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The Device for Communication in the Tool for Measurement in Boreholes

In this paper an implementation and test of the device for communication between Telemetry system and Surface unit with the tool for measurement of pipe diameter, fluid velocity and direction of flow in the borehole (Calliper-Fullbore Flowmeter - CFF) are presented. This communication is done according to SIPLOS (Simultaneous Production Logging String) protocol and it is used by Hotwell company [1] as a part of a larger system for borehole investigations..

1. Introduction

A typical system for boreholes investigation consist of: a Surface unit for analysis and presentation of measurement results, logging tools, a cable for mechanic and communication link between logging tools and the Surface unit and equipment for relocating tools (Fig. 1).

Digital systems for borehole measurement measure more parameters at the same time than analogue systems. Because of this advantage, the process of logging is much shorter and cheaper. At the same time, more parameters are measured and processed data are sent to the Surface unit. Because of larger number of sensors and electric devices for processing data and smaller dimensions of digital tools than analogue tools, projecting of mechanical parts and PCBs (Printed Circuit Board) are much more difficult. Digital logging strings are smaller, more reliable and more effective for processing and storing data than analogue logging strings.

The digital system for borehole investigation – SIPLOS consists of a Surface unit (Fig. 2), the Telemetry tool and other tools in a logging string. The SIPLOS is projected to work in high temperature conditions, up to 180ºC and under high pressure, up to 103.4 MPa (15000 psi). Logging tools have to be very reliable because these measurements are very expensive, take a lot of time and should be done in the first attempt. The Surface unit is located in a special motor vehicle near the borehole pipe, where the measurement is performed. It provides, via a cable, DC supply for logging tools.

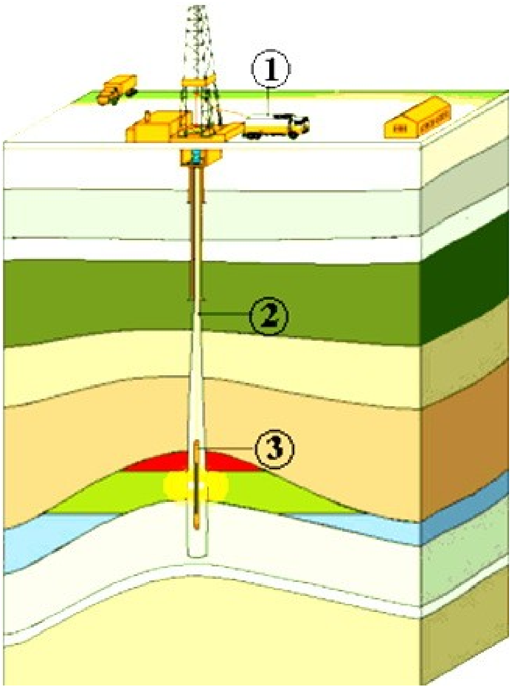

Figure 1. A typical system for borehole investigation

The Surface unit consists of a computer with Warior software which collects, processes and shows graphical and numerical formats of data. There is also a control table for display of the voltage that supplies the tools and current that is necessary for the tools. Warior is a universal program for display of data from various types of tools. In addition, there is a possibility for calibrating and adjustment of data received from boreholes. There are also programs for analyzing measured values. Based on this analysis, the final report of a borehole potential is done.

The Telemetry tool is the first and the only necessary tool in the string of production tools and it is connected to the top of the cable head. It has capability for logging of CCL (Casing Collar Locator), internal temperature, external temperature, pressure, fluid identifier and gamma ray. The Telemetry tool sends synchronization bits for all other tools in the string. In addition, there is all necessary electronics (amplifiers, signal conditioners, DC/DC converter, line driver, etc.) inside the Telemetry tool. On the bottom of the Telemetry tool there is a single connector with line voltage where it is possible to connect other tools in the string for simultaneous production logging [2].

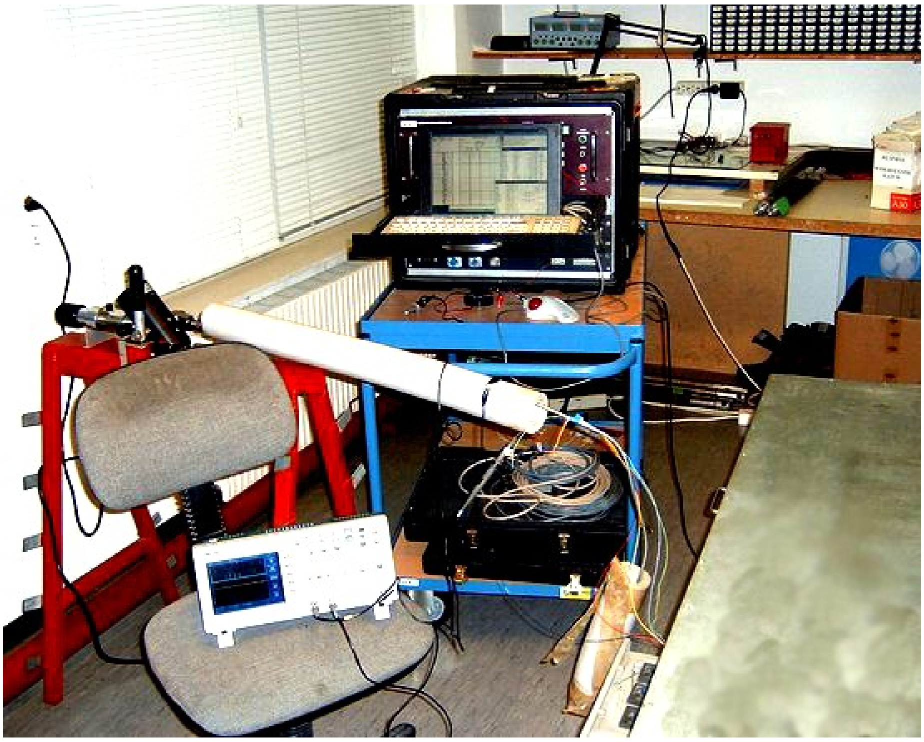

Figure 2. The Surface unit of the SIPLOS system.

CFF tool combines a two axis (X-Y) calliper with a fullbore flowmeter in a single device. Fig. 3 depicts the analog and the digital CFF tool.

The CFF tool measures pipe diameter in range 21/2”-7” (6.35-17.8 cm). X-Y calliper is designed for downhole pipes diameter measurements in two axes, X-Y. The pipe diameter that is sensed by the calliper arms is magnetically transferred to a linear position sensor. The position sensor is a part of electronics that converts linear position to the output pulses. Flowmeter performs bi-directional measurement of the rotational speed and direction of a turbine wheel (spinner or impeller), in relation to fluid flow inside the well [3]. The four-arm CFF device is designed to provide autonomous displacement in X and Y-axis, and uniquely allows the spinner to rotate whilst partially closed. The protocol device has to provide an accurate and reliable communication between the CFF tool with the Telemetry tool and the Surface unit in very difficult conditions for measurement in a borehole. The main problem is high and variable temperature (up to 180 ºC) causing significant drop of frequency of the oscillator in microcontroller and changes characteristics of some electronic components.

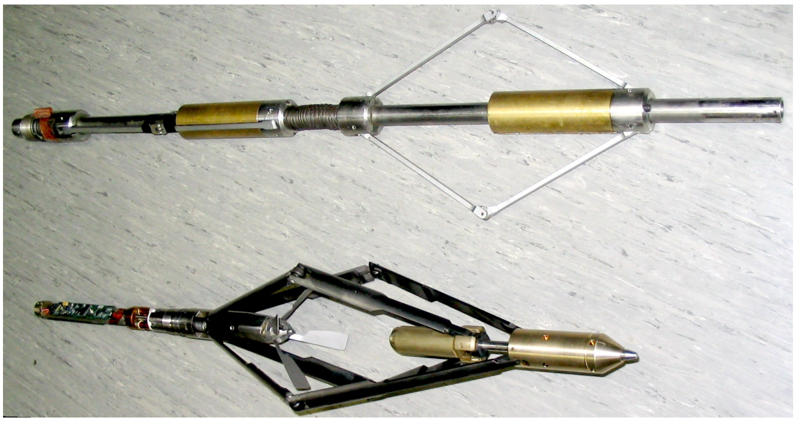

Figure 3. CFF tools.

2. Sensors part of the CFF tool

Figure 4 represents a CFF calliper block diagram. The calliper arm position is measured by using a transformer based position LVDT sensor.

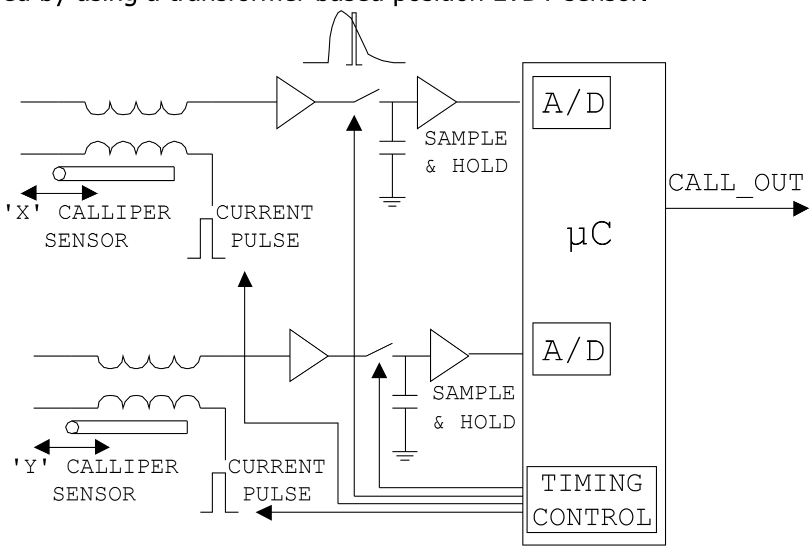

Figure 4. CFF calliper block diagram.

When a diameter of a pipe is changed, a metal rod is moved within the transformer core that has the effect of varying the coupling between transformer's primary and secondary (Fig. 5).

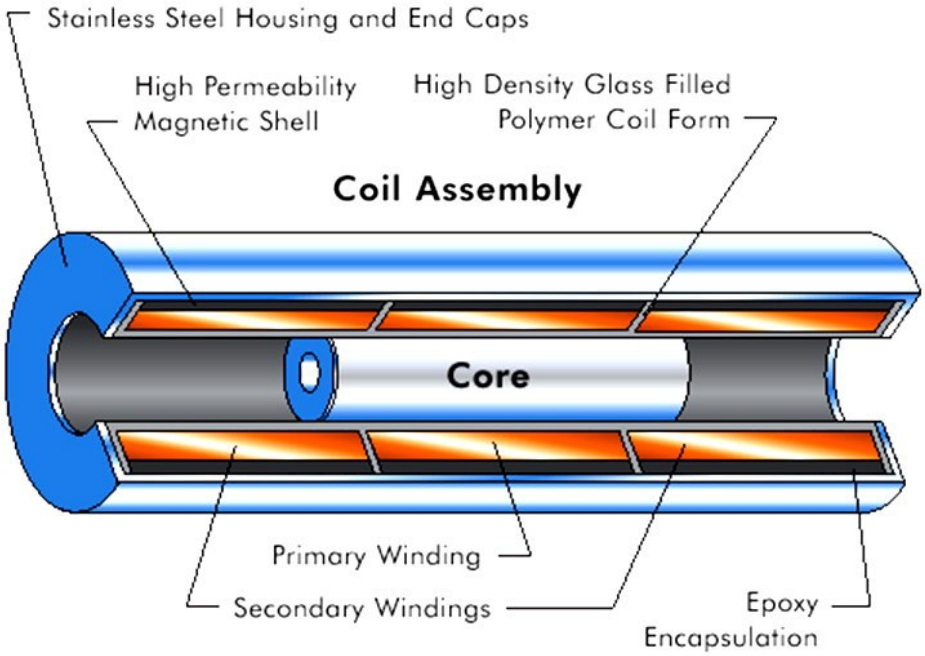

Figure 5. Concept of constructing a LVDT sensor [4]

The transformer primary is driven by a fixed amplitude voltage pulse and the degree of coupling is determined by measuring the resultant signal in the transformer secondary. Thus the amplitude of the detected secondary signal is proportional to the arm position and hence to the diameter of the well-bore. The complete calliper system is controlled by a microcontroller PIC 16F876. It controls timing of the primary drive signals and uses an internal A-D converter to sample the transformer secondary signals. In operation, voltage pulses are applied to the transformer primary. The voltage across the transformer secondary will rise sharply with the rising edge of the pulse and then decay at a rate dependent on the inductance of the transformer system. This inductance depends on the position of the sensor rod within the transformer core. If the decay waveform is sampled at a precise time after the rising edge of the primary pulse, the magnitude of the sampled voltage will be linear proportional to the rod position. This voltage is measured by the A-D converter. The processed data are transmitted by UART to the CFF protocol device in standard RS232 format (1 start bit, 8 data bits and 1 stop bit) with rate of 115,2 Kbaud.

The flowmeter uses an array of five fixed Hall effect sensors operated by a rotating magnet assembly containing two outward facing poles (Fig. 6). This results in 10 sensor operations per revolution of the impeller. The sequence of sensor operations indicates the direction of rotation. The rate of sensor operations is proportional to the flow rate. The flow rate and direction signals are sent by microcontroller PIC 16F876 to the CFF protocol device.

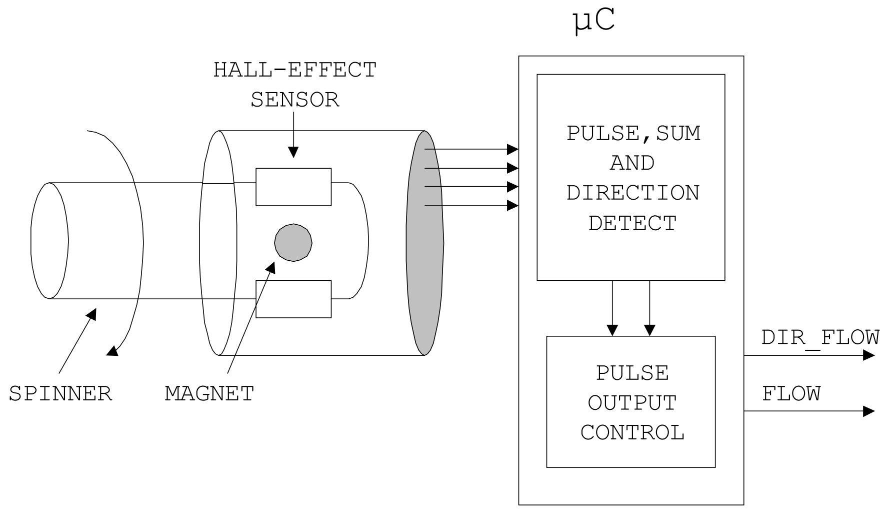

Figure 6. CFF flowmeter block diagram

3. CFF protocol device

All tools, which are connected together, send packets of processed data from sensors during 200 ms according to SIPLOS protocol, which is described in detail in [2]. Fig. 7 depicts block diagram of hardware realization of CFF tool's part for communication between sensors and surface system according to pulses from the Telemetry tool. A microcontroller PIC 16F627 (μC_1 and μC_2) are chosen for realization of CFF protocol device [5], because it has: a large number of programmable pins, serial UART port, internal pull-ups and it works on higher temperature very reliably, which is tested experimentally. LINE is bi-directional signal from Telemetry tool that consists of a line voltage (70V) from the Surface unit and negative pulses (START, STOP, SYNC) from the Telemetry tool and CFF protocol device (DATA bits).

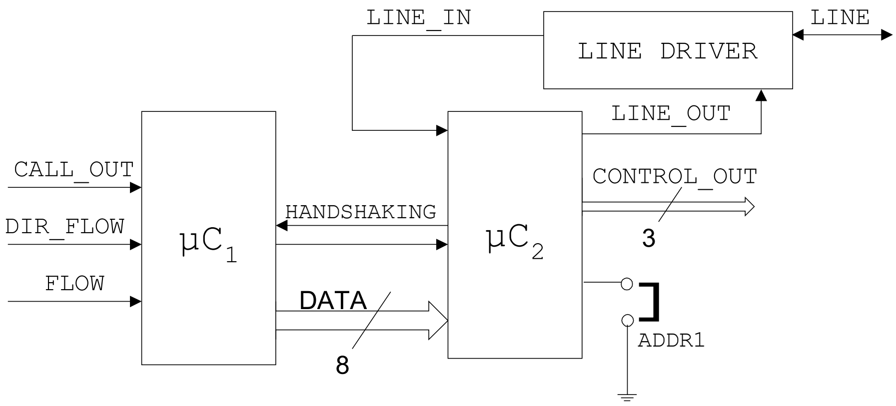

Figure 7. Block diagram of CFF protocol device.

Telemetry tool transmits START, STOP and SYNC pulses to all other tools. DATA bits are transmitted by all measuring tools to surface unit in determined interval of time. LINE DRIVER is a device that converts line voltage into CMOS voltage level, discriminates pulses from LINE signal and makes LINE_IN signal. LINE_IN signal contains START, STOP and SYNC pulses that determine timing for sending DATA from CFF to surface unit. LINE DRIVER receives LINE_OUT signal from μC_2 that is converted into corresponding pulses, positioned in the middle of a data-bit frame, whose duration is 50μs ± 10% and sends it to surface unit. CONTROL_OUT are signals for verification purpose, which contain an error signal and two signals for verification of synchronization. μC_1 receives signals CALL_OUT, DIR_FLOW and FLOW from sensors. CALL_OUT contains information about pipe diameter from calliper in RS232 protocol form. DIR_FLOW and FLOW contain information about flowmeter impeller direction and frequency given in a pulse form.

Algorithms for programmes of both microcontrollers, which are shown in [2], respect possible obstruction and changes in time intervals because of high and variable temperature conditions.

4. Result of simulations

Simulations of work of microcontrollers PIC 16F627 were performed successively by MPLAB IDE [6] and PIC IDE. Simulator Stimulus options were used to simulate input signals. DIR_FLOW, ADDR, and HANDSHAKING signals were simulated by Asynchronous Stimulus option where it is possible to change state of particular pins during the simulation.

LINE_IN signal is programmed before a start of a simulation using Pin Stimulus option. LINE_IN signal, which represents START and STOP pulses from the Telemetry tool and Data pulses from other tools, is simulated by making files in a textual format. In this way some SIPLOS sequence '0' and '1' are presented. When a signal is programmed in a textual format, it should be started in simulator at desirable moment. There is a possibility of temporary stop of the simulation of some signals, which is very useful for testing functionality of some parts of the program. FLOW signal, which presents pulses from Hall sensors, is shown as periodical signal of equal pulses. It is done by Clock Stimulus option, using a lot of pulse sequences of various duration, which simulates change in rate of impeller. During this time, temporaries that count number of revolution for two directions are observed. CALL_OUT signal is simulated by setting the duration of sequence '0' and '1' in RS232 form for 115,2 kbaud rate protocol.

Program PIC IDE, unlike MPLAB, has more options for simulation of serial communication, A/D conversion and simulator is more descriptive. Output signals, SFR registers and memory content were observed during the simulation step by step. All of input signals were simulated for ideal and the worst temperature conditions [3] and expected output signals were obtained.

5. Experimental results

Fig. 8 shows a scheme of a test board, which was used before final version of PCB is made. Serial port of a computer and program PIC IDE are used for generating CALXY signal. Parallel port of a computer and program SIPSIM are used for generating LINE_IN signal. This manner of testing, with generating test signals that send sensors from the CFF tool and the Telemetry tool, is used because the tools were not always accessible during the testing. In addition, this method provides checking of accuracy of communication for known sequences.

Program SIPSIM sends LINE_IN signal to the second microcontroller via parallel port and receives LINE_OUT signal from it. Duration of all pulses from LINE_IN signal is possible to change simultaneously via keyboard. In this manner, checking of work of microcontroller is done for occasion when frequency of oscillator is changed because of the increase of temperature. On the monitor of a computer number values of data are displayed, which are sent according to the SIPLOS protocol. If synchronization is not correct or there are some wrong pulses, program will show a message that indicates a mistake. FLOW signal is supplied via function generator in pulse form. Testing of serial communication on real hardware via serial port of a computer is provided by using *PCs serial port terminal* option in PIC IDE program. Particular bytes and sequences are sent at desirable rate to RS232 microcontroller serial port (UART). In this manner CALXY signal is generated and correctness of the communication with the sensors for measurement of a pipe diameter is inspected.

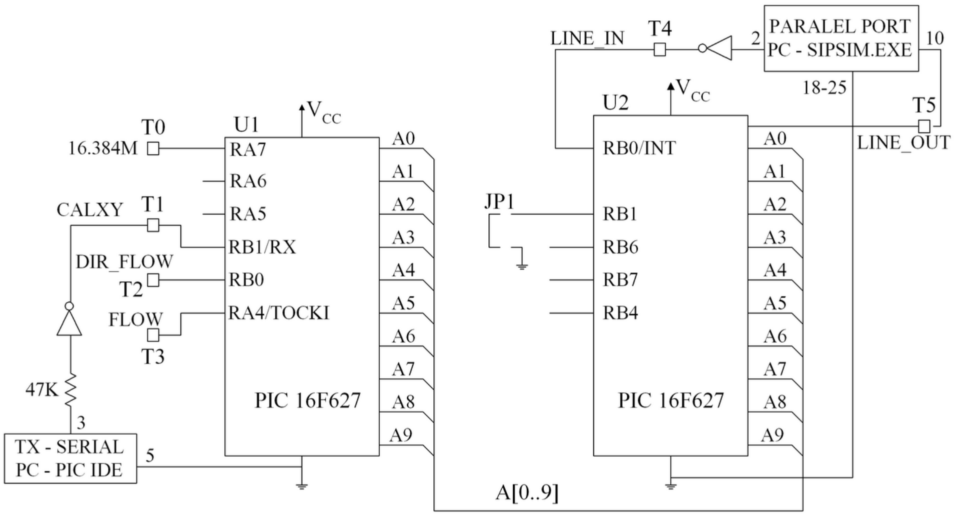

Figure 8. Block diagram of test board

Fig. 9 shows the devices used for testing work of a microcontroller PIC 16F627 on high temperatures. The microcontroller is located in an oven. Some particular pins are welded with high-temperature tinol to wires isolated by teflon. These wires are connected to voltage supply, a tact generator (if external tact for microcontroller is used) and a digital oscilloscope. The temperature of the microcontroller is measured by a universal instrument. The program in the microcontroller sends pulses, whose frequency is four times less than clock frequency of the microcontroller on the output pin. This signal is observed on an oscilloscope during the heating of the microcontroller.

Testing of the microcontroller on high temperatures is performed by increasing the temperature gradually up to 180°C, and then this temperature is hold for two hours. During these experiments the supply of the microcontroller is turned on and off, to check the correctness of the work of the microcontroller. It is very important to check, because, in well-bores, momentary turning off of a supply might happen. The microcontroller was tested for three different configurations of clock frequency. The first configuration was internal clock with 4 MHz frequency, which was very good for the microcontroller operation. At the second configuration output, crystal quartz 16 MHz frequency was used and it was very bad. Problems were already on 80°C, where the clock frequency changed quickly. During turning off and on the supply the oscillator did not work. At the third configuration output, an unstable multivibrator with about 16 MHz frequency is used. In this case the work frequency decreased gradually with increasing of the temperature. The greatest drop of the frequency was 6%, whereas there was no problem after turning off and on the supply of the microcontroller

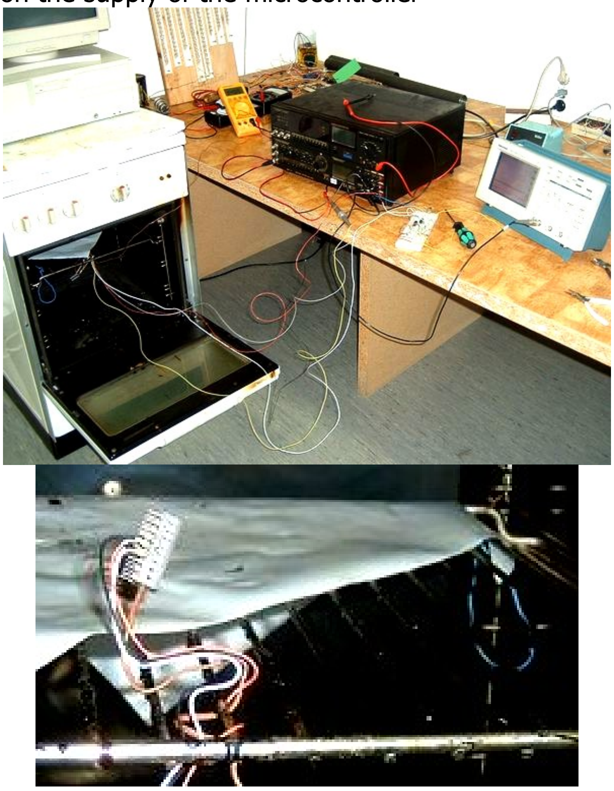

Figure 9. Testing of works the microcontroller on high temperatures.

Figure 10 shows devices for testing the work of the Telemetry and the CFF tool on high temperatures and pressures. At first, the Telemetry and the CFF tool are connected together and link to the Surface unit. Then all tools are put into the oven which is like a chest and has switches for adjusting desirable temperature. Characteristic signals are observed by digital oscilloscope and they are connected by wires to the CFF tool.

Testing the work of the flowmeter and in the CFF tool is done by a compressor, which turn over the impeller by directional air beam. Fig. 10 (right) shows the manner of turning over the impeller while the tools are heating. On the display of the Surface unit values, which are presented in number of revolution per second, for both direction of rotate of the impeller, are observed. The compressor with a nozzle is located at different sides of the oven to check the work for both direction of rotating. Checking the work of caliper in the CFF tool is done by metal pipes with known diameter, where the tool is put. During the heating it is very important that , on all temperatures, the Surface unit displays adequate equal value (nearly constant) for one sort of a pipe. The result of testing during two hours, for all characteristic sorts of checking, was regular on temperatures up to 180°C.

Fig.ure 10. Devices for testing the work of the Telemetry and the CFF tool

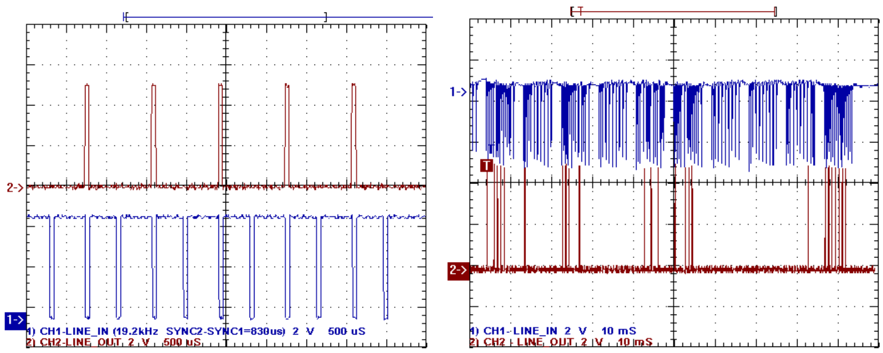

Figure 14. Review of signals LINE_IN i LINE_OUT with a digital oscilloscope.

3. Conclusion

In this paper the problem of measurement of the diameter and fluid flow inside boreholes is considered under high pressure (up to 103.4 MPa) and temperature conditions (up to 180°C). Problem of transfer of measured data to the surface computer, which is used for collecting and displaying data and control of measurement, exists in boreholes. SIPLOS protocol is used where the possibility of appearance of a mistake during the transfer is minimized, by putting synchronization during sending each bit.

The control of synchronization of connected digital tools with the Surface unit is done by the Telemetry tool. The communication system that collects, processes and sends data from measured sensors to the Surface unit according to SIPLOS protocol has been realized. Program for communication has been written and tested by the simulators and the test board. Realized communication system inside the CFF tool (connected with the Telemetry tool) has been tested on the room temperature, then on high temperatures (up to 180 °C). It has been noticed that correct results, which are similar to those obtained by simulators, has been obtained.

The first serial of PCBs has been made and complet measurement system has started working in practise. The first results are very good

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