Brushless DC motor control system based on submarine hybrid transmission technology

Wenfang Liu[1], Qiaodi Zhou[2,1], Qinghua Sheng [1], Qingpeng Kong [1]

[1]School of Electronic & Information, Hangzhou Dianzi University

[2]School of Information Engineering, Hangzhou Dianzi University

Email:wenfang1026@126.com

Abstract—The energy and data hybrid transmission technology is one of the most important technologies in the field of submarine investigation and exploitation. It is urgent to study high-power and high-speed hybrid transmission technology. All kinds of submarine equipments, using electric motor to drive the actuating mechanism, require the kind of technology to solve the energy and data hybrid transmission problem. In order to solve this problem, our research team designs and verifies one kind of submarine motor control system, which is based on the Hybrid transmission technology and BLDC (Brushless Direct Current) motor control technology. A single coaxial cable, which has the length of 10km, is used for the high-voltage DC power source transmission. The high-speed data is coupled on the same cable by capacitance. The system can supply 3KW power to submarine equipments. It has achieved good results that the platform on the deck can monitor and control underwater motor system in real time. The experiments show that the system is feasible and practical. It will be used by all kinds of underwater equipments widely.

I. INTRODUCTION

The development and utilization of marine resources, marine environment and security has become the focus of the world economic and technological competition. The motor is used in the submarine equipments widely. DC motor is the good choice in many motors, because it has good controllability and it can output more power in same volume. However, with certain defects, the electric brush of the conventional DC motor limits the life of itself. The system with the motor will cost more for maintenance significantly. The brushless DC motor maintains the excellent characteristics of the DC motors, and replaces the mechanical brush institutions to make the life of the motor extend greatly, and improves its efficiency. Brushless DC motor has been widely used in underwater equipments. The key technical issues need to be addressed for the application of the submarine motor system underwater power supplying, brushless DC motor control, and remote data communication.

There are some solutions to solve the mentioned problems. Submarine power supply technology can be divided into two categories according to the methods. One is that a big high-power battery array is installed in the system additionally. Another is that submarine system gets the power by cables connecting with the deck power source. The latter improves the continuity of the underwater equipment in contrast, and overcomes some disadvantages of the former. Much kind of Remote communication technology has been used into submarine electronic system. It is divided into the optical fiber communication technology and the communication coaxial cable communication technology according to the media. The former has a very high communication speed; however, the system is complex and expensive. So it is always applied in optical system. Because of the semiconductor technology and computer technology has achieved tremendous development; the motor control technology also turns into the stage of digitalization. The motor control technology based on the high-performance microprocessors makes the application of distributed motor control system more flexible. We propose a basic motor control system is proposed ,which can be used as a basic platform for submarine system. a system which is used in the towed submarine detection system is also designed. Afterwards, we will talk about the details of the system.

II. SUBMARINE MOTOR CONTROL SYSTEM SCHEM

A. System architecture

Submarine motor control system integrates a variety of techniques. Its topology is illustrated in Fig.1.

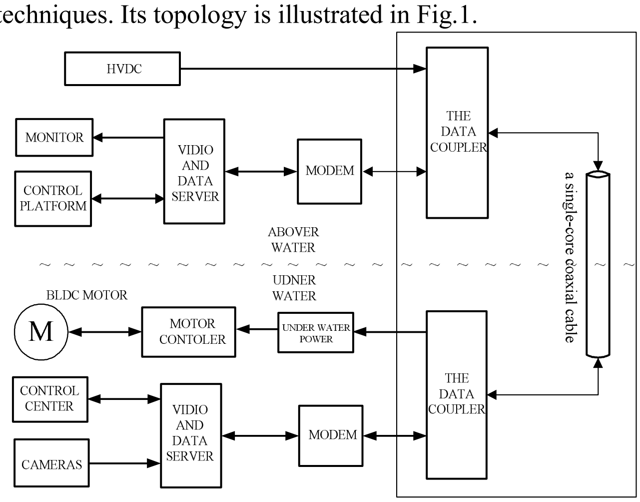

Fig.1 Block diagram of a hybrid transmission system

The system consists of two parts, one is the onboard and another is the underwater. They are connected with a single-core coaxial cable; its length is about 10 kilometer. The onboard electronic source supplies high-voltage DC（HVDC） power to underwater system by the cable. The value of the voltage is adjusted according to the specific application environment. The underwater DC power converts HVDC

This work was supported by National High Technology Research and Development Program of China (No. 2010AA09Z206) and Zhejiang Key Discipline of Marine Technology and Systems.

978-0-933957-40-4 ©2013 MTS

power to DC power of different voltage. The control center onboard sends commands to underwater system by the same single-core coaxial cable. The data will be modulated, and then coupled on the HVDC transmission line by the data coupler. Another data coupler on the other end of the cable separates the data signal from the mixed-signal. The data signal is demodulated to get the real data. In the end, the data is send to motor controller by underwater control center. Underwater modulator and data coupler transmit video data and other data to the onboard system. Based on this principle, we can control submarine motor system and monitor it in real time.

B. Hybrid transmission system design

The hybrid transmission system designed includes the data coupler and the coaxial cable. We must use the armored cable to endure huge strain and stress of the underwater system in the deep ocean. It has some advantages over other forms of conductors. The first is that it is suitable for the transmission of the wide band signals and power; the second is that its geometry confines noise in switching-mode power supply with high frequency to its inner. Information transmission can be combined with power supply on a single coaxial cable saving cost and encouraging simplicity. Fig.2 shows the form of the data and power mixture transmission. The data coupler we design makes it come true finally.

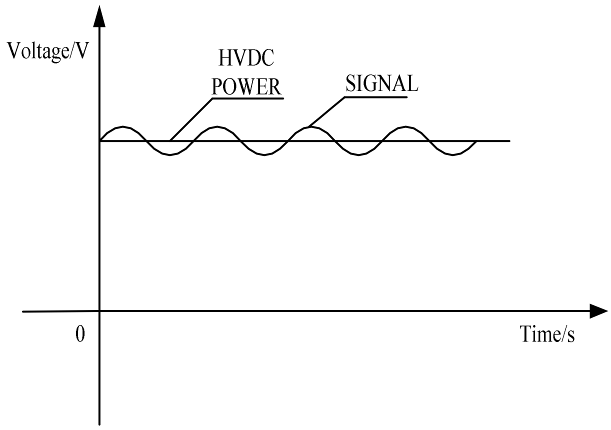

Fig.2 The mixture of Data and Power

In order to achieve efficient transmission of energy, we have to consider the loss during transmission. The resistance of the cable used in the system is the main factor. If we want to get 3000W power on the underwater system, we must use HVDC transmission power to improve efficiency. Then we choose the 1000V, and the efficiency is 84%.

The system uses the SHDSL data access technology to achieve long-distance data transmission. All of the data to be transferred is modulated by a modem and then is coupled on the cable. The data coupler is composed of several filters, including low-pass filter, high-pass filter and common mode filter. As shown in Fig.3 that High-pass filter as long as the role is to provide access to high-frequency data carrier signal, and isolate the high voltage direct current; Low-pass filter is designed to prevent the carrier signal loss and suppress common-mode noise in circuit. The inductors of filters are made of ring-type iron core with the stable and inexpensive characteristics.

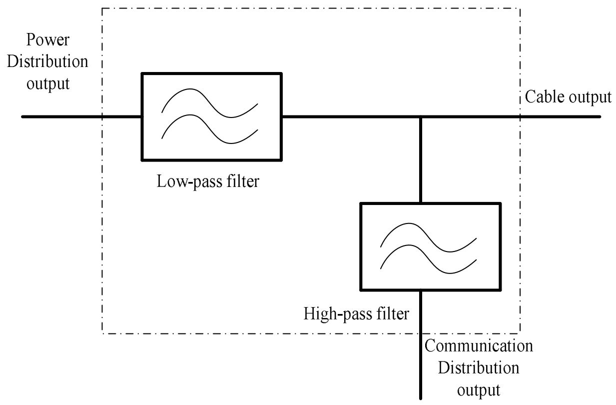

Fig.3 The data coupler basic function block

C. BLDC motor structure and its controller design

The BLDC motor we used has three phase and four poles with the HALL sensor inside. Fig.4 shows the main structure of the motor. In order to driver the motor effectively and stably, the voltage Applied on the motor windings should be controlled accurately.

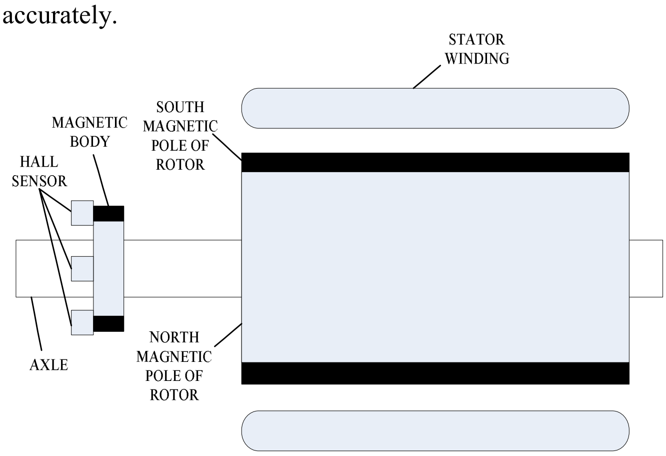

Fig.4 The data coupler basic function block

Actually in order to output the sustained and steady torque, we need to control the current wave reasonably. Now we take an ideal case of the motor into consideration, its equation of induced electromotive force and electromagnetic torque just as follows:

$$E = \frac{2}{3}\pi N_p Blr\omega \tag{1}$$

$$T_e = \frac{4}{3}\pi N_p Blr\omega \tag{2}$$

Where N_p is the number of electric conductor of the motor winding; B is air gap magnetic flux density occurred by permanent magnet of the motor rotor; l is the length of stator core; r is the rotor radius; i_s is The mechanical angular velocity of the rotor; ω is the stator current. Those equations show the induced electromotive force is proportional to the rotor speed and electromagnetic torque is proportional to the stator current.

We choose the STM32 MCU as the core microprocessor of hardware system. The main power circuit of inverter is designed with intelligent power module FSBB30CH60. It enhances driving and application capabilities for BLDCM when the maximum DC voltage is 300V and the maximum current is 10A. The scheme is illustrated as Fig.5.

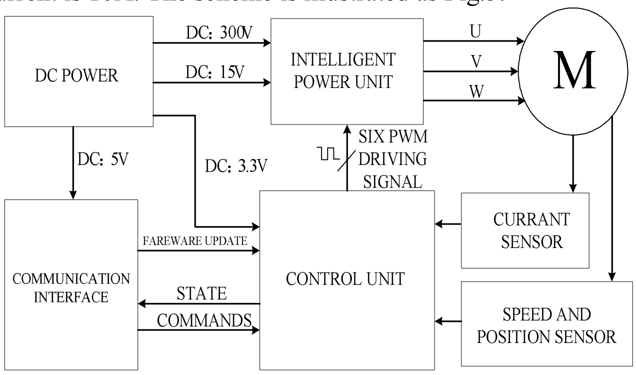

Fig.5 The motor controller function block

The DC power of motor system mainly supplies 300V/10A to drive motor, and some kinds of power modules provide relevant low voltage for different components. A hall sensor is used to detect the position of motor rotor and calculate the speed. In order to improve the speed regulation performance of the controller, the PID control algorithm is designed to achieve double-closed-loop control system. The motor controller receives commands and sends the data via the UART interface which connects to the underwater control center. At last, we complete remote control of the motor.

D. The realization of PID control algorithm

As the uncertainty of the load carried by the motor, its speed and torque will be affected. The system of the motor has the nonlinearity, time-varying parameters, uncertainty and random disturbance; all of those make it difficult to establish the mathematical model. However, the incremental PID algorithm employed by our control system makes the motor achieve ideal effect. Formula (3) is the conventional incremental PID control algorithm. $\Delta u(k)$ is the calculated incrimination during each control interval, $e(k)$ is the error occurred this period, the error of last period is $e(k-1)$, before $e(k-1)$ the error is $e(k-2)$; all of those can be achieved according to the parameters of dual-loops feedback.

$$\Delta u(k) = K_p[e(k) - e(k-1)] + K_i e(k) + K_d[e(k) - 2e(k-1) + e(k-2)] \quad \textbf{(3)}$$

K_p is the proportional gain;

K_i is the integral coefficient;

K_d is the differential coefficient;

By using incremental PID control, the adaptability and stability of the system are enhanced. The process of dual-loops feedback construction including speed loop and current loop are given as follows:

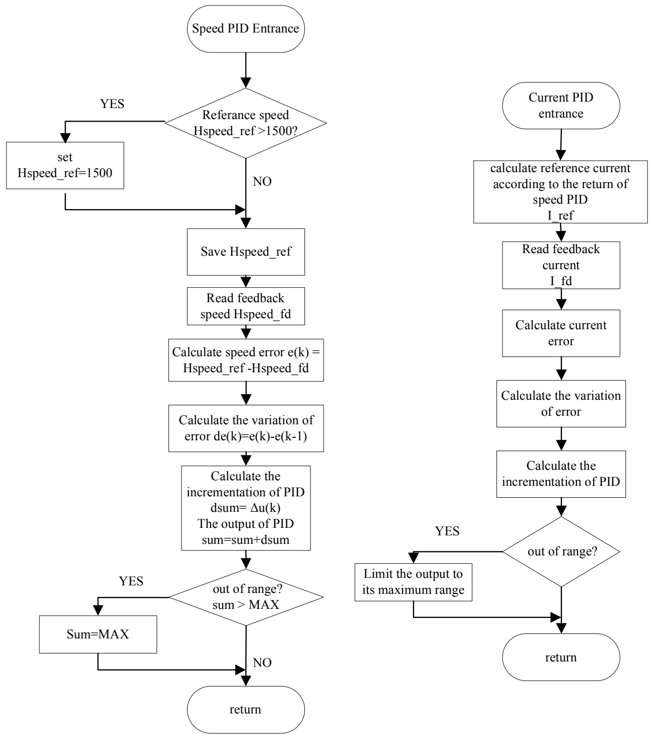

Fig.6 The PID process of speed loop and current loop

III. EXPERIMENTAL RESULTS

We have done a lot of experiments to validate the performance of our designed scheme. We build a simulation platform based on our submarine TV grab (TVG). The type of motor we used is XDLC-4 which is installed in a hydraulic station. We get much valid data. They are shown in the table 1. We can get a result from the test data showed in the table that the scheme achieves design expectations.

Table.1 The result of the experiments

U_S(V)	I_S(A)	P_S(W)	U_P(V)	I_P(A)	P_M(W)	Speed(RPM)	Pressure(MPa)	Video
700	1.20	840.00	300	2.3	690.00	1450	0	GOOD
700	1.48	1036.00	300	3.0	900.00	1450	2	GOOD
700	1.76	1232.00	300	3.6	1080.00	1450	4	GOOD

U_S(V)	I_S(A)	P_S(W)	U_P(V)	I_P(A)	P_M(W)	Speed(RPM)	Pressure(MPa)	Video
700	2.12	1484.00	300	4.2	1260.00	1450	6	GOOD
700	2.86	2002.00	300	5.8	1740.00	1450	10	GOOD
700	3.21	2247.00	300	6.6	1980.00	1450	12	GOOD
700	3.56	2492.00	300	7.4	2220.00	1450	14	GOOD
700	3.92	2744.00	300	8.1	2430.00	1450	16	GOOD

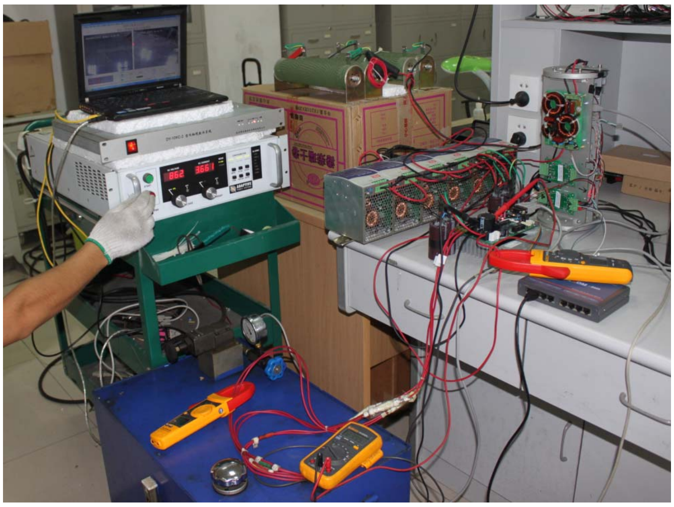

Fig.7 System Testing

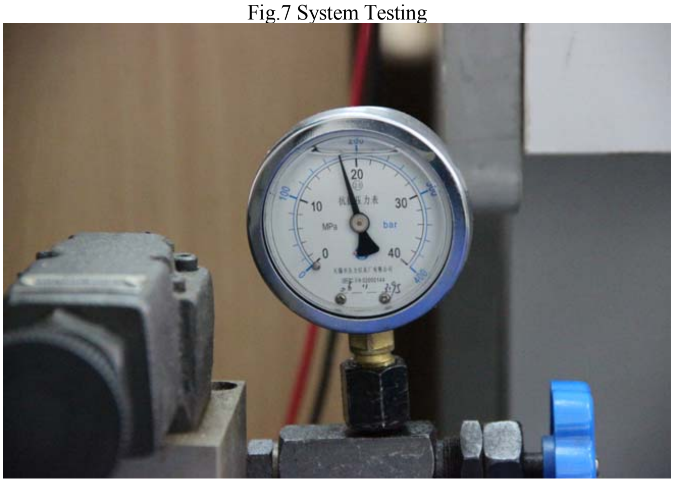

Fig.8 pressure indicator

IV. CONCLUSIONS

This solution not only can be applied in deep-sea inspection system, but also be widely used in many fields. It can be applied to the investigation and monitoring of submarine and offshore marine resources exploration and marine water near the coast and river pollution monitoring and disaster prediction, submarine aquaculture, submarine cable or pipeline operations, underwater vehicles and so on.

ACKNOWLEDGEMENT

This paper is founded by the National High Technology Research and Development Program of China (863 Program) (No. 2010AA09Z206) and Zhejiang Key Discipline of Marine Technology and Systems.

REFERENCES

[1] Asplund G. Application of HVDC Light to power system enhancement. In: Power Engineering Society Winter Meeting, 2000. IEEE, 2498-503
[2] Daecke D. Overview of SHDSL system performance. In: BroadBand Communications for the Internet Era Symposium digest, 2001 IEEE Emerging Technologies Symposium on, 2-6
[3] Liu Huai. Research on Development of Overseas Deep Ocean Technologies[J].Ships & Yachts,Vol.258,6-18,(2006).
[4] Hardt Eric. BLDC motor control options [J]. Electronic Products, 2011, 53(4):128-131.
[5] Niu Haiqing, Xie Yuanxiang. Development of BLDCM and Its Control [J].micro motor,2002,(5):36-38