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Original Paper

Processing of stress dataset with rain-flow counting method

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ABSTRACT

In this contribution we are dealing with application of rain-flow method to processing the experimental stress data. Vibration of agricultural plough on duty was measured by sensor of acceleration ADXL345 Inertial Sensor mounted on the Pottinger Plough frame. Measured acceleration data was transformed to the stress on the frame. The mathematical algorithm of rain-flow method was based on the recommendation of ASTM code. The simple mathematical model was developed and the algorithm was implemented to the environment of PTC® Mathcad Prime® 4. Processing of experimental data was realized with Microsoft™ Excel® format table importing to the Mathcad Prime® software. The results from raw data and filtered data were compared.

KEYWORDS: signal processing, frame vibration, counting algorithm

JEL CLASSIFICATION: C65

INTRODUCTION

In many application of constructions life analysis were used the strain gauges to measure the stress in the materials under the random loading. The measurement is complicated because the gauges must be glued to the whole construction in the certain points and directions. Data recording and processing must be provided with the very wide skills [10]. The time-domain approach was defined by [1, 2] in which the response time history is calculated by static stress analysis by superimposing all stress influences from the applied loads at each time step, lacks the dynamics of the structure especially for vibration-based problems when a loading excites the natural frequencies of the structure. The use of strain gauges is possible for limited locations only and moreover requires early knowledge of critical fatigue locations. On the other hand, using the sensors of acceleration is very useful in measurement of vibrations of beams, where the beams are the components of the framed structures. Mathematical definition of Rain Flow Cycle (RFC) was first time defined by [8]. The method presented by [8] attaches to each maximum of the strain function the amplitude of a corresponding cycle or two half cycles, which are evaluated independently from each other.

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Algorithm of RFC was analyzed by [3, 9]. Practical application of RFC in fatigue life prediction was published by many authors. We can include to major works [4, 5, 6, 7].

MATERIAL AND METHODS

Measurement system and object

Object for measurement was a plough Pottinger depicted on Figure 1. The basic parameters of plough are listed in the Table 1 [11]. Measurement on plough was realized on deep plow. The plowed ground was planar without rough parts. The plough was mounted on tractor Fendt Vario 930.

Table1 Parameters of plough

Parameter	Value	Unit
Manufacturer	Pottinger	
Type	Servo 65 Plus	
Mass (m_P)	2370	kg
Distance between bodies	1	m
Bodies	7	m
Beam ($a \times a \times t$)	0,16x0,16x0,010	m

Figure 1 Plough Pottinger

Figure 2 Detail of sensor location

Figure 3 Sensor Eval - ADXL 345Z-DB

For measurement of plough vibration was used the Eval - ADXL 345Z-DB data acquisition board. The board measured accelerations in the XYZ axes. Measured data was recorded to the MiniSD card. The relevant direction for us was the accelerations in Z axis direction.

Mathematical model

As mentioned below, the measured vibration data were transformed to the stress data set. For the transformation we designed the simple mathematical model based on the theory of cantilever beam design theory. We substituted the real plough with model as depicted on Figure 4. For utilizing the designed model we set up the basic assumption as follows:

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- three-point linkage stiffness is similar as a fixed connection of the cantilever beam,
- for bending moment is used the effective length of plough,
- plough support wheel damping is contained in the acceleration data,
- used loading is the weight of the plough,
- neutral axis of the beam lay to the beam axis of symmetry,
- neglecting the shear deformation.

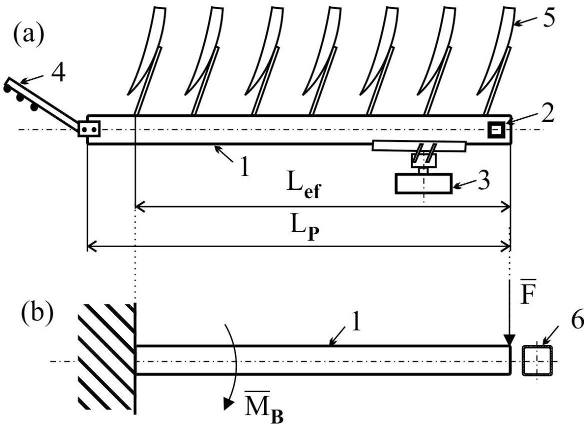

Figure 4 Plough and its model
(a) 1-plough beam, 2-acceleration gauge, 3-wheel, 4-three point linkage mechanism, 5-body
(b) 1-plough beam, 6-beam profile, $\overline{F}$ -force, $\overline{M}_B$ - bending moment

The algorithm was designed for computer processing and all variables are indexed. Bending moments dataset solving was realized with Equation 1. The beam cross section modulus was derived from equation of moment of inertia for square tube. Final Equation is 2. Stress formula was derived from stiffness condition equation for simple bending. Combination of Equations 1, 2 we get the Equation 3.

$M_{B(i)} = m_P . ac_{(i)} . L_{ef}$, where:

$M_{B(i)}$ - bending moment of the plough beam,
m_P - plough mass,
$ac_{(i)}$ - measured acceleration array,
L_{ef} - effective length of plough $= 6m$. (1)

Bending section modulus was solved by Equation 2.

$$W_B = \frac{a_1^4 - a_2^4}{6a_1} = \frac{1}{6}\left(a_1^3 - \frac{a_2^4}{a_1} \right), \qquad (2)$$

where: $a_1 = a$, $a_2 = a - t$.

For purpose of processing the experimental data we transformed acceleration dataset to the stress data set. Finally we get a formula for stress of beam with Equation 3.

$$\sigma_{B(i)} = \frac{6.a_1 m_P.ac_{(i)}.L_{ef}}{a_1^4 - a_2^4} \quad (3)$$

We processed the raw accelerations data set and filtered data set. Stress dataset from raw data is depicted on Figure 5. The raw accelerations data was filtered with Butterworth maximally flat magnitude filter (see Equations 4). The transformed data from filtered dataset is depicted on Figure 6.

$$B_n(s) = \prod_{k=1}^{\frac{n}{2}} \left[s^2 - 2.s.\cos\left(\frac{2k+n-1}{2n}.\pi\right) + 1 \right], n = even$$

$$B_n(s) = (s+1) \prod_{k=1}^{\frac{n-1}{2}} \left[s^2 - 2.s.\cos\left(\frac{2k+n-1}{2n}.\pi\right) + 1 \right], n = odd \ , \quad (4)$$

where n - order of filter

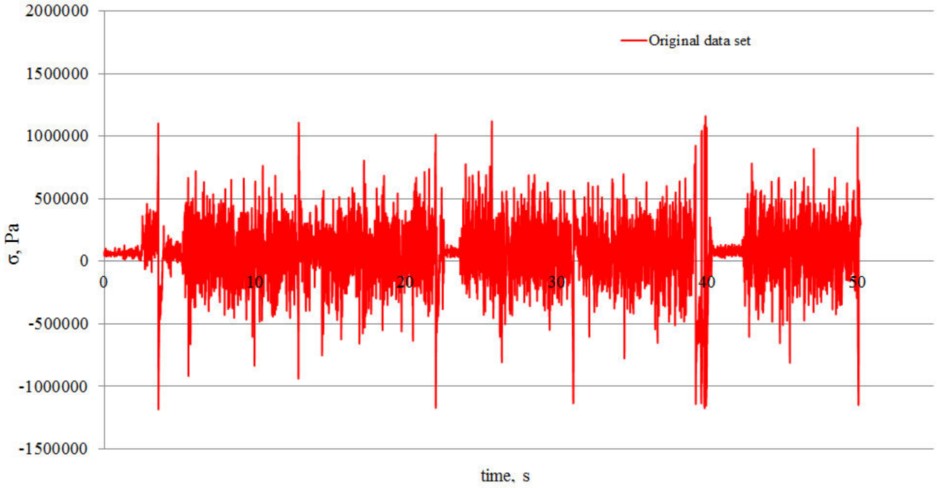

Figure 5 Stress from raw data

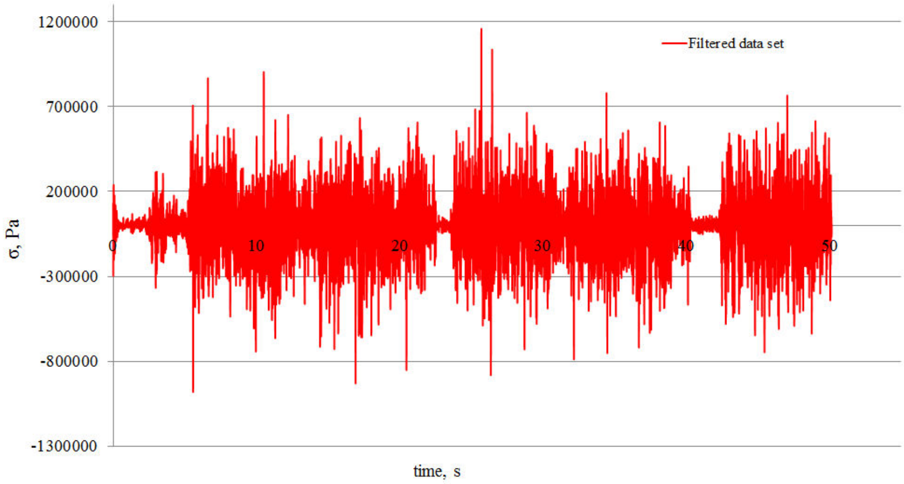

Figure 6 Stress from filtered data

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Rain flow counting cycle (RFC)

For processing the transformed data we used the Mathcad Prime® 4 software. Rain flow counting method is used to decomposition of the load signal. The load signal is represented by maxims and minima. Increasing and decreasing parts are counted as half cycles. Initial and final extreme do not have to follow behind, other half cycles can run between them. The name of the method is based on the idea, that after recording the load drops of water flow and drain as from the roof. Our algorithm is based on the [3, 5] descriptions. For method we set up basic rules for half cycle identification with respect the Figure 7, as follows:

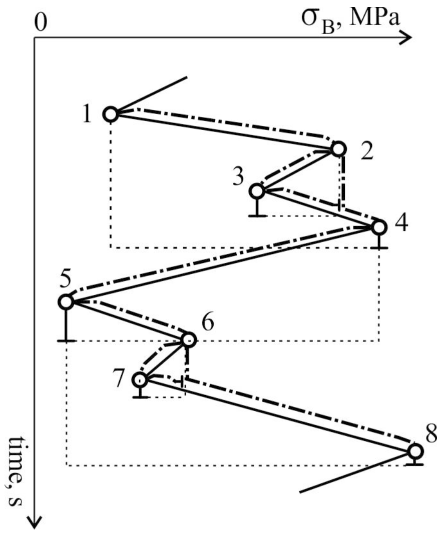

Figure 7 Rain flow method, where σ_B is stress of beam in Pa.

1) In every local extreme begins a half cycle,
2) half cycle ends if the edge of the outermost roof is reached(1-4, 2-3, 4-5, 5-8, 6-7),
3) half cycle ends if the drop strikes the dripping drop from the higher roof (3-4, 7-8).

The result of the method is the maximum and minimum stress, respectively, after recalculation, mean stresses in the rain-flow cycle (σ_B^M) and amplitude stress in the rain-flow cycle (σ_B^A) and these was solved by Equations 5, 6, where σ_B^{Max} is local maxima and σ_B^{Min} is the local minima. For the setup the cycle algorithm we design a flowchart with all conditions, variables and counts. The flowchart is depicted on Figure 8.

$$\sigma_B^A = \frac{\left|\sigma_B^{Max} - \sigma_B^{Min}\right|}{2} \quad (5)$$

$$\sigma_B^M = \frac{\sigma_B^{Max} + \sigma_B^{Min}}{2} \quad (6)$$

RESULTS AND DISCUSSION

Applying the RFC to the raw and filtered data we get the significant results about the both datasets. The values are solved by Equations 5, 6. For the raw data we set the results to the

Table 2. Tables 2 and 3 directly correspond with Figures 9, 10. Bin in the Tables 2, 3 means interval width of histogram.

Table 2 Results from rain-flow matrix histogram from raw data

	Min	Max	Bin
σ_B^M	-1.097451 x 10^6	7.43956 x 10^5	6.138022 x 10^4
σ_B^A	2.310422 x 10^3	1.162142 x 10^6	5.79916 x 10^4

Table 3 Results from rain-flow matrix histogram from filtered data

	Min	Max	Bin
σ_B^M	-3.805818 x 10^5	3.786286 x 10^5	2.530701 x 10^4
σ_B^A	4.9067252 x10^1	1.24555 x 10^6	6.227507 x 10^4

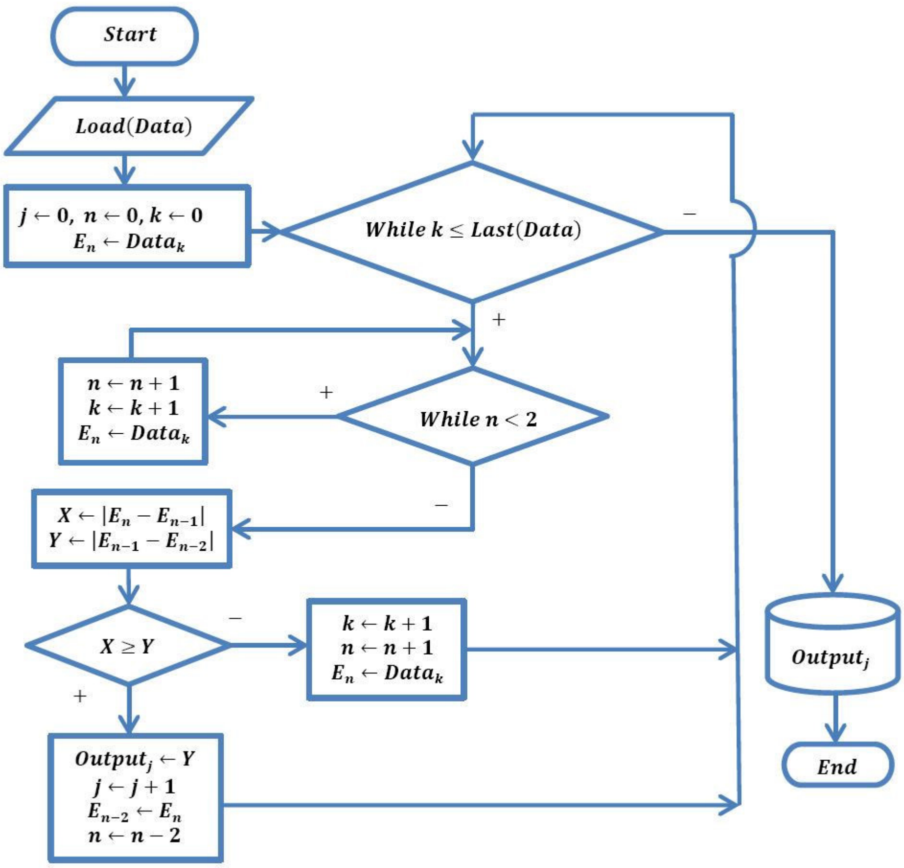

Figure 8 Flowchart of RFC

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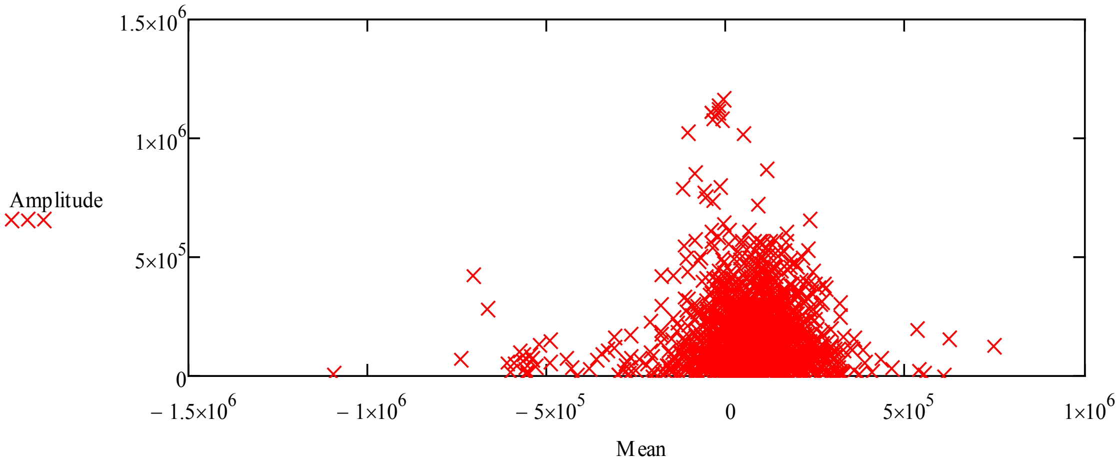

Figure 9 Stress raw data amplitudes and means layout

Description for the RFC flowchart algorithm (Figure 8):
X – range under consideration, Y – previous range under consideration,
range means difference between two following peaks of stress.
1) Read the next peak (if out of data stop)
2) Form ranges X and Y (if the vector contains less than 3 points go to step1)
3) Compare ranges X and Y, if $X < Y$ go to step 1, if $X \geq Y$ go to step 4
4) Count range Y, discard the peak of Y, go to step 2.

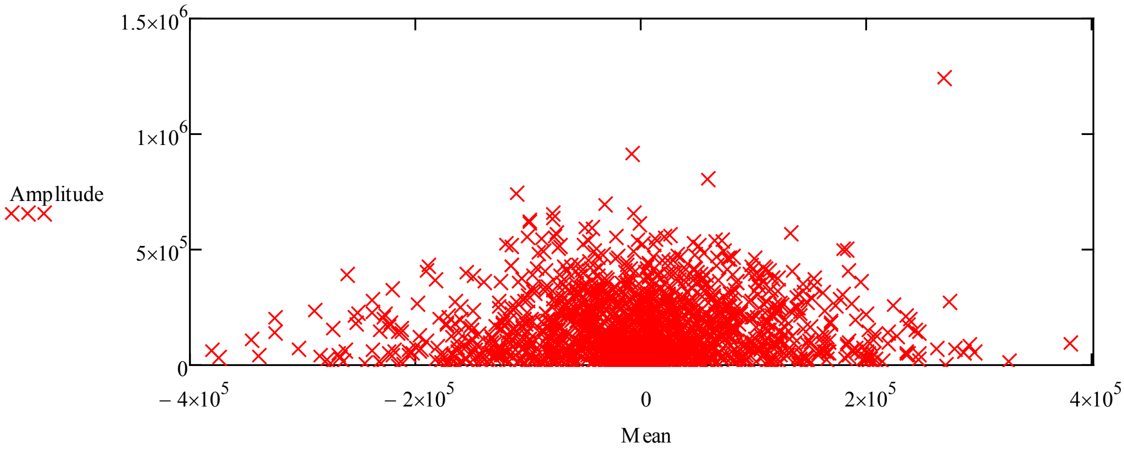

Figure 10 Stress filtered data amplitudes and means layout

RFC method gives the analysts the information about the concentrating the stress values in materials. From the Figure 9 and 10 we can see that the filtering data is valid because the range of raw stress data is in interval $\langle -1.5\cdot 10^6, 1\cdot 10^6 \rangle$ and the filtered stress data range is reduced to the interval $\langle -4\cdot 10^5, 4\cdot 10^5 \rangle$ in Pa. The negative values means that the loading is pressure and the positive values means that the loading is tension. With RFC algorithm we removed the no relevant values from stress data set. Another significant parameter about distribution of data is histogram. In Figure 11 we can see counts histogram of means and amplitudes for raw stress data. In Figure 12 we can see counts histogram of means and amplitudes for filtered stress data. The distribution data in rain-flow matrix is more uniformly as on Figure 11.

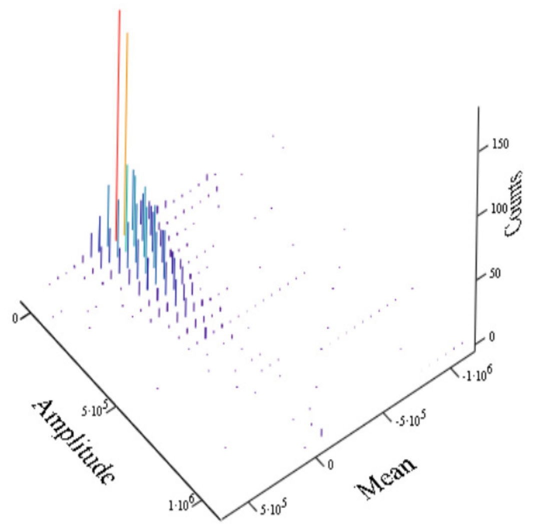

Figure 11 Rain-flow matrix histogram from raw data

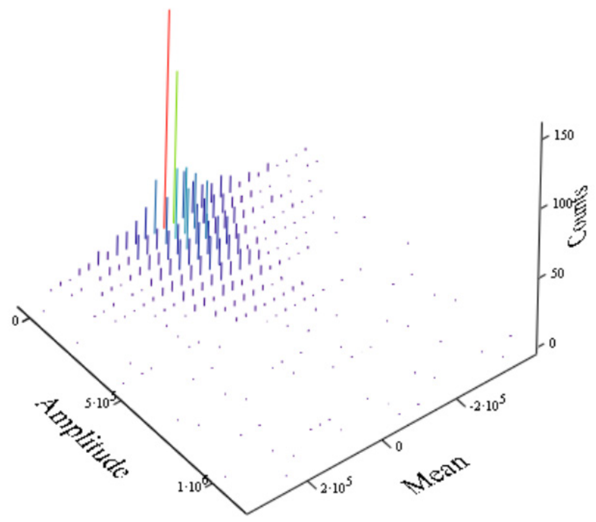

Figure 12 Rain-flow matrix histogram from filtered data

CONCLUSIONS

In this paper we are dealing with stress data processing by rain-flow counting algorithm. Data was obtained from experimental measurement of vibration of plough beam. The accelerations were converted to the stress time series. For signal processing we used the Butterworth maximally flat magnitude filter. In software Mathcad Prime 4 we designed the algorithm for establishing the relevant stress dataset by rain-flow counting algorithm. We processed the raw and filtered data. Result of RFC is rain-flow histogram matrix. From analysis we get the result that the raw data gives more irrelevant range of values than filtered data. The distribution of filtered data is more evenly distributed.

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