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DEVELOPMENT OF AN ELECTRIC MEASUREMENT SYSTEM FOR RAPID DETERMINATION OF THE FRICTION COEFFICIENT

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Abstract: Development of an electric measurement system for rapid determination of the friction coefficient is discussed in this paper. The electric system is capable to use with a ball cage guide bush unit. Two beam load cells are included into the system and the measured values of the forces are processed by microcontrollers. In the course of measurements, normal- and tangential forces of inner or outer surfaces of different enamelled specimens could be determined. A data acquisition program is developed to record the force values to a personal computer. Linear interpolation method is required to synchronize the values of the load cells, which is necessary to calculate the coefficient of friction.

Keywords: *friction coefficient, microcontroller, Arduino*

1. INTRODUCTION

The friction as phenomenon can be experienced in everyday life. The behaviour of mechanical systems, which contain moving parts, strongly influenced by the friction [1]. There are several friction models, e.g. Dahl, viscous, Stribeck model, etc., which can be used for different aspects [1], [2]. The most common model is the Coulomb model of friction, which deals with the dry friction. In many problems, this model is adequate to use.

The so-called friction coefficient can be measured experimentally with different methods. The static and kinetic friction coefficients can be calculated with use of an inclined plane [3], [4]. These experimental setups consist a slope and its angle can be varied. Due to the change of the angle, the specimen may begin to tilt on the plane. When the specimen starts to move, the current angle of the inclined plane provides the static friction coefficient. In [5] an experimental setup contains a S-shaped load cell, which used to measure the tensile force of the friction.

The main purpose of the paper is to develop an electrical device for the measurement system, which is capable to use for rapid and approximate determination of the friction coefficient. Mechanical design of the construction is detailed and summarized in [6]. Internal and external surfaces of the measured specimens, e.g., enamelled aerosol cans, have different friction coefficients. The measurement system contains two load cells, three Arduino Nano prototype board with AVR type ATmega328 microcontrollers [7], two A/D converters, and two transmission sensors.

This paper is organized as follows: Section 2 contains the designing aspects of the electrical system and describes the whole device. Section 3 deals with the programs developed for the microcontrollers and for a laptop. Section 4 details the determination of the friction coefficient. A special purpose program is developed to use the linear interpolation method to synchronize the values of the load cells for the same timestamp. A test measurement is also demonstrated. The Section 5 has concluding remarks.

2. DESIGNING OF THE MEASUREMENT SYSTEM

The main function of the machine is to determine rapidly the friction coefficient. The model of the unit is shown in *Figure 1*. A specimen of an aerosol can, which may have different diameters can be fixed to a ball cage guide bush with a hold-down element. The radial surface of a holder is manufactured to a revolver one. Therefore, specimens can be inserted onto the holder with different diameters. Due to revolver shaped holder the friction coefficients of the inner and outer surfaces of the cans can be also measured. A steel tool, which is placed onto the specimen, is kept in a permanent position by a sheet metal in the course of the measurement.

The guide bush is moved with a handle manually. Since the measurement of both normal- and tangential forces are required at the same time to determine the friction coefficient, the system contains two beam shaped load cells. The tangential force is measured by a load cell LC_t and the normal force is determined by another load cell LC_n *(*see *Figure 1)*. A predefined load in normal direction can be adjusted with a winding knob. A ball bearing is in the bottom of LC_n to roll when the guide bush is moved. The capacities of the above-mentioned load cells are different. The maximum allowable forces of LC_t and LC_n are 50 N and 200 N, respectively. The positive velocity of the guide bush is denoted by v+. A spring is added to the threaded shaft to provide a relatively constant normal force during the measurement.

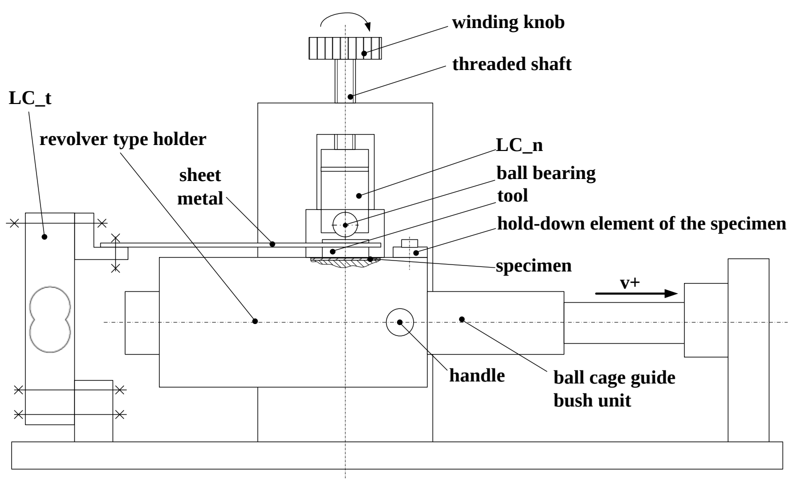


Figure 1. Model of the measurement system

The block scheme of the electrical system is shown in *Figure 2*. A beam load cell contains four strain gauges, which are wired to each other in a Wheatstone bridge configuration. Due to bridge configuration the change of resistance is transformed to change in the bridge voltage. The voltage can be measured by a HX711 type 24-bit sigma-delta A/D converter [8] with 80 Hz sampling rate. The data are sent via serial communication protocol to the microcontrollers MC 1 and MC 2. The forces are determined by a self-devised program. Scaling of incoming data is performed by the program. These values are transmitted to a laptop with UART communication protocol.

Two transmissive sensors are used to calculate the average velocity of the guide bush. These optical sensors have a phototransistor and an infrared emitter in a face-to-face configuration. The elapsed time between the base and end position is measured by a microcontroller MC 3, which provide an average velocity in aware of the distance:

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{79\ mm}{\Delta t}. \qquad (1)$$

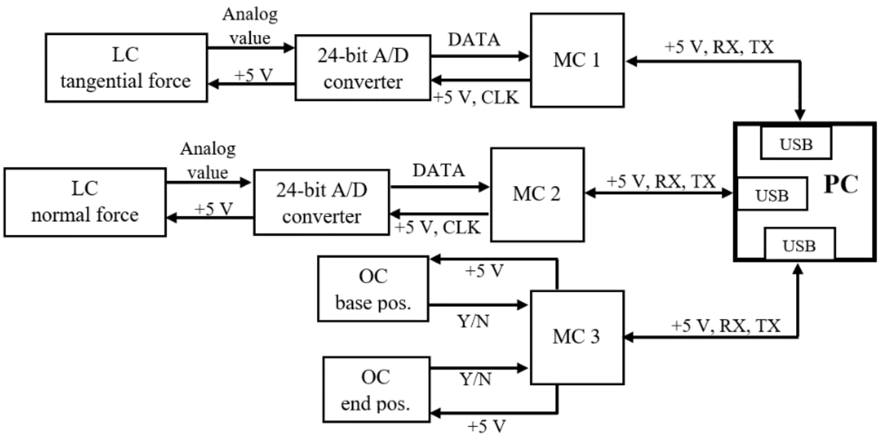
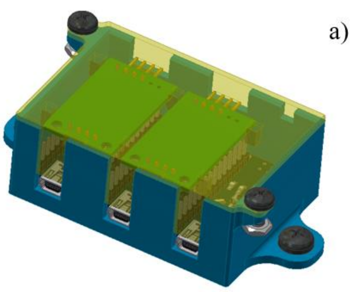


Figure 2. Block scheme of the electric system



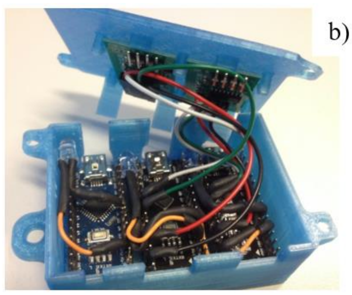


Figure 3. a) 3D modelling of the electric box,
b) Assembling of the electric components

The electric system and its box are designed in Autodesk Inventor software. The box and its cap are manufactured by 3D printing technique using polylactic acid (PLA) filament. Layers are 0.1 mm with rectilinear filling method prescribing 10% infill parameter. The 3D model of the electric box is shown in *Figure 3a* and the manufactured one is given in *Figure 3b*. Three state LEDs with limiting resistors are also built in the box.

The complete measurement system can be seen in *Figure 4*. The electric system is attached to the structure. Cable protection channels are used to prevent the damage of the wires from moving of the handle.

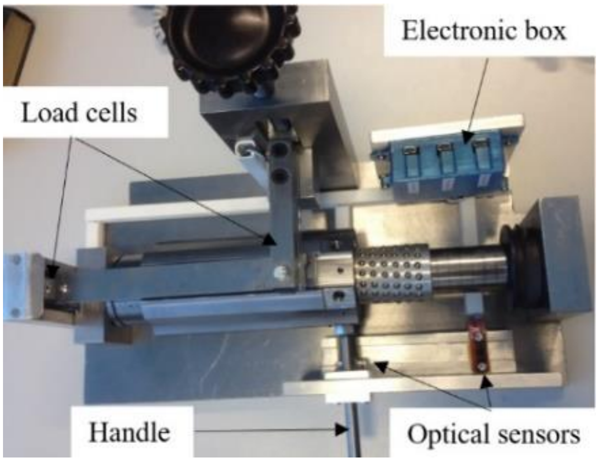


Figure 4. The measurement system

3. Programs developed for microcontrollers and laptop

The programs of MC 1–3 are developed in Arduino IDE software in C programming language. The flow chart of the force measurement microcontrollers is shown in *Figure 5*.

Variables and its initial values are defined in the beginning. The pins are initialized at the program part void setup(). The void loop() section is an infinite loop, where MC 1 and MC 2 are reading values from the serial ports connected to a laptop. An if statement is used to carry out a conditional decision based on the incoming characters. If the character is 'a' the reading process from the A/D converter is performed and a state LED indicates that the force measurement is active until the incoming character is 'c'. Before sending the force value to a laptop the float type force values are converted into string of length 10 byte. When the laptop sends character 'c', the program jumps to the beginning.

The state LED is inactive when the incoming character is not equal to 'a'. If the laptop transmits character 's' the microcontroller stores a new base value of the load cell to the onboard EEPROM. The size of the EEPROM is 1 kB. Since the A/D converter has 24 bit resolution therefore, 4 bytes are required to store its raw value.

Two functions have been written for saving and reading raw values. Binary right and left shift operators are used to disassemble and assemble the values of the converter for saving and reading, respectively.

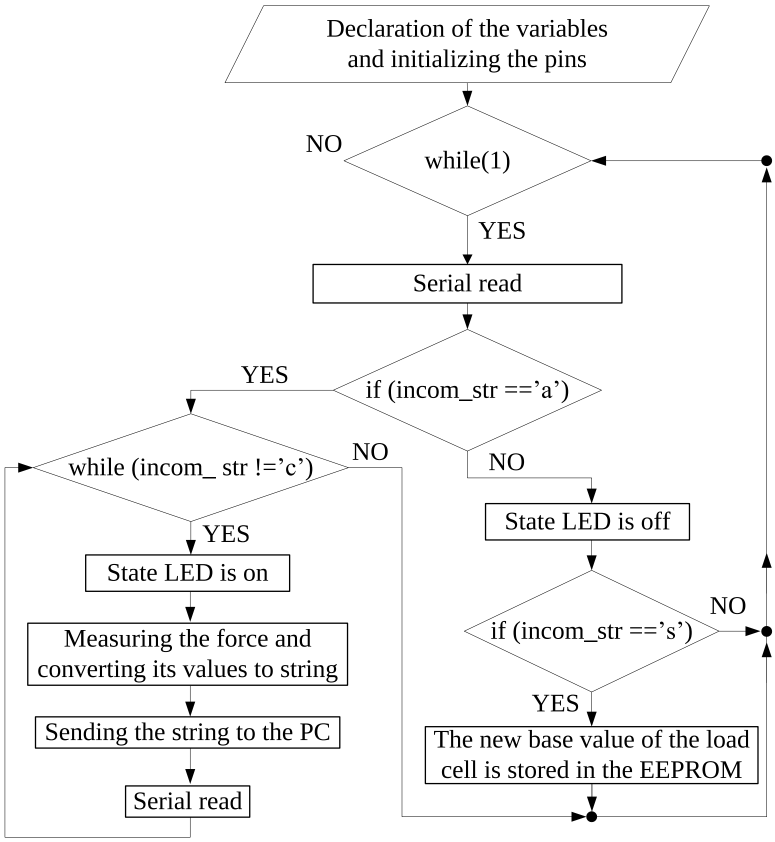


Figure 5. Flow chart of the force measuring microcontrollers

MC 3 measures the elapsed time between the base and the end position of the handle. The flow chart diagram of the MC 3 program can be seen in *Figure 6*. The ATmega328 microcontroller has two external interrupt capabilities.

The definition of the pins and the declaration of the variables and its initial values are belonging to the first step *(*see *Figure 6)*. The initialization of the Interrupt Service Routine (ISR) is the next step. The ISR can be triggered if the logic state of the pin is changed. There are four possibility to initiate an ISR, i.e., LOW, RISING, FALLING, CHANGE modes [9]. When a FALLING mode is chosen the ISR will be executed if the signal has a falling edge from logical 1 to logical 0. The optical sensor of the base position has been attached to D3 pin, which has an ISR capability.

A condition is defined in the void loop() section. If the handle leaves the base position and it arrives to the end position the condition is fulfilled. Thereafter the state LED indicates that the condition is satisfied, and the measured time is sent to the laptop.

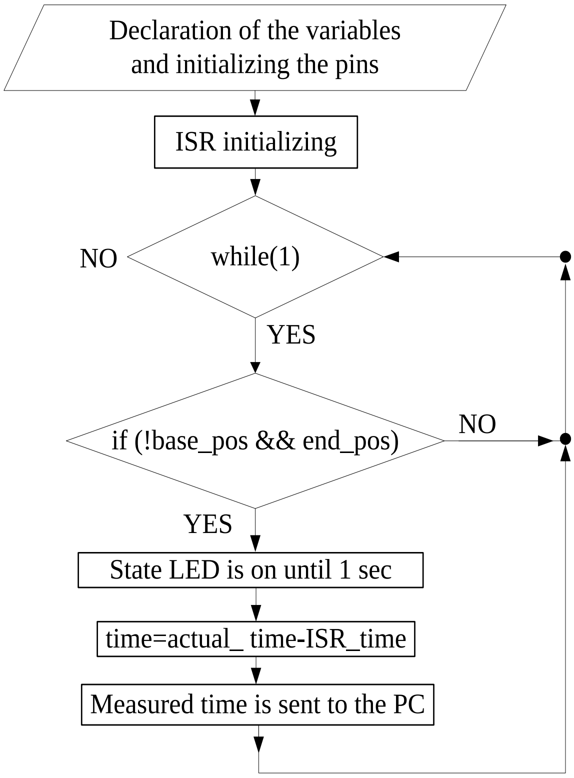


Figure 6. Flow chart of the microcontroller, which measures the elapsed time

A data acquisition program is developed in LabVIEW [10] software. The main frame of the program is created by flat sequence option to ensure a sequence of order in the course of execution. The flow chart of the program can be seen in *Figure 7*. In the first step the variables are initialized. The second step contains a loop with a condition. If the OK button is pressed in the Graphic User Interface (GUI) of the program (see *Figure 8)* the zero values of the load cells will be set. When the START button is pressed the program jumps to the third step, where the configuration of the chosen serial ports takes place. The character 'a' is sent to MC 1 and MC 2. The fourth step contains the receiving and displaying section of the incoming data. If the predefined sampling time is over or a STOP button is pressed the program jumps to the fifth step, where the serial ports are closed. The last step of the flat sequence offers a data saving option to store it in .csv file format.

The GUI provides the possibility to prescribe the working serial channels and the sampling time, etc., (see *Figure 8)*.

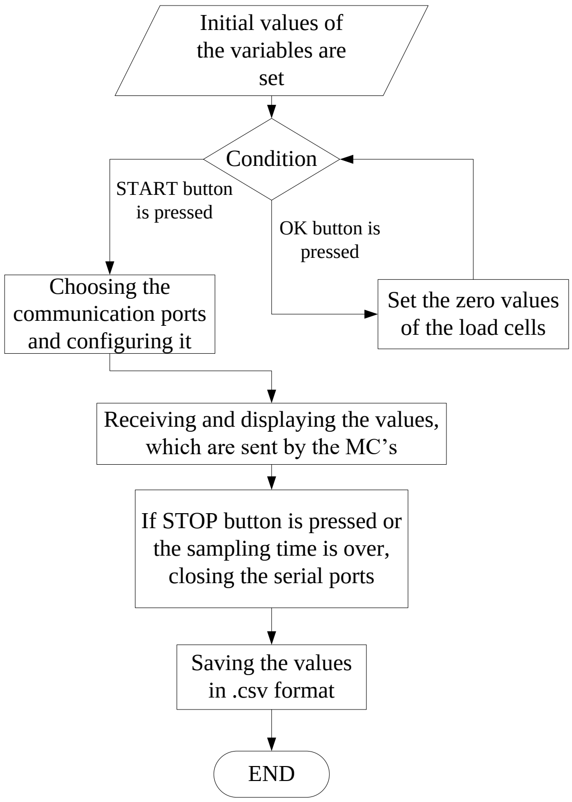


Figure 7. Flow chart of the LabVIEW program

The values of the normal- and tangential forces are displayed with XY Graphs separately. A table is created to store the time and the calculated average velocity of the guide bush.

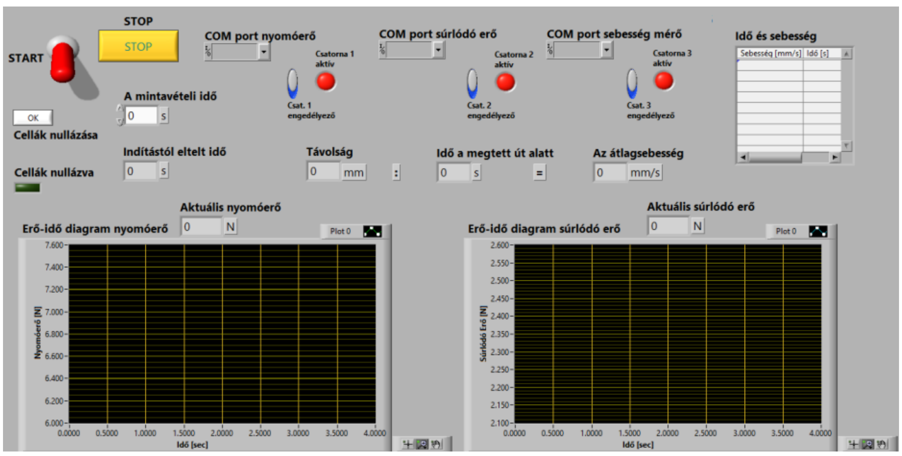


Figure 8. User interface of the program

4. DETERMINATION OF THE FRICTION COEFFICIENT

A special purpose program has been developed in Scilab software [11] to determine the friction coefficient. In order to provide the values of the two load cells in the same time a linear interpolation method [12] is required. Since the A/D converters of the load cells cannot be synchronized, therefore the interpolation can resolve this problem.

The interpretation process is shown in *Figure 9*. In the program the values of the tangential forces are interpolated to the timestamp of the normal forces. The interpolation function *(*see *Table 1)* can be written as follows:

$$S_{interp} = S(i,2) + \frac{[S(i+1,2)-S(i,2)][N(i,1)-S(i,1)]}{S(i+1,1)-S(i,1)}, \quad (2)$$

where $S(i,2)$ is the i^{th} value of the tangential friction force, $S(i+1{,}2)$ is the $(i+1)^{th}$ tangential force, the time values of these force values are $S(i,1)$, $S(i+1{,}1)$, respectively. The $N(i,1)$ is the time value, in which the tangential force (S_{interp}) is interpolated.

Table 1

The linear interpolation function in Scilab program system

```
if (N(i,1)>=S(i,1) & N(i,1)<S(i+1,1))
then
   dt=N(i,1)-S(i,1)
   Dt=S(i+1,1)-S(i,1)
   ds=S(i+1,2)-S(i,2)
   S_interp(i,1)=S(i,2)+ds*dt/Dt
   flag=1
end
```

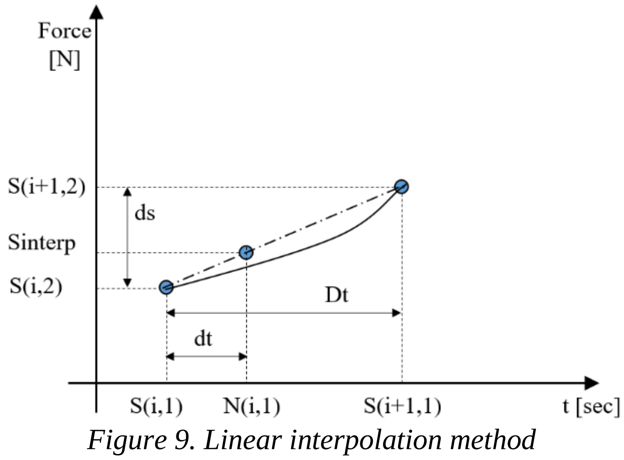


Figure 9. Linear interpolation method

The program reads the raw data in .csv file format. Thereafter the program determines the friction coefficients related to the discrete time values. The friction coefficient μ is obtained by Coulomb friction law

$$\mu = \frac{F_T}{F_N}, \quad (3)$$

where F_T is the tangential force and F_N is the normal counterpart.

Test measurements are performed with different specimens. The result of a test measurement is shown in *Figure 10*, where black solid line represents the measured value, the thin red line its linear regression. The elapsed time of the manually moved handle between the initial and the end position was 0.65 s.

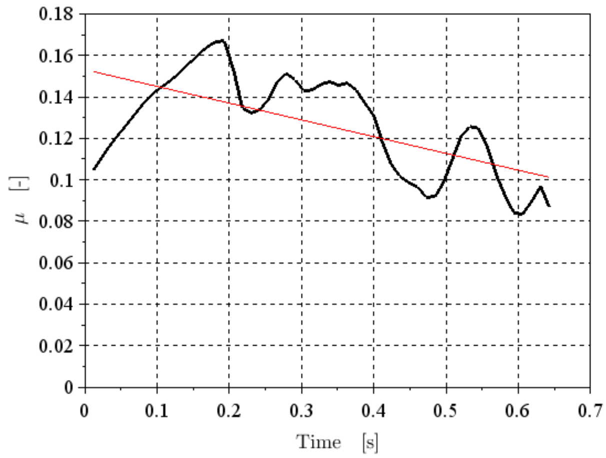


Figure 10. Result of the test measurement

The oscillating result of the friction coefficient μ shows a decreasing tendency, its median value for an aerosol can is approximately 0.125.

The analyzed example demonstrates the effectiveness of the proposed measurement method for rapid testing.

5. SUMMARY

Development of an electric system of a device, which is capable to measure friction coefficient rapidly has been discussed in this paper. The system contains two beam load cells to measure the normal- and the tangential forces. Three microcontrollers are built-in to provide the measured data for a laptop. One of these microcontrollers is used to measure the average velocity of the handle. A box was designed and manufactured with 3D printing technique to protect the electric system. Special purpose programs were developed for the microcontrollers and a data acquisition program was also developed to display and store the force values. A Scilab program was written to postprocess of the measured values in order to determine the median value of the friction coefficient.

The test measurements show that the developed device is well applicable in practice. The friction coefficients of inner or outer surfaces of specimens could be determined.

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