Modernization of the Control System of the Abrasive Stone cutting Machine with a Reinforced Rope

Krasneuski Dzianis, Shaban Lizaveta, Sushko Hanna, Alexander Svistun, Pantsialeyeu Kanstantsin

Abstract— The object of development is an automated control system for an optical grinding machine. The aim is to modernize the existing control system of the stone wire abrasive cutting machine. In the process of development, an automated control system for an optical machine for abrasive stone cutting with a reinforced cable based on an STM32 microcontroller was developed, control boards were developed and performance tests were carried out. The development stage: the system has been introduced into production.

Keywords— microcontroller, abrasive stone cutting machine with reinforced rope, encoder, control, automation.

I. Introduction

The wire rope abrasive stone cutting machine is easy to manufacture, design and cheap. Consider its general design, shown in Fig. 1 [1].

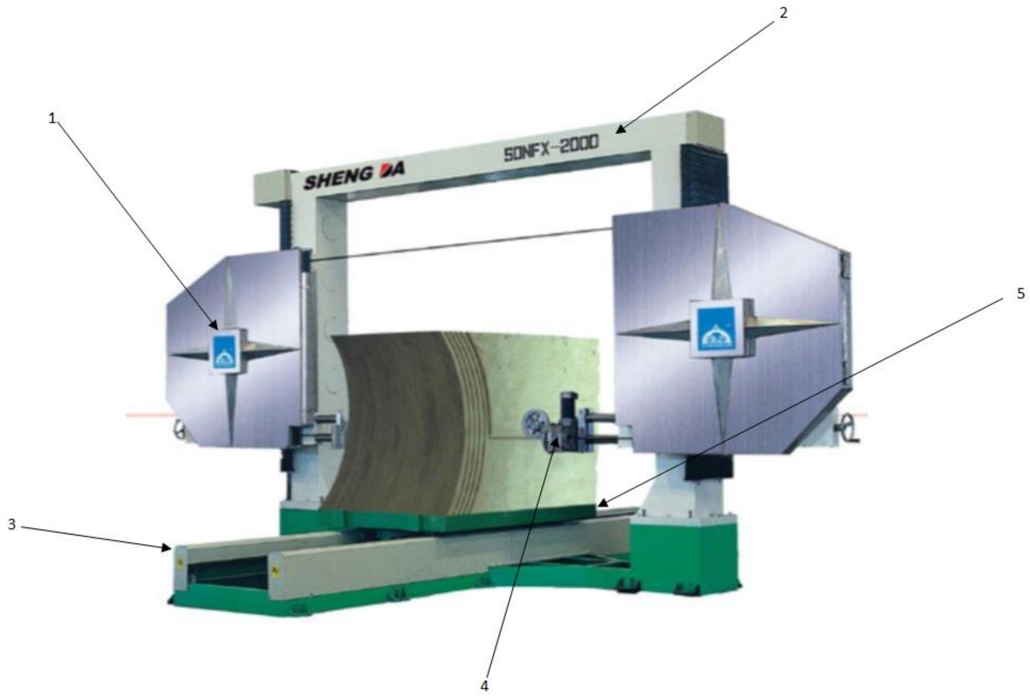

Fig. 1. Machine for abrasive cutting of stone with a reinforced rope: 1 – wheel with one electric motor; 2 – machine frame with toothed guides; 3 – bed with toothed guides for the table; 4 – device for finally tightening the reinforced cable; 5 – table

The principle of the machine is built as follows. The wheels of the wheel are reinforced cable, and the electric motor rotates and drives the cable up to high speeds. The whole system then moves down the frame, along the cogged rails, using another electric motor. Then, when the

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passage of the reinforced cable to the end was completed, the table, along with the workpiece, moves along the bed and rotates [2].

To ensure safety, the system is equipped with limit switches that turn off the electric motors when the base material is cut, and optoelectronic sensors for human action in the perimeter of the installation.

Modification of this installation to perform fully automated work allows you to adjust the parameters of the machine, thereby adjusting it to various materials, volumes of work and reducing wear on equipment and components.

II. Literature Analysis

A. General structure of the control system

To implement the control scheme, the following blocks were implemented:

• Control block;
• Personnel protection unit;
• DC motor control unit;
• Block for measuring system parameters;
• Display unit;

The control unit, based on the STM32 microcontroller, is designed to process data received from the device sensors and form a control mode based on this data.

The personnel protection unit monitors the presence of a person in the danger zone of the machine. If the operating mode is violated, a sound signal will be given.

The DC motor control unit is used to turn on and regulate the speed and direction of rotation of the belt feed motor, depending on the operating mode of the system: if the belt on the conveyor is covered more than the specified distance, the motor changes direction of rotation, unwinding the belt to the desired size.

The unit for measuring system parameters sends an information signal and sends it to the control unit for further processing.

The display unit displays the system parameters on the display, or any other indicator.

III. Object, Subject And Methods Of Research

The electronic control system is responsible for the following machine parameters:

– rotational speed of the motor shaft, which is responsible for the cutting speed;
– speed of lowering of the frame with the cutting cable;
– table movement along the frame;
– table rotation.
– Fig. 2 shows the control panel diagram.

The operation algorithm of the control system of the abrasive stone cutting machine with a reinforced cable is as follows: two potentiometers are responsible for the rotation speed of the electric motors, changing the supplied power, and therefore the rotation speed. Toggle switch number 3 is responsible for the type of movement of the table, it will rotate or move along the cable. The toggle switch at number 4 is responsible for the direction of movement, clockwise or counterclockwise, when rotating and backward forward, when the table moves longitudinally.

Also, in the control system, automated cycles of the machine's operation are thought out. When one of the buttons numbered 7, 8 or 9 is pressed, one of the work cycles programmed in the microcontroller will be started. This will disable the manual control panel and will not function until the cycle is interrupted or ended.

To display the current parameters of the system, pins were placed on the board, allowing you to connect a display or additional sensors to them, at the request of the technical task.

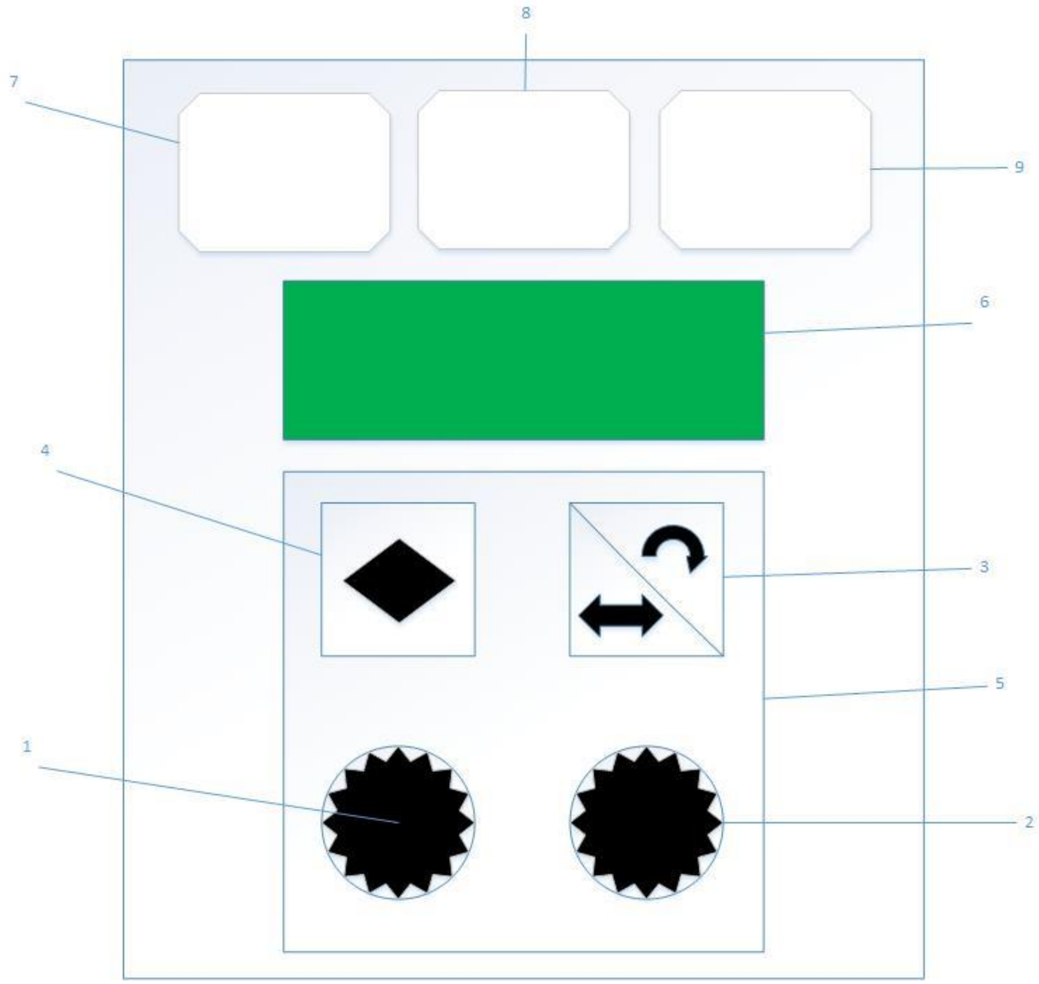


Fig. 2. Diagram of the control panel: 1 – potentiometer responsible for cutting speed; 2 – potentiometer responsible for the lowering speed of the frame with the cutting cable; 3 – toggle switch corresponding to the type of movement (rotation or longitudinal movement); 4 – toggle switch responsible for the direction of movement or rotation of the table; 5 – manual control unit; 6 – indicator (display); 7–9 – buttons responsible for activating a pre-assigned cycle

IV. RESULTS

A. Control block

To implement the control unit, the STM32F103C8T6 microcontroller is used (Fig. 3). STM32F103C8T6 (hereinafter STM32) is a low-power, but at the same time high-performance microcontroller. It can be powered by a 2V 72MHz core clock with all peripherals turned on and only draw 36mA. In power saving mode, the STM32 consumes 2 µA.

One of the requirements for modern devices is to ensure the safety of the program code from unauthorized access. For STM32 Flash memory, read protection through the debug port can be set. When read protection is enabled, Flash memory is also write protected to prevent the possibility of incorrect code being placed in the interrupt vector table. STM32 microcontrollers also contain a real-time clock and a small battery-powered SRAM area. The contents of this area are automatically cleared by an interrupt from the Tamper Protection Module [3].

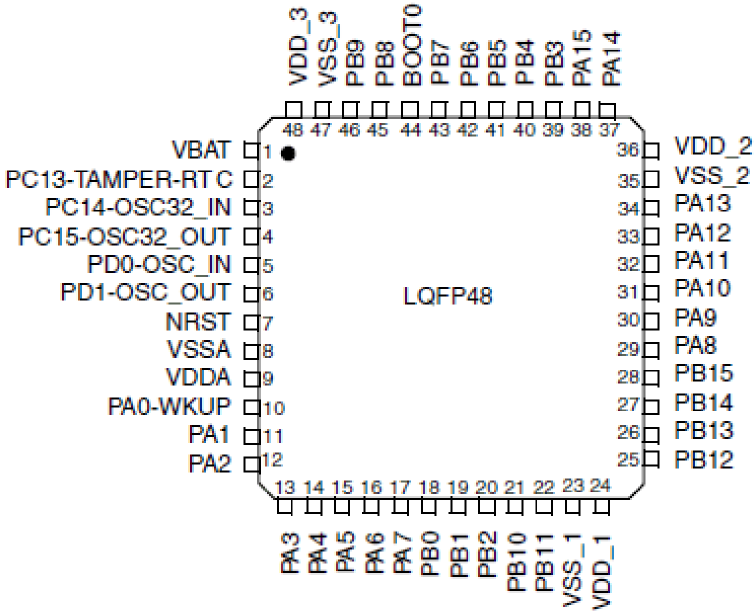


Fig. 3. UGO STM32F103C8T6

The STM32 requires a single power supply with a voltage ranging from 2.0V to 3.6V. An on-board regulator is used to generate 1.8V for the Cortex core. STM32 can have two additional power supplies. When using an ADC, the VDD power supply voltage must be between 2.4 V and 3.6 V. The 100-pin packages have additional pins, VREF + and VREF-, to connect the reference signal. The VREF- pin is connected to VDD, and VREF + should be between 2.4V and VDDA. In all other packages, the reference signal is internally connected to the ADC power supply pin. Each voltage source must have stabilizing capacitors.

The STM32 is well equipped with general purpose GPIO I / O ports and can have up to 80 bi-directional pins. They are grouped as five ports, each containing 16 I / O lines. Each digital pin can be configured as a GPIO pin or as an alternative function pin. Each pin can simultaneously operate as one of 16 external interrupt lines.

The ports are labeled A through E and are all 5V tolerant. Many of the external pins of the microcontroller can be switched to serve user peripherals such as the USART or I2C instead of performing I / O functions.

The individual pins of each GPIO port can be configured as input or output of various drivers. Ports contain registers into which you can write information in word format or manipulate their bit fields. After making the settings, the registers can be locked.

A port pin can be defined as input or output, and its load characteristic can be selected. If the pin is defined as an input, the built-in register can be used to "pull" the pin to ground or supply voltage. If the pin is defined as an output, it can be configured as push-pull or open-drain. Each output can also be configured to operate at frequencies up to 2 MHz, 10 MHz, or 50 MHz.

In addition to an excellent set of general-purpose peripherals, the STM32 contains five different types of communication peripherals. The STM32 contains SPI and I2C interfaces to exchange information between components on a printed circuit board. There is a CAN bus for communication between different modules of the device, and a USB device interface for communication with a PC. The STM32 also uses the popular USART interface.

For fast data exchange between PCB components, the STM32 contains two SPI modules, which provide full duplex data transmission at frequencies up to 18 MHz. It is important to note that one of the SPI modules is located on the APB2 high-speed peripheral bus, which operates at up to 72 MHz. The second SPI is located on the low speed APB1 bus, clocked at up to 37 MHz. For each SPI, you can set the clock polarity and phase. Data can be transmitted as 8 or 16-bit words, MSB or LSB first. This allows both SPI modules to act as master or slave and communicate with any other SPI device.

To organize high-speed data exchange, each SPI module contains two DMA channels: one for transmitting data and the other for storing received data in memory. The use of DMA allows high speed data exchange in two directions under hardware control.

STM32 can communicate with other components on the PCB via I2C interface. The I2C interface can operate as a slave or master, and arbitrate in a multi-master system. The SPI interface supports standard data rates up to 100 kHz and fast data rates up to 400 kHz. The I2C module supports 7-bit and 10-bit addressing modes. Essentially, the I2C module simply transmits and receives data over the bus. The I2C module generates two interrupts for the Cortex processor, one to limit error propagation and one to control addresses and data transfers. In addition, two DMA channels are allocated through which you can read from and write data to the I2C transmit buffer. Thus, after coordinating the addresses of devices in the network and data for transmission, the exchange of information can be carried out under the hardware control of the STM32.

The STM32 contains up to three USARTs, each of which supports several advanced modes to work with modern serial devices. Each of the three USARTs can communicate at speeds up to 4 Mbps. For each USART, you can set the data length (8 or 9 bits), parity stop bit and baud rate. One USART is located on the APB2 bus, which operates at up to 72 MHz, while the rest are on the APB1 bus, which clocks at up to 36 MHz.

B. The diagram for controlling the speed and direction of movement of the DC motor shaft

To control the speed and direction of movement of the DC motor shaft, we used a circuit coupled with a control unit based on the IRS2186 microcircuit of the 74HCT08 logic gate and the FGH40N60SMD transistor [5].

The 8-pin SOIC IRS2186 is a high voltage, high speed MOSFET and IGBT driver with independent output channels. Patented anti-latching HVIC and CMOS technologies provide a solid monolithic design. The logic input is compatible with standard CMOS or LSTTL output, up to 3.3V logic. The output drivers have a high surge current buffer stage designed to minimize driver cross-conduction. The IRS2186 is a 600V low and high level driver. Driver output currents are ± 4 A, 3.3 and 5 V control logic compatibility, undervoltage protection.

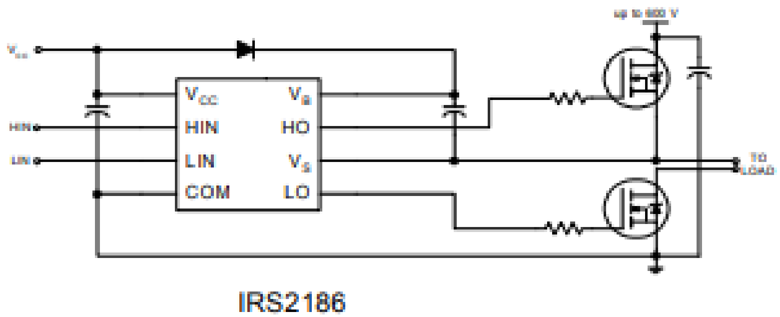


Fig. 4. Connection diagram of the IRS2186 driver

In many situations, we have to use field effect transistors as top-level switches. Also, in many situations, we must use field-effect transistors as switches, both high and low levels. For example, in bridge circuits. In incomplete bridge circuits, we have 1 high level MOSFET and 1 low level MOSFET. In full bridge circuits, we have 2 high level MOSFETs and 2 low level MOSFETs. In such situations, we need to use both high and low level drivers together. The most common way to drive FETs in such cases is to use a low and high level key driver for the

MOSFET. By far the most popular driver IC is the IRS2186. And in this article I will talk about it.

Let's first take a look at the block diagram and the description and pin locations in Fig. 5 and Table 1.

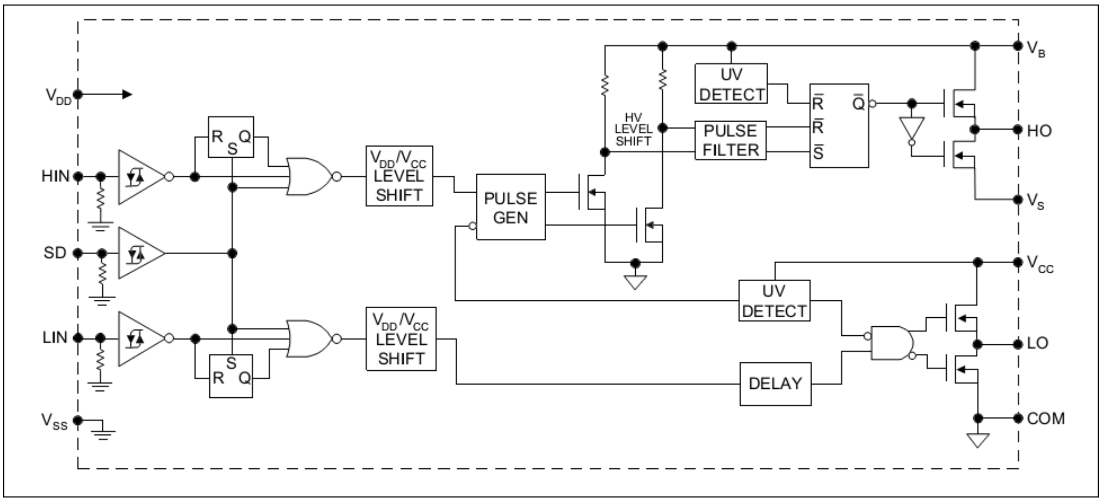


Fig. 5. Functional block diagram of IRS2186

Table 1. Description of IRS2186 pins

Symbol	Description
HIN	Logic input for high side gate driver output (HO), in phase
LIN	Logic input for low side gate driver output (LO), in phase
V_{SS}	Logic ground (IRS21864)
V_B	High side floating supply
HO	High side gate drive output
V_S	High side floating supply return
V_{CC}	Low side and logic fixed supply
LO	Low side gate drive output
COM	Low side return

It's also worth mentioning that the IRS2186 comes in two packages – a 14-pin PDIP for pin mount and a 16-pin SOIC for surface mount.

Now let's talk about different contacts. VCC is the low level power supply, must be between 10V and 20V. VDD is the logic power for the IR2110, it must be between + 3V and + 20V (relative to VSS). The actual voltage you choose to use depends on the voltage level of the input signals.

Usually a VDD of + 5V is used. At VDD = + 5V, the input threshold of logic 1 is slightly higher than 3V. Thus, when VDD = + 5V, the IR2110 can be used to drive a load when the "1" input is higher than 3 (somewhat) volts. This means that the IRS2186 can be used for almost all circuits, as most circuits tend to be powered by about 5V. When you use microcontrollers, the output voltage will be higher than 4V (after all, the microcontroller often has VDD = + 5V). When a SG3525 or TL494 or another PWM controller is used, it is likely that they will have to be powered with a voltage greater than 10V, which means that the outputs will be more than 8V with a logic one. Thus, the IR2110 can be used almost anywhere.

You can also lower the VDD to about + 4V if you are using a microcontroller or any chip that provides 3.3V output (eg dsPIC33). When designing circuits with the IRS2186, I noticed that sometimes the circuit does not work as expected when the IR2110's VDD is less than + 4V. Therefore, I do not recommend using VDD below + 4V. In most of my circuits, signal levels do not have a voltage less than 4V as "1" and therefore I use VDD = + 5V.

If for some reason in the circuit the level of the logic "1" signal has a voltage less than 3V, then you need to use a level converter / level translator, it will raise the voltage to acceptable limits. In such situations, I recommend raising to 4V or 5V and using the IRS2186 VDD = + 5V.

Now let's talk about VSS and COM. VSS is the land for logic. COM is "low return" - basically the low ground of the driver. It might look like they are independent, and one might think that it might be possible to isolate the driver outputs and the driver signal logic. However, that would be wrong. Although not connected internally, the IRS2186 is a non-isolated driver, which means that VSS and COM must both be connected to ground.

HIN and LIN are logic inputs. A high signal at HIN means that we want to control the high key, that is, a high level is output to HO. A low signal on HIN means that we want to turn off the high-level MOSFET, that is, a low-level pin is made on the HO. The output to HO, high or low, is considered not relative to ground, but relative to VS. When the level is high, the level at HO is equal to the level at VB, in relation to VS. At a low level, the level at HO is VS, in relation to VS, virtually zero.

A high LIN signal means that we want to drive a low switch, that is, a high level output is carried out on LO. A low LIN signal means that we want to turn off the low level MOSFET, that is, a low level pin is applied to LO. The exit to LO is relative to ground. When the signal is high, the level in LO is the same as in VCC, relative to the VSS, effectively ground. When the signal is low, the level in LO is the same as in VSS, relative to VSS, effectively zero.

SD is used as stop control. When the level is low, IR2110 is enabled - stop function is disabled. When this pin is high, the outputs are turned off, disabling control of the IRS2186.

Now let's take a look at the frequent configurations with IRS2186 to drive MOSFETs as high and low switches - half-bridge circuits (Fig. 6).

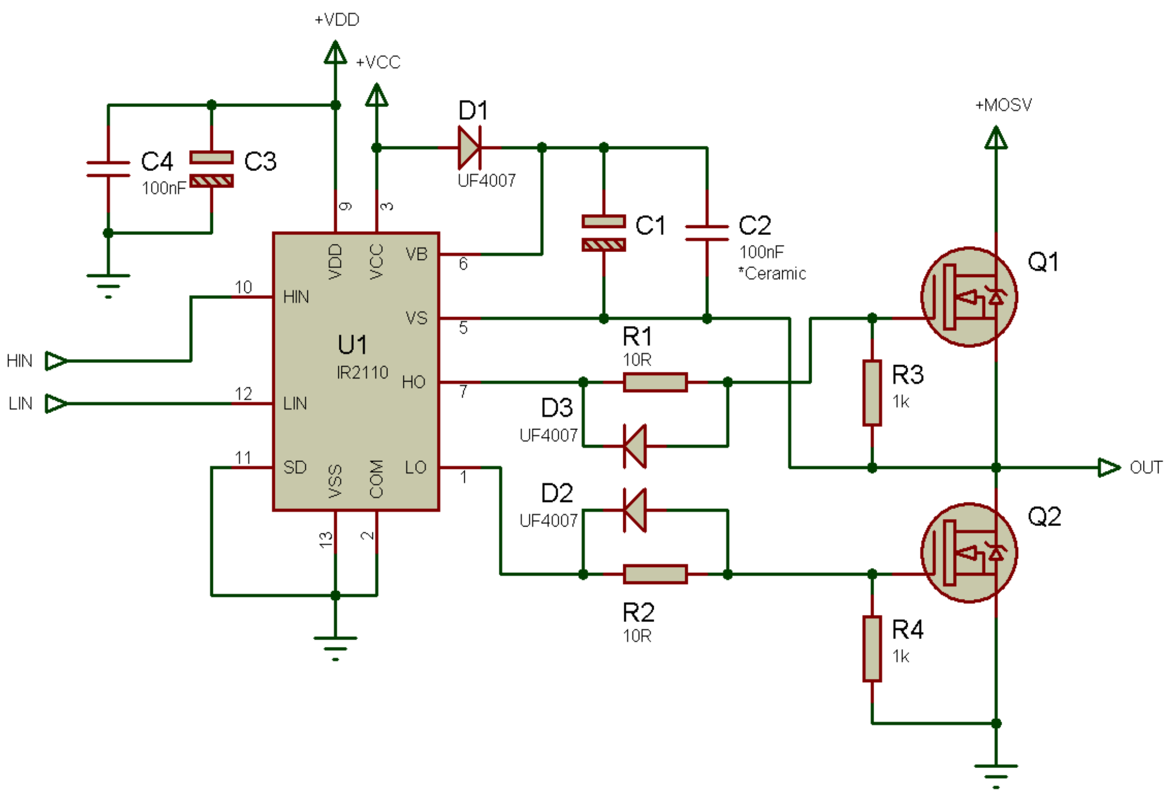


Fig. 6. Basic circuit on IRS2186 for half-bridge control

D1, C1 and C2 together with the IRS2186 form an amplifier circuit. When LIN = 1 and Q2 is on, C1 and C2 are charged to VB because one diode is located below + VCC.

When LIN = 0 and HIN = 1, the charge on C1 and C2 is used to add additional voltage, VB in this case, above the Q1 source to drive Q1 in the high-key configuration. A large enough capacity must be chosen for C1 in order for it to be sufficient to provide the necessary charge for Q1 for Q1 to be on the entire time. C1 should also not have too much capacity, as the charging process will take a long time and the voltage level will not increase enough to keep the MOSFET on. The longer the time it takes in the on state, the more capacity is required. Thus, a lower frequency requires a higher C1 capacity. Higher fill factors require higher capacities C1. Of course, there are formulas for calculating the capacity, but for this you need to know many parameters, and some of them we may not know, for example, the leakage current of a capacitor. Therefore, I just estimated the approximate capacity. For low frequencies such as 50Hz, I use 47µF to 68µF. For high frequencies such as 30-50kHz, I use 4.7µF to 22µF. Since we are using an electrolytic capacitor, a ceramic capacitor must be used in parallel with this capacitor. A ceramic capacitor is optional if the booster capacitor is tantalum.

D2 and D3 discharge the gate of the MOSFETs quickly, bypassing the gate resistors and reducing the turn-off time. R1 and R2 are current limiting gate resistors. + MOSV can be 500V maximum. + VCC should come from a source without interference. You must install filtering and decoupling capacitors from + VCC to ground for filtering (Fig. 7, 8).

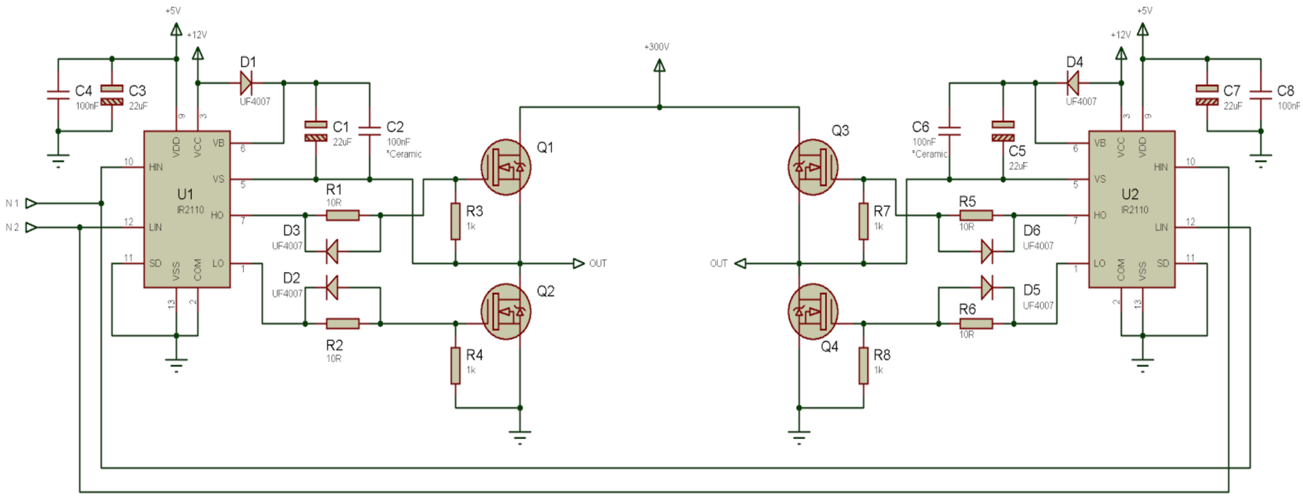
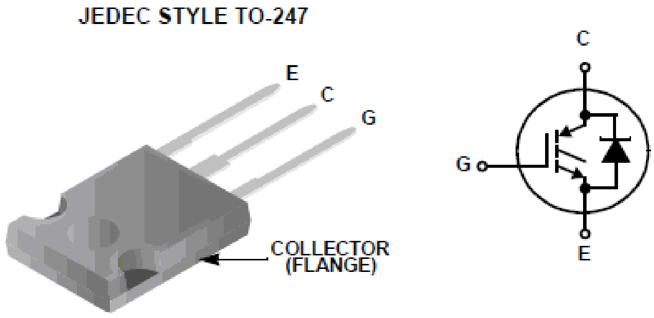


Fig. 7. Applied scheme

Parameters of the HGTG30N60A4D bipolar transistor [6]:

– Technology / Family – SMPS;
– Built-in diode – yes;
– Maximum CE voltage, V – 600;
– Maximum CE current at 25 ° C, A – 75;
– Pulse collector current (Icm), A 240;
– Saturation voltage at rated current, V 2.6;
– Maximum power dissipation, W 463;
– Turn-on delay time (td (on)) at 25 ° C, ns 25;
– Turn-off delay time (td (off)) at 25 ° C, ns 150;
– Operating temperature (Tj), ° C -55 ... + 150;
– Corps to-247;
– Weight, g 7.5.



Picture 8 - HGTG30N60A4D transistor

C. System of the system parameter measurements

The OPA4277UA operational amplifier is used in this circuit for combining differential signals (Fig. 9).

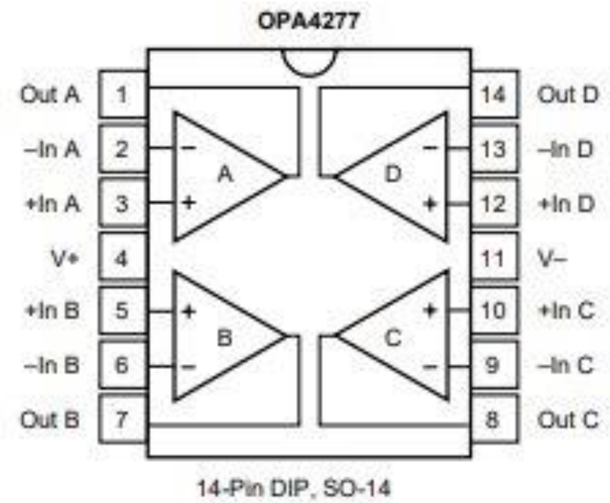


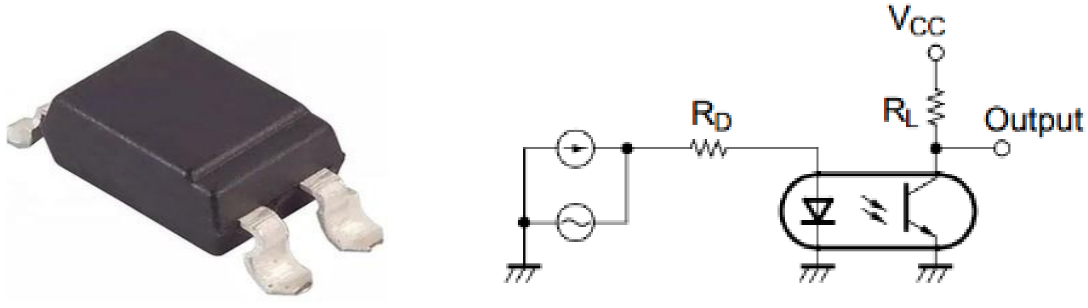
Fig. 9. OA OPA4277UA

Parameters of the OA OPA4277UA:

- 10 µV Ultra-low offset voltage;
- ± 0.1 µV / ° C Ultra-low drift;
- 134 dB high open loop gain;
- 140 dB, high suppression of the common mode signal;
- 130 dB Deviation of high supply voltage;
- Maximum low bias current of 1 nA;
- 800 µA / amplifier Low quiescent current;
- Eco-friendly product and the absence of Sb / Br;
- Typical voltage of the single supply - 36 V;
- Manufacturer - Texas Instruments;
- Power supply type – Single;
- Type of shell – PDIP;
- Type of installation - board in the holes;
- Rail to Rail – No;
- Number of contacts – 14;
- Typical multiplication factor - 1 MHz.

D. **Scheme of matching the levels of the signal of the control and load unit**

To use the control scheme, the main logic and low-current structures must be separated from the high-current ones using an optocoupler. This construction uses the PC817 optocouplers shown in Fig. 10 [4].



a b

Fig. 10. The optocoupler PC817 (a) and standard wiring circuit (b)

Parameters of the PC817:

– Maximum isolation voltage input-output - 5000 V
– Maximum forward current - 50 mA
– Maximum collector-emitter voltage - 35V
– Maximum power collector power dissipation - 150 mW
– Maximum pass frequency - 80 kHz
– Operating temperature range - 30 ° C … + 100 ° C

E. **Designing a make of the circuit board**

To implement the control board (Fig. 11), the following blocks were used:

– Control unit;
– DC motor control unit;
– Block for measuring system parameters;
– Display unit;
– Block for connecting inductive sensors with optical isolation.

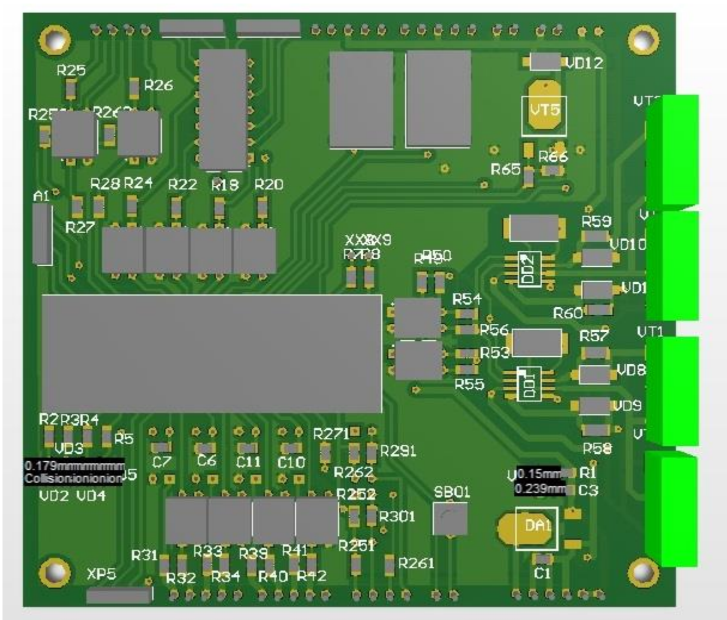


Fig. 11. General view of the control board

The device is controlled by an STM32F103C8T6 microcontroller located on its own board with power protection (Fig. 12.).

Fig. 12. The layout of the STM32 board on the control board

The DC motor control unit is implemented by high-voltage high-speed IR2186 drivers and HGTG30N60A4D high-voltage transistors. This scheme is controlled by the outputs of the microcontroller of the control unit. The location of the DC motor control unit is shown in Fig. 13.

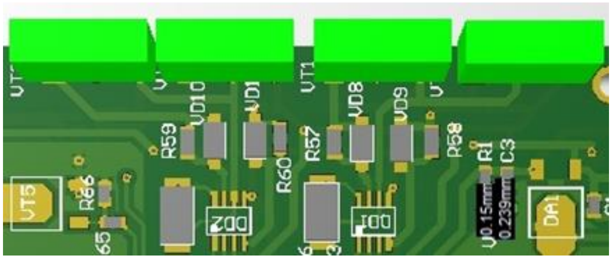


Fig. 13. The layout of the engine control unit on the control board

The unit of the inductive sensors with optical isolation is implemented using inductive sensors and PC817 optocoupler. Optical isolation is required to match the level of the signal which arrives at the microcontroller input of the control unit and the output signal of inductive sensors. The layout of the optically isolated inductive sensor block on the control board is shown in Fig. 14.

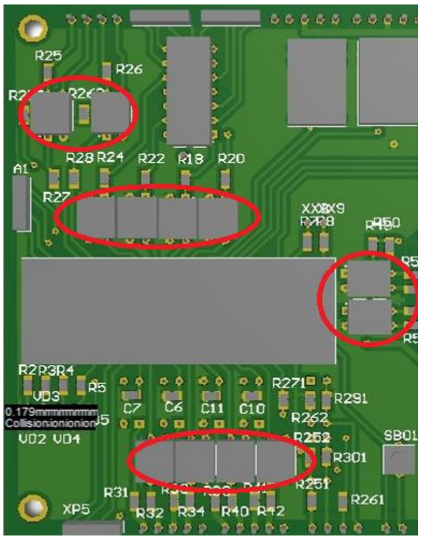


Fig 14. The layout of the optically isolated inductive sensor block

The display unit (the display) is connected to the pins in Fig. 15.

Fig. 15. The layout of the pins on the control board

V. Conclusions

The developed technical solutions were used in the modernization of a Russian-made PCM-2000/2500 machine (Chinese analogue – SDNFX-2000). It shown in the Fig. 16. The design fully meets all the goals set by the customer's terms of references.

Fig. 16 – The control unit

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