Xenon lamp control signal and drive circuit design of Er: YAG laser

Chen Chuncheng[1,2,3], Lu Zhiyi[1,2,3], Fan Yisong[1,3], Guo Qiang[1,3*]

[1]Anhui Institute of Optics and Fine Mechanics, Hefei Institute of Material Science, Chinese Academy of Sciences, Hefei 230031

[2]ChinaScience Island Branch of Graduate School, University of Science and Technology of China, Hefei 230026, China

[3]Advanced Laser Technology Laboratory of Anhui Province, Hefei 230037, China

Abstract. When the Er: YAG laser pumped by a xenon lamp emits laser light, the energy, frequency and pulse width of the emitted light are closely related to the discharge of the xenon lamp. This article uses the 8MHz external crystal oscillator that comes with the STM32F4 development board, generates a clock source through frequency division and frequency multiplication, and configures a pulse width modulation (PWM) signal to control the laser. Since the signals sent by the development board are weak signals, it is necessary to design a corresponding drive circuit to amplify the power of the signal. Finally, the voltage of the pulsed xenon lamp is adjustable from 0 to 1400V, and the pulse width is adjustable from 50 to 300μs to achieve stable laser output.

1 INTRODUCTION

Through the $^4I_{11/2} \rightarrow {}^4I_{13/2}$ energy level transition of Er^{3+} in the highly doped Er^{3+} YAG laser [1], a laser of 2.94μm can be emitted. Because of its ability to be strongly absorbed by water, it has become a better choice for medical lasers. As early as the 1980s, after the erbium laser was successfully developed abroad, it began to explore medical applications. Through laser irradiation, the human tissue was vaporized to achieve the cutting effect. A miniaturized and stable erbium laser is still a hot research topic in China, and it is very important to design a stable and efficient control scheme.

With the rapid development of electronic technology [2], more and more chips and processors appear. With the continuous upgrade of ARM chips, STM32 series development boards can already run embedded systems, and more and more lasers use this type of chip to develop and operate control systems. Because the current chips are equipped with abundant peripherals and the performance is also very superior, the laser control system is simpler than before, with higher integration and more functions. With the improvement of chip technology, higher performance STM32 chips will gradually be applied to laser control systems.

The control signals issued by the control system are generally divided into switch-type signals and PWM signals. The output of the switch type signal is a high and low level signal, which directly controls the output to be 0V and 3.3V; the PWM signal is a pulse width modulation signal with an adjustable duty cycle. Because the output voltage and current of the control signal are very small, the power is so low that it cannot drive specific equipment. Therefore, the corresponding control circuit must be designed to obtain the corresponding drive capability. At the same time, when the laser is working, it is necessary to equip the corresponding auxiliary module and design the corresponding power supply circuit.

2 Control signal design

The control of the laser xenon lamp mainly includes the xenon lamp switch key, the xenon lamp voltage value control key, the discharge frequency adjustment key, and the discharge pulse width adjustment key. Among them, the xenon lamp pre-ignition switch can be controlled by controlling the designated I/O port to send high and low levels through the control keys of the human-computer interaction interface. The I/O port of the STM32 development board outputs high and low levels, and the corresponding voltage values are 0 and 3.3V respectively. The xenon lamp voltage and discharge pulse signal are controlled by the modulation pulse width signal of the development board configuration. Xenon lamp discharge signal control requires STM32 development board to output PWM signal (pulse width adjustment signal).

Xenon lamp voltage signal control, through the first PWM signal configuration signal output high level height, to control the corresponding signal output port voltage adjustable between 0~3.3V.

Pulse frequency adjustment control, configure the external crystal oscillator of STM32F407 to 8MHz by

* Corresponding author: qguo@aiofm.ac.cn

configuring the second PWM signal. Set the corresponding frequency divider coefficient M=8[3], the frequency multiplier coefficient N=336, the frequency divider coefficient P=1, and finally the output high-speed clock PLLP obtained by the PLL (high-speed clock):$\mathrm{PLL} = 8\mathrm{MHz} * \frac{\mathrm{N}}{\mathrm{M*P}} = 8\mathrm{MHz} * \frac{366}{8*1} = 84\mathrm{MHz}$.

By selecting HSE (external high-speed clock) as the clock source of the PLL, and setting the SYSTEM clock source to PLL at the same time, the SYSTEM clock is configured to 84MHz. Finally, call the function: void TIM14_CH2_PWM_Init (u32 arr, u32 psc) to complete the frequency division, u32 arr and u32 psc are the auto-reload value and the clock prescaler coefficient. Adjust the pulse frequency by setting these two coefficients. Set u32 psc to 840-1 to achieve 840 frequency division. The clock signal obtained after frequency division is 100KHz, and then only need to set the value of u32 arr to realize the pulse Period is the adjustment of repetition frequency. The specific principle is shown in Fig 1.

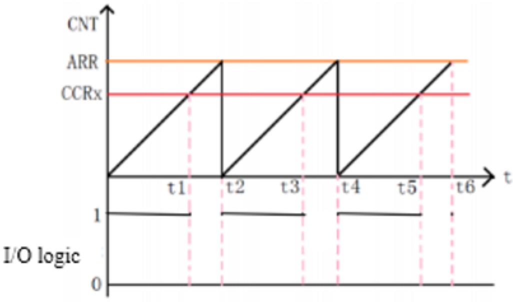

Fig.1. Schematic diagram of PWM principle

As shown in the figure u32 arr setting determines the time t2, the time of a cycle, that is, the frequency is determined. Set the corresponding u32 arr value according to your needs, you can adjust the output signal of different frequencies. According to actual work requirements, we set the frequency from 1 to 30, a total of 30 specific values, and some settings refer to Table 1. Since TIM14_CNT is calculated from 0 each time, we must subtract 1 from the original basis when setting the u32 arr value.

Table 1. Automatic reload value-frequency comparison table

Autoload value	**f/Hz**	**Autoload value**	**f/Hz**	**Autoload value**	**f/Hz**
100000-1	1	20000-1	5	4000-1	25
50000-1	2	10000-1	10	3333-1	30
33333-1	3	6667-1	15		

To adjust the discharge pulse width, we can control the duty cycle of the high and low levels of the cycle. Since we already know that the counting frequency of the system is 100KHz, the time of each counting is 10μs. When the xenon lamp voltage is set, the output duty cycle of CH1 can be controlled by setting the TIM14_CCR1 comparison value, and then the high-level duty cycle can be adjusted to configure the voltage pulse width. Adjust the pulse width by setting PWM_DAC_VAL=Pulsepwmval counter. The commonly used pulse width configuration of the system is shown in Table 2:

Table 2. Pulse width-comparison value comparison table

Pulse width /μs	50	100	150	200	250	300
Comparison value	5	10	15	20	25	30

Through the development board clock technology, the discharge pulse width of the xenon lamp can be accurately controlled, so as to realize the control of the discharge signal of the xenon lamp. Signal code for pulse frequency signal:

```
//TIM14 CH1 PWM output settings
//PWM Output initialization
//arr： Auto-reload value
//psc：Clock prescaler number
void TIM14_CH1_PWM_Init(u16 arr,u16 psc)
{
  RCC->APB1ENR|=1<<16;
  RCC->AHB1ENR|=1<<0;
  GPIO_Set(GPIOA,PIN3,GPIO_MODE_AF,GPIO_
OTYPE_PP,GPIO_SPEED_100M,GPIO_PUPD_PU);
  GPIO_AF_Set(GPIOA,3,3);
  TIM14->ARR=arr;
  TIM14->PSC=psc;
  TIM14->CCMR1|=6<<12;
  TIM14->CCMR1|=1<<11;
  TIM14->CCER|=1<<4;
  TIM14->CR1|=1<<7;
  TIM14->CR1|=1<<0;
}
```

In the main program, the clock signal is set to 100KHz by calling TIM14_PWM_Init(reload,840-1), and the frequency can be adjusted by changing the reload value. By setting PWM_DAC_VAL=Pulsepwmval counter, changing the value of Pulsepwmval to adjust the pulse width duty cycle.

3 Drive circuit design

The main function of the drive circuit is to use the received chip emission signal as a drive signal, and control the on and off of the IGBT after being processed by the drive circuit. At the same time, the circuit should provide protection for the normal operation of the IGBT to avoid some failures. The superiority of the drive circuit can ensure the safety and reliability of IGBT operation. This summary analyzes the design of the IGBT drive circuit. Larger power IGBT drive requires three main performances: it is necessary to ensure that the main circuit is electrically isolated from the drive circuit, the circuit itself has a certain fault protection capability, and it matches the PWM drive signal provided by the system. The realization of power supply work is shown in Fig 2.

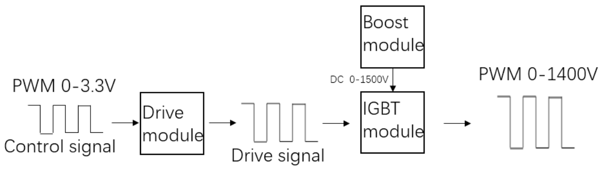

Fig.2. IGBT module control principle

Since IGBT is mainly used to control voltage, it can be turned on and off by adjusting the gate voltage of ICBT, [4] usually has a very low on-state voltage drop when it is turned on. The safe operating area and switching characteristics of the IGBT will change with the adjustment of the drive circuit.

At present, IGBT dedicated drive modules with both driving and protection performance are generally used. The drive circuit designed in this article is shown in Fig 3.

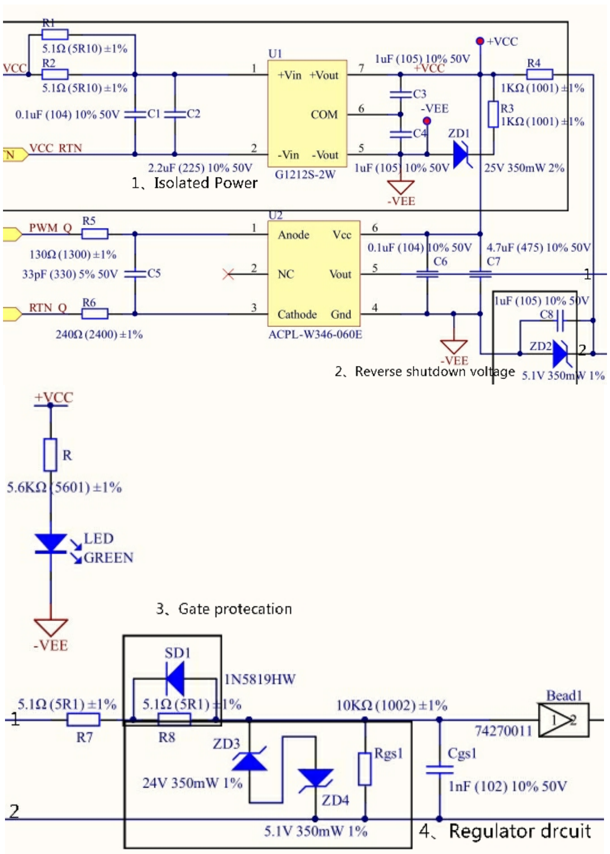

Fig.3. Schematic diagram of the driving circuit

Isolated power supply: The purpose of using isolated power supply is that if the power supply of the drive chip has harmonics, it will cause distortion of the high-frequency drive signal, which is not conducive to the opening and closing of the MOSFET switch tube, and even leads to false triggering. Since the isolated power supply is through a tightly coupled transformer, under the principle of a flyback switching power supply, there is no direct electrical connection between the left and right sides to transmit energy. Therefore, the isolated power supply can be selected to isolate the harmonic signals that have an impact on the drive. Choose G1212S-2W type isolated DC-DC converter, 12V input ± 12V output characteristic to drive the power supply scheme of the chip.

Reverse voltage: The negative bias voltage of the gate can prevent the IGBT from mis-turning due to too much surge current in the turn-off condition. The negative bias voltage is usually set to -5V.

Gate protection part: The driving voltage VGE between the gate and the emitter of the IGBT is at ±20V. When the voltage between the gate and the emitter exceeds ±20V [5], the IGBT will be damaged. In the actual design, a gate voltage limiter circuit should be added to the IGBT drive circuit. When there is an open circuit between the gate and emitter of the IGBT, the voltage applied between the collector and emitter at this time will change with the collector potential. Usually there is a parasitic capacitance between the gate and the collector and the emitter, causing the gate potential to rise, and there will be a current between the collector and the emitter [6], when the collector and emitter are working at a high voltage state, It will cause the IGBT to heat up or be damaged. When the equipment is transported and vibrated, the grid circuit is disconnected. If it is not found and voltage is applied to the main circuit, the IGBT is very easy to cause damage. To avoid this type of event, a resistor of tens of kΩ needs to be connected in parallel between the gate and emitter of the IGBT. This resistor needs to be near the gate and emitter during design. A set of parallel resistors and diodes are connected in series with the gate to ensure that the voltage between the gates can be discharged as soon as possible, so that the IGBT switch tube can be turned off quickly, reducing switching losses.

Voltage stabilizing circuit: Turning off the IGBT will cause a higher drop rate of the collector current, and when the drop rate is high, it will cause collector overvoltage. There are stray inductance and load inductance in the circuit. It is possible that a great surge peak voltage Uce=Ldic/dt will appear at both ends of the IGBT c and e, and the overvoltage withstand performance of the IGBT is insufficient. This situation may cause the IGBT Breakdown, so it is very important to add over-voltage protection when designing the circuit. If the absorption loop is used, when the IGBT is turned off, the energy released in the inductance is absorbed to reduce the turn-off overvoltage. Components are selected during circuit design. In practical applications, capacitor C usually selects high-frequency low-inductance coils around polyethylene and polypropylene. Some ceramics are used and the capacity is about 2F. When the capacitance is selected to be relatively large, the corresponding surge peak voltage will be reduced, and if it is too large, it will not match the discharge time. The resistance R is usually an oxide film non-inductive resistance. The resistance of this resistance should ensure that the discharge time is shorter than the main circuit switching period. It can be calculated by the formula R≤T/6C, where T is the main circuit switching period. The diode needs to satisfy the soft characteristic snubber diode with lower forward transition voltage and shorter reverse recovery time. The specific object is shown in the fig 4:

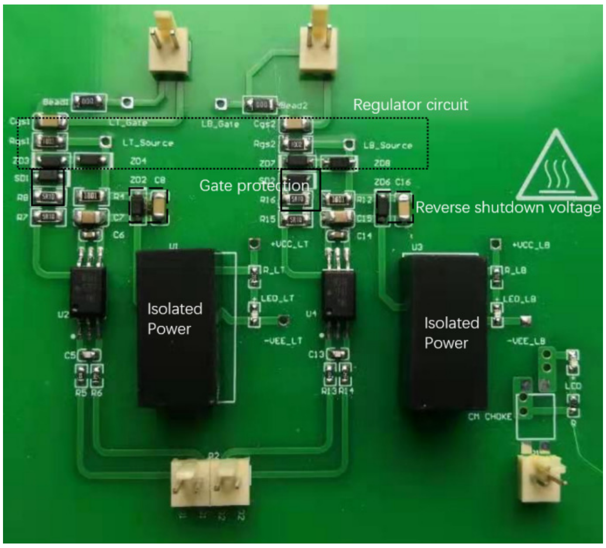

Fig.4. The physical picture of the drive circuit board

4 Results

4.1 Performance test of laser power drive circuit

The frequency and pulse width of the laser light are adjusted according to the frequency and duty cycle of the PWM control signal. Therefore, the quality of the driving circuit directly affects the quality of the laser light. Test the drive circuit designed for this system. In the specific program, configure the prescaler to set the clock frequency to 84MHz. The frequency adjustment is realized by configuring the corresponding waveform period through the timer. Different duty ratios can be obtained by adjusting the corresponding comparison value. In this system, the frequency is configured as 100kHz, and when the automatic reload value is 5000-1, adjust the corresponding comparison value to obtain a frequency of 20Hz. By changing the comparison value, you can get PWM waveforms with different duty cycles, and measure them with an oscilloscope. The results are shown in the figure:

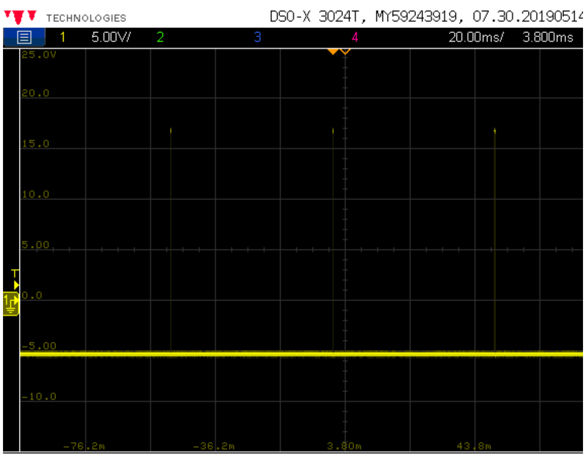

Fig.5. PWM wave with a 20Hz duty cycle of 0.1%

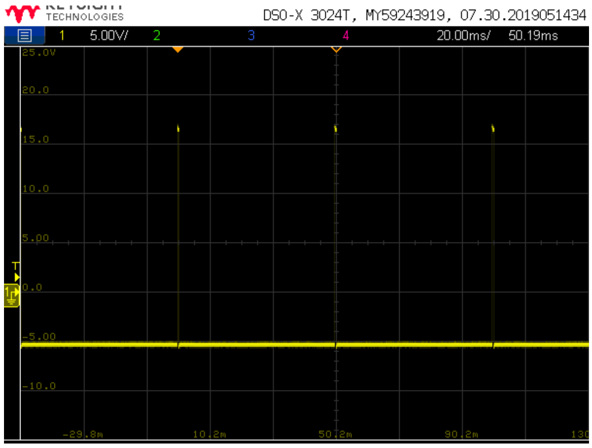

Fig.6. PWM wave with 20Hz duty cycle of 1%

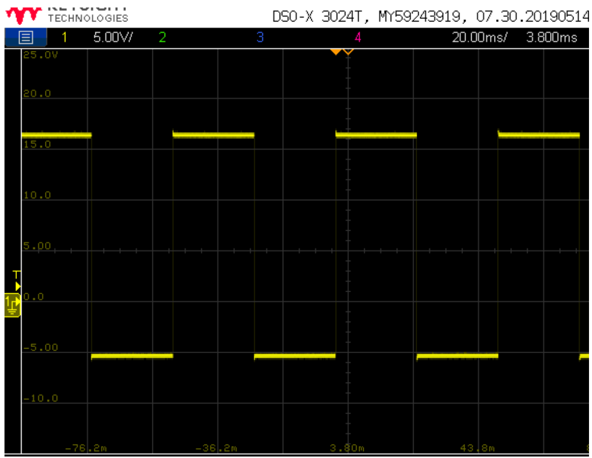

Fig.7. PWM wave with 50% duty cycle of 20Hz

4.2 Laser performance test

The performance of the laser is determined through experiments. In this experiment, the output energy of the erbium laser is measured when working at different frequencies. Since the end face of the crystal is coated with a film, that is, the cavity length of the resonant cavity is 100mm, the size of the laser crystal is φ4×100mm, and the test experiment is carried out in a water cooling mode.

This design has made a comprehensive test on the performance of the laser. The tested laser power is 3kW, the laser capacitance is 60μF, and the pump pulse width is 200μs. When the frequency is 5, 10, 20Hz, the relationship between the injected energy and the output energy is shown in the table

Table 3. The relationship between the output energy of the erbium laser and the injection voltage when the frequency is 5Hz

Inject voltage (V)	800	900	1000	1100	1200	1300	1400
Inject energy (J)	19.2	24.3	30.0	36.3	43.2	50.7	58.8

Output energy （mJ）	4.75	21.5	51.3	90.8	140.2	195.4	255.8

Table 4. The relationship between the output energy of the erbium laser and the injection voltage when the frequency is 10Hz

Inject voltage （V）	800	900	1000	1100	1200	1300	1400
Inject energy （J）	19.2	24.3	30.0	36.3	43.2	50.7	58.8
Output energy （mJ）	4.42	21.31	54.2	98.8	153.7	214.1	279.5

Table 5. The relationship between the output energy of the erbium laser and the injection voltage when the frequency is 20Hz

Inject voltage （V）	800	900	1000	1100	1200	1250	1300
Inject energy （J）	19.2	24.3	30.0	36.3	43.2	46.88	50.7
Output energy （mJ）	4.75	21.5	51.3	90.8	140.2	195.4	255.8

According to the obtained data, the corresponding voltage and energy relationship curve can be obtained through the drawing software, as shown in Fig 7.

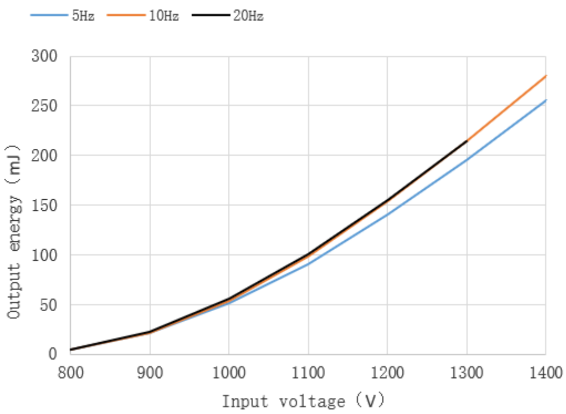

Fig.8. The relationship between xenon lamp voltage and output energy at different frequencies

From the relationship diagram between voltage and energy, we can see that the laser output energy is relatively stable at different frequencies.

5 Conclusion

By measuring the performance of the laser power drive circuit, the pulse width and frequency of the control signal are adjusted. Then the output of the drive circuit is tested, and the result shows that the drive circuit has good performance and can amplify the control signal well without distortion. Then the conversion efficiency and energy of the laser are measured and analyzed. Measure the corresponding laser output energy by adjusting different voltage values. The final result shows that the control signal can perform stable work.

References

1. Ren Zhong. Research on Erbium-doped YAG solid-state laser [D]. Changchun University of Science and Technology, 2002.
2. Tang Yuru. Cortex-A9 Embedded Minimal System Design [D]. Huazhong University of Science and Technology, 2018.
3. Zhang Guofei. Control system design of automobile electronic throttle detection platform[D]. Southeast University, 2018.
4. Niu Renkai. Research on non-contact on-load tap changer of distribution transformer based on power electronic devices[D]. Chongqing University, 2015.
5. Renqin Dou, Preparation of 2.9μm rare earth tantalate laser material, 2017, University of Science and Technology of China.
6. Li Zhifeng. Switched reluctance wind power generation system simulation [D]. Tianjin University of Science and Technology, 2010.