Sensor System with Accelerometer for Tilt Measurement

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Abstract: - Presented paper describes design and realization of a sensor system for tilt measurement in x and y axes directions in the range of 680°. For construction non-standard connection with accele rometer is used. Measurement is controlled by a microprocessor, measured data are sent to a PC via RS232. The PC is used for data storage, further calculations and display of measured tilt. Convertor of logic levels is used for communication of the sensor system with the PC via RS232 bus. X-ANALYZE in LabView development environment is utilized for service program. Realized sensor system has measurement precision of 0.5° for each axis in the range of 680°, not measurable hysteresis, immediate response to tilt change.

Key-Words: - Microsystems, intelligent systems, sensors, measurement, control, tilt data communication.

1 Introduction

Tiltmeter is widely applicable to measurement of angle or deviation from horizontal, vertical or any other plane in various domains of human activities. It can be used for measurement of angle deviations or for position regulation and system stabilization in connection with actuators, e.g. production machines, construction and forest mechanisms, military vehicle, aircrafts, ships, submarines, etc. It is applicable to mining industry where it is mounted to drilling heads for precise leading of sub-earth bores. In connection with GPS system it can be used for car driving control and navigation. Objects with complex shapes can be scanned in slices and successively digitalized for further processing, i.e. modeling. In entertainment industry it is used in drivers for game consoles and for simulations of virtual reality. In most cases, angle deviation from reference plane - earth horizon - is measured. Various measuring methods may be used for deviation measurement. We focus on following parameters: sensitivity, linearity, resistance to errors and interference, hysteresis, offset, drift, dynamic properties, signal – noise ratio (SNR). For realization of "classical" tiltmeter, the most frequently used principle is the principle of Earth gravitational or magnetic field, tilt potentiometers, capacitive, inductive and magnetic sensors, optoelectronic sensors, electrolytic tilt sensors. Designed sensor system presented in this paper uses non-standard connection with a sensitive sensor - accelerometer.

Designed sensor system must comply with following requirements: measurement in wide range of tilt, parallel measurement of tilt in X and Y axis, minimum dimensions, digital processing of measured quantity, programmability of the system with possibility of adding further functions, communication, data transmission and evaluation using PC, minimum power consumption.

2 Concept of the Sensor System

Designed concept of the sensor system results from required properties, stress has been laid on sensitivity,

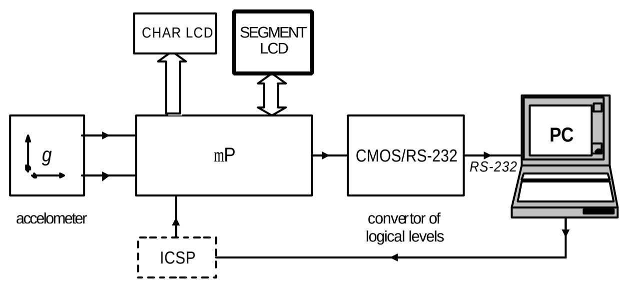

Fig.1 Concept of sensor system for measurement of tilt in X and Y axis

accuracy, hysteresis, fast sensor response to tilt angle change with good discrimination. The concept satisfies on-line data transmission and processing using suitable software. Concept of sensor system connection is illustrated in Fig. 1.

2.1 Accelerometer as tilt sensor

Using accelerometer for tilt measurement is relatively non-standard solution of the problem. For construction, there has been used a sensitive two-axes accelerometer ADXL202AQC with analog and digital output with PWM modulation with adjustable period length. It enables direct connection to evaluating microprocessor without A/D convertor. Typical structure of described accelerometer has length of 400 μm and consists of 40 cells of differential capacitors. Notwithstanding, their capacity is only 0.2 pF and excitation by acceleration of 1 g causes mechanical shift of 1 per cent out of the position and capacity change of 100 fF. Such a small shift causes linear change of capacity that can be processed by surrounding electronics easily [1]. Minimum detectable shift is 2.10^{-11} m, thus less than atom diameter.

This sensor with range of ±2g can be used not only for sensing dynamic acceleration – vibrations, collisions, etc. – but also for sensing static acceleration – gravitational effect. Given measurement range ensures sufficient accuracy for measurement of the vector of gravitational acceleration at tilt in two axes and thus after inversion of arcsin functions we acquire values of tilt:

$$j_x = \arcsin\left(\frac{a_x}{1g}\right) \qquad j_y = \arcsin\left(\frac{a_y}{1g}\right) \qquad (1)$$

If the sensor chip is placed horizontally, its sensitivity to this tilt is the greatest, because at this point the arcsin function has the greatest steepness. On the other side, around vertical positions (perpendicular to Earth plane, i.e. ±90°) the sensor is nearly insensitive. Both features are given by projection of the vector of gravitational acceleration into the axes of sensor sensitivity.

It follows from accelerometer parameters that used digital outputs have nominal sensitivity value of 12.5 (±2.5) %/g for both axes. Internal convertor realizing both outputs has discrimination of 14 bits, which exceeds discrimination of accelerometer itself. Connected microprocessor must be able to measure mark-space ratio of modulated signal in the range 35-65% with sufficient accuracy for acquisition of information about tilt. It is ideal to use a microprocessor with integrated 16-bit counter/timer and double capture system as its peripheral accessory for this purpose. It is not necessary to measure with high accuracy because discrimination is limited especially by the noise of sensor itself (up to 1 mg/$\sqrt{Hz}$). Not used analog outputs have given sensitivity value of 312 mV/g and with respect to interference they are blocked with capacitors to ground (GND) [2], [3].

2.2 Microprocessor for control of Measurement Process

Since it is necessary to measure mark-space ratio of output signals of used accelerometers and send measured data via serial link, a microprocessor with integrated 16-bit counter/timer and double capture system, circuit for synchronous and asynchronous transmission and sufficient number of INPUT/OUTPUT (I/O) outlets have been chosen. There has been chosen a microcontroller of medium performance class based on RISC architecture - PIC16F876. The processor is of hardware type, i.e. it has separate memory for data and program (8 kB, word length 14 bits). Timing can be done by external signal of frequency up to 20 MHz. It can reach 5 MIPS (5.10^6 instructions/sec).

On the chip there are peripheral circuits [4]: Two 8bit and one 16bit counter/timer with programmable predivider, two capture, comparing and PWM output modules, 10bit A/D convertor with fivefold multiplex input, synchronous serial port (SSP) supporting SPI™ and I^{2}C™ transfer protocols in both Master and Slave modes, universal synchronous/asynchronous receiver-transmitter (USART/SCI) with 9-bit address discrimination, Brown-out Reset for monitoring decrease of supply voltage.

ICSPÔ - option to program in application.

PIC microcontrollers of medium performance class, including used PIC16F876, are nowadays equipped with ICSP™ function (In-Circuit Serial Programming) as standard. This function enables microcontroller programming in finished application in the following way: at first the application with microcontroller (hardware) is designed and then it is programmed (software); in case of FLASH program memory it can be programmed repeatedly. This property brings substantial advantage in design and compilation of application execution because it is not necessary, for example, to take the microcontroller out of precise socket and put into programmer socket for re-programming and back. Instead of continuous strain of its outlets, the adjusted application can be directly connected with the programmer by five-wire cable. If needed it is possible to update the program saved in FLASH memory, add new functions and properties.

While developing the program stress has been laid on its transparency, maximum simplicity and hierarchical arrangement. We have abandoned the idea to utilize interrupt system because it complicates both program compilation and fault analysis. From the total 8kB of memory, approximately 2.5 kB of memory has been used, out of which 1 kB for conversion table of the arcsin function. Memory reserve is planned for adding new functions and properties, as for example compensation of temperature dependence of measuring system. Input of till now unused integrated 10bit A/D convertor can be used for connection of temperature sensor.

2.3 Communication Circuit for PC

For transfer of measured data to PC, the system has been extended by a convertor that converts CMOS (TTL) voltage levels to RS 232 (PC serial port uses negative bipolar logics that interprets logical zero as voltage in the range 5-15 V and logical 1 as voltage in the range -5 - -15 V). Information is transferred using higher voltage through interconnecting wires because in this way we can acquire higher resistance to interference. Information transfer runs asynchronously with fixed transfer speed and synchronization by trailing edge of start pulse [5]. For creation of bipolar voltage level, the MAX3223 convertor of logical levels has been used. The convertor has very low consumption (1 µA), namely using saving mode AutoShutdown™. Circuit "sleeping mode" starts in the moment when the receiver detects invalid signal level at RS 232 (lower than ±5V) or when the connected peripheries at the transmitter side are off. After receiving valid logical level at the receiver or transmitter side the circuit is activated immediately to normal operational mode with typical consumption of 300 µA [6]. Since the measured data are sent to the transmitter continuously the circuit stays in saving mode only when the serial cable is not connected to the measuring board. Connection of the main part of the sensor system is illustrated in Fig. 2.

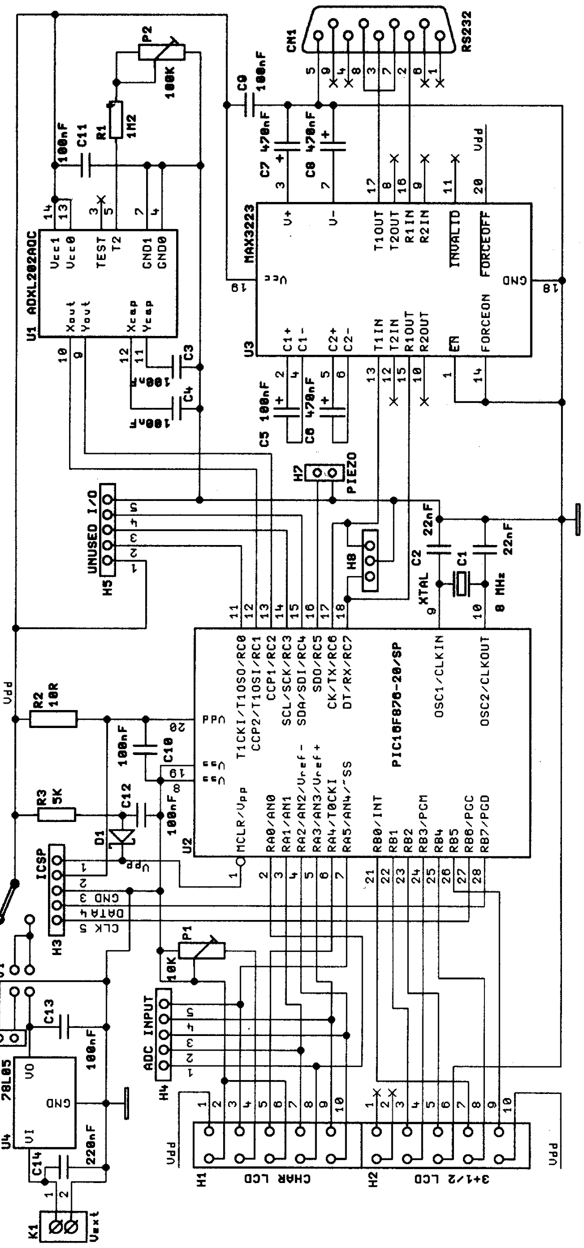

Fig.2 Circuit connection of the sensor system core

2.3 Communication Circuit for PC

Program X-ANALYZE has been used for testing of two-axes accelerometer on the development kit. Program has been used especially for testing measured data transfer via serial RS 232 bus to PC where data are further processed and displayed. Program is equipped with sensor calibration mode – using options "Configure" and "Connection".

The microcontroller sends data to the program in the form of pure PWM mark-space ratio of both axes (with the accuracy of hundredths of per cent), thus influenced by offset and change of accelerometer sensitivity. This option has been chosen for verification of sensor parameters and their comparison with catalogue data and for optimal design of microcontroller program. This option hides function of data storage to a file in a selected directory as well, either using chosen or maximum (i.e. sampling) speed. In the latter case every sample is saved. This speed depends on the period length of PWM output, processing speed in microcontroller and PC and selected transfer speed (here 9600 Bd). Further options “Log All Connections” and “Stop Logging” enable and disable writing to the file respectively.

3 Reached Results

Designed and realized system has been tested for tilt in both axes and for tilt in the range of 360° for each axis. While measuring the deviation of the measured quantity, i.e. tilt, from the real value, results shown in Fig. 3 have been reached. There are shown deviations (error in °) in dependence on real tilt.

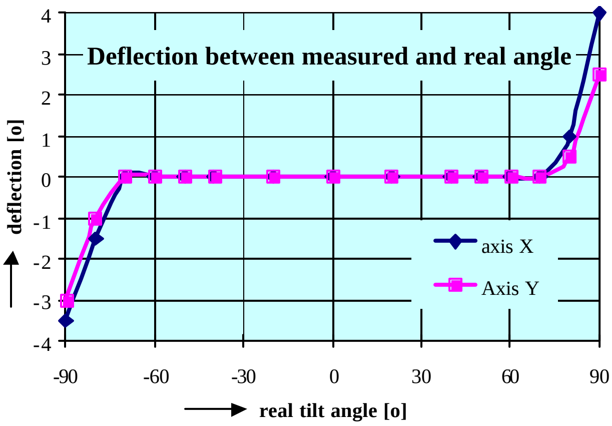

Fig.3 Measurement error in dependence on tilt angle

It is obvious from the curve of conversion function arcsin that in the areas around the values ±90° there are so-called dead zones, namely zones with zero sensitivity. This fact is reflected in measurement accuracy in the highest ranges. There have been measured temperature dependences as well. Since the sensor itself is temperature dependent (according to catalogue data), then the whole sensor system is temperature dependent. At present the development of temperature compensated sensor system continues. When testing stability of the measuring system at constant measuring temperature there have not been detected practically any time changes in measured data. Due to intrinsic sensor noise the mark-space ratio of output signals varies in certain interval that can be decreased by averaging, however choosing discrimination value of 0.5° the measured value is sufficiently stable.

4 Conclusions

There has been designed non-standard connection of sensor system for tilt measurement using integrated accelerometer. The whole device has been realized in miniature setup. Local display or PC connected via RS 232 can be used for evaluation of information about measured tilt. PC serves for measured data storage and processing. If the system is well calibrated, then it can be used for tilt measurement in both axes in the rage of 680°, tilt angle 90° represents “dead” point of measurement. Measurement accuracy value in the given range has been 60.5° at the laboratory sample; hysteresis has been negligible (not measurable). Setting of the sensor system for measurement at given location is enabled thanks to fast and simple calibration (the system itself evaluates data). The system manifests certain temperature dependence, however we are currently working on its suppression.

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