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Modernized MESSDOSE intelligent force sensor

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ABSTRACT

This article describes the development of an Intelligent Force Sensor (IFS) that can be easily installed between the crossheads of a sucker rod pumping unit. By placing the traditional MESSDOSE dynamograph and the microcontroller module based on modern microprocessor, communication and measurement devices in a single housing, a perfect measuring device, IFS, is created and the issue of its continuous feeding from an alternative energy source is considered.

1. Introduction

Sucker rod pumping units (SRPU) are the most common pumping equipment used in oil wells. The main reasons for its widespread use are its relatively simple structure, as well as its convenience in the operation of low- and medium-flow rate wells [1].

In order to ensure the established technological mode of operation of the well and the deep-well pumping unit and to detect the reasons for deviations from this mode, the output of the well should be regularly monitored by measuring the amount of fluid, gas and sand pumped by the pump with group metering devices.

Based on the flow rate measurements and the calculated efficiency coefficients of the deep-well pump, it is possible to make an opinion about the correctness of the technological mode for the well, or to detect obstructions in the operation of the pump.

The main method of examining the operating conditions and operating mode of the pump is to study the dynamometer charts of the wells. Using a dynamometer chart, one can study: the movement of the plunger and the polished rod, the effect of the load on the polished rod, the work of the force acting on the polished rod, the fluid leakage from the intake and discharge valves, as well as the gap between the plunger and the cylinder, the breakage of the rods, the effect of the gas on the pump, etc. [2, 3].

The main equipment in the automation of wells operated by SRPUs is load cells and the device that records their readings, as they allow obtaining the necessary data to analyze the operating modes and malfunctions of the deep-well pumping units.

The dynamometry data of the well is obtained through displacement and force sensors.

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Displacement sensors determines the movement parameters of the rod string: it shows the length of travel of the suspension point of the string consisting of pump rods, the period of rotation and the moments when the rod passes through the lower and upper dead points.

Force sensor sets the parameters of the total load acting on the polished rod: it shows the total load, which is the sum of the fluid lifted from the well and the weight of the pump rod, plus the frictional forces of the pump and the string.

The use of the most modern applications of tensometry, microelectronics, mathematical processing, metrology, reliability in the creation of load cells that allow determining the output of oil wells is one of the most important and complex issues that require a complex solution approach.

These sensors must withstand the effects of moisture, sulfur, and other destructive factors in wells operated by SRPU for a long time in a wide range of temperatures, must be resistant to overloading, and must operate in hazardous areas [4].

Analysis of dynamometer charts shows that the most critical and important factor in analyzing the operation modes and malfunctions of deep-well pumping units is the creation of force sensors, because there are very strict requirements, such as sensitivity, reliability, precision, simple design and ease of installation, that must be met.

Various types of force sensors have been created for use in SRPU wells, which differ in the location and method of installation [5].

2. Problem statement

In the article, a requirement is made for the modernization of the traditional force sensor: a microcontroller (MC) module with a sensitive force sensor mechanism should be placed in a single housing, it should be easily installed and changed between the crossheads of the SRPU, it should exchange information with control and other devices by radio communication, it should be resistant to the electromagnetic effects of the engine and frequency converters. and the price should be low. A general flowchart of the modernized force sensor is given in Fig. 1:

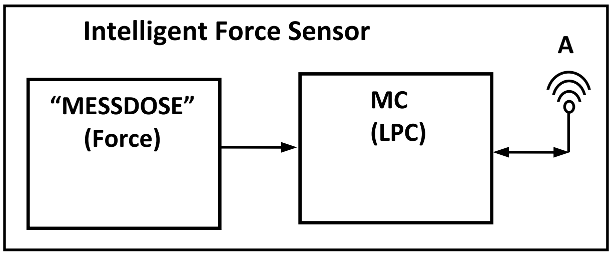

Fig. 1. A general flowchart of the modernized force sensor

3. Solution

The currently manufactured hydraulic GDM-3 MESSDOSE dynamograph allows measuring the force within a range of 40kN, 80kN and 100kN in the wells operated by SRPU. The dynamograph is horseshoe-shaped and can be easily installed between the crossheads of the SRPU [6].

The strain force of the rod string is reduced to measuring the fluid pressure in the MESSDOSE dynamograph. To measure the fluid pressure, a pressure sensor is installed in the MESSDOSE dynamograph [5].

Placement of the MC module with the MESSDOSE dynamograph in a single body is proposed as shown in Fig. 2:

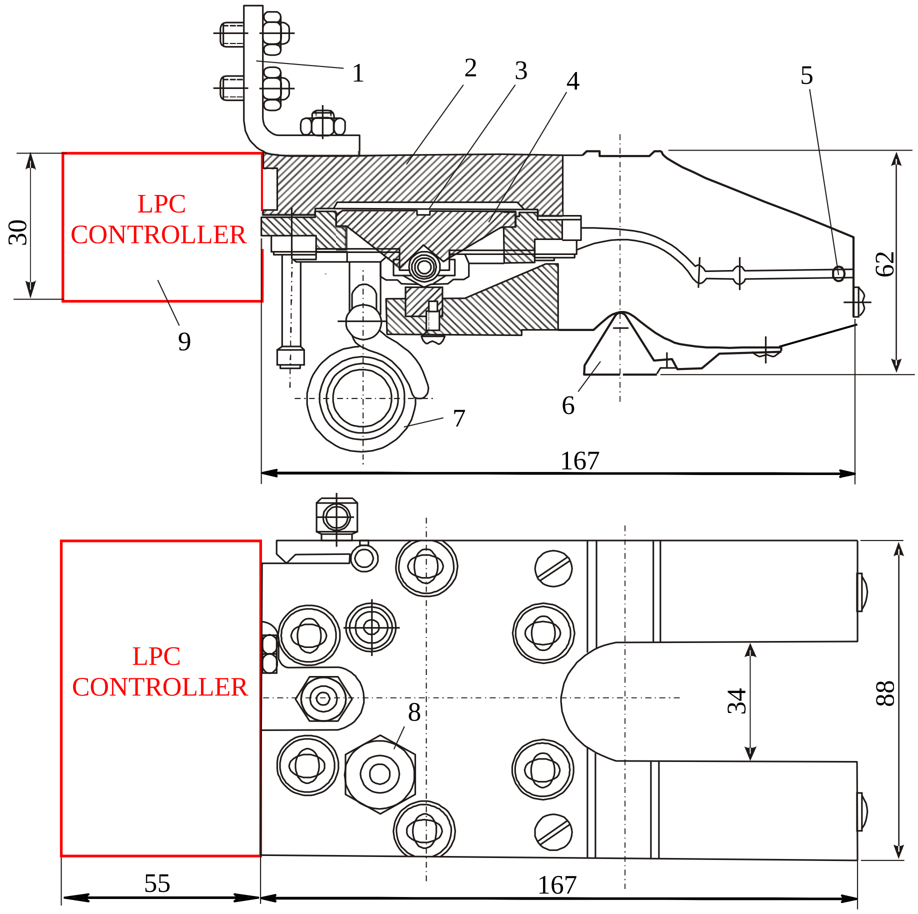

Fig. 2. Modernized MESSDOSE dynamograph

Here 1 – Connecting curve; 2 – Upper arm; 3 – Membrane; 4 – Piston; 5 – Support roller; 6 – Prism; 7 – Feeding roller; 8 – Needle cap; 9 – Microcontroller.

Integration of the MESSDOSE dynamograph with the MC module in a single housing brings new consumer qualities to the dynamometer sensor:

1. Since it is in the same housing as the MC, there is no need to connect the force sensor to the control station with a cable, electromagnetic effects disappear, measurement errors are reduced;

2. Since the measurements are made quickly, the dynamometry results are more accurate;

3. Information is transmitted to the control station by radio communication;

4. Sufficient amount of memory makes it possible to provide complete dynamometry data both point-by-point during the real travel and during the swing period by collecting all the points in an array;

5. Since it requires little energy, it can be fed from alternative sources (AB – Accumulator Battery, SP – Solar Panel).

The wide application of MC in industrial devices leads to an increase in their technical and economic indicators (cost, energy consumption, overall dimensions are reduced, while reliability, accuracy, speed, sensitivity are increased). At the same time, it gives them new consumer qualities (extended functionality, upgradeability, adaptability, integration, etc.). Therefore, in order to simplify the electric circuit of the force sensor, to increase its reliability and ensure its flexibility, it is proposed to create it on the basis of a single microcontroller CHIP (single-crystal chip).

To achieve the set goal, a number of single-crystal MC chips were analyzed and the most suitable LPC was selected among them.

Taking into account the above, an intelligent force sensor (IFS) powered by alternative energy was created, with a traditional MESSDOSE dynamograph and a single-crystal LPC microcontroller structurally and electrically placed in a single housing. The block diagram the IFS device is presented in Fig. 3.

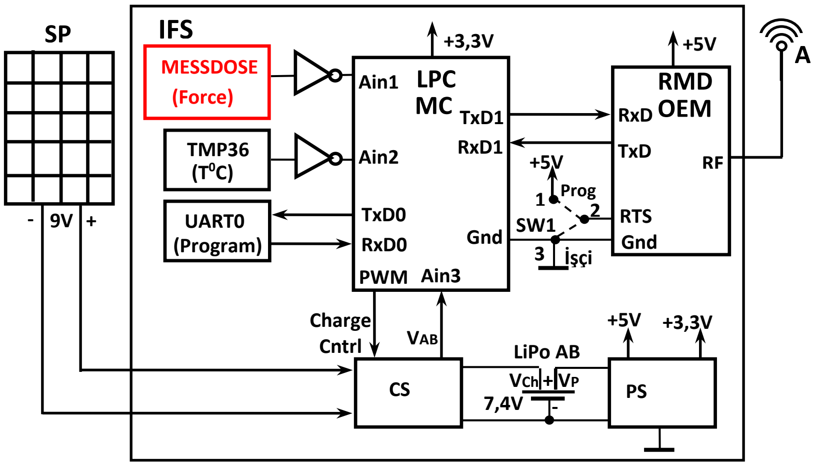

Fig. 3. Block diagram of IFS

The IFS device consists of a MESSDOSE dynamograph with a pressure sensor, a TMP36 temperature sensor, a single-crystal microcontroller (LPC - Linear Programming Control), a radio modem (OEM - Original Equipment Manufacturer), an AB power supply source (PS), a mode switch (SW1) and a transmitting antenna (A). In order not to run out of AB energy and remain at the same level, the IFS device includes a Charging Station (CS) and a Solar Panel (SP) that constantly feed the energy source.

The successful operation of the force sensor with the above structure mainly depends on the correct MC selection. To solve this problem, various MCs with 8-bit MCS-51 (Micro Computer System), 8/16-bit AVR (Advanced Virtual RISC) and 16/32-bit ARM7 (Advanced RISC Machine) cores were comparatively analyzed, their structures, operating systems were studied.

As a result of the analysis of MC features and architecture, the most appropriate choice, taking into account the requirements, is the STAMP controller module created on the basis of LPC microprocessor (MP) with AMBA (Advanced Microcontroller Bus Architecture) architecture, manufactured by NXP [7].

STAMP controller module. LPC2148FBD64 microprocessor LPC2148-STAMP controller module (further STAMP) has an ARM7 core with 16/32-bit memory cells and operation registers and 512KB flash memory, 40KB random access memory (RAM), 32KB storage memory (EEPROM), USB2.0, SPI, 2 unit UART, 2 unit I2C and SSP interfaces, 14 channel 10-bit ADC (Analog-Digital Converter), 10-bit DAC (Digital-Analog Converter), 6 unit Dedicated peripherals such as PWM (Pulse-Wide Modulation), 45 unit I/O (Input/Output), 2 unit 32-bit Counter, RTC (Real Time Counter) and WDT (WatchDog Timer), as well as ISP/IAP (In-System/In-Application Programming) and VIC (Vectored Interrupt Controller).

The internal controller and peripheral nodes of the multiprocessor, open-bus architecture LPC interact freely with each other. Since it is equipped with a free vectored interrupt controller, interrupt functions are performed very quickly and without interfering with other operations. LPC's ARM7-core AMBA System Controller (SC) can increase its operating frequency up to 6 times to a maximum of 60MHz compared to the quartz frequency. If the MP works with 10MHz quartz and executes a simple operation in one cycle, it will perform a maximum of 60MIPS (Million Instructions Per Second) - 60 million operations per second. Therefore, ARM7 core MP works 60 times faster than MCS-51 core CISC (Complex Instruction Set Computing) with the same quartz frequency [8, 9].

Intelligent devices use various mathematical operations in data processing and calculations. Compared microprocessors also differ in the type, complexity and number of stages of mathematical operations.

MCs with MCS-51 and AVR cores perform only simple operations on integers such as addition, subtraction, multiplication and division. And in MC with ARM7 core, all mathematical operations (addition, subtraction, multiplication, division, raising to square, taking square root, raising to cube, taking cube root, obtaining absolute value, finding remainder, division into integer and fractional parts, rounding, finding the maximum and minimum of two expressions), calculating the exponent, trigonometric functions (sine, cosine, tangent, arcsine, arccosine, arctangent), logarithmic functions (natural logarithm, base 10 logarithm), etc. performed at great speed [10].

ARM processors (ARM 7/9/11, Cortex-A50, Cortex-A, Cortex-M, Cortex-R) have Embedded Coders. Embedded Coder generates and converts MATLAB codes compiled with C ++ coder and executes them on ARM processors: easily configures mathematical operations and functions, manages software interfaces, optimizes execution performance, minimizes memory consumption and uses a real-time operating system (RTOS) [11].

Embedded Coder enables ARM processors to function as a complete system within a small CHIP [12].

Due to its fast operating system, many alternative functions, fast analog and digital inputs and outputs, high buffer capacity, low power consumption, etc., the LPC-based STAMP module becomes an indispensable work tool widely used in communication and protocol converters, measurement and control devices, modems, voice recognition devices and so on.

The STAMP module is a "Stamp" board mounted on the FM-BASE board and allows unlimited use of all the features of the LPC2148FBD64 MP.

The STAMP module consists of the ARM7-core LPC microprocessor, 12MHz controller quartz, 32768Hz real-time quartz for RTC (Real Time Counter), 64-Pin plug for connecting to the BASE module, Test Led diode, and +3.3V power supply source assembled on a 25x65mm double-sided PCB (Printed Circuit Board). The appearance and dimensions of the printed circuit board are given in Fig. 4.

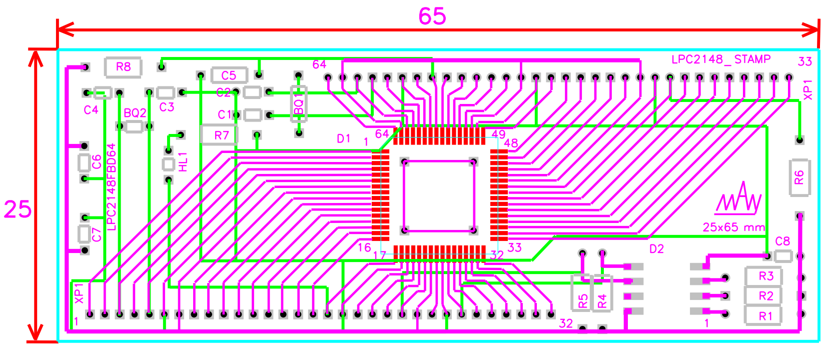

Fig. 4. Circuit board and dimensions of the STAMP module

Programming of the STAMP module. STAMP's LPC controller is programmed using the BASE module's UART0 port via Flash Magic. The Flash Magic program runs in the WINDOWS environment and is designed to upload files in HEX format to the controller via UART0. Flash Magic can be downloaded from the webside http://www.flashmagictool.com.

The software of the ARM7-core LPC controller is created on PC with KEIL development tools using C++ coder. A C++ file is added to the project to compile the code. A HEX file is created from the C++ codes compiled with KEIL and uploaded to the STAMP controller.

KEIL development tool allows one to create a project without hardware and correct program errors, to simulate output ports without a microcontroller board in debug mode. KEIL software can be downloaded from the website http://www.keil.com.

When voltage is fed to the STAMP module, a special test program pre-loaded with the working program into the LPC microprocessor, which forms its core, starts to monitor all peripherals, and if the result of the test is normal, the HL1 LED confirms the correctness of all functions by blinking several times.

LPC2148FM-BASE module (further FM-BASE) is the baseboard of the IFS and was designed on special demand.

The function of the FM-BASE module is to interface the STAMP microcontroller module with peripherals. FM-BASE is a 50x85mm double-sided printed circuit board with XS1 (64-Pin) and XS2 (40-Pin) sockets for connecting STAMP and RMD400-OEM modules. Consists additionally TMP36 temperature sensor, UART0 programming port, RESTART button, RMD mode switch, RF antenna terminal, op amp and power supply source. The appearance and dimensions of the printed circuit board of the FM-BASE module are given in Fig. 5.

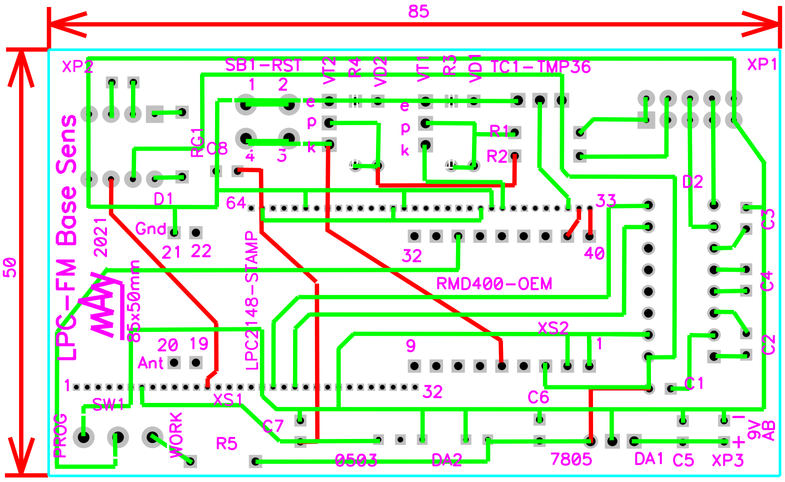

Fig. 5. Circuit board and dimensions of the FM-BASE module

The function of the **RMD400-OEM Radiomodem module** (further RMD) is to exchange data between the IFS and a remote external device. The OEM module is built on a 433MHz RF transmitter element [13].

The appearance and overall dimensions of the OEM module are given in Fig. 6:

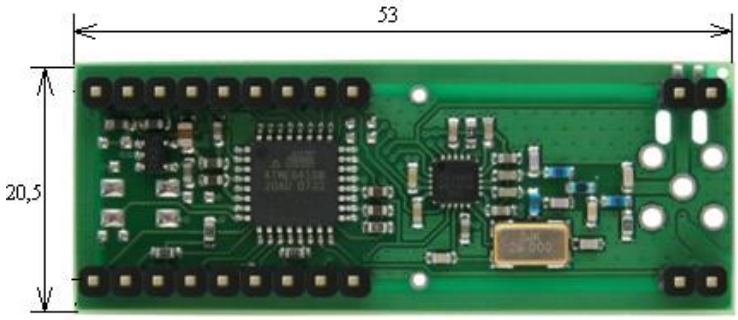

Fig. 6. Appearance and dimensions of the OEM radiomodem

Power supply source (PS) provides the necessary voltages for the normal operation of the IFS. Since the IFS requires little power, it can be powered for a long time by a +7.4V, 3000mAs Lithium Polymer (LiPo) rechargeable battery. The voltage of the +7.4V LiPo battery is first converted to +5V by the L7805 stabilizer and then to +3.3V by the TMA0503 DC/DC converter, feeding the necessary nodes of the IFS. A LiPo battery must be replaced with a new one when its capacity is exhausted. If the LiPo battery is powered by the solar panel, it will not need to be replaced and the IFS can be operated without stopping for a long time.

Charging Station (CS) monitors the output voltage of the power supply source and charges the AB from the solar panel using the Pulse-Width Modulation (PWM) method when the voltage drops below the set threshold.

Operating algorithm. Taking into account the above advantages of IFS, the working algorithm of the STAMP MC module created on the basis of the LPC2148FBD64 microprocessor is proposed as shown in figure 7, and the functions of its individual modules are described.

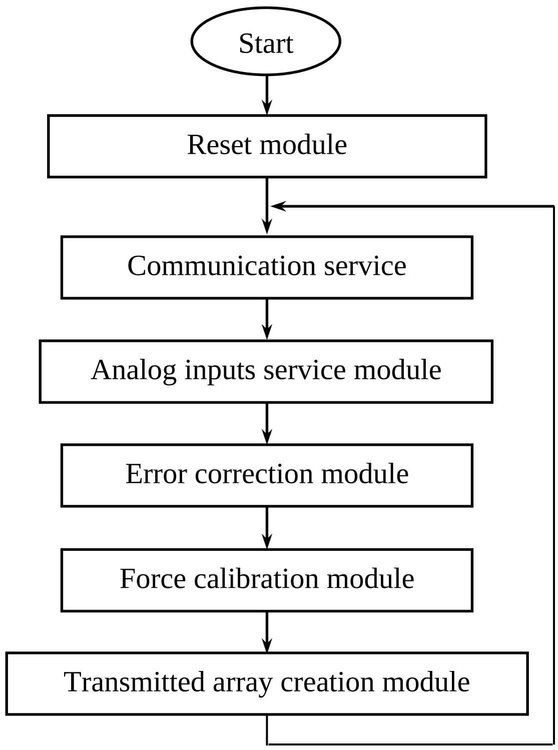

Fig. 7. Simplified flowchart of the operating algorithm of the STAMP MC module

The operating algorithm of MC consists of the following modules:

1. The function of the reset module is to clear the MC memory every time power is fed, to set Ports (PA, PB, PC, PD), to load the transmitter parameters (RF frequency, UART speed, Ethernet speed, Interface type, etc.) directly from FLASH program memory into the RMD memory, to transfer the preset coefficients (gain, correction, calibration, etc.) for the force sensor from the voltage-independent EEPROM memory to the RAM.

2. The function of the communication service module is to exchange information with other devices via RMD over the MODBUS RTU protocol.

3. The function of the analog input service module is to alternately measure the outputs of the pressure (MESSDOSE) and temperature (TMP36) sensors by connecting them to the analog-digital converter (ADC) of the MC and convert them into binary code.

4. The function of the error correction module is to adjust the values of the pressure sensor based on the actual readings of the temperature sensor.

5. The function of the force calibration module is to convert the applied pressure into a corresponding force based on the calibration data in the memory.

6. The function of the transmitted array creation module is to record measurement data for exchange with external devices in the following order: 1st two bytes of pressure value before correction; 2nd two bytes value of pressure after correction; 3rd two bytes converted value of force corresponding to pressure; 4th two bytes processed value of force; 5th two byte temperature value; 6th two byte control code resulting from checking the data transmitted over the communication channel.

4. Conclusion

By combining the GDM-3 MESSDOSE dynamograph with the MC in a single housing, it was possible to create a modern, simple and cheap IFS that can be easily installed between the crossheads of the SRPU, that is connected by a radio modem, and runs on alternative energy. The constant charging of the feeder AB from a solar panel ensures the stable operation of the IFS, and the measurement results are not distorted.

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