Improving strain measurements at Tidal Station Vyhne, Central Slovakia: Technological modernization using a capacitive transducer

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Abstract: The year 2024 marks the 40-th anniversary of observation of Earth tides at the tidal station of Vyhne, Central Slovakia. The station was established through an international scientific collaboration in 1984. Since then, it has monitored the geodynamical phenomena almost continuously. At the beginning, the station was equipped with an extensometer with an analogue photo-recorder. Later on, the extensometer was fitted with a new sensor unit based on the principle of a capacitive transducer. The subject of this paper is the design and construction of a new sensor for measuring subtle displacements in the Earth's crust due to the action of tidal and tectonic forces. Similarly to the currently operating sensor, it is based on the simple principle of measuring voltage changes on a movable sensing electrode fastened to a quartz glass tube. However, compared to the previous analogue version, a solution using the contemporary possibilities of high computing power of a modern microcontroller as well as its integrated peripherals are employed. Measured values are stored in a flash memory in off-line mode. The device is ready for operation in on-line mode for remote data collection in real time, as well. The first recorded data indicate that the instrument is working correctly, successfully registering the tidal phenomena. However, a significantly longer measurement period is required to ensure its proper operation and to rule out any potential adverse effects. Parallel measurements are to be carried out using both the new and former sensors, and the consistency of the results shall be examined.

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1. Introduction

Observations of Earth tides belong amongst the fundamental means of studying the global deformations of the Earth. They are still of significant interest for studying the recent geodynamical processes. The deformations observed at the Vyhne tidal station can be divided into two sub-categories: tidal, which are the consequences of tidal forces affecting the Earth, and non-tidal. Non-tidal deformations can be caused by a variety of contributing factors, such as hydrological and atmospheric pressure loading effect, or local tectonics. They can also originate from thermal changes, consisting of two main components. The first one would be periodical with a period of roughly one year. According to *Brimich and Hvoždara (1988)*, this type of observed deformation can be attributed to the effect of thermoelastic deformation due to annual temperature variation. The second component is not periodical, where *Brimich et al. (1989)* suggests that it could be rooted in the thermoelastic deformation effect due to an anomalous heat source.

An extensometric network was established in the Carpatho-Pannonian region consisting of tidal stations in Sopron and Budapest in Hungary, Beregovo in Ukraine, and Vyhne in Slovakia. The Carpatho-Pannonian area is of scientific interest due to its tectonic activity and the presence of other related geodynamical processes. The Vyhne tidal station was established in 1984 as a result of scientific collaboration between the Geophysical Institute of the Slovak Academy of Sciences and the Institute of Physics of the Earth of the USSR Academy of Sciences, Moscow. A quartz-tube extensometer with a photo-recorder device was installed (*Brimich, 1988; Brimich and Latynina, 1989*) for recording the Earth tide and recent tectonic movements. In 1998, the instrument was renovated, and the photo-recorder device was replaced by a capacitive transducer sensor unit developed at the Geodetic and Geophysical Institute of the Hungarian Academy of Sciences (*Mentes, 1991; 2008; 2010*).

Throughout the lifetime of the station, data has been shared and evaluated in collaboration with colleagues from the Hungarian Academy of Sciences and the Schmidt Institute of the Earth Physics, Russian Academy of Sciences (*Brimich et al., 2008; Mentes et al., 2021*). In early 2020, the station was burglarized, and the extensometer was severely damaged by vandals, rendering the station inoperable. It took almost a year to get the instrument repaired, stabilized and the station operational again (with the help from colleagues G. Mentes and T. Molnár from the Institute of Earth Physics and Space Science, Hungary Academy of Sciences). Since then, first data were processed and analysed for the year of 2021 (*Bódi et al., 2023*).

Although the current sensor is still fully operational, after more than 20 years since the last renovation the need for another modernisation has become apparent. As of 2024, a new sensor unit based on the principle of a capacitive transducer was designed, constructed and installed. A new infrastructure for the data communication system has also been established, incorporating a new data logger and improved communication pathways. The development of the sensor was carried out by P. Fabo and M. Kuba, from the Faculty of Special Technology of the Alexander Dubček University in Trenčín. In the nearest future, parallel measurements using both the existing and new sensors are planned, in order to verify the qualitative performance of the new sensor.

2. Extensometer construction

2.1. Requirements

The complicated environment of the former mine gallery, which is characterized by low temperature, high humidity and the presence of condensed water, places high demands on the technical implementation of the extensometer, which is intended for long-term and accurate measurement of displacements of rock blocks in the order of nanometers.

The general requirements for equipment designed to measure physical quantities in such an environment can be summarized in the following points:

- robust measurement principle that resists adverse environmental effects for a long time
- compact design without external adjustment elements
- minimal or completely maintenance-free operation
- minimal impact on the environment and measurement conditions
- a cost-effective solution.

The extensometer is based on the proven principle (*Mentes, 1991*) of measuring voltage changes on the plate capacitor electrode system. The electronics of the extensometer uses the possibilities of a modern microcontroller and is based on a minimalist principle, which assumes a minimum of external analogue circuits in signal processing with maximum use of the possibilities and properties of the internal blocks of the microcontroller. The stated principle allows adjustments and changes to the operating parameters of the device as well as adjustments and changes to data processing algorithms without the need for change the hardware configuration of the device.

This principle enables the continuity of long-term monitoring of the investigated events, even after reaching the device's lifespan, as well as after the end of production of the used components. This can be done by transferring and adapting the software to a current microcontroller. Given the dynamics of the current technological development, we can expect even higher performance and better capabilities in comparison with the current state.

2.2. Extensometer configuration

The measurement of the tidal deformation (i.e. the relative displacement difference within the rock massif) is based on the measurement of the displacement difference between two sufficiently distant points of the rock massif. To one of the points, a 20.5 m long quartz glass tube is firmly fixed. The tube is deemed to be undeformable. Its role is to transmit the displacement of the former point to the point of observation, where the stationary plates of the capacitive transducer register the position of the movable plate fastened to the free end of the tube (Fig. 1). The tube is composed of several segments and suspended on hinges using an invar wire, which enables its axial movement and dampen radial oscillations. At the fixed end of the tube, a calibrating magnetostrictive element connects it to a concrete block. At the other, free end, a sensing electrode is placed, under which the excitation electrodes of the extensometer are placed on the second concrete block together with auxiliary analogue electronic circuits.

The section of the mine containing the measuring device is thermically isolated, without air flow, with a stable temperature with an annual variation of 0.04 degrees of Celsius. In this section, there is also an auxiliary

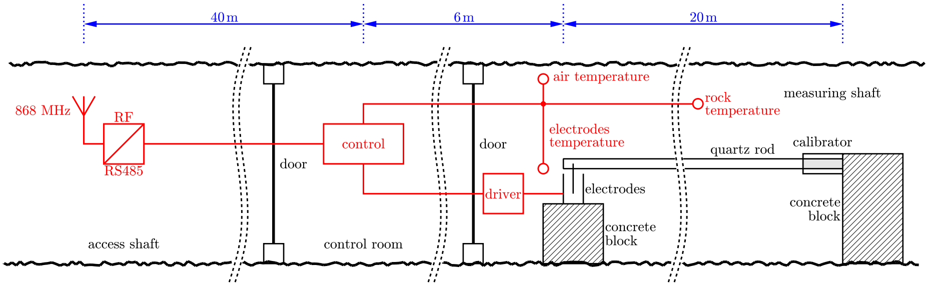

Fig. 1. Schematic depiction of the extensometer configuration at the workplace.

measurement of the temperature of the metal base of the electrode holder and the measurement of the air temperature. The auxiliary measurement of the rock temperature is yet to be put into operation.

The electronic control systems of the extensometer are located in a separate, sealed control room, which is situated approximately 80 m from the entrance to the mining gallery separated by the access corridor. A communication radio module for wireless access to the device was connected to the control unit by a data cable and installed approximately in the centre of the access tunnel.

2.3. The principle of displacement measurement

The basic electric circuit of the extensometer consists of two parallel planar excitation electrodes, Fig. 2, the area of which is S, which are fixedly placed from each other by a distance of L. The electrodes are powered by sinusoidal voltage waveforms $u_1(t)$ and $u_2(t)$ respectively with an angular frequency of ω_0 and with a relative phase shift between both waveforms of π radians. A movable sensing electrode fixed on a quartz glass tube is placed between the excitation electrodes. The sensing electrode is connected to zero electric potential through the resistor R. The electric voltage waveform $u(t)$ on the resistor is a function of the position of the middle electrode and the dielectric constant of the environment ϵ, provided a constant size and distance of the excitation electrodes.

Let $\dot{U}_1$ and $\dot{U}_2$ are complex amplitudes of sinusoidal voltage waveforms $u_1(t)$ and $u_2(t)$ respectively and let j is the imaginary unit. The following relationship can be derived for the dependence of the complex amplitude $\dot{U}$

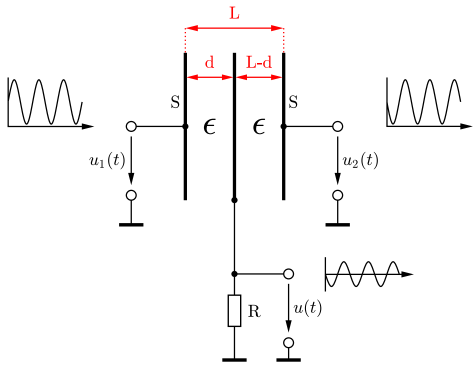

Fig. 2. Extensometer electrodes circuitry.

of the sinusoidal voltage waveform $u(t)$ on the sensing electrode depending on the change in its position d:

$$\dot{U}(d) = \frac{\left(1 - \frac{d}{L}\right)\dot{U}_1 + \frac{d}{L}\dot{U}_2}{1 - j\left(1 - \frac{d}{L}\right)\frac{d}{\omega_0 \, R \, \epsilon \, S}} \, .$$

The relationship will be purely linear for $R \to \infty$, which is, however, unrealizable for practical reasons. The phase of the output voltage will change to a certain extent depending on the position as well as the value of the resistor, which can be practically used to check the state of the insulation resistance of the sensing electrode.

2.4. Extensometer construction

The electrodes of the extensometer are laser-burnt from stainless steel with a thickness of 0.5 mm and dimensions of 10×5 cm. The excitation electrodes are fixed on a massive block made of duralumin with a thickness of 20 mm. This block is placed on a 5 mm thick stainless steel plate, which is glued with construction adhesive to the concrete block, and therefore it can be rectified with three screws with a fine thread. The sensing electrode is fixed on a tube made of quartz glass by means of a sleeve. On the block with electrodes, analogue electronics for excitation of the electrodes and an impedance converter for the sensing electrode are placed in hermetic metal boxes (Fig. 3). The distance between the excitation electrodes is 5 mm. The entire structure of the electrodes is placed in a cover made of polyurethane foam, which ensures the protection of the electrodes from dripping water from the mine shaft ceiling.

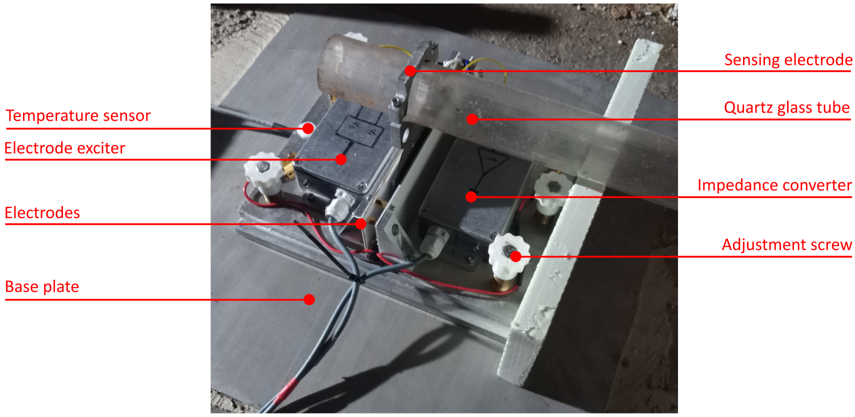

Fig. 3. Electrode arrangement without the heat shield.

In the design and implementation of electronic circuits, control and data collection from the extensometer (Fig. 4), the internal functional blocks available on the chip of a modern microcontroller were used to the maximum extent. The ARM STM32L476 microcontroller, belonging to the class with very low consumption and operating clock frequency of 80 MHz, was chosen as the implementation platform.

The basis of the extensometer control is the generator of harmonic signals for excitation of the electrodes (Ea, Eb) and circuits for processing the signal from the sensing electrode (Ec). The principle of direct digital synthesis was used to generate the excitation signals of the extensometer electrodes using a two-channel digital-to-analogue converter (DAC) through a direct memory access (DMA) channel. Synchronous with the DAC converters, the analogue-to-digital converter (ADC) is also controlled by the timer (TIM), which converts the voltage waveform on the sensing electrode of the extensometer into numerical values and uses a separate DMA channel.

Other blocks used in the extensometer are the real-time clock (RTC) controller, which serves to control the measurement time sequence and generate time stamps, serial interface communication circuits (USART1, USART2), serial interface (SPI) for communication with an external 16 Mbit flash memory and parallel interface (GPIO) for controlling connected thermometers via a 1-wire interface and LED indicators.

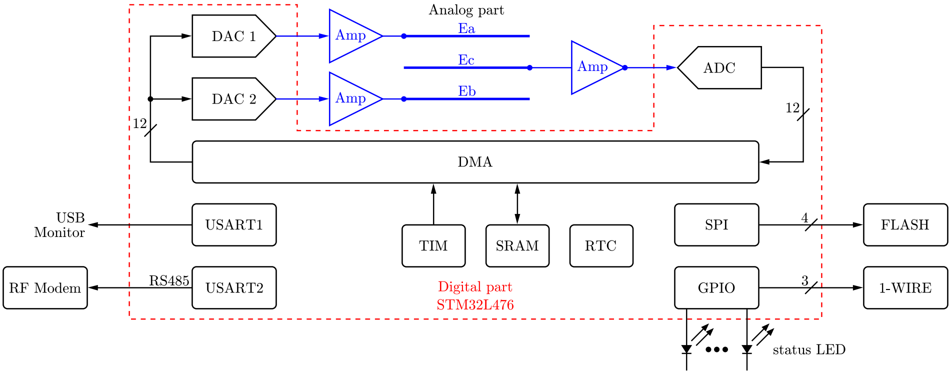

Fig. 4. Simplified block diagram of the extensometer.

2.5. Analogue circuits

The electrodes of the extensometer are connected to the control electronics by cables several meters long, therefore it is necessary to match the impedance of the excitation electrodes as well as the sensing electrode to the impedance of the cables, which is approximately 120 Ω, in order to eliminate the cable capacitances. The excitation electrodes are connected to the outputs of the DAC converters via a twisted-pair line. Excitation signals from DAC converters are additionally amplified by inverting amplifiers located directly near the excitation electrodes.

The signal from the sensing electrode is fed through an impedance converter and a twisted-pair line to a second-order bandpass filter, where it is also amplified 10-times and its DC level is shifted to half the range of the ADC converter (Fig. 5).

2.6. Analogue-digital interface of the extensometer

The analogue-digital interface of the microcontroller includes a two-channel 12-bit DAC converter for generating signals for the excitation electrodes using direct digital synthesis algorithms and a 12-bit ADC converter for converting the analogue signal from the sensing electrode into digital form.

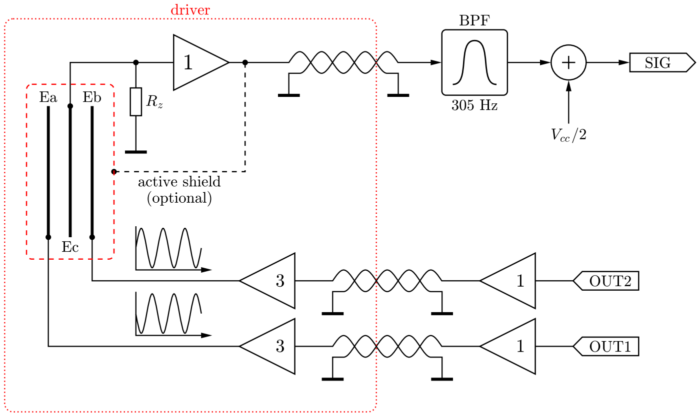

Fig. 5. Block diagram of analogue circuits.

The two-channel direct digital synthesis (DDS) generator, Fig. 6, is implemented on a microcontroller chip by program means without the use of external components. For both channels of the generator, it is possible to individually set the frequency, amplitude and DC offset of the generated

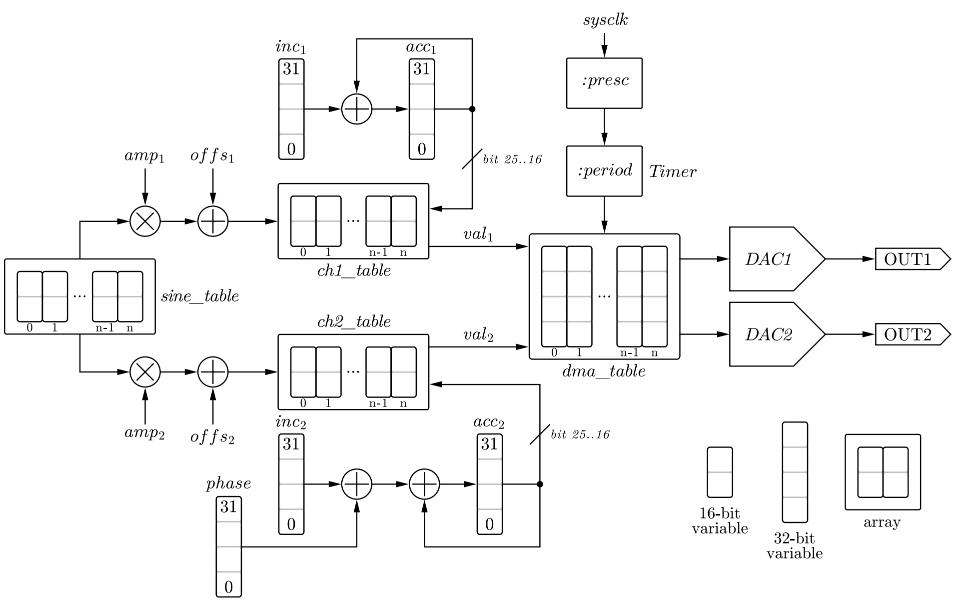

Fig. 6. Structure of a two-channel direct digital synthesis generator.

harmonic waveform, as well as the phase shift between the two channels. In the extensometer, both channels of the generator operate at the same fundamental frequency and their mutual phase shift is π radians.

The principle of operation of the DDS generator is based on the use of a phase accumulator register acc_n whose width is $N = 26$ bits. However, its content is stored in a standard 32-bit register. The upper 10 most significant bits of the 26-bit phase accumulator register are used to address the look-up table (LUT), which contains the values of one period of the sine function. It follows from the above that the total number of values in the LUT table is $2^{10} = 1024$, so the length of the LUT table is $n = 1024$ values (samples).

The operation of the DDS generator is based on updating the value of the acc_n phase accumulator register so that the value of the phase increment inc_n is regularly added to its content. The highest 10 most significant bits of the resulting value of the phase accumulator register form the address to the LUT table *chn_table*, which determines the current value in the LUT table, which will be written into the *dma_table* buffer. The values from this buffer are sent at regular time instants determined by timer *Timer* to the digital-to-analogue (DAC) converter through direct memory access (DMA) without the intervention of the processor (CPU) of the microcontroller. The stated principle enables the generation of harmonic signals with minimal load on the microcontroller processor.

The LUT table *chn_table* is derived from the reference LUT table *sine_table* such that each value in *chn_table* is obtained from the corresponding value in *sine_table* by multiplying this value by the amplitude value amp_n and finally the value of the DC offset $offs_n$ is added to this value so that the final value in *chn_table* is obtained. Both channels of the DDS generator are identical, the second channel ensures the phase shift between the channels so that the value of the phase shift between the channels is added to the value of the phase increment of the second channel of the DDS generator.

The sampling rate F_s of the DDS generator is given by the timer clock signal frequency, which is given by the CPU speed $sysclk = 80106$ Hz and the timer values prescaler $presc = 16$ and the period $period = 16$ according to the following relationship:

$$F_s = \frac{sysclk}{presc \cdot period} = \frac{80 \cdot 10^6}{16 \cdot 16} = 312500 \text{ samples per second.}$$

The fundamental frequency F_0 of the generated harmonic signal from the DDS generator is given by the value of the sampling frequency $F_s = 312500$ Hz, the value of the phase increment $inc_n = 65536$ and the value of phase accumulator register width $N = 26$ bits of the DDS generator according to the following relationship:

$$F_0 = F_s \frac{inc_n}{2^N} = 312500\,\frac{65536}{2^{26}} = 312500\,\frac{65536}{67108864} = 305.17578125\ \text{Hz}.$$

With the current configuration of the DDS generator parameters, the length of the buffer *dma_table* is the same as the length of the LUT table *chn_table*, and it is chosen so that at a given value of the sampling frequency $F_s = 312500$ samples per second and at a given value of the frequency of the generated signals $F_0 = 305.17578125$ Hz will be exactly one period of the generated signal in the *dma_table* buffer, because the following applies:

$$n = \frac{F_s}{F_0} = \frac{312500}{305.17578125} = 1024\ \text{values (samples)}.$$

The ADC converter is controlled by the same timer as the DAC converters, which guarantees their mutual synchronization and connection between the generated and measured data. After ADC conversion, the measured values during defined time intervals are accumulated in a separate buffer *acc_table*, Fig. 7. The purpose of the accumulation of the measured data is to suppress the influence of noise and interference on the measured data and to increase

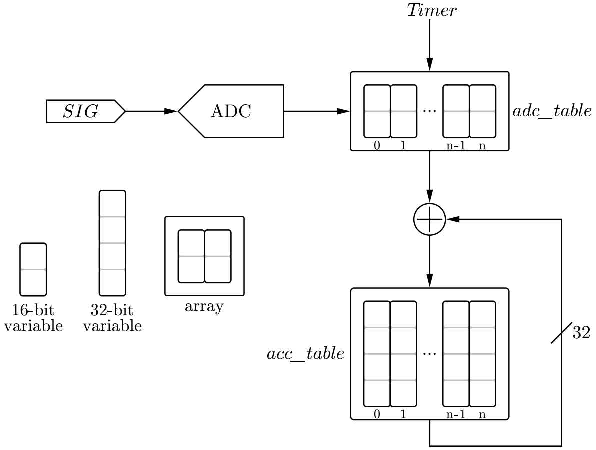

Fig. 7. Analogue-digital converter and principle of data accumulation.

the accuracy (numerical resolution) of the measured data. The conversion speed of the ADC converter is determined by the number of samples per one period (in this case 1024) of the generated waveform and its frequency. In the configuration that was used in the extensometer, it is the same as the conversion speed of the DAC converters.

2.7. Local memory of measured data

The extensometer can work in two communication modes, in the on-line mode it is possible to read the last measurement results together with their time stamp, at the same time the measured data is stored in a large-capacity memory, from which they can be read in the off-line mode. Access to the data is possible at any time, without interrupting ongoing measurements.

For storing the measured values, the extensometer uses a flash memory W250Q128FV with a capacity of 128 Mbit, Fig. 8. The memory is internally organized into 4096 pages of 4096 bytes, writing is possible up to 65536 segments with a length of 256 bytes. The size and structure of the memory is a determining factor for the format of the stored data as well as for the time parameters of the measurement. For the extensometer, a measurement period of 4 seconds was chosen, with 15 measurements per minute, which, together with the time stamp, fill 128 bytes of memory. The results of two minutes of measurement are written into one segment with a length of 256 bytes. Data from 30 minutes of measurement (15 segments) is stored in one page of 4096 bytes, with one segment reserved for service information.

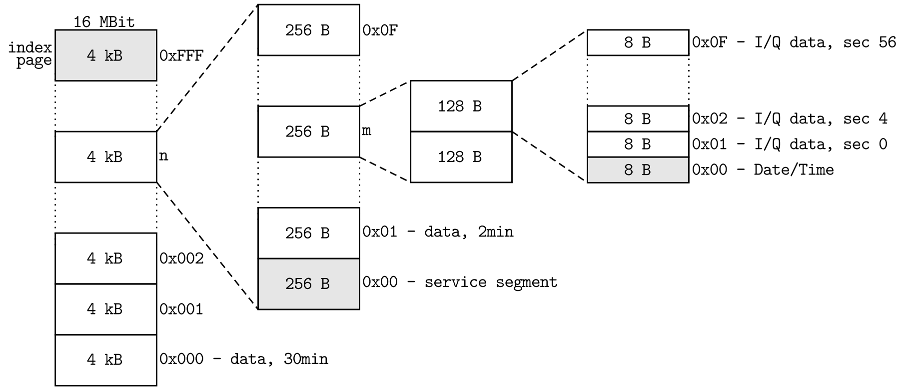

Fig. 8. Memory structure for storing measured values.

Measured temperature values as well as auxiliary operating information for later device diagnostics are stored in the service segment.

In one hour, 2 pages of memory are filled with measured values, the last page of memory is intended for the marking of occupied blocks, based on which the measurement configuration is restored in the event of a power failure or after a system reset. The total recording time is 2047 hours, which is approximately 85 days.

2.8. Temperature measurement

The temperature measurement serves to check the temperature regime of the extensometer environment and, if necessary, for temperature compensation of the measured data. Digital sensors DS18B20 for 1-wire bus were used for temperature measurement. The sensors are calibrated by the manufacturer, the resolution of the measured temperature is 0.0625 °C. Thermometers can work in parasitic power mode, in which case one 1-wire bus wire and ground is enough for communication, while several sensors can work simultaneously on one bus. Such a configuration is only suitable for thermometers connected with short wires. When using longer wires to sensors with a length of units up to tens of meters, it is necessary to use an auxiliary external driver. A modified circuit was used for the extensometer according to the manufacturer's recommendation.

2.9. Communication circuits

The control unit contains two communication interfaces. One is intended for programming the microcontroller's memory and service diagnostics via the USB interface, the other is intended for standard communication via a radio modem. Due to the fact that any physical access to the device affects the temperature conditions and the measured results, wireless access was chosen for communication with the device using a pair of XBee modems operating at a frequency of 868 MHz. The radiated power of the modem is 300 mW, which is sufficient for access from the outside without the need to enter the mine shaft.

Both the modem and the rod antenna are placed in the access shaft in a plastic hermetic case. They are located approximately 40 m from the control unit. The control unit of the extensometer communicates with the radio modem via the RS 485 bus cable. Through the communication interface, it is possible to download the measured data, set the operating parameters, as well as to perform a complete diagnostic of the extensometer operation. The transmission speed of the RF data link is 115.2 kbit/s.

3. Data processing and software

The time sequence of the measurement, Fig. 9, is controlled by the real time clock (RTC) controller, which is part of the microcontroller. A sequence of 15 measurements during one minute starts at the zero second of the minute. One measurement cycle lasts 4 seconds. Within this cycle, the measured data corresponding to 512 periods of the harmonic signal on the sensing electrode are accumulated 512 times during the time marked *Acc* in Fig. 9. The 32-bit values of the two I/Q components ($2 \times 4 = 8$ bytes) are subsequently calculated from the accumulated values, which are stored in the flash memory. 15 pairs of I/Q component values ($15 \times 8 = 128$ bytes) from one minute of measurement are written to the flash memory.

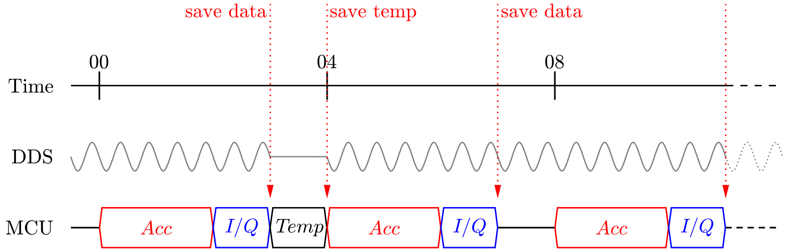

Fig. 9. Time diagram of the measurement process.

The temperature measurement is started using thermometers on the 1-wire bus at the zero second of the minute after the end of data processing. Because there are strict requirements for the timing of communication with thermometers, there must be no interruption during communication. Therefore, it is necessary to suspend the DDS generator for this time period.

The software of the extensometer was created in the C language using libraries supplied by the manufacturer. Part of the software is a simple command interpreter, with the help of which it is possible to access the flash memory via the modem, load the status of the device and modify its parameters. The software on the side of the host computer was created in the Python language, the graphical interface for diagnostics, testing and creation of protocols the open-source Jupyter-Lab environment was used.

The measured data are processed in the extensometer into 32-bit values of I/Q components, from which the amplitude and phase of the signal on the sensing electrode are calculated after being transferred to the host computer, and the data are further processed and evaluated by standard visualization procedures.

An optical interferometer was used to calibrate the functional prototype of the extensometer to assess the concept of the device and test the properties of the basic functions. Due to the fact that the entire measuring chain of the installed device is relatively complicated and burdened with a number of operating parameters, an external magnetostrictive calibrator permanently installed as part of the quartz glass tube fixing is used for checking and calibrating the measured data. Daily, at 00:00 GMT, a current pulse, Fig. 10, with a duration of 90 seconds is fed into the calibrator, which causes a deflection of the sensing electrode by a known value $\Delta l = 2.283$ nm.

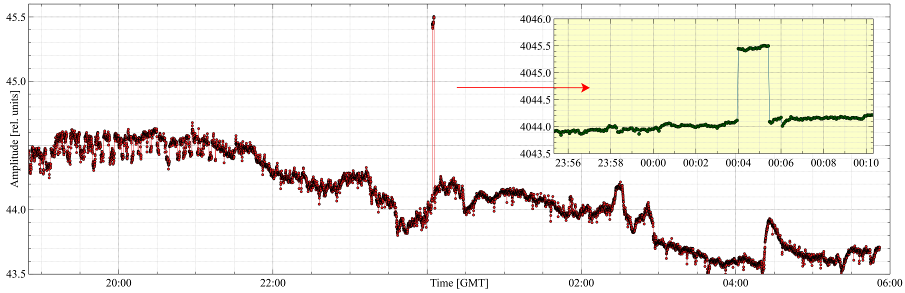

Fig. 10. Calibration pulse.

4. Results and discussion

During the construction of the extensometer, it was necessary to solve a number of problems related to the overall concept of the device, as well as the technologies used, especially when they are used in the hostile environment of the mine.

In Figure 11, data from first testing measurements are shown in comparison against the original (former) device. For the sake of comparison, the signals were numerically adjusted to have similar amplitudes, and the data from the extensometer were numerically filtered using an averaging filter with a time constant of approximately 20 minutes. The filtered signal is labelled as EXT-AVG. To enable parallel measurements, sensing electrodes of both new and old device are mounted both on the free end of the quartz tube of the extensometer. The former, analogue device operates in a two-channels regime, the first channel (SAV-DATA) handles data respective to the displacement of the sensing electrode in a time interval of 10 minutes (in fact, it is the average value of multiple measurements during the time interval). The second channel (SAV-CALIB) consists of independently measured values of the calibration pulses generated by the magnetostrictive actuator.

The presented sensor saves data in four second intervals after some basic analogue processing, ADC conversion and numerical accumulation, resulting as the data EXT-FILTER. These data include the calibration pulses, which are planned to be separated using a suitable filter in the future. The EXT-FILTER curve exhibits a certain degree of noise, which consists of

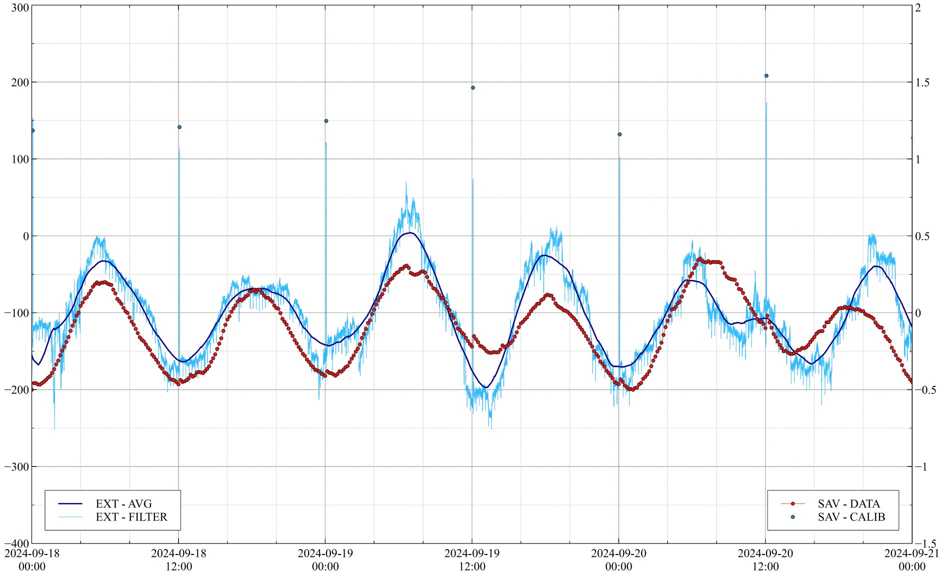

Fig. 11. Preliminary comparison of the original extensometer sensor (SAV) with the new version (EXT), in relative units related to the amplitudes of the calibration pulses. The values on the y axis are expressed in mV (relative), due to the fact that the calibration constant of the new sensor has not yet been determined, therefore conversion to nanostrains [nstr] cannot be successfully executed.

two main components. Every 15 minutes, ongoing displacement observations are interrupted for a temperature measurement (Fig. 9). Following the resumption of observations, the analogue components of the instrument undergo gradual stabilization, resulting in a regularly recurring noise output. Another noise component originates in the mechanical construction of the extensometer, particularly the weak (not firm enough) mounting of the sensing electrode on the quartz tube. This translates into noise due to oscillations of the tube with various origins, such as microseismical events, and parasitic oscillations caused by the calibration pulses. Furthermore, temporal changes of geometry of (and between) excitation electrodes and overall properties of utilized materials also played a non-negligible role.

The undesired effects mentioned above have manifested themselves in the data as long-term drift, as well as seemingly random, sudden changes in the amplitude of the observed signal. Based on these observations, we can conclude that the electronic part of the instrument works satisfactorily, with good sensitivity and temporal resolution. It is also necessary to emphasize that the data shown in Fig. 11 should be considered very preliminary and no definitive conclusions can be derived from them.

The primary task at present and in the near future dwells in the treatment of the adverse effects caused by degrading of mechanical components, some of which have already been rectified in a recently installed, upgraded version. The mechanical construction of electrodes was slightly altered, their surfaces were treated using a protective epoxy-resin coating, their fastenings were fabricated using only materials not susceptible to corrosion, and any plastic components were excluded due to stability issues. Another problem became apparent due the high air moisture level and consequential water condensation over the sensitive components. This was recently addressed by installing an experimental heat source based on electrical resistance with a stable power output of 1 Watt. The area in the proximity of the electrodes was fitted by a separate thermometer probe. Furthermore, the electronic part will be upgraded so measurements of displacement and temperature can be carried out independently, thus removing one noise component effectively.

The design of the electrodes, their size and location, was limited by the available space between the concrete block and the quartz glass tube. In the space where the electrodes are located, only elementary analogue electronics are placed in sealed metal boxes, and the control of the extensometer itself is located outside the measuring part of the mine shaft.

Based on the results mentioned so far, it is possible to conclude that:

- A minimalist approach to the design of the extensometer, which uses a minimum number of external elements with the maximum possible use of the computational performance of the modern microcontroller, as well as its integrated peripherals, proved to be practically usable. This approach allows easy replication of the device in the future as well as simple modification or development of alternative algorithms and procedures without the need for changes to the hardware configuration of the device.
- With the use of the functionality of the direct memory access controller peripheral, it was possible to ensure a fast and efficient exchange of data among the integrated peripherals of the microcontroller, and thus it was possible to effectively use the time of the processor and minimize its load, which allows access to already measured and current data in real time without interrupting the measurement. The control concept and the communication protocol of the extensometer will enable, after the tidal station is supplemented with online access, online access to current as well as historical data of the extensometer.
- The used concept of numerical data processing with the use of accumulation made it possible to achieve high sensitivity and resolution of the device. In the current configuration, observed data are related to 4-second intervals, and are the result (average) of 524 288 readings of the ADC converter, while it is possible to further improve the device's temporal resolution. The previous device (capacitive sensor and its electronic control unit) has limited measurement dynamics, i.e., if the maximum displacement value of the sensing electrode is exceeded, the entire system must be mechanically rectified. The subject of further experiments with the developed extensometer will be the verification of the virtual centring of the sensing electrode by using the properties of the DDS generator to change the values of the amplitudes of the excitation signals and use their mutual phase shift to increase the sensitivity of the device.
- The subject of further research will also be the verification of technological procedures and materials suitable for the construction of electronic devices working for a long time in a harsh mine environment, such as

potting and sealing compounds, combinations of metal materials to eliminate electrochemical potentials, surface treatments to prevent corrosion of metal and degradation of plastic materials.

It is important to state that the environment, where the instrument is situated is hostile to electronic devices, due to extremely high air humidity, condensation and dripping water. Therefore, careful observation of all components of the prototype under in-situ conditions will be necessary for a reasonable amount of time. Checks for corrosion or other damage will be done routinely. We are prepared to intervene with component changes or upgrades if any damage is detected. Parallel tidal measurements will be carried out using the previous and the new registration device. Tidal data obtained using both devices will be evaluated and compared. All this will be done in effort to ensure long-term stability of the readings in a continuous measurement regime.

Data availability. Raw (unprocessed) extensometric data for the years 2022 and 2023 are available in the attached supplement. The data were obtained using the former, still operational transducer and the CR10X datalogger by Campbell Scientific.

The data file is ASCII with a row structure. Each row starts with a data type identifier. The parts of the data in the row are delimited by commas. To describe the data in detail, we select an extract containing all types of data:

```
104,9.39,12.94
1,280,2024,12,0,-58.682,-58.713
2,280,2024,12,5,252.85,258.61
104,9.29,13.08
1,280,2024,12,10,-49.393,-49.479
```

`104` is the identifier of the temperature data. The identifier is followed by the inner temperature at the datalogger site, and the outer temperature at the entrance to the gallery, both in [°C].

`1` is the identifier of the standard extensometric data. The identifier is followed by the Julian day, the year, the UTC hour and minute. The seconds of the time stamp are always `00` and therefore are omitted. The row is terminated by the extensometric data itself, first the decimated/filtered data sample, then the instantaneous data sample without decimation. The physical unit of this data is [mV]. The time stamp of the extensometric data row applies to the previous temperature data row, as well.

`2` is the identifier of the calibration extensometric data. They have the same structure and units as the standard extensometric data.

To convert the extensometric data to nstr, they need to be multiplied by the calibration factor of the extensometer -0.1503 [nstr/mV].

Both the standard and the calibration extensometric data in the forelast item of the respective row are computed by a one-stage decimation filtering implemented in the data acquisition program in the datalogger. In both cases, the same Kaiser FIR filter of the order 0, $\beta = 8$ and length 59 is applied to the input data. The only difference is the sampling period of the input samples to be decimated. In the standard extensometric data, it is 8 s. In the calibration extensometric data, it is 1 s. The details of the extensometer calibration and data decimation procedures and are described in *Bednárik and Brimich (2005)*.

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Author contributions. The authors declare that they contributed equally to this work.

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