Integrated brake disc temperature measurement system

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Abstract The braking efficiency of vehicles is an important indicator guaranteeing high traffic safety. One of the determining parameters for achieving maximum braking efficiency is the temperature of the elements of the braking system. Achieving the maximum braking performance the temperature of the parts of the braking system must be maintained in the optimal range, any deviation from this range results in a deterioration of the braking performance of the vehicle, which influences the safety of the traffic. The temperature of the brake discs is one of the critical variables of the system, so it is essential to monitor the temperature variation during the movement of the car. The present study aims to develop an integrated system for monitoring the temperature of the brake discs while the vehicle is moving. Through the implementation of such a system in an experimental car, a research database will be formed for the change of the temperature of the brake discs at different speeds and braking modes.

1. Introduction

The generation of heat from friction in the brakes may consist of repetitive cycles. The characteristic feature of such a process is that the brake cannot cool down to the initial temperature after short periods of heat dissipation, therefore, the total temperature of the contacting components becomes higher. Another type of braking with a significant heat load is called a continuous or braking resistance process.

The temperature of the brake disc has a significant effect on the efficiency of the braking system, both in the short and long term. The braking process basically converts the kinetic energy of the vehicle into heat. Standard mass-produced brake discs are made of gray cast iron, and the brake pads consist of mixtures of metals, fillers and lubricants. In comparison between the brake pad and the brake disc, a large amount of heat energy absorbed by the brake disc, which causes expansion of the brake disk. Different types of deviations from the normal shape of the brake disc include a change in the geometric shape, a conical deviation on one side and wavy deviations on its periphery (Figure 1).

The coefficient of friction in the contact pair of the braking system varies with temperature change which results in alteration of the braking effectiveness of the system. Optimal braking efficiency is directly related to traffic safety, so knowing the temperature of the brake discs of the system is directly dependent on ensuring safe driving, which is why the aim of this work is to develop and implement a real-time temperature measurement system of the vehicle's brake discs.

It is necessary to measure the interface temperatures during the actual braking friction tests so that the exact operating conditions are known for design purposes. Measuring the temperature of the friction pair interface is a difficult task. Several methods have been reported [1 - 4] and can be categorized as non-contact measurement, which includes methods such as optical and infrared measurement and contact measurement, which includes methods such as thermocouple and thermo sensitive coating of the material (or paint).

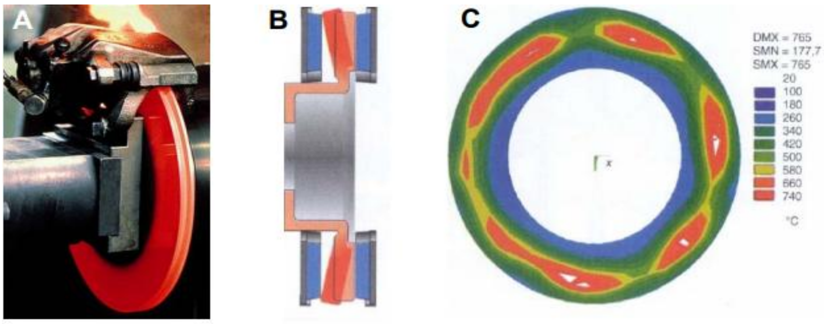

Figure 1. Brake disc, A-heating up to 713 °C, B-shape deviation, C-temperature distribution.

These methods mentioned above are not very effective in measuring interface temperatures. The thermocouple technique for measuring the temperature of the grinding interface, developed by Qi and his colleague [5], has been reported as an effective method for measuring the temperature of the friction pair interface. The difference in the technique of the open thermocouple compared to the conventional method of the built-in thermocouple is that the hot joint of the thermocouple is located directly at the friction limit. Work on the validation of Xu [6] shows that the technique of the exposed thermocouple can measure the temperature as accurately as other conventional methods, and confirmed that the direct contact of the tip of the hot coupling of the thermocouple to the interface of the friction couple has little effect on the quality of the produced temperature signal. The presented thermocouple technique was adopted when measuring the temperature of the brake disc / pad in the previous work of the authors [7]. In this study, the technique of the exposed thermocouple interface temperature measurement is used in the investigation of the factors that affect the friction braking interface temperatures under designed experimental conditions and it is not applicable for measuring the temperature of brake discs on road vehicles.

Present vehicles are equipped with multiple electronic systems to increase traffic safety, driving comfort and travel, also in [8] was developed and presented an in-vehicle monitoring system The proposed system is capable to monitor not only the main environment parameters such as the in-vehicle temperature and humidity, but also the eCO_2 and tVOC levels via an IAQ sensor and driver reactions during the acceleration and braking situations via MEMS inertial sensor. For the purposes of the auto technical expertise from [9] an experimental study was carried out to determine the change of the braking deceleration of the vehicles depending on the coefficient of adhesion of the road surface. Special technical equipment was used to conduct the experimental study to determine the braking deceleration. The presented development is suitable for conducting experimental studies to determine the braking deceleration, which is an important stage of the activity of the auto technical expertise in determining the causes of an already occurred traffic accident.

Development of an integrated system for real-time monitoring of the temperature of the brake discs will provide further improve traffic safety. It will also serve as a diagnostic tool for determining the technical condition of the braking system and will allow the formation of array data for temperature analysis of the elements of the brake system to determine the optimal temperature range of the braking system to ensure maximum efficiency.

2. Prerequisites and means for solving the problem

To measure the temperature of the brake disc, a sensor is required that has high speed and a small measurement error in a wide operating range up to 900 ºC. The sensor must be able to operate in conditions of high ambient temperatures, dirt and vibration. The sensor must also generate a signal that is convenient for further processing.

After a study and analysis of the technical characteristics of different thermocouples for the specific study, it was found that the set requirements meet the thermocouple 30S Type K for contact measurement of the temperature of the brake disc. The sensor provides a quick response in real time, has a miniature, mineral insulated thermocouple (0.5mm diameter) which is welded to the floating micro plate, and covered in a housing of stainless steel, in order to prevent the thermocouple from contamination. The sensor can be easily adjusted by adjusting the spring pressure using an adjusting screw. This allows precise adjustment of the sensor in various applications [10]. The thermocouple is mounted through a 5 mm fixing hole, which is made in the main body. The standard version is equipped with a wire with a stainless steel shield, which is designed to shield the wire in order to insulate it from EMC and high temperatures. The 30S type K thermocouple is shown in Figure 2.

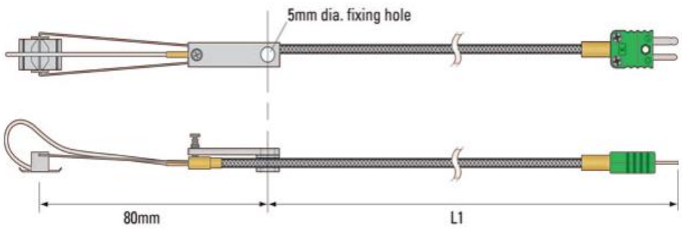

Figure 2. Thermocouple 30S type K.

The thermocouple has an operating temperature range from 0 ºC to 1100 ºC, providing an operating range for short-term measurements from -180 ºC to +1350 ºC. Nickel-Chrome and Nickel-Aluminum are used for the production of the thermocouple.

The MAX6675 Cold-Junction-Compensated K-Thermocouple to-Digital Converter is used to convert the analog signal from the temperature receiver into a digital signal suitable for the operation of the microcontroller. The module has a built-in 12-bit analog-to-digital converter, a cold connection for mounting the electrical connectors of the thermocouple to it, providing compensatory reading and correction of information, a digital controller and an SPI-compatible interface. This module is designed to work with an external microcontroller (μC) or other devices whose applications are associated with thermostatically management, control or monitoring. The conversion module and its circuit are scheme in Figure 3. [11]

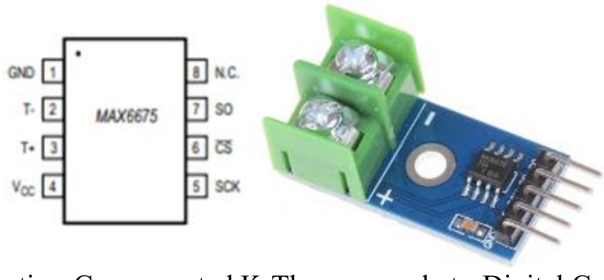

Figure 3. Cold-Junction-Compensated K-Thermocouple to-Digital Converter MAX6675.

The processing of the received digital signals is performed by a microcontroller, which can communicate with other devices, be able to control alphanumeric digital and graphic displays, to measure different quantities and to control technological processes and also must provide reprogramming

Based on the preliminary investigation to establish responsibility of the intended application is a microcontroller Arduino Nano (Fig. 4). It is a small and convenient board based on the ATmega328 microchip (Arduino Nano 3.0). The microcontroller is used to build digital devices and interactive objects that can "feel" using different receivers, as well as control the devices connected to them. The

ATmega328 microchip is a low-power CMOS 8-bit microcontroller based on the RISC architecture. The operating voltage (logic level) of the microcontroller is 5 V, while its recommended input voltage is 7-12 V at limits between 6-20 V. The specifications that characterize the microcontroller are: 14 digital I / O Pins of which 6 allow wide pulse modulation; 8 analog inputs; DC current for I / O Pin: 40 mA; 32 KB flash memory, of which 2 KB used by the bootloader - controls the upload and execution of program code that is fed to the processor; 2 KB SRAM; 1 KB EEPROM; 16 MHz processor speed. [12]

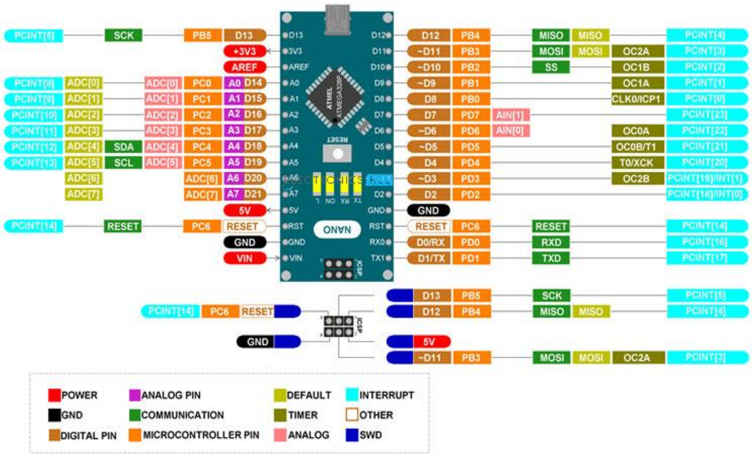

Figure 4. Arduino Nano microcontroller.

A Bluetooth module is required for wireless transfer and visualization of information. This module must be compatible with the microcontroller and ensure that the information is sent at a distance of not less than 4 m, while at the same time having a minimum overall dimensions. These requirements are met by HC-05, which has the following technical characteristics: • 4V to 6V (usually + 5V) operating voltage; 30mA operating current; the working range is up to 100 m; works with serial communication (USART) and TTL compatible; the standardized IEEE 802.15.1 protocol follows; uses the hopping frequency spectrum (FHSS); can operate in Master, Slave or Master / Slave mode; can be easily connected to a laptop or mobile phone with Bluetooth; supported transmission speeds of 9600, 19200, 38400, 57600, 115200, 230400 and 460800 bit / s. [13]

Programming the microcontroller is carried out through a program Arduino Software (IDE), which is developed by the controller manufacturer. The Arduino Projects Book [14] is used for programming, which describes the necessary syntax requirements. Library is used to connect the module max6675 with Arduino. Written and loaded into the microcontroller code is shown in Figura 5.

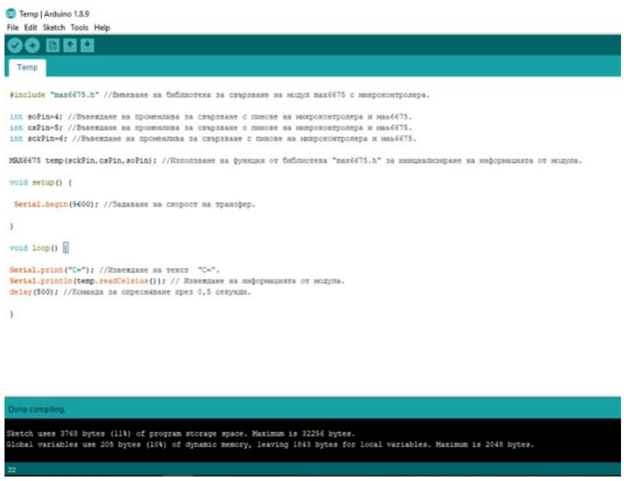

Figure 5. Software providing of the microcontroller.

To visualize the information about the measured temperature of the measured part, in this case a brake disc, a mobile application is developed, which connects to the Bluetooth module and visualizes the necessary information on the display of the device on which the specially developed application is installed. [15]

The software product Mit App Inventor 2 is used to create the application. The essence and the algorithm of operation of the application are presented in the block diagram of Figures 6 and 7, and the design of the application is presented in Figure 8.

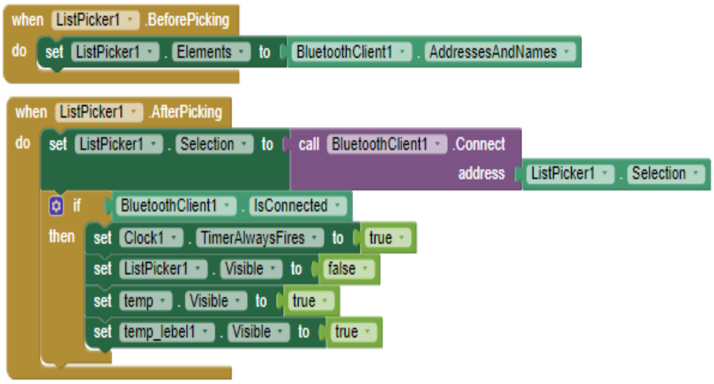

Figure 6. Block diagram of the created application - part I.

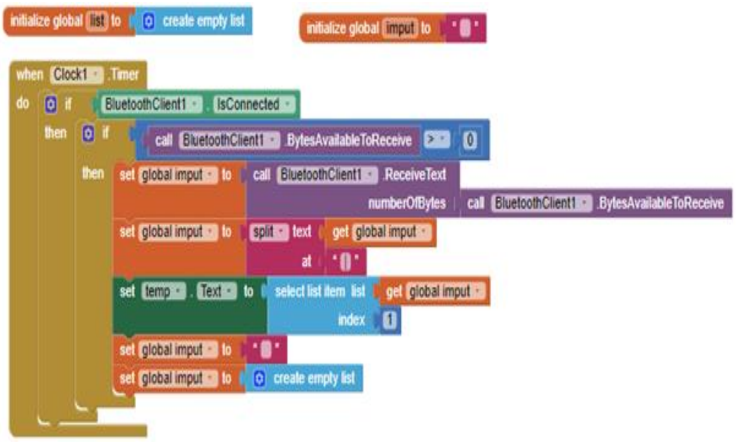

Figure 7. Block diagram of the created application - part II.

Figure 8. Application for visualization of temperature.

The sequence of the application is expressed in the creation of a block that activates the visualization of the active Bluetooth modules and devices. When a connecting device is selected, the information preview fields become visible and the list preview button becomes invisible. Then a loop is compiled, which if there is a connected device that sends information, the loop creates a list of variables in which it records the information and then visualizes it in the appropriate fields.

3. Results and discussion

The implementation of the system is carried out on the car Chery QQ, owned by the Technical University - Sofia. The scheme of the developed integrated system for measuring the temperature of the brake discs is shown in Figure 9. The thermocouple is attached to a specialized stand and the distance between it and the brake disc is adjusted by means of an adjusting screw.

To simulate road tests to determine the accuracy of the system, the experimental study of the temperature of the brake disc is performed on a dynamometer for safety and compliance with legal regulations due to the experimental design changes in the car (Fig. 10). The thermocouple is located at a controlled distance of 0.25 mm from the working surface of the disk.

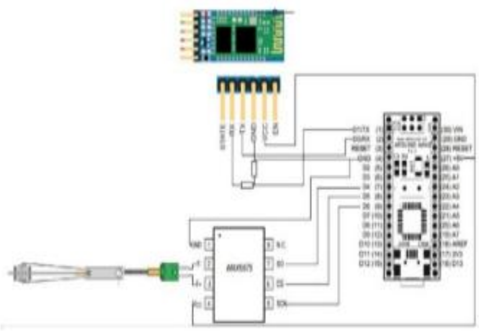

Figure 9. Wiring diagram of the components.

Figure 10. Location of the brake disc thermocouple and of the vehicle on a dynamometer stand.

In the performed experimental studies with the developed system, in order to check the adequacy of the obtained temperature values, a Flir E40 thermal camera is used according to the methods presented in [16-18]. The results of the performed measurements are presented in Table 1.

Table 1. Obtained measurement results with integrated system and thermal camera.

№	V, km/h	Temperature measured by the system, °C	Temperature measured by thermal camera, °C	Absolute difference from measurement methods, °C	Absolute difference from measurement methods, %
1	0	24	25,1	1,1	4,38
2	20	47,25	48,9	1,65	3,37
3	0	46,5	47,9	1,4	2,92
4	30	83	87	4	4,60
5	0	77	80,8	3,8	4,70
6	40	108	112	4	3,57
7	40	130	136	6	4,41
8	0	167	171	4	2,34
9	50	128	132	4	3,03
10	50	198	206	8	3,88
11	0	209	218	9	4,13
12	0	186	198	12	6,06
13	60	161	169	8	4,73
14	60	159	167	8	4,79
15	60	208	216	8	3,70
16	60	258	269	11	4,09
17	60	319	329	10	3,04
18	0	212	221	9	4,07
19	0	188	194	6	3,09
20	0	142	148	6	4,05
21	0	63	67	4	5,97

It is noticeable from Figures 11 and 12 that the values obtained from the measurement with the developed system are lower, which is due to the location of the thermocouple relative to the working surface of the brake disc. The non-contact mounting of the thermocouple (at a distance of 0.25 mm from the disc) is required by the following considerations: absence of wear in the thermocouple and disk; avoiding measurement errors due to curvatures and irregular wear of the brake disc, and from the accumulation of fine dust particles in the area of contact between the thermocouple and the disk; excluding the negative variation of the background noise of friction in contact and others. Due to the above considerations, the difference of about 4% obtained in the measurement results can be compensated by recalculating the results by reprogramming the microcontroller. The obtained results confirm the applicability of the proposed system for integration in vehicles for the purpose of monitoring, diagnostics and accumulation of an array of data for performing statistical surveys.

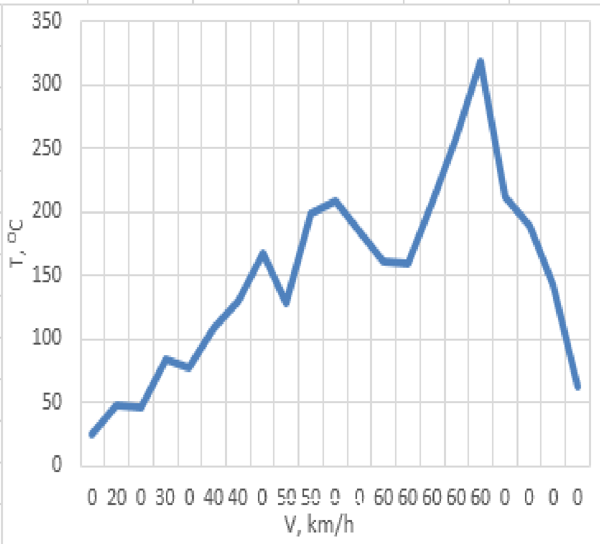

Figure 11. Measured temperature through an integrated electronic system

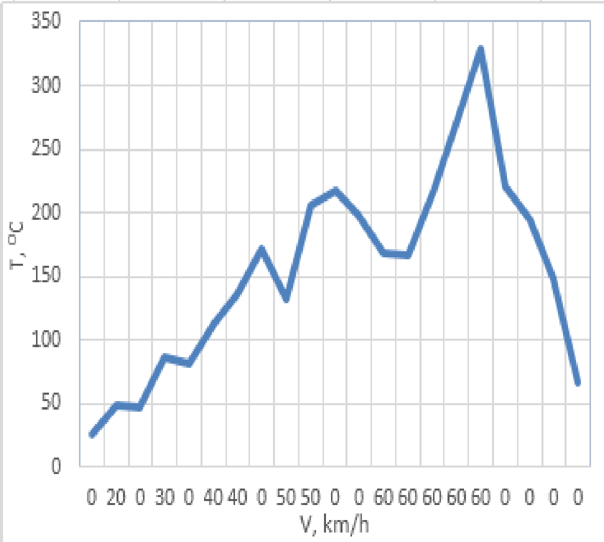

Figure 12. Measured temperature by thermal camera

4. Conclusions

The results of the research conducted in the present study confirm the accuracy of the measurement through the developed integrated system for monitoring the temperature of the brake discs. A comparison of the results from both methods of temperature measurement shows that the average difference is about 4%. Presented in absolute values, the difference varies in the range between 1 °C and 12 °C depending on the temperature range of the measurement.

The analysis of the results shows that the error obtained from the measurement with the integrated system is within acceptable limits and, accordingly, the system provides the accuracy necessary for the practice. In addition from the performed measurements it was established that the error does not accumulate from each previous measurement, but is individual for each individual measurement, therefore it is possible, by reprogramming the microcontroller to minimize the error value for each individual measurement.

The performed research provides the basis and prerequisites for improving the developed system and conducting in-depth research and analysis of the temperature of both the brake discs and other main components of the brake system. In this way, an array of data will be created, the analysis of which will ensure the determination of optimal limit values for the operating temperature range of the braking system. This will ensure an improvement in the braking quality of vehicles, which will lead to a reduction in road accidents and a corresponding increase in traffic safety.

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