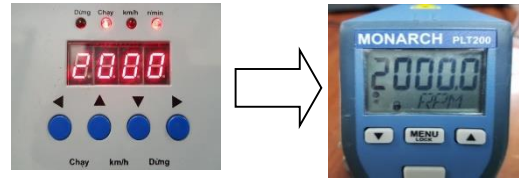**Fig. 9 Microprocessor control pulse generation mechanism**

Fig. 10 Test results of TD3000's speed setting ability

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6. Conclusion

The research content presented in the article has solved the following problems: Synthesizing and evaluating motor speed controllers according to vector control principles. Simulate the motor speed controller according to vector control principles on Matlab Simulink simulation software. Successfully applied the motor speed controller using the vector control method on the TD3000 device. Thereby, it was found that the controller based on this principle has promoted its strengths and produced positive results compared to the traditional controller. The results were verified through simulation using Matlab Simulink and tested in practice on TD3000 devices. The system has achieved control quality criteria such as small setup errors, fast response time and good stability when the load changes.

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