A New Laboratory Equipment for Characterization of Smart Concrete Materials

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***Abstract*—"Smart Concrete" materials are concrete composites prepared according to the final application to achieve high electrical conductivity or strain gauge characteristics. Large electrical conductivity is used for heating control (protection sidewalks and roads from freezing). Strain properties can be used to measure the deformation of concrete structures (bridges, beams, pillars) or for weighing-in-motion of road vehicles.**

***Keywords*—smart concrete; impedance measurement; heating controll**

I. INTRODUCTION

"Smart materials" are drawing more and more attention these days. One of the most common structural materials used in engineering construction is cement and its mixtures (concrete and mortar). Cement is slightly conducting material, but its electrical conductance, EMI shielding effectiveness and wave absorbing property are very poor. In order to increase the ability of cement materials to conduct and shield EMI, additional conductive or absorbent fillings and loadings have to be introduced to admixture to provide higher EMI preventing effectiveness [1]. "Smart concrete" (SC) and its derivatives could be consider as a material of the future. Due to its attractive features, SC can be used as a strain-sensing element, as a resistive heating or as an EMI shielding.

II. MEASUREMENT OF STRAIN PROPERTIES

Strain properties of the composite can be evaluated by impedance changing. The impedance changing sensitivity regarding the deformation can be widely affected by a proper choice of concrete admixtures [2]. Generally, in all types of admixtures, the real component is not much affected by the deformation, on the other hand, the imaginary component is, and can be used to detect the changes [3]. For impedance measuring, an excitation frequency of 1 KHz, and an excitation voltage of 1 V (peak-peak) were experimentally set [4]. During the measurements of experimental samples, a necessity to a simple, relatively inexpensive and portable device has been raised.

A. Construction of "Z-meter"

This battery-powered device facilitates its usage in the experimental field. According to the aforementioned requirements, a block diagram of the instrument has been suggested. The diagram is shown in Fig. 1. The device function is based on 16-bit MSP430F5438 microcontroller, which uses RISC architecture. This microcontroller can be "in circuit" programmed via JTAG interface. Interface also allows real-time debugging of firmware, which ensures all device functions. A 16-level yellow Organic Light Emitting Diode (OLED) graphical display that has 256 x 64 pixel resolution is used for visualizing the measured values and navigating during measurement parameters setting. The communication with OLED display is done via Serial Peripheral Interface (SPI). The function of those pushbuttons is determined during the navigation and shown on the bottom part of the display. The device is equipped with a buzzer that warns the user of important states of the device. This feature is built for convenient usage of the device. An integrated 4 Mb memory and SD card, which can be inserted into a side slot, are enclosed for saving the measured data. Both memories communicate with the microcontroller via SPI interface. A special circuit designed by FTDI Company enables USB interface connection for transferring the measured data into the PC. This circuit communicates with the microcontroller via UART.

Moreover, the aforementioned USB is used for device supplying and internal Li-Pol accumulator charging. This feature helps to supply the device in case of necessity to perform outdoor measurements. The supply voltage supervising is maintained by a group of supply blocks located at the bottom part of the diagram, shown in Fig. 1. The charge control circuit, designed by Microchip Company, controls the accumulator changing, and stops it when the maximum voltage is reached. A buck-boost converter provides 3.3V for supplying the digital circuits. On the other hand, analog blocks are supplied by 5 V and 3 V. The 5 V supplying circuit is realized by charge pump. The 3 V supplying circuit is realized by the reference voltage source with minimal noise, designed by Analog Devices. The reference voltage 3 V is used for supplying the AD5933 impedance converter [5].

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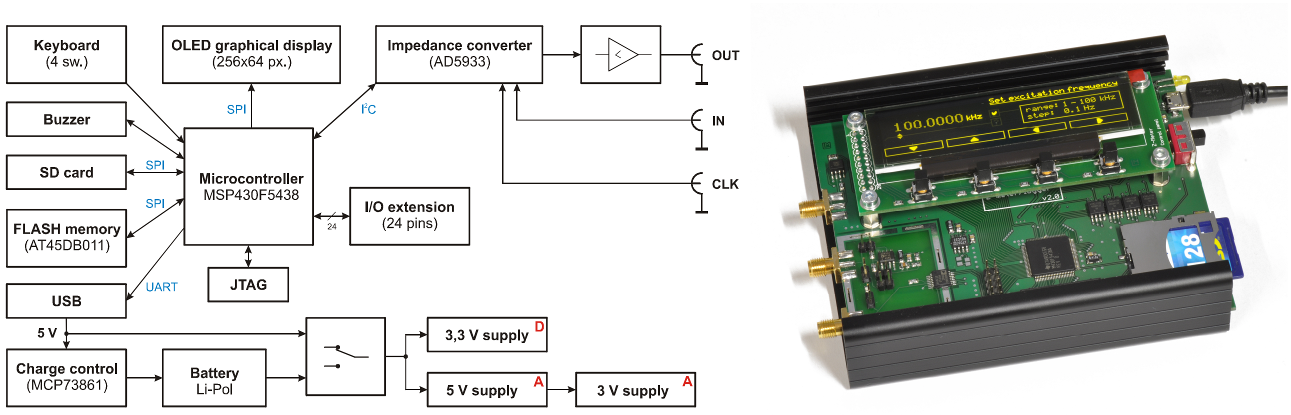

Figure 1. The block diagram and physical appearance of proposed Z-meter

The 24 unused I/O pins of the microcontroller are attached to an expansion connector for universal use. The mechanical design of the proposed device is realized according to the following requirements: portability and durability. The printed-circuit boards along with the supplying accumulator are enclosed in the aluminum case.

B. *Impedance converter AD5933*

The impedance measuring depends on the AD5933 integrated circuit, which permits setting the required value of the excitation voltage and frequency. The excitation frequency can be set between 1 and 100 kHz in steps of 0.1 Hz. The impedance measuring range is 100 Ω to 10 MΩ with a 12-bit resolution. The communication with the circuit is done via the serial I^{2}C bus.

C. *Measurement automation and data processing*

The device is equipped with a galvanic isolated external input that triggers the start of the measurement and synchronizes it with other measuring devices. Some measuring devices don’t have that external trigger. The proposed device handles that synchronization according to a time sequence. The measured data can either be stored in the device internal memory (FLASH, SD card) or transferred via USB interface to the PC.

III. Heating Control and Monitoring

The aim when designing the control electronics for the new panel has been tempered to direct regulation of cement composite with carbon nanoparticles based on processes inside the composite material tempered. The system is controlled by a set of sensors located inside and outside the composite (tempered) panel. Sensors implemented inside the composite material provide immediate information on the status of the material, external sensors will evaluate the state of environment and to effectively regulate the entire system.

Using SC as a resistance heating is a complementary method that needs to be investigated. The resistivity of concrete can be diminished by using an electrically conductive admixture, such as discontinuous carbon nanofibers, discontinuous steel fibers, steel shaving and graphite particles [6], [7]. Combining and changing an admixture ratio leads to different value of resistivity. A control device had to be designed to test and evaluation of the samples and to find the ideal admixture ratio and heating element pattern.

A. *Construction of temperature control unit - “RCT”*

The control unit can be divided into two parts, namely the power and control. Power section contains only a toroid transformer 230 V / 2 x 24 V (500 W), which provides ample power for heating elements and tempered serves to control the power that is supplied from the converter with high efficiency 3.3 V. Unit can independently control Load up to 3 (3 tempered components) with power consumption up to 6 A for each channel. The maximum allowable current is monitored as the sensor current and fuse.

The control part consists of parts, which includes the control part with the microcontroller, high-contrast alphanumeric LCD display, backlit, a system of sensors to measure temperature, humidity and electrical power, power section with a converter with high efficiency, switching thyristors excited by optotriacs, Bluetooth Module Class 1 terminal server (XPort) for communication over Ethernet. The overall block diagram and physical appearance is shown in Figure 2. Data is automatically saved on the SD / MMC card or via Ethernet to a remote server or over Bluetooth to other mobile devices. Choice of connection depends only on the user.

The control section provides all system functions RCT. MCU processes the data from sensors, switches different circuits, stores data on SD / MMC card, controls the communication with the environment and writes the current data on the LCD display. For sufficient computing power was voted an 8-bit Microcontroller Atmel ATmega128 with the type designation.

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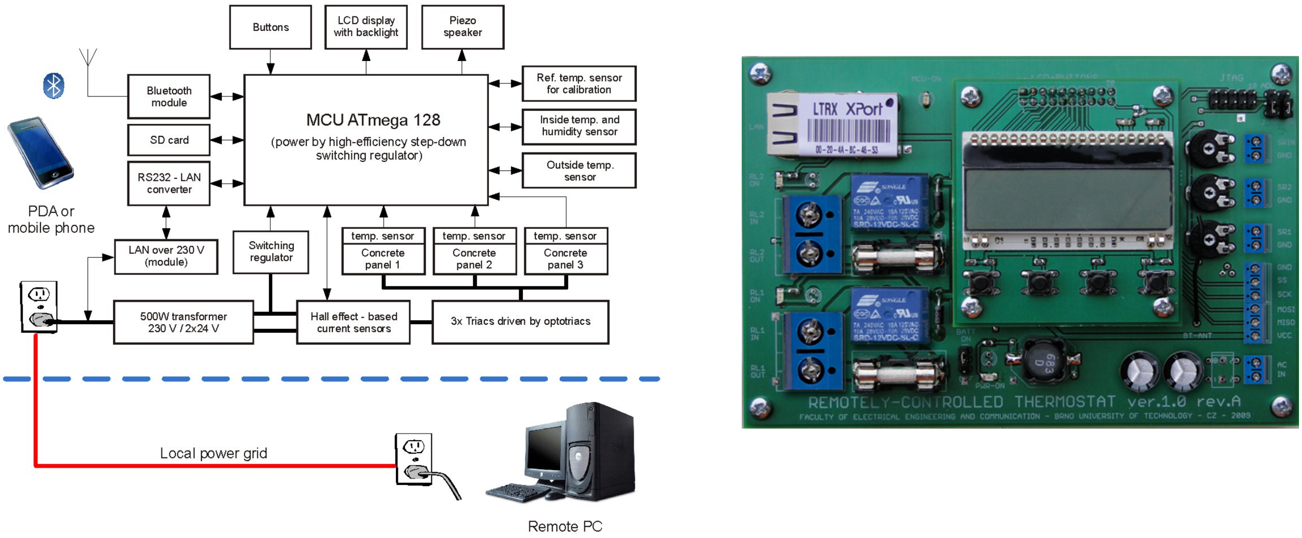

Figure 2. The block diagram and physical appearance of proposed RCT device

RCT contains several types of sensors. To measure temperature of composite materials there are used three PTC thermistors connected to the MCU. Analog inputs for sensing outdoor temperature are used for accurate 12-bit digital sensor. Indoor temperature and humidity devices RCT captures digital sensor SHT11. Electric current flowing through each sample is scanned 20 A hall sensor.

B. *Communication*

RCT is equipped with a Bluetooth module WT11 that offers a range of up to 100 m. Any Bluetooth-enabled devices (PDAs, mobile phones) can be used to control RCT. Another way to check RCT is Ethernet (TCP / IP). Terminal server - Xport - converts data from the UART directly to Ethernet. XPort supports 10/100 Ethernet, built-in web server provides a complete set of network protocol, security, speed and other parameters. The output of the XPort is brought to Ethernet Bridge module. This allows control over RCT grid 230 V without pulling the LAN cable.

C. *Data storage*

For storing data can be used for standard SD / MMC cards. The presence of the card is detected during system initialization. RCT also supports high-capacity SDHC cards. Data can be written in a different format of settings and needs. The default format is a CSV file. Output data can be readily evaluated using standard PC software.

D. *Working modes*

Workload management components can be tempered to use four different modes:

- The first mode “STANDARD” allows you to control each channel separately. The system controls the temperature of each channel and switches individually tempered connected component, if the temperature drops below the set limit. In this mode, does not reflect the ambient temperature.
- The second mode is called “COMMON”. In this mode, all channels driven simultaneously and critical temperature of the ambient temperature. If the temperature drops below the set level, all channels are closed.
- The third mode is the “ECO” mode. This is the last COMMON mode, which is also supplemented by the upper and lower limits. Thus, if the outside temperature drops below the preset extreme (e.g., -15 ° C), the concrete panels would no longer be able to effectively drowning, therefore they will shut down and power saving. You can also set the upper limits (e.g. 5 ° C), in which parts are no longer needed further tempered.
- The fourth mode is called “SWITCH” mode, because there is a periodic switching (distributing) of energy between different parts of tempered parts. It can thus make better use of the overall device performance, or you can use a transformer with one secondary and acclimatized to force him more sections. Time can be set from 1 to 60 seconds.

In the heating / tempering carried out production of several types of heated parts. In their design had to take into account the reciprocal interaction of composite heating insert and the concrete member itself, and I address this issue in analyzing the processes that occur inside components. The heating panel was implemented copper electrodes, used to bring the necessary capabilities, and temperature sensors that allow evaluating the process inside the composite material. An integral part of the analysis of thermal images was a composite panel that

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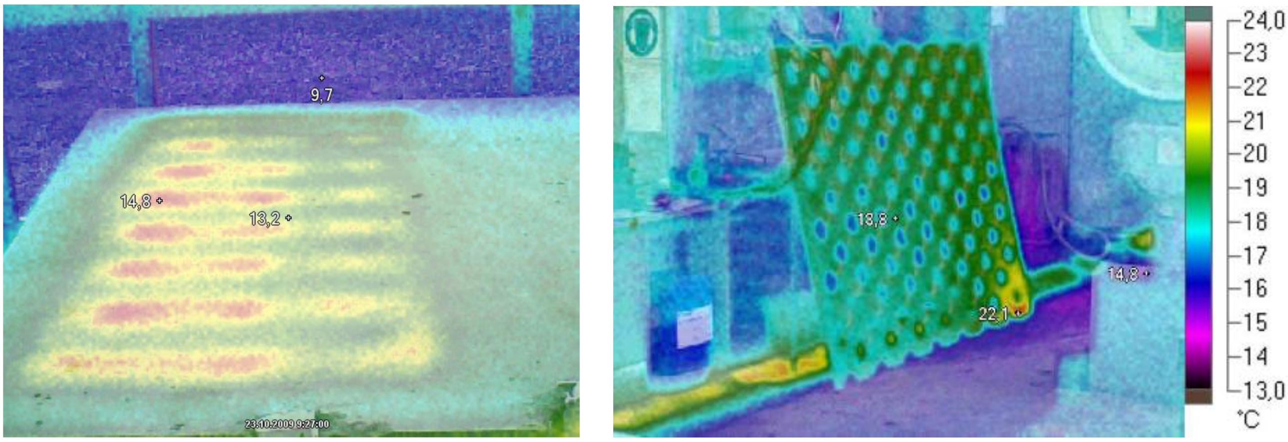

Figure 3. Infrared photos of heated concrete panel with admixture of conductive fillings

make it possible to precisely define the current load of locations composite liners. Subsequently, this area developed control unit. It is a three-channel digital thermostat with data recording (data logger) that is equipped with advanced features and allows remote control via Ethernet or Bluetooth, and data storage on an SD card.

The facility has implemented a number of heating modes. Among the most elaborate one "ECO" mode is based on evaluation of environmental conditions regulates the heating of composite material so as to avoid unnecessary heating of components in a time when the power system is not sufficient to prove the part is tempered heat up.

Both concrete samples include a temperature sensor integrated in the middle of the concrete block to provide precise internal temperature. Currents that flow through concrete samples are measured by Hall effect-based current sensors and controlled by 10 A relays. Together with the outside temperature sensor, RCT can effectively control dissipation power of the resistive heating and hold set temperatures.

As an example, two concrete blocks were tested (Fig. 3). Resistance varies from 4 Ω to 6 Ω that gives output power up to 114 W when using 24 V voltage source.

Conclusion

A development of new laboratory instruments was presented in this paper, the suggested block diagram, realization and design of the PCBs and overall structure of the design. These instruments are currently used for laboratory measurements and characterization of smart concrete panels at department of microelectronics.

Acknowledgment

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