Design of the Multichannel Measurement System for Strain Gauge Sensor Evaluation

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Abstract: - This paper deals with design of multichannel measurement system for strain gauge sensor evaluation in laboratory of mechanical engineering. Device is based on 8-bit Freescale microcontroller MC9S08GB60 which is due its properties intended for general purpose applications. Device implements modular hardware design enabling easy functionality expansion in future demands. This is fulfilled by dividing of the whole measurement system to main board and input / output eventually measurement modules. Main board of the device contains master microcontroller, USB communication interface, power supplies and interface for expansion cards. Modules for strain gauge sensor evaluation consist of amplifier with selectable gain followed by 4^{th} order Bessel low-pass filter eliminating ripple in analog signal and finally 12-bit analog-to-digital converter connected via serial peripheral interface (SPI) and other control signals with main board. Communication with supervision system is provided by USB interface which is recognized as standard serial port in host operating system.

Key-Words: - Strain gauge, data acquisition, microcontroller, MC9S08GB60, communication

1 Introduction

Process measurement is one of the most important tasks in laboratory environment. Present-day there is available number of devices performing data acquisition tasks – standard cards for PCI or ISA (today rare but still present in special measurement systems where its PCI alternative is not available) bus which are suitable for standard personal computers and its industrial versions and modules for industrial automation usually equipped with RS485, CAN and other interfaces. Independent category is formed by smart sensors incorporating sensor, converter to unified signal and data acquisition device in one embedded system with very compact dimensions and low power consumption. They have number of advantageous features such as automatic diagnostic and calibration, high accuracy and immunity against electromagnetic interference due to short signal paths. On the other hand lower operating temperature range reduces their usage to laboratory applications, automotive and aircraft industry where compact dimensions and low weight are crucial. Quite often occurred situations when it is necessary to measure data in terrain where it is not possible to use standard computer equipped with data acquisition card. In these cases laptop computer equipped with portable data acquisition device may be very advantageous. This measurement system structure is suitable for laboratory environment too due to frequent transfers of the measurement equipment between each workplace.

The paper proposes design of multichannel measurement system for strain gauge sensor evaluation in laboratory of mechanical engineering. The utilization of the device is mainly focused on three axis measurement of cutting forces.

2 Strain gauge sensor evaluation

Strain gauge sensors can be basically divided to the metal and semiconductor gauges. Metal type gauges are used in wide range of applications depending on their type. They can be divided to the three categories by physical design:

- Thin wire strain gauges
- Foil strain gauges
- Metal film strain gauges

Thin wire strain gauges can be used for wide range measurements with long-term dynamical straining. Some special types can operate at high temperatures. Today are very perspective foil strain gauges due to better transfer of deformation to the sensor and wide possibility of their mechanical construction configuration. Metal film strain gauges are especially suitable for pressure sensors where

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sensing film is a part of main measurement membrane. Semiconductor gauges are due to their high sensitivity suitable for measurement of very small deformations. Very advantageous is their high resistance and long-term stability.

Because of resistance change of strain gauge sensor related to strain is very slight it is suitable to use Wheatstone bridge for its evaluation. Suppose we have bridge which schematic is depicted in the Fig. 1 consisting of four resistances R_1, R_2, R_3, R_4 supplied by constant voltage source U_{in}. To the bridge output is connected voltmeter measuring U_{out}. Due to its very high internal resistance (theoretically infinity) its influence to circuit functionality can be omitted. Then it is possible the Wheatstone bridge consider as two unloaded voltage dividers. Output voltage U_{out} is equal to difference of voltages on dividers formed by R_1, R_2 and R_3, R_4:

$$U_{out} = U_{in}\frac{R_2}{R_1 + R_2} - U_{in}\frac{R_4}{R_3 + R_4}\,. \quad (1)$$

Equation (1) can be rewritten to the form:

$$U_{out} = U_{in}\left(\frac{R_2 R_3 - R_1 R_4}{(R_1 + R_2)(R_3 + R_4)}\right). \quad (2)$$

From expression (2) is obvious that Wheatstone bridge is balanced (output voltage U_{out} is zero) when equation (3) is fulfilled.

$$\frac{R_1}{R_3} = \frac{R_2}{R_4} \quad (3)$$

Suppose R_1 is the strain gauge sensor which changes resistance due to influence of tension or compression and R_2, R_3 and R_4 are fixed value resistors. If no strain is applied to sensor all resistances or equal and bridge is balanced.

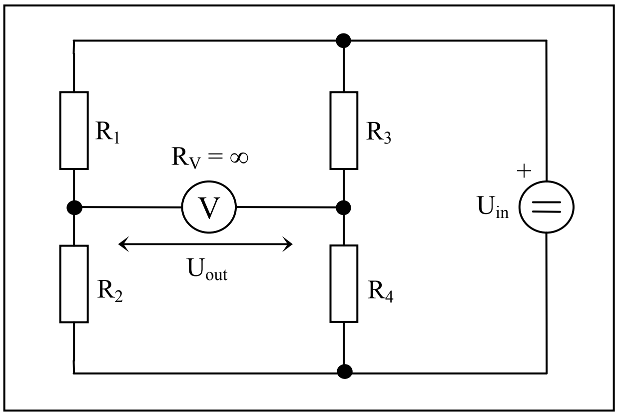

Fig. 1 Wheatstone bridge schematic.

When strain gauge sensor changes its resistance equation (3) is not satisfied so bridge is unbalanced and output voltage U_{out} is therefore nonzero. This small voltage must be before processing stage amplified in the instrumental amplifier to the level suitable for analog-to-digital converter in the data acquisition device. In practice are commonly used for circuit sensitivity increasing two or four gauges in the bridge.

3 Measurement device design

Design of the measurement device for strain gauge sensors evaluation is adapted to easy functionality expansion in future applications by simple adding of measurement modules with required features. This is achieved by splitting the whole measurement system to the two basic parts:

- Main control board consisting of master microcontroller, communication interface, power supplies and expansion connectors;
- Measurement modules which will be inserted to expansion connectors in main board. Because of board interface is fully digital each module must be equipped with analog-to-digital converter in case of need.

3.1 Main control board hardware design

Main control board electronic circuits are based on Freescale MC9S08GB60 microcontroller (MCU) coordinating all operations of the measurement system. It is a member of low-cost, general purpose, high-performance 8-bit flash-based microcontrollers with Von-Neumann architecture. Central processor unit with enhanced HCS08 core is fully upward compatible with Freescale HC05 family. CPU architecture is fully optimized for C language compilers.

On the chip are integrated following modules [1]:

- One 3-channel and one 5-channel 16-bit timer/pulse width modulator modules
- Two serial communication interfaces
- Serial peripheral interface
- Inter-integrated circuit bus module
- Internal clock generator module
- 10-bit analog-to-digital converter with 8-channel analog multiplexer
- On chip 64KB FLASH memory with in-circuit programming capability
- 4KB on-chip RAM
- 56 general-purpose I/O pins (16 high-current pins)
- 8-pin keyboard interrupt module
- On-chip debug module (DBG)

- Software selectable pull-ups on ports when used as input
- Watchdog system
- Low-voltage detection
- Illegal operational code and address detection

Central processing unit (CPU) features [2]:

- 40 MHz operation at 3V
- 8-bit accumulator (A)
- 16-bit stack pointer (SP) with new stack manipulation instructions
- 16-bit index register (H:X) with index register instructions
- Memory to memory moves without using the accumulator
- Fast 8-bit by 8-bit multiply and 16-bit by 8-bit divide instructions
- 64 Kbytes program/data memory space

Correct program function is monitored by integrated watchdog system and illegal operational code and address detection. Internal program loading and debugging is provided by on-chip debug module (DBG). Internal bus frequency can be 20 MHz at 2.08 to 3 V supply voltage range or 8 MHz at 1.8 to 3 V supply voltage range.

Communication with supervision system is provided by FT232BM USB universal asynchronous receiver / transmitter (UART) integrated circuit (IC). It is capable to communicate at TTL levels with data transfer rates up to 3 MBd. On chip integrated transmit and receive buffer with capacity of 128B and 384B enables high data throughput. It operates from single power supply with voltage of 5 V. USB input / output interface is supplied from integrated 3.3 V voltage regulator. Due to integrated level converter for UART I/O signals it is possible to connect it with logic operating at 3.3 V or 5 V [3]. FT232BM is wired in manufacturer recommended wiring for self powered application with 3.3 V I/O interface. Connected EEPROM memory 93C46 is optional and can be used for storage of USB vendor identification (VID), device class definition for physical interface devices (PID), serial number and product description strings. Clock signal is generated externally by crystal oscillator Q_2 with frequency of 6 MHz. Activity of serial interface is indicated by two LEDs LD_1 and LD_2 for receive and transmit mode separately. UART I/O interface is connected to corresponding pins of microcontroller IC1.

Eight 30 pin expansion connectors JP2 to JP9 include all signals necessary for expansion modules function. They provide all available voltage sources 3.3V, 5V for digital and +15V, -15V for analog circuits, serial peripheral interface for communication with master microcontroller and finally 8 input and 8 output general purpose digital interface which is utilized for internal logic control of the connected modules. Currently active expansion connector is selected by microcontroller in cooperation with decoder 74HC138 on which outputs are available eight board select signals BS_0 to BS_7 active at low state. Only one expansion module can be in active state and communicate via SPI interface with microcontroller. Other modules (with board select signal in high state) must stay in the high impedance state. Simplified schematic of the main control board without power supplies is depicted in the Fig. 2.

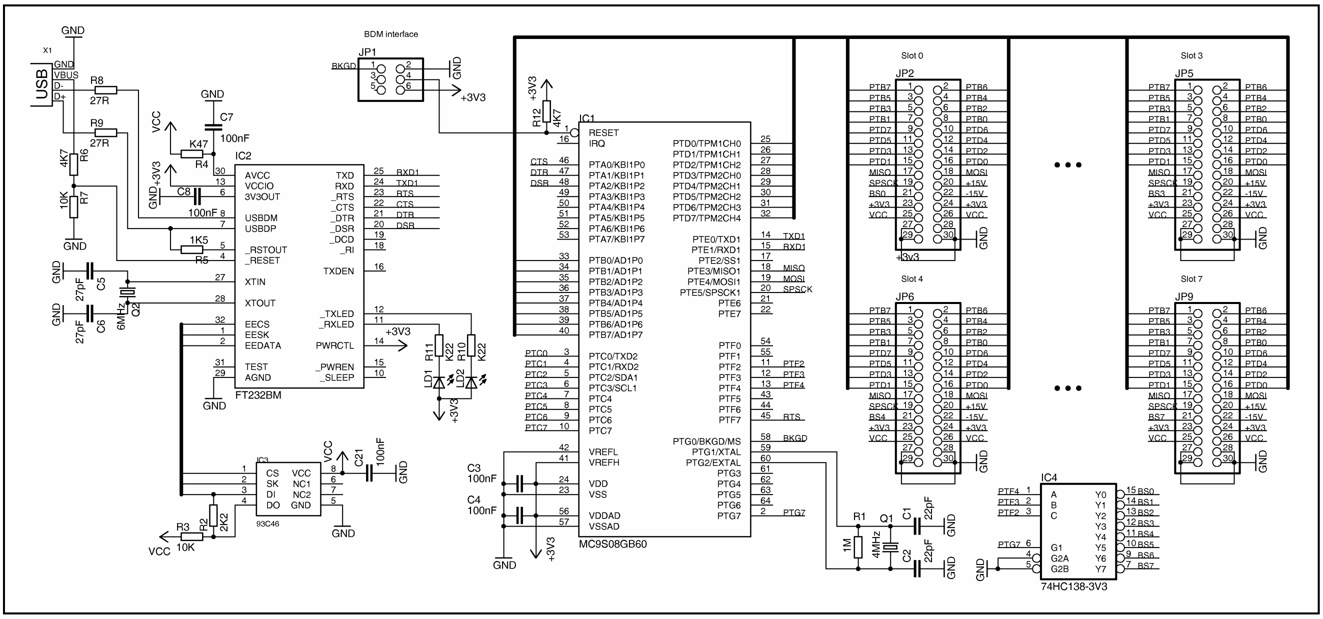

Fig. 2 Main control board schematics.

3.2 Strain gauge measurement module

Electronic circuits of the strain gauge measurement module can be divided into the six functional blocks as illustrated in the Fig. 3: amplifier with selectable gain, 4th order low pass filter, offset null circuit, D/A converter, A/D converter and input / output interface for communication with main control board.

Input voltage signal from strain gauge sensor is amplified to suitable voltage level for analog-to-digital converter in two stage amplifier utilizing two low offset and drift JFET operational amplifier LF411. First stage works as differential amplifier with fixed gain of 5 followed by non-inverting stage with five program selectable gains of 1, 1.5, 3, 10 and 30. This leads to module input voltage ranges of ±10 mV, ±30 mV, ±100 mV and ±300 mV.

Amplified input signal passes 4th order active low pass Bessel type filter with Sallen–Key topology implemented by operational amplifiers to eliminate ripple in the input signal. Filter parts was designed for cutoff frequency of 200 Hz and gain of 0 dB in the passband. This type of the filter was chosen due to advantageous step response with small overshot as depicted in the Fig. 4. On the other hand its drawback is smaller slope of the stop-band part of the frequency characteristic in comparison with Chebyshev or Butterworth approximations.

Filtered signal enters to offset null circuit which sums it with digital-to-analog converter output voltage. This voltage is controlled by master microcontroller to obtain zero readings when no strain is applied to sensor. Circuit utilizes Microchip MCP4921 12-bit D/A converter.

Analog-to-digital conversion is performed by the A/D converter Microchip MCP3202. It is low power, dual channel, 12-bit A/D converter which can operate on 2.7 V to 5.5 V power supplies [4]. Communication with microcontrollers is handled by SPI interface.

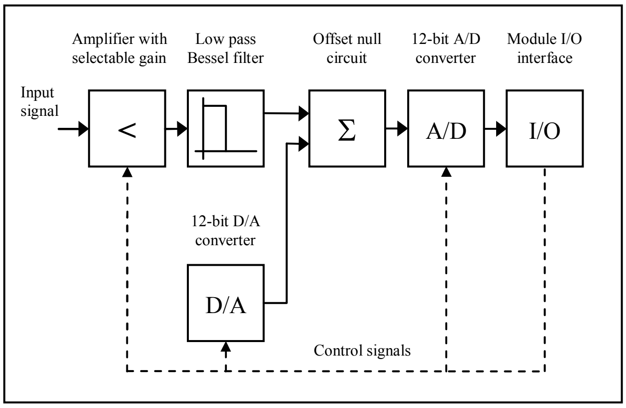

Fig. 3 Block diagram of the measurement module.

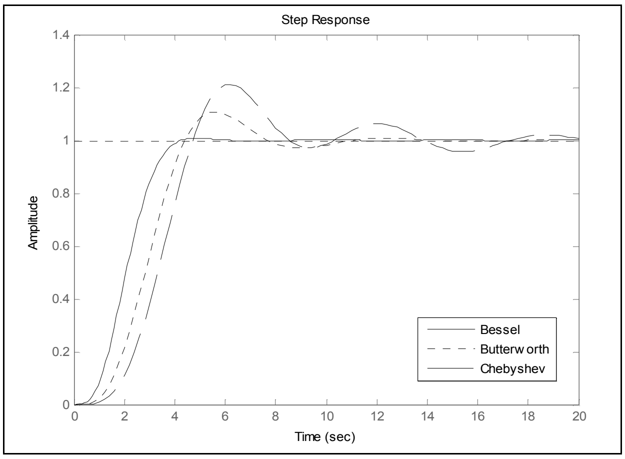

Fig. 4 Step responses of commonly used filters.

4 Acknowledgment

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5 Conclusion

This contribution deals with design of the multichannel measurement system for strain gauge sensor evaluation. Device implements modular hardware design dividing of the whole measurement system to main control board and input / output eventually measurement modules. Expansion modules are automatically recognized by master microcontroller by unique identification number in the range 0 to 6. Communication with supervision system is provided by USB interface which is recognized as standard serial port in the host operating system.

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