FLOWMETER HARDWARE REALISATION

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Abstract **Borehole measurement systems are used for measuring parameters in borehole exploration facilities. Measuring methods include the use of various sophisticated tools that are descended into boreholes. This paper presents a hardware realisation of a device for bi-directional measurement of the rotational speed of a turbine wheel (spinner), related to flow inside the well. This device provides additional rotational parameters, related to the frequency of the fluid vortices. Also, provides synchronization and transmition (of measured data) to the surface unit. This device has three functional parts: flow device, line driver and digital section.**

Keywords – **Microcontroller, Flowmeter, Hall sensors, Magnets, Rotation.**

I. INTRODUCTION

The flow of liquids and gases is of considerable importance for both wellbores and surface pipes. In a borehole, the flow pattern is one of a number of factors affecting the well's performance. Wellbore flows may be classified conveniently as single-phase, two-phase and multy-phase. Single phase flow includes water or oil flowing alone in the wellbore. Two-phase flow includes water and oil flow together. An example of multi-phase flow is the concurrent movement of water, oil and free gas [1].

Borehole measurement systems (Fig. 1) are used for measuring various parameters in gas, oil, water and other borehole exploration facilities [2]. A typical system for boreholes investigation has:

1. a surface unit for analysis and monitoring of measurement results,
2. a cable for mechanic and communication link between logging tools, the surface unit and equipment for relocating tools, and
3. logging tools.

Measuring methods include the use of various sophisticated tools that are descended into boreholes up to 5 kilometers of depth [3, 4]. Nowadays there is a strong tendency of replacing analogue with digital well logging systems. Digital systems for borehole measurement are capable of tracking more parameters at the same time than analogue systems. Using this advantage, the process of logging, overall time and costs can be reduced. Digital logging strings are smaller, more reliable and more effective for processing and storing data in comparison to analogue logging strings [5].

Establishing digital systems the complexity of processing data from sensors and communication between tools and the Surface unit are larger.

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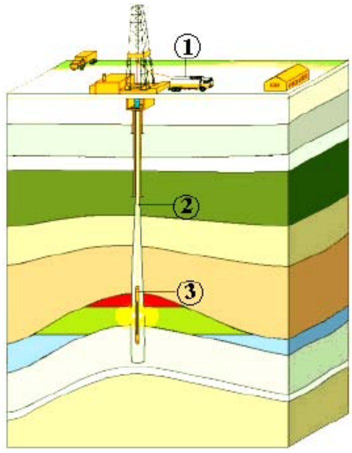

Fig. 1. A typical system for borehole investigation

At the same time, a lot of 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.

The Surface unit of this system is located in a cabin of a special motor vehicle in which a human operator can observe the measured data. It provides, via a cable, DC supply for logging tools. The Surface unit consists of a computer with an appropriate software which collects, processes and shows graphical and numerical formats of data.

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.

This paper presents a hardware realisation of a device for bi-directional measurement of the rotational speed of a turbine wheel (spinner), related to flow inside the well.

II. PROBLEM DESCRIPTION

Borehole measuring systems consists of a borehole and measuring equipment. Mesuring equipment in our case consists of flowmeter and the data acquisition unit.

The flowmeter incorporates an impeller that is rotated by moving fluid. The rotating impeller is arranged to generate a series of electrical pulses which are transmitted by the wireline for receipt by surface equipment, that surface unit is placed away from the borehole site (usually in a truck). At the surface, the pulse frequency is detected, permitting measurement of the revolutions per second (RPS) of the impeller. The flowmeter continuously generates useful measurements even as the wireline (cable) is moved with or against the direction of fluid flow [1]. The purpose of the flowmeter is to measure the velocity and direction of the moving fluid. The acquired data are used afterwards (offline) for various calculations that are a valuable input in analysis of geophysical properties of the borehole [6].

III. FUNCTIONAL DESCRIPTION

This flowmeter performs bi-directional measurement of the rotational speed of a turbine wheel (spinner) related to flow inside the well. Provides additional rotational parameter, related to the frequency and intensity of the fluid vortices. Synchronizes and transmits measured data in accordance with the CAN protocol.
The block diagram of flowmeters probe is shown in Fig. 2.

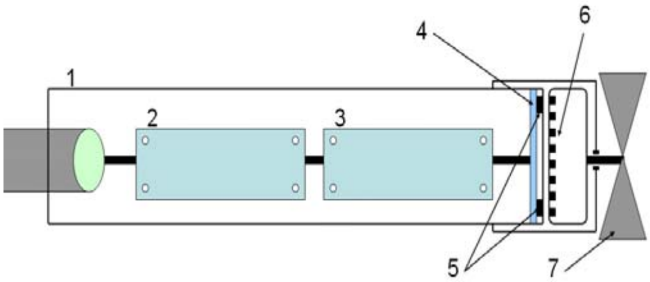

Fig. 2. Block diagram of flowmeters probe

Main parts of this probe:

1. Probe shassie
2. Voltage regulator board
3. Digital (microcontroller) board
4. Hall sensors board
5. Hall sensors
6. Disk with twelve (12) permanent magnets
7. Turbine wheel (spinner)

The block diagram of the flowmeter presented in this paper is depicted in Fig. 3.

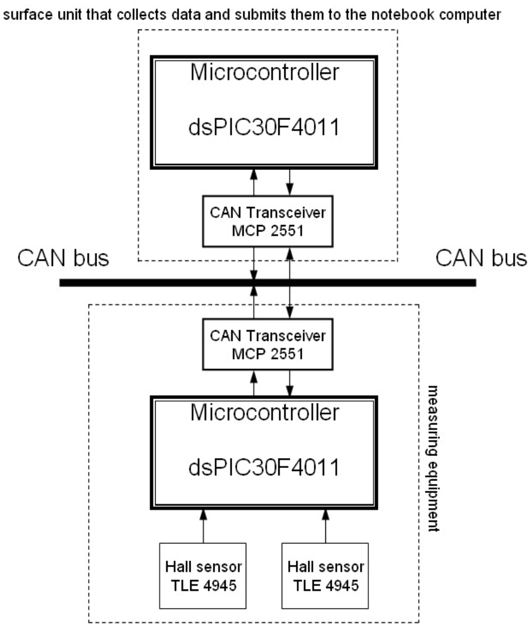

Fig. 3. The block diagram of the system

This flowmeter has three functional parts :

- Hall sensors - TLE 4945 (Infineon)
- Line driver, voltage regulator
- Digital section, built around microcontroller dsPIC30F4011 (Microchip).

This mocrocontroller performs collecting and processing data from Hall sensors, then acros CAN transceiver (MCP 2551 - Microchip) sends data to the surface unit, over CAN bus.

IV. SYSTEM DESIGN DESCRIPTION

Two Hall sensors mounted od the board, provides electrical signals for determination of speed and rotation direction of a flowmeter’s turbine. Those sensors register passing of 12 permanent magnets rotated together with the turbine.

Hall sensors – characteristics

This flowmeter uses two Infineon’s magnetic sensors TLE 4945. These sensors provide digital signal being switched “on” or “off” at the presence of a sufficient magnetic field. The summary of this sensor characteristics is given in Table 1.

Table 1. Summary of the characteristics of TLE 4945

Supply voltage	3.8V to 24V
Supply current	4mA
Turn-ON induction	-6mT to 10 mT
Turn-OFF induction	-10mT to 6mT
Ambient temperature	– 40°C to 150°C
Package	P-SSO-3-2

More details can be found in data-sheet (www.infineon.com).

The principle of operation

Twelve (12) permanent magnets are placed in holes on a disk that rotates together with the turbine. Hall sensors is placed on the edge of circular printed circuit board, on the other motionless part of flowmeter, facing the disk with the magnets.
Figure 4. shows the position of Hall sensors in relation to the magnets.

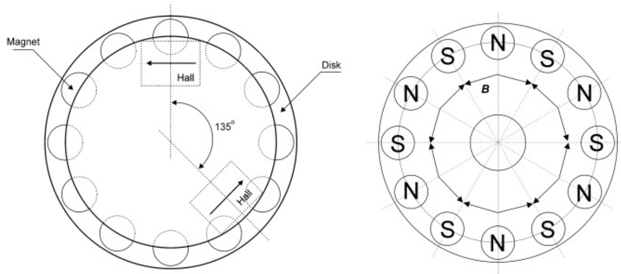

Fig. 4. Position of two Hall sensors relative to magnets and permanent magnets placement and their magnetic field B

The permanent magnets are placed on the disk alternating their north (N) and south (S) magnetic poles. This results in two pairs of six regions with differently oriented magnetic field between the magnets. If the magnetic field in one region is clockwise oriented, than the neighboring regions will have counterclockwise oriented magnetic field [7]. Advantage of integrated Hall sensors is simplicity of electrical circuit, that is the reason for easy projecting of printed circuit board.

As it can be seen, from Fig. 5, these sensors changes its digital output from “on” (5V) to “off” (0V) and vice versa, if the magnetic field reverses its orientation relatively to the sensors sensitive direction. This is exactly what happens when one of permanent magnets passes beneath the Hall sensor.

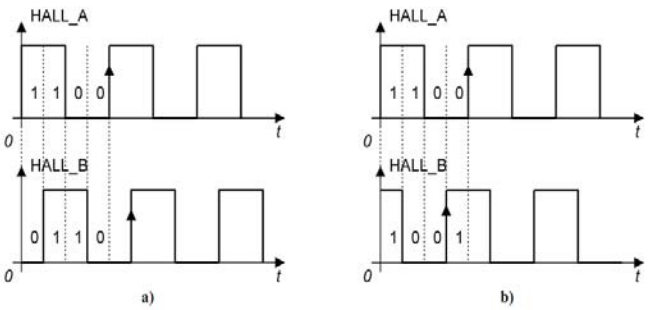

Fig. 5. Digital outputs of the sensors in case of a) counterclockwise rotation and b) clockwise rotation

One full rotation of the disk with 12 magnets results in 6 periods of a square signal at the digital output of the sensor. Obviously, frequency of this signal is 6 times higher than the rotation frequency of the disk (i.e. turbine) itself [7].

Two Hall sensors are required for direction determination of disk’s rotation. If the first sensor is initially placed exactly at the edge of two regions with differently oriented magnetic field and the second sensor is initially placed in the middle of another region, sensors are displaced for 135°, there will always be 90° phase shift between their signals, duty cycle is 50%. The direction of rotation will determine whether the output from the second sensor changes its state before or after the output of the first sensor [7].

In one period of the output signal, from Hall sensors A and B, there are four different states (10,11,01,00), Fig. 5, which enables resolution of the angular displacement measurement of 15° (360°/($6_{periods}$ x 4_{states})).

Microcontroller board functional description

The digital (microcontroller) board consist of one Microchip dsPIC30F4011, operating at frequency of 7,3728 MHz. On that board is also Microchip CAN transceiver MCP2551 and the required electronic parts for proper functioning of microcontroller and transceiver.

Microcontroller is used for counting signals from both Hall sensors, in order to describe the spinner movement (and related rotational speed changes) as accurately as possible [7].

For solving this problem we applied Quadrature Encoder Interface (QEI) module, used in position and speed detection of rotating motion systems. A typical incremental encoder includes a disk with 12 magnets which is attached to the turbine wheel and the Hall sensors that sensing the movement of magnets on the disk. We use two outputs Hall 1 and Hall 2, they provide us information that can be decoded to provide information on the movement of the disk including direction and rotational speed.

The two channels, Hall 1 (QEA) and Hall 2 (QEB), have a unique relationship. If Hall 1 leads Hall 2, then the direction (of the disk) is deemed positive or forward. If Hall 1 lags Hall 2 then the direction (of the disk) is deemed negative or reverse [8]. See Fig. 6. for a relative timing diagram of these two signals.

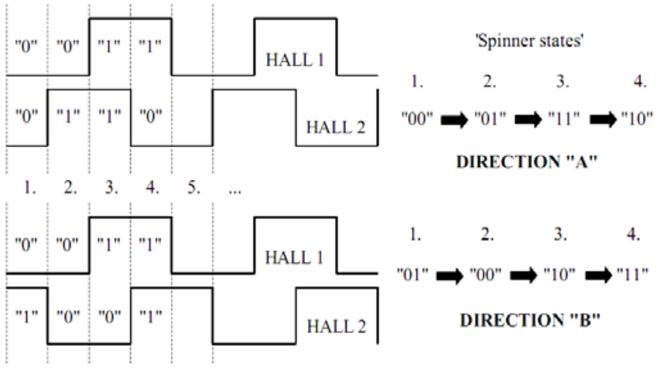

Fig. 6. Hall sensors signal demodulation [7]

The quadrature signals produced by the Hall sensor can have four unique states. These states are indicated for one count cycle in Fig. 6. Note that the order of the states are reversed when the direction of travel is changed.

The QEI consists of quadrature decoder logic to interpret the Hall 1 and Hall 2 signals and an 16-bit up/down counter to accumulate the count. A quadrature decoder logic captures the Hall sensors signals and converts the information into a numeric count of the position pulses. Generally, the count will increment when the disk is rotating one direction and decrement when the disk is rotating in the other direction [8].

The 16-bit up/down counter counts up or down on every count pulse, which is generated by the difference of the Hall 1 and Hall 2 input signals. The counter acts as an integrator, whose count value is proportional to position. The QEI logic generates an UPDN signal based upon the Hall 1 and Hall 2 time relationship. The direction of the count is determined by the UPDN signal.

The QEI count error interrupt is disabled. The position counter continues to count after an error has been detected. The POSCNT register continues to count up/down until a natural rollover/underflow. The interrupt is generated when there is a change in direction of the count. For one direction of the count we have rotational direction “A”, and for other rotational direction “B”.

We decided to use ‘x2’ measurement mode (fast fluid flow), the QEI logic only looks at the rising and falling edge of the Hall 1 input for the position counter increment rate. Every rising and falling edge of the Hall 1 signal causes the position counter to increment or decrement. The software can be easily changed to the ’x4’ measurement mode if finer resolution data is required, we use this mode for slow fluid flow.

The RPM of the disk will vary, and that will determine the frequency of the QEA and QEB input signals. The count pulse is generated for every quadrature signal edge. The number of those pulses during exact time period will determin the frequency. The QEI allows a quadrature frequency of up to FCY/3. For example, if FCY = 30 MHz, the QEA and QEB signals may have a maximum frequency of 10 MHz.

The digital noise filter section can recognize and reject low-level noise and large, short duration, noise spikes on the incoming quadrature signals.

All these measured parameters are set up to the CAN transmit buffer (register), and microcontroller send them over CAN bus to the other microcontroller.

The Controller Area Network (CAN) module is a serial interface useful for communicating with other peripherals or microcontroller devices. This interface/protocol allow communications within noisy environments. Fig. 3. shows an example of CAN bus network. The dsPIC30F4011 device have one CAN module. The CAN bus module consists of a protocol engine and message buffering/control. The CAN protocol engine handles all functions for receiving and transmitting messages on the CAN bus. Messages are transmitted by first loading the appropriate data registers. Status and errors can be checked by reading the appropriate registers. Any message detected on the CAN bus is checked for errors and then matched against filters to see if it should be received and stored in one of the receive registers [8].
The MCP2551 is a high-speed CAN, fault-tolerant device that serves as the interface between a CAN protocol controller and the physical bus. The MCP2551 provides differential transmit and receive capability for the CAN protocol controller and is fully compatible with the ISO-11898 standard, including 24V requirements. It will operate at speeds of up to 1 Mb/s. Typically, each node in a CAN system must have a device to convert the digital signals generated by a CAN controller to signals suitable for transmission over the bus cabling (differential output). It also provides a buffer between the CAN controller and the high-voltage spikes that can be generated on the CAN bus by outside sources [9].
A part of digital board is voltage regulator circuit as shown on the Fig. 7. On input connector (KON2) is approximately 40V, which is conveyed to the LM2576 step-down voltage regulator (National semiconductor). We can adjust the voltage on that regulator between 1.23V to 37V (in our board voltage is set up to 15V) on output. Those 15V are input for voltage regulator L78L05ABZ, 5V voltage on output of second regulator is used as a power supply for microcontroller and other component on that board.

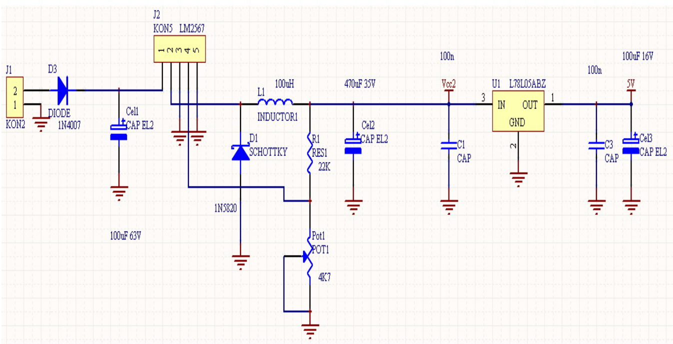

Fig. 7. Scheme of voltage regulator circuit on digital board

Voltage regulator board functional description

Voltage regulator circuit is shown in Fig. 8. On input connector (left on Fig. 8.) is voltage that can be between 0V and 125V.
Relay is in “on ” state as long as the voltage is lower than 65V. In that case the output is between 0V and 40V (max.) on output connector (right on Fig. 8.).
When the voltage is higher than 65V, relay is in “off” state. In that case the output is 0V.

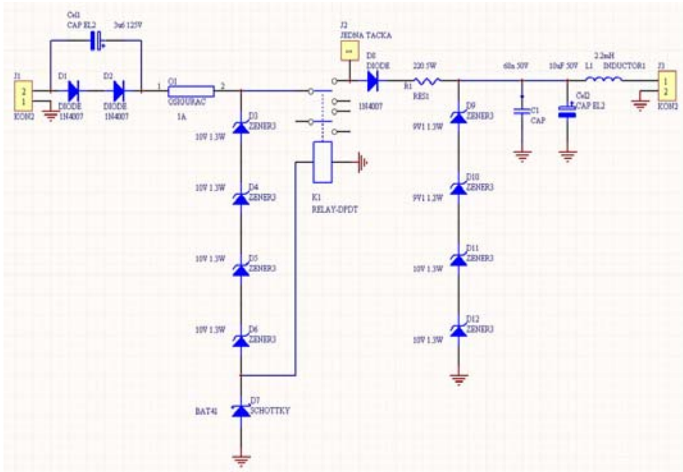

Fig. 8. Scheme of voltage regulator board

V. CONCLUDING REMARKS

This paper presents a hardware realisation of flowmeter. In this paper is given solution to a problem for bi-directional measurement of the rotational speed of a turbine wheel related to flow inside the well. The solution enables analysis of fluid flow in borehole.
The final product is in realisation proces at the Department of Electronics, Faculty of Technical Sciences in Novi Sad.

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