IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Designing a Validation Method for Remote Measurements Dedicated To Investigation of Bucket Wheel Excavator Lattice Structure Internal Stress in Harsh Environment

To cite this article: M Risteiu *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **209** 012066

IOP Conf. Series: Materials Science and Engineering **209** (2017) 012066 doi:10.1088/1757-899X/209/1/012066

Designing a Validation Method for Remote Measurements Dedicated To Investigation of Bucket Wheel Excavator Lattice Structure Internal Stress in Harsh Environment

M Risteiu[1*], R Dobra[1], I Andras[2], M Roventa[2] and A Lorincz[3]
[1] Computer Science and Engineering Department, "1 Decembrie 1918" University of Alba Iulia, Gabriel Bethlen Str. No.5, 510009 Alba Iulia, Romania
[2] Machinery Department, University of Petrosani, University Street, No. 11, Petrosani Romania
[3] Automation Department, University of Petrosani, University Street, No. 11, Petrosani Romania

E-mail: mristeiu@uab.ro

Abstract. The paper is a summarizing the validation stage of the strain gauges based remote measurements in bucket wheel lattice structures. The validation process is required when multiple and synchronized measurements are required in harsh environment. The authors propose virtual models with specific interaction facilities demanded in dynamic measurement systems (like FFT parameterization). The provided data from the remote measurement system (8 heads, discrete values) are processed in time and frequency for completing the range of values, for data synchronization for realistic strain distribution for proposed lattice structures. The proposed validation method is also acting for cleaning the inter-channel influences in measurements.

1. Introduction

The specific strength cutting of coal and of surface rocks, from the mine quarries, varies to great values in the mining field. For this reason, the splintering forces on the cutting teeth also have significant variations in the different mining fields. The size and direction of the forces from the cutting teeth also depends on the geometry of the teeth, their place and the direction of mounting in the bucket of the bucketed wheel [1,3].

Due to the complexity of the excavation process and of cinematic of the cutting tool, the accurately determination of the forces in the cutting teeth can be realized only through an experimental method in situ, reason for which it has been searched to conceive and to realize dynamometric teeth identical to the regular cutting teeth, which to provide a dynamometric bucket, and an electronic installation for measuring data into locations established previously and suited for it.

Because the measured information and recorded is represented by the specific displacements from the applying points of the SG onto the teeth, the relations between them and the components of the resulting points have been established for each tooth (normal, lateral, tangent) [8,9].

a) b)

Figure 1. Bucket wheel excavator tooth: a) The tooth with the places where the strain gage will be placed, b) The tooth with soldered strain gage.

Due to the complexity of the excavation process and of cinematic of the cutting tool, the accurately determination of the forces in the cutting teeth can be realized only through an experimental method in situ, reason for which it has been searched to conceive and to realize dynamometric teeth identical to the regular cutting teeth, which to provide a dynamometric bucket, and an electronic installation for measuring data into locations established previously and suited for it [1,3,7].

2. Bucket wheel excavator stress intensity factor

The specific strength cutting of coal and of surface rocks, from the mine quarries, varies to great values in the mining field. For this reason, the splintering forces on the cutting teeth also have significant variations in the different mining fields. The size and direction of the forces from the cutting teeth also depends on the geometry of the teeth, their place and the direction of mounting in the bucket of the bucketed wheel [2,5].

2.1. Stress intensity factor considerations

To establish the program to gather and modify the data obtained from the measurements it is necessary to establish the relations between the forces F_{x1}, F_{y1}, F_{z1} with random values, which act onto the dynamometric tooth in the splintering process, his geometrical parameters and the specific linear displacements. A crack intensity factor is referring to three different types of loading that cause displacements of the crack plane, tends to open the crack. The approach I is valid when the force is applied normal to the crack plane (tends to open the crack). The approach II refers to in-plane shear and causes the two crack surface to slide against each other. The approach III is valid when out-of-plane shear is applied and tends to tear the two crack surface apart.

First approach:

$$\sigma_x = \frac{K_1}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right)$$

$$\sigma_x = \frac{K_2}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right)$$

$$\tau_{xy} = \frac{K_1}{\sqrt{2\pi r}} \sin\frac{\theta}{2}\cos\frac{\theta}{2}\cos\frac{3\theta}{2} \qquad (1)$$

Second approach:

$$\sigma_x = -\frac{K_2}{\sqrt{2\pi r}} \sin\frac{\theta}{2}\left(1 - \cos\frac{\theta}{2}\cos\frac{3\theta}{2}\right)$$

$$\sigma_y = \frac{K_2}{\sqrt{2\pi r}} \sin\frac{\theta}{2}\cos\frac{\theta}{2}\cos\frac{3\theta}{2}$$

$$\sigma_{xy} = \frac{K_2}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right) \tag{2}$$

This last approach of deformation called out-of-plane shear mode, does not occur in the plane elastic problem. The stress intensity factors for all three types of approaches are denoted as K_1, K_2 and K_3.

The parameters $\tau_{xy} = \tau_{yz} = 0$ for plane stress and plane strain. The parameters $\sigma_z = 0$ for plane stress and $\sigma_z = (\sigma_x + \sigma_y)$ for plane strain [4].

Third approach:

$$\sigma_{xz} = \frac{K_m}{\sqrt{2\pi r}} \sin\frac{\theta}{2}$$
$$\sigma_{yz} = \frac{K_m}{\sqrt{2\pi r}} \cos\frac{\theta}{2} \tag{3}$$

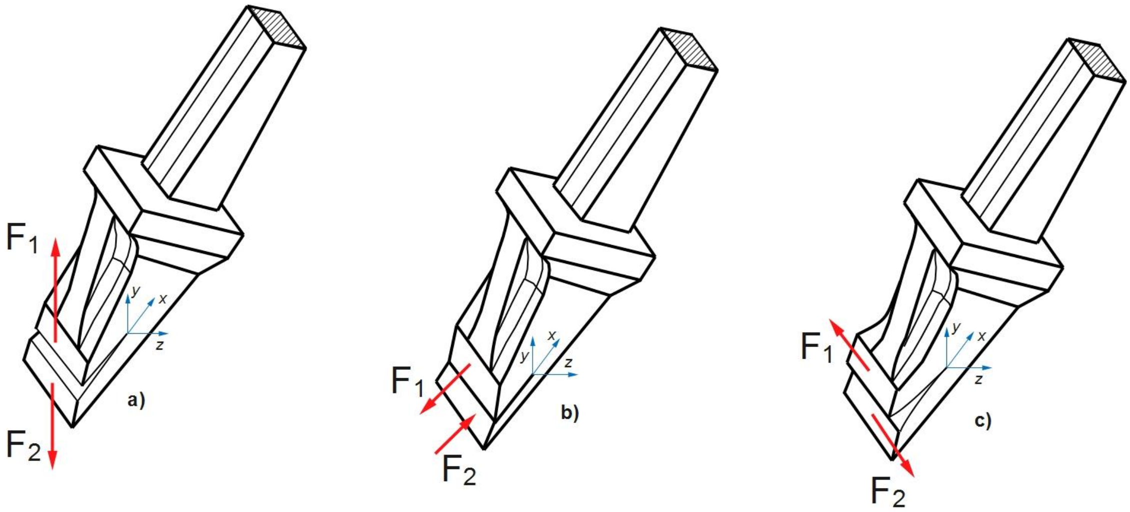

Figure 2. Deformation of the crack for bucket wheel excavator tooth.

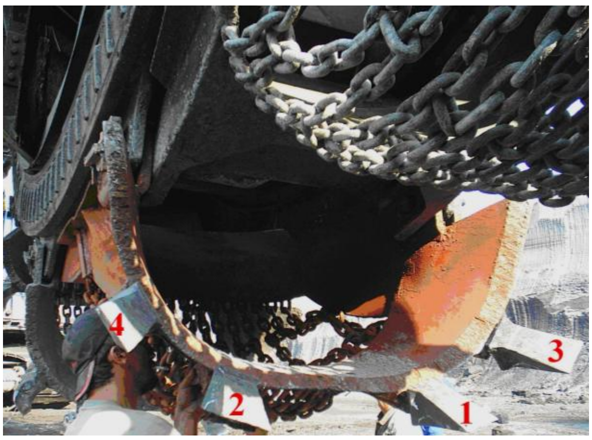

Figure 3. Dynamometric bucket mounted onto RS 1300 type excavators.

According to figure 3 the specific deformations the forces F_{x1}, F_{y1}, F_{z1}, applied to the center of the edge of the tooth and the geometrical characteristics of the section, the following relations are obtained [6,8]:

$$\begin{cases} E\cdot\varepsilon_1 = F_{x1}\left(-\dfrac{1}{A}+\dfrac{e_1\cdot y_1}{I_z}\right)+F_{y1}\dfrac{l\cdot y_1}{I_z}-F_{z1}\dfrac{l\cdot z_1}{I_y} \\ E\cdot\varepsilon_2 = F_{x1}\left(-\dfrac{1}{A}+\dfrac{e_1\cdot y_1}{I_z}\right)+F_{y1}\dfrac{l\cdot y_2}{I_z}-F_{z1}\dfrac{l\cdot z_2}{I_y} \\ E\cdot\varepsilon_3 = -F_{x1}\left(\dfrac{1}{A}+\dfrac{e_2\cdot z_3}{I_y}\right)+F_{y1}\dfrac{l\cdot y_3}{I_z}-F_{z1}\dfrac{l\cdot z_3}{I_y} \end{cases} \tag{4}$$

From the solving of the equations system it yields:

$$\begin{cases} F_{x1} = E\dfrac{(\varepsilon_2 y_3-\varepsilon_3 y_2)+\dfrac{(\varepsilon_1-\varepsilon_2)(z_2 y_3 - z_3 y_2)}{z_2-z_1}}{y_3\left(-\dfrac{1}{A}+\dfrac{e_1 y_1}{I_z}\right)+y_2\left(\dfrac{1}{A}+\dfrac{e_2 z_3}{I_y}\right)} \\ F_{y1} = \dfrac{EI_z}{ly_3}\left[\varepsilon_2+\dfrac{(\varepsilon_1-\varepsilon_2)z_2}{z_2-z_1}-\dfrac{(\varepsilon_2 y_3-\varepsilon_3 y_2)+\dfrac{(\varepsilon_1-\varepsilon_2)(z_2 y_3 - z_3 y_2)}{z_1-z_2}}{y_3\left(-\dfrac{1}{A}+\dfrac{e_1 y_1}{I_z}\right)+y_2\left(\dfrac{1}{A}+\dfrac{e_2 z_3}{I_y}\right)}\right] \\ F_{z1} = EI_y\dfrac{\varepsilon_1-\varepsilon_2}{l(z_2-z_1)} \end{cases} \tag{5}$$

With these values the upper relations become:

$$\begin{cases} F_{x1} = 3020\cdot 10^4(-39{,}4584\varepsilon_1+39{,}6684\varepsilon_2-35{,}21\varepsilon_3) \\ F_{y1} = 5683\cdot 10^4(8{,}7668\varepsilon_1+1{,}2396\varepsilon_2-1{,}3072\varepsilon_3) \\ F_{z1} = 6109\cdot 10^4(\varepsilon_1-\varepsilon_2) \end{cases} \tag{6}$$

It is specified that between the forces F_{x1} F_{y1} F_{z1} and the forces on the tooth resulted from the cinematic of the working tool, the forces F_x, F_y (tangent and normal to the trajectory resulted from the rotating movement of the bucketed wheel) and F_z (resulted from the horizontal tipping of the bucketed wheel by the excavator arm for cutting radial) there are the following relations:

IOP Conf. Series: Materials Science and Engineering **209** (2017) 012066 doi:10.1088/1757-899X/209/1/012066

$$\begin{cases} F_{x1} = -F_y \sin 52^\circ + F_x \sin 38^\circ \\ F_{y1} = F_x \cos 38^\circ + F_y \cos 52^\circ \\ F_{z1} = F_z \end{cases} \tag{7}$$

2.1.1. Hardware implementation

The bucket wheel excavator lattice structure internal stress is measured with the developed programmable system.

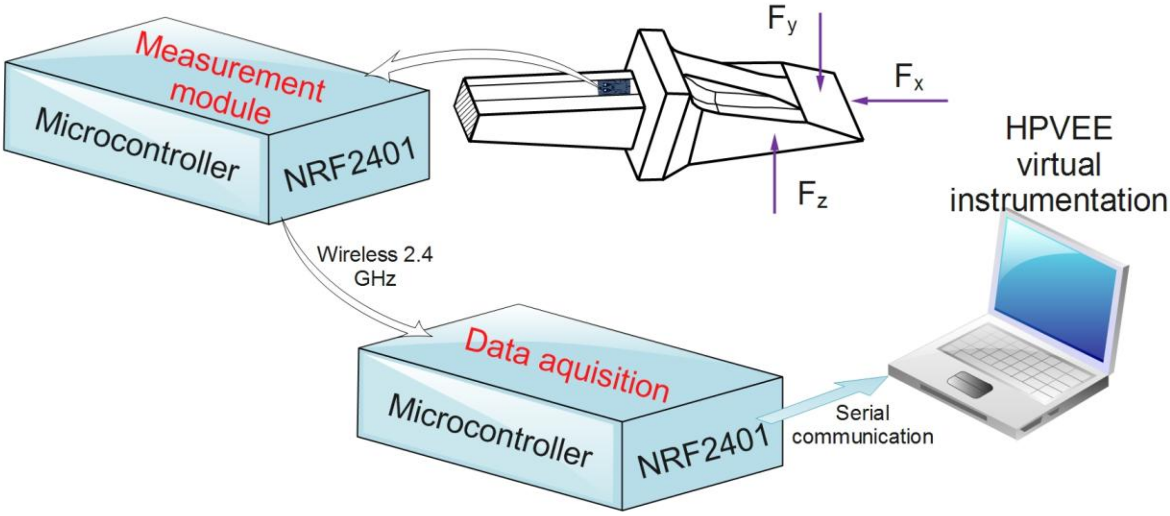

Figure 4. Remote measurements system for investigation of bucket wheel excavator.

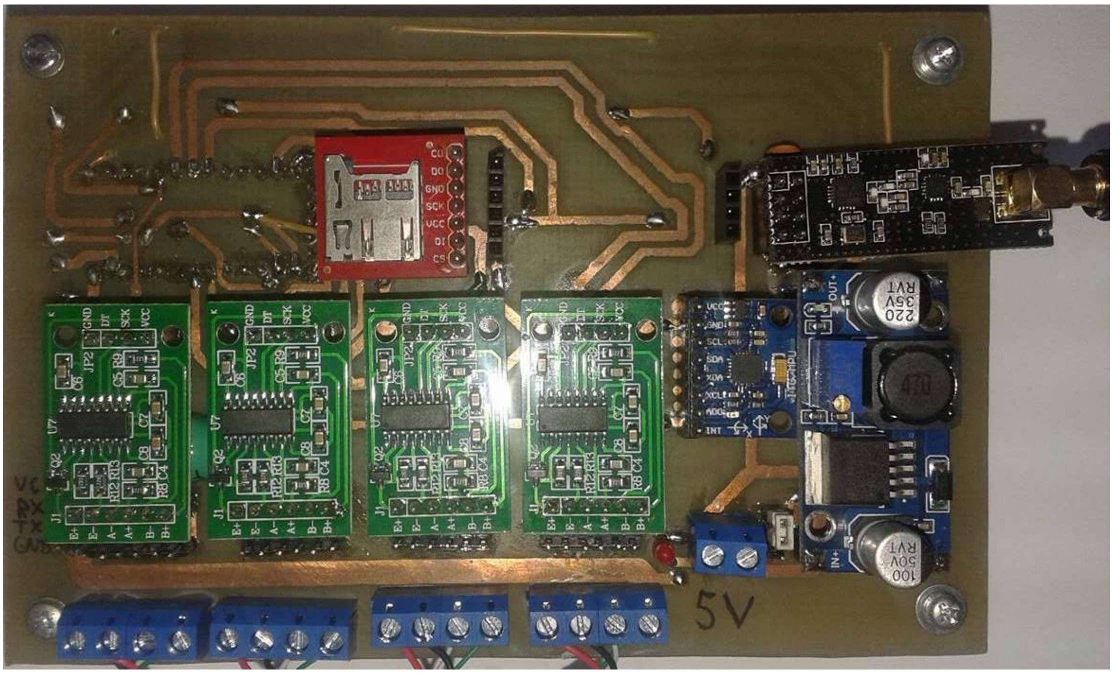

Figure 5. Testing measuring module based on Teensy microcontroller.

IOP Conf. Series: Materials Science and Engineering **209** (2017) 012066 doi:10.1088/1757-899X/209/1/012066

The nRF24L01 module is an RF module that works on the 2,4 GHz band and is perfect for wireless communication in a industrial application because it will penetrate even thick concrete walls. The nRF24L01 has a function to automatically check if the transmitted data is received at the other end. There are a couple of different versions of the NRF-family chips and they all seem to work in a similar way. These modules has an impressive range, with some versions that manages up to 1000 m (free sight) communication and up to 2000 m with a bi-quad antenna.

2.1.2. Software implementation

To start working with the Teensy, all you need to do is plug in your USB cable to your computer and your Teensy board. There are two options for programming the Teensy boards - your favorite C compiler or the Arduino IDE.

```
#include <SPI.h>
#include <SD.h>
#include "RF24.h"
#include "HX711.h"
#include<Wire.h>

#define csn 10                       //nRF24 --> csn
#define cs 6                         //microSD --> cs

const int MPU_addr=0x68;

//HX711 scale(DT,SCK);   //pinout example

HX711 scale1(A8, A9);    // #1  DT-->A8  SCK--> A9 parameter
HX711 scale2(A0, A1);    // #2  DT-->A0  SCK--> A1 parameter
HX711 scale3(3, 4);      // #3  DT-->3   SCK--> 4 parameter '
HX711 scale4(A6, A7);    // #4  DT-->A6  SCK--> A7 parameter

int nr_crt=1;

int T1 = 0;                  //T1= data from  HX711  #1
int T2 = 0;                  //T2= data from  HX711  #2
int T3 = 0;                  //T3= data from  HX711  #3
int T4 = 0;                  //T4= data from  HX711  #4

int16_t AcX=0;
int16_t AcY=0;
int16_t AcZ=0;

int16_t GyX=0;
int16_t GyY=0;
int16_t GyZ=0;
```

```
File datafile;               //creating the file for SDcard
RF24 radio(2, 10);           //initializing nRF24

byte addresses[][6] = {"0"};

struct pachet                        //creating data package
      {

        int nr_crt = 1;

        int T1 = 0;
        int T2 = 0;
        int T3 = 0;
        int T4 = 0;

        int16_t AcX=0;
        int16_t AcY=0;
        int16_t AcZ=0;

        int16_t GyX=0;
        int16_t GyY=0;
        int16_t GyZ=0;

        int16_t Temp=0;
        //char text[200]="empty";
        char text[200] = "NR_crt\t  T1,\t   T2,\t     T3,\t

      };

typedef struct pachet Pachet;
Pachet data;
```

```
void setup ()
{

  pinMode(cs, OUTPUT);
  pinMode(csn, OUTPUT);
  pinMode(2, OUTPUT);

  Wire.begin();
  Wire.beginTransmission(MPU_addr);
  Wire.write(0x6B);  // PWR_MGMT_1 register
  Wire.write(0);
  Wire.endTransmission(true);

  Serial.begin(9600);
  Serial.print("CLEARDATA");
  Serial.println("LABEL, NR_crt,T1,T2,T3,T4,AcX,AcY,AcZ,GyX,GyY,GyZ,Temp micros");
```

IOP Conf. Series: Materials Science and Engineering **209** (2017) 012066 doi:10.1088/1757-899X/209/1/012066

```
void setup ()
{

  pinMode(cs, OUTPUT);
  pinMode(csn, OUTPUT);
  pinMode(2, OUTPUT);

  Wire.begin();
  Wire.beginTransmission(MPU_addr);
  Wire.write(0x6B);  // PWR_MGMT_1 register
  Wire.write(0);
  Wire.endTransmission(true);

  Serial.begin(9600);
  Serial.print("CLEARDATA");
  Serial.println("LABEL, NR_crt,T1,T2,T3,T4,AcX,AcY,AcZ,GyX,GyY,GyZ,Temp micros");

  Serial.println("INITIALIZING SD CARD...");                //Verifing SDcard
  delay(300);
  if (!SD.begin(cs))

    Serial.println("SD CARD NOT DETECTED :(");

  else
    Serial.println("SD CARD READY FOR WRITING :)");



  datafile = SD.open("data.csv", FILE_WRITE);                //writing data_file to SDcard

void loop()
{
  Wire.beginTransmission(MPU_addr);
  Wire.write(0x3B);  // starting with register 0x3B (ACCEL_XOUT_H)
  Wire.endTransmission(false);
  Wire.requestFrom(MPU_addr,14,true);  // request a total of 14 registers

  AcX=Wire.read()<<8|Wire.read();  // 0x3B (ACCEL_XOUT_H) & 0x3C (ACCEL_XOUT_L)
  AcY=Wire.read()<<8|Wire.read();  // 0x3D (ACCEL_YOUT_H) & 0x3E (ACCEL_YOUT_L)
  AcZ=Wire.read()<<8|Wire.read();  // 0x3F (ACCEL_ZOUT_H) & 0x40 (ACCEL_ZOUT_L)
  Tmp=Wire.read()<<8|Wire.read();  // 0x41 (TEMP_OUT_H) & 0x42 (TEMP_OUT_L)
  GyX=Wire.read()<<8|Wire.read();  // 0x43 (GYRO_XOUT_H) & 0x44 (GYRO_XOUT_L)
  GyY=Wire.read()<<8|Wire.read();  // 0x45 (GYRO_YOUT_H) & 0x46 (GYRO_YOUT_L)
  GyZ=Wire.read()<<8|Wire.read();  // 0x47 (GYRO_ZOUT_H) & 0x48 (GYRO_ZOUT_L)
  Temp=Tmp/340.00+36.53;           //equation for temperature in degrees C from datasheet

  T1=scale1.get_units(10);
  T2=scale2.get_units(10);
  T3=scale3.get_units(10);
  T4=scale4.get_units(10);
```

Monitoring and processing system of mechanical effort with high performance microcontroller is done with the aid of weight sensors which are connected to a data acquisition board .The objective of this project is to create an smart electronic weighing system programmed by MC, this device has

IOP Conf. Series: Materials Science and Engineering **209** (2017) 012066 doi:10.1088/1757-899X/209/1/012066

capacity to specify the measured weight, weight differences over time and weight thresholds. Data taken from these input devices will be transmitted with an antenna, via wireless, can be stored on a card or can be read directly. Weighing sensors or tensometric stamps reprocessed by an HX711 instrumentation module. In the case of the weight sensor reading module this must be programmed, programming is done on Serial and can be done with an Arduino programmed as a programmer.

3. Results and discussions

The virtual mechanical strain bridge instrument consists on the Data acquisition module presented previously, connected to the Personal computer, the needed software for hardware functioning (Windows XP and the application strain bridge instrument program, developed with Keysight VEE Pro software).

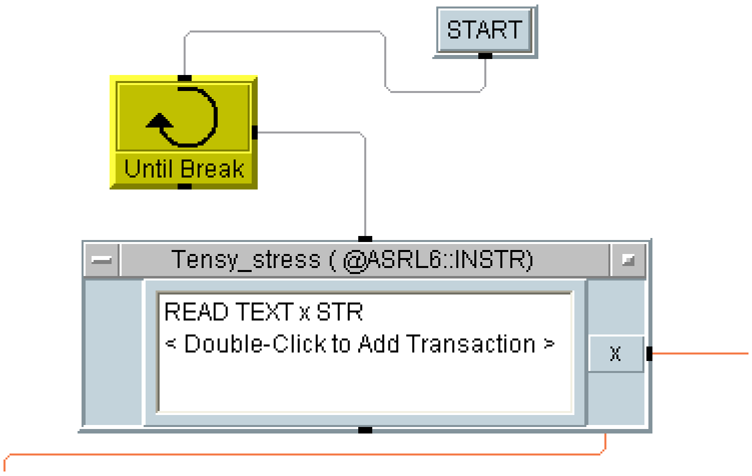

Figure 6. Measuring module configuration.

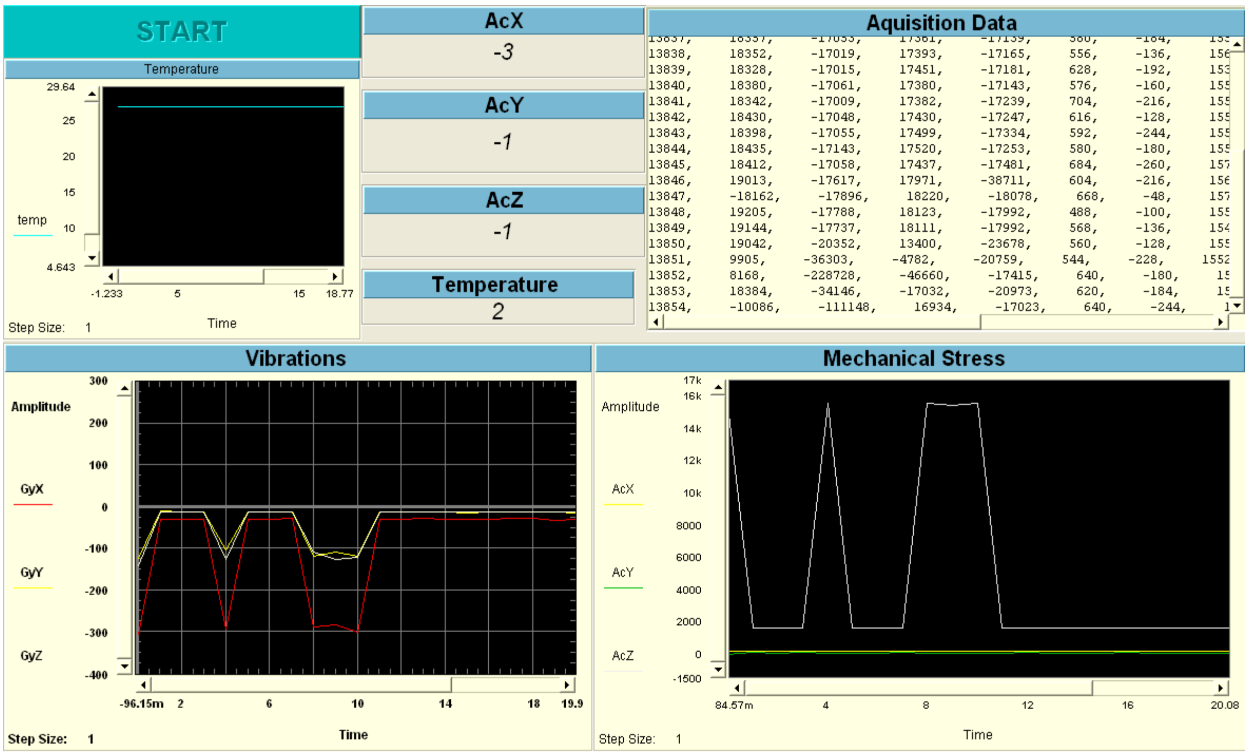

Figure 7. The graphical panel of the virtual mechanical stress measurements.

The software solution for the virtual bridge instrument was developed using the Visual Programming Environment for Data Acquisition, HP VEE and Matlab Script, Hewlett Packard .

Using the MatlabScript software, each bridge equation was specifically expressed and a graphical program was developed (figure 7). The main instruments are the acquisition data where the values from the measuring module.

Using the magnitude spectrum graphical instrument the frequency of the signals are displayed (like FFT parameterization).

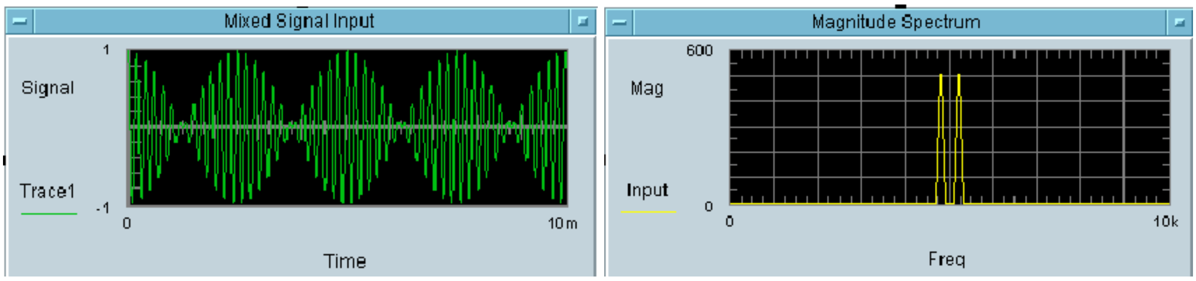

Figure 8. Spectral FFR analysis.

Based on the results of such measurements performed by the statistical processing, the relevant characteristics have led to the mechanical cutting of lignite.

4. Conclusions

The results of research performed regarding the cutting tools of the bucket wheel excavators; in order to reduce the energy consumption and the teeth wear during the lignite and overburden rock are presented.

On the basis of the methodology of analytical determination of force and energetic characteristics, starting from the results of experimental results in laboratory and taking into account the technical characteristics of the excavators

It has also been established that the dynamometric tooth to have the same geometrical parameters and to work in the same conditions as the real teeth. Following the analysis of the bucketed wheels and the way that the teeth is fixed into the holders it has resulted that the strain gage should be placed onto the tail of the tooth, in the free area between the tooth's shoulder and it's holder, in places covered with metallic plates to protect from mechanical hits, and environmental factors.

References

[1] Dumitrescu I, Nan M S, Kovacs I, Jula D, Mihăilescu S and Praporgescu G 2007 Design of an asymmetrical bucket for EsRc 1400 X 30/7 X 630 rotor excavators in agreement with the natural conditions displayed by Jilţ quarries *Analele Universităţii din Petroşani* **9 (XXXVI)** 127-132

[2] Kovacs I, Nan M S, Jula D and Tomuş O B 2007 Contributions to the study of the working mode of the rotor excavators in operation at Jilt sud and Jilt nord lignite open casts *Analele Universităţii din Petroşani* **9 (XXXVI)** 197-209

[3] Nan M S, Kovacs I, Dumitrescu I, Dimirache G, Burlan D and Radu D 2007 Study regarding the possibilities to improve the parameters of teeth on the rotor excavators in operation at Jilt sud and Jilt nord open casts *Analele Universităţii din Petroşani* **9 (XXXVI)** 63-72

[4] Ridzi M C and Zoller C 2007 Messung der Kräfte am Zahn eines Tagebaukohlebaggers *Messtechnische Briefe* **2** 16-24

[5] Ridzi M, Dumitrescu I, Zoller C and Radu D 2005 Aspects concerning the conceiving realization of dynamometric teeth of electrical measurement sketch of the displacement forces from the excavator teeth *Annals of The University of Petrosani* **7 (XXXIV)** 130-136

[6] Raaz V 2000 Optimierung der maschinen- mid verfahrenrechnischen parameter von

schaufelradbaggem für einen abbau von harteren materialen ím tagebau. *Braunkohle in Europa: Innovationen für die Zukunfl*

[7] Zoller C, Kovacs I and Ridzi M C 2007 Interpolation software to mea length of cutting arch , mesure mechanical forces on the bucket wheels of the excavators *2nd International Conference ICQME* 11-14

[8] Zoller C and Ridzi M 2005 Using Hp Vee 6 software to measure mechanical strains on the bucket wheels from the excavators *Annals of The University of Petrosani* **7 (XXXIV)** 101-108

[9] Zoller C and Simaschevici H 2003 Virtual mechanical strain bridge instrument *3rd International Conference Research And Development In Mechanical Industry RaDMI*

Acknowledgments

The paper is based on research activity that is the subject of the invention: Installation for in-situ measuring and recording the forces acting upon the teeth of the cutting element in rock shattering machines, Patent number RO 123483 B1

The paper is a part of an European Union research project founded by the Coal and Steel Founding, RFCS agreement No. RFCR-CT-2015-00003 (BEWEXMIN)