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SHORT COMMUNICATION

Alternating Current All-electrical Gun Control System in Tanks

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ABSTRACT

The ac all-electrical gun control system is composed of permanent magnetic synchronous machine-drive control systems and the ball-screw by replacing the complicated electrohydraulic systems. At the same time, the variable-structure system with sliding modes makes the gun control systems to have higher performances using the only rate flexure gyroscope. Thereby, vehicle hull gyroscope and angular gyroscope are left out. The new ac all-electrical gun control systems developed are reduced by 40 per cent in weight, decreased by 30 per cent in volume, increased by 35 per cent in efficiency, and enhanced by three times in service life as compared to the current gun control systems.

Keywords: PMSM-drive control system, gun control system, screw drive, flexure gyroscope, permanent magnetic synchronous machine-drive control system, ac motor speed control technology

1. INTRODUCTION

The traverse subsystem of most tank gun control systems is composed of electrical drive control system, and the elevation subsystem is composed of electrohydraulic system.The hydraulic system has many disadvantages, such as leaking oil, firing easily, happening second effect, maintenance complication, higher cost, shorter service life, etc. So every country in the world is trying to improve the elevation subsystem to apply electrical drive control system, thereby, it becomes all-electrical gun control system. In 1970s, UK adopted all-electrical gun control system.whose traverse and elevation subsystems were all amplidyne-motor systems, on Chieftan main battle tank. The system is dc all-electrical gun control system which overcomes many disadvantages of the hydraulic system,but still has some disadvantages, such as large volume, heavy weight, low efficiency, and having brush and commutator.

In 1990s, France's Leclerc main battle tank adopted dc all-electrical gun control system controlled by the pulse width modulation (PWM) which had smaller volume, lighter weight, and higher efficiency, but had the disadvantage of serious electromagnetic disturbance because of still having brush and commutator, which often affect the normal operation of communication system from within and outside of the tank.

Nowadays, the ac motor speed control technology has become mature, and the present study applies the latest ac motor speed control technology to study ac all-electrical gun control system in tanks.

2. MAIN COMPONENTS OF TANK GUN CONTROL SYSTEM

Since the tank gun control system needs to operate on the three states of aiming, stabilisation,

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and servo in the battlefield, its traverse and elevation subsystems are composed of electrical-drive control system, gyroscope, regulators, and mechanical drive set.

2.1 Traverse Subsystem

2.1.1 *Electrical-drive Control System*

(a) *Motor*

Because permanent magnetic synchronous machine(PMSM) possesses many advantages, such as brushless, smaller volume, lighter weight, and higher efficiency, which meet the development needs of the tank gun control technology. It is adopted in the electrical-drive control system,whose permanent magnetic material is samarium-cobalt alloy. PMSM adopts hollow structure/to redude the moment of inertia and to speed up the response of the system.

Let one has the following assumptions to compute the power of the motor required:

Turret weight (G) = 9000 kg

Moment of inertia *(J)* = 2500 N x m^2

Total moment of friction (f_T) < 1500 N x m

Distance between gravitational centre and rotation axis of turret (r) = 0.4 m

Tactics technology demands the maximum rotating speed of traverse subsystem (v_{max}) = 30 °/s

Minimum rotation speed of traverse subsystem (v_{min}) = 0.024 '/s

Maximum acceleration (a_{max}) = 0.5 rad/s^2.

The power of the motor required is computed based on the maximum acceleration as

$$\wedge = (/_r + /«_{max}) \times v_{max}757.3$$

$$= (1500 + 2500 \times 0.5) \times 30 / 57.3$$

$$= 1439.7 \text{ W} \qquad (1)$$

Now the gun was moved at rotating speed of 10 °/s to compute the power of the motor required based on tank listing 15°:

$$P_H = (/_{„} + Gr \sin l5°) \times 10/57.3$$

$$= (1500 + 9000 \times 9.81 \times 0.4 \times \sin!5°) \times 10/57.3$$

$$= 1856.8 \text{ W}. \qquad (2)$$

Finally, the power selected was 2 kW.

The motor of the traverse subsystem, which is decelerated with mechanical-drive set, drives tank turret to rotate, thereby, gun rotates traversely.The deceleration ratio of mechanical-drive set is *i* = 400, then the rotating speed of motor is *n* when the traverse speed of turret/gun is 30 °/s:

$$"_{max} = 30 \times 60 \times I / 360$$

$$= 30 \times 60 \times 400 / 360$$

$$= 2000 \text{ r/min} \qquad (3)$$

When the traverse speed of turret/gun is 0.024 °/s:

$$n_{min} = 0.024 \times 60 \times i / 360$$

$$= 0.024 \times 60 \times 400 / 360$$

$$= 1.6 \text{ r/min} \qquad (4)$$

It is obvious that the power of the motor is 2kW and the rotation speed is 1.6 ~ 2000 r/min.

(b) *Control Modes*

Permanent magnetic synchronous machine (PMSM) adopts sine pulse width modulation (SPWM) control, which is implemented by SLE 4520 chip. SLE 4520 chip is a three-phase PWM programmable integrated circuit which can transform 8-bit digital quantity to three PWM signals to form three-phase SPWM wave cooperated with computer, so as to drive a three-phase converter. It has been shown in Fig. 1 that SLE 4520 chip cooperates with 8031 computer, forms SPWM wave to drive IGBT converter.

The output voltage ((/) of the electrical drive control system changes linearly with frequency(/) namely:

$$\frac{U}{\sim 7 \, J} = \text{Constant} \qquad (5)$$

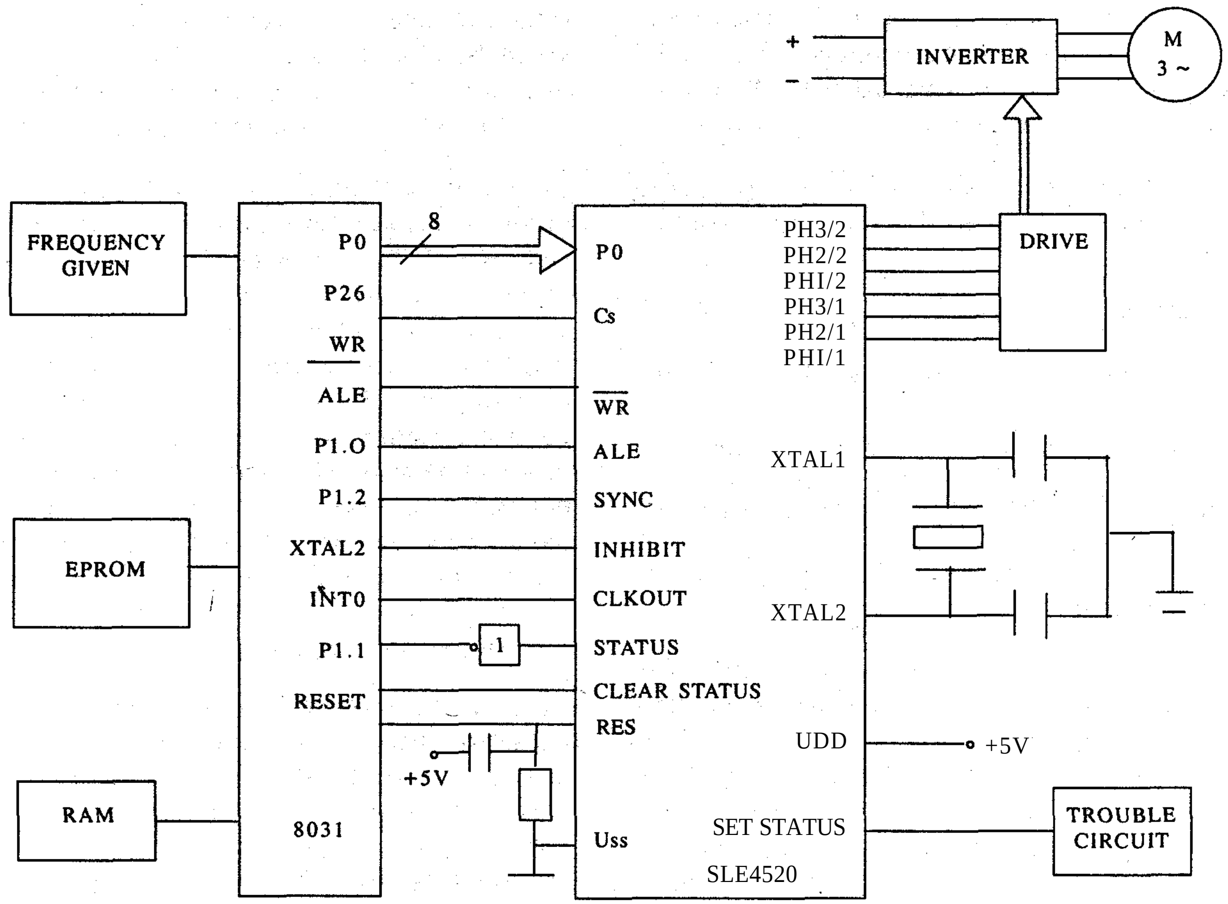

Figure 1. Sine pulse width modulation control implemented by SLE 4520 chip

The control clock frquency(f_{CT}) is computed as follows when the frequency(f) modulation range is 0.5-60 Hz:

$$f_{CT} = 3360 \times f = 1.68 \sim 201.6 \text{ Hz} \tag{6}$$

The pulse modulation width is determined as follows:

$$t_{pu} = \frac{T_t}{2}\left[1 + \frac{M}{2}(\sin \omega t_1 + \sin \omega t_2)\right] \tag{7}$$

where ω is the $2\pi f$, t_{u} is the pulse width, T_t is the period of trigonometric function, M is the amplitude modulation ratio, and t_1 t_2 are the time of intersection points between sine wave and triangle wave.

2.1.2 *Flexure Gyroscope*

During marching forward, the vehicle hull, including gun of the tank vibrates with the undulation of landform so as to affect gun aiming at the target. To keep gun aiming automatically at the target, and make gun not to vibrate with the vibration of the hull, gyroscope is often set on the gun body. When the gun departures the aiming target due to some reasons, gyroscope immediately sends a signal amplified by power amplifier, that is further passed on to electrical-drive system which makes the gun move to the original position until it restores the original aiming angle. This is usually called stabilisation state.

The flexure gyroscope, which has more stable position of gravitational centre (because its rotor is suspended on the axis), is a kind of speed gyroscope developed recently. Simultaneously, the supporting friction, only depending on inner friction of flexible material, is smaller. The flexure gyroscope is a kind of higher performance and lower cost gyroscope which substitutes flexure support for traditional support to bring a series of advantages and is used widely in inertia navigation. After a detailed discussion, the speed flexure gyroscope was used in the studies.

Based on the demand of technology index, the performance data of the flexure gyroscope should be:

Minimum speed sensitivity < 0.02 °/s

Maximum speed sensitivity < 30 °/s

2.1.3 *Composition of Traverse Subsystem*

The traverse subsystem block diagram is shown in Fig. 2. It is made up of the electrical drive control system, gyroscope, and mechanical drive set and regulator.

The speed regulator is proportion integral differential (PID) regulator and the current regulator is proportion integral (PI) regulator in the block diagram. The current feedback element and the current regulator form current loop. The speed measuring equipment, (which is the speed feedback element of the motor) and the speed regulator, make up for the speed loop. The speed gyroscope is used to measure the angular speed of turret/gun departure from the original position and to transform it to electrical signal; the electrical signal, reflecting the angular speed, becomes the angle signal by integral function of PID regulator. So the speed gyroscope and the speed regulator constitute the position loop.

Based on the the traverse subsystem operating on aiming state or stabilisation state, logic judgement and switch element make the traverse subsystem to become two-loop system composed of current and speed loop when operating on aiming state, or that composed of current and position loop when operating on stabilisation state. The former is speed control system which can gain wide speed control range to meet the demand of aiming; the latter is position control system, namely servo system, which has very high response speed. Consequently, traverse subsystem possesses high stable precision.

2.2 Elevation Subsystem

The characteristic of an elevation subsystem is that the rotation of the motor of the electrical-drive control system should be transformed to beeline movement to drive the pitching of the gun. The present study adopts screw drive mode, mainly using ball-screw and nuts to realise the transformation from the rotation of the motor to the pitching of the gun. To reduce the conversion mechanism in length, the valid travel of ball-screw and nut is put

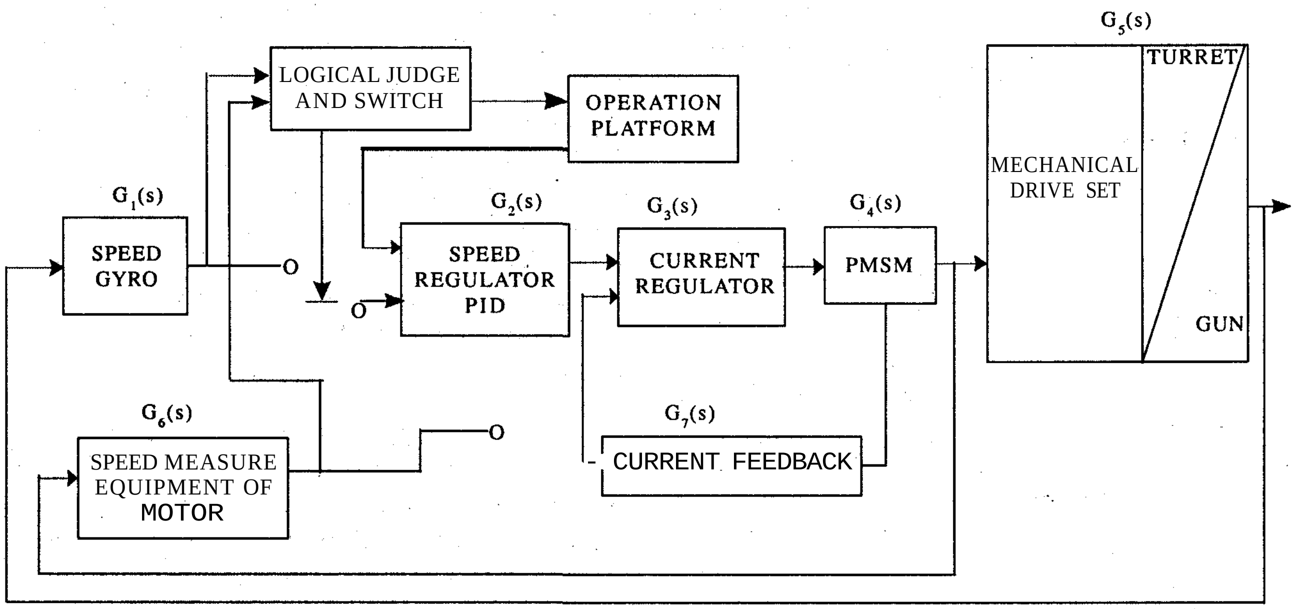

Figure 2 Traverse control subsystem block diagram

Table 1. Comparison of ac all-electrical gun control system with the original system

	Max speed (deg/s)		Min speed (deg/s)		Stable precision (mil)	
	Traverse	Elevation	Traverse	Elevation	Traverse	Elevation
ac all-electrical gun control system	33	8.8	0.021	0.018	1.0	0.6
Original system	18	5.5	0.050	0.050	2.0	1.0

set (composed of amplidyne and its dc drive motor) and dc turret motor [Figs 5(a) and 5(b)]

Direct current 28 V on the tank is inverted into 3-phase ac 18 V to directly supply PMSM also to drive the pitching of the gun by ball-screw in the elevation subsystem of ac all-eletrical gun control system, which replaces complicated electrohydraulic system composed of dc oil-pump motor, hydraulic amplifier, oil tank, and power cylinder, etc. [Figs 6(a) and 6(b)]

Alternating current all-electrical gun control system adopts flexure gyroscope to replace frame gyroscope and accessorial rotary converter and tube amplifier. So, the parts of ac all-electical gun control system are reduced from 11 to 5, its weight reduced from 115 kg to 62 kg, its volume is reduced from 53500 cm^3 to 36500 cm^3, its efficiency is increased from 50.5 per cent to 86 per cent.

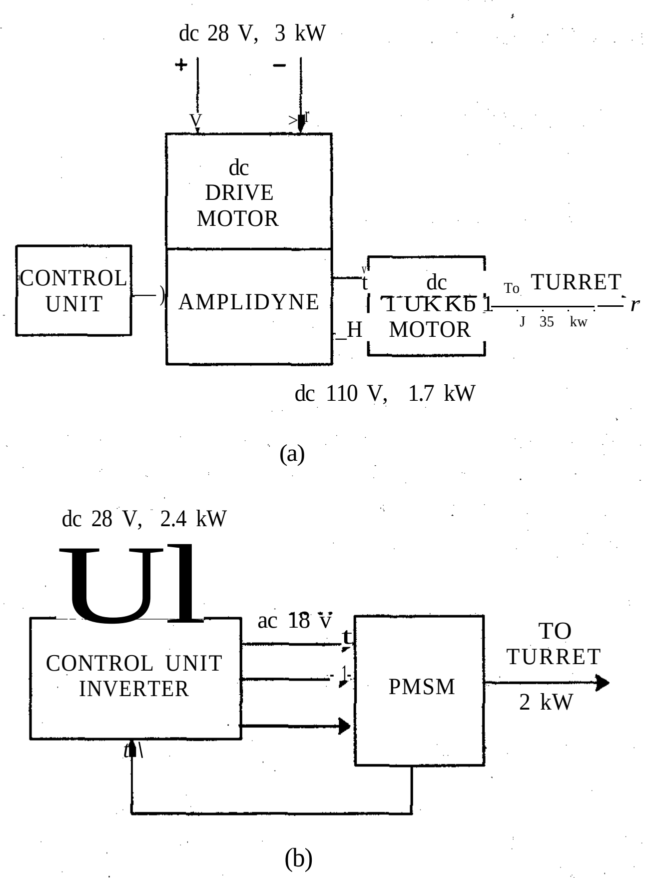

Figure 5. (a) Original traverse subsystem and (b) traverse subsystem of all-electrical gun control system.

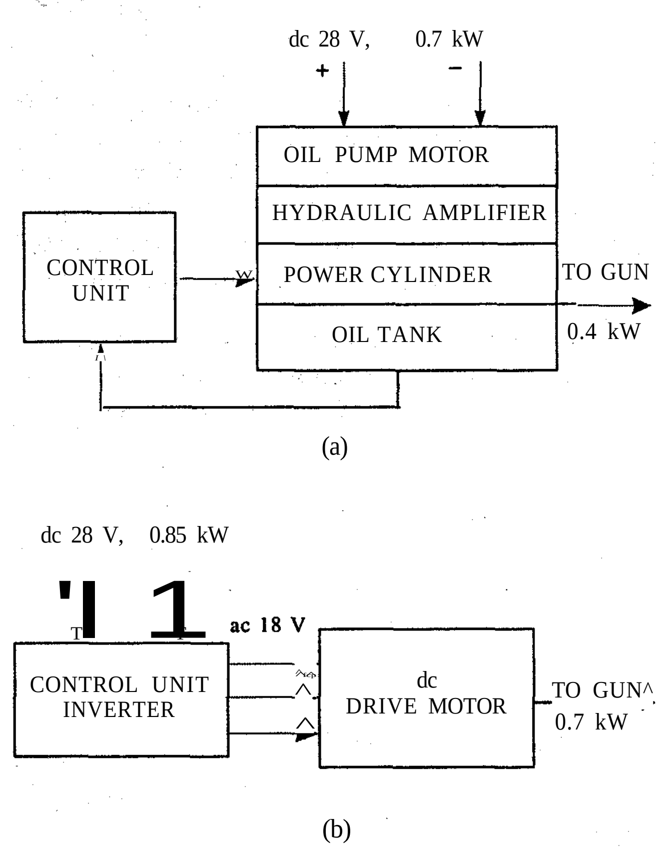

Figure 6. (a) Original electrohydraulic system and (b) elevation subsystem of ac all-electrical gun control system.

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