RAIN-FLOW ANALYSIS OF PLOUGH FRAME BEAM

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Abstract
The article is focused on experimental measurement of the acceleration of plough in certain point of construction and the certain direction. The simplified model of plough allows converting the acceleration into the force. The bending moment function of the plough frame was calculated. Differentiating the bending moment we got the shear force acting inside the frame profile. The reduced stress function was calculated by Von Misses hypothesis method. The reduced stress function was processed by rain-flow counting method. Histogram of cyclic stress is created from rain-flow analysis.

Key words: *steel fatigue; rain-flow; damage criterion; counting methods.*

INTRODUCTION

The assessment of life fatigue of steel constructions in agricultural machines is still very interesting area of research. The derivation of the statistical expression for the fatigue life at a welded connection is outlined which requires only constant amplitude stress/life data and the standard deviation and ruling frequency of the stress history (*Harral, 1987*). The aim of this study is to determine the stress ranges in the beam of plough which operating on the ground. The study is based on the research provided in the Faculty of Engineering in the past. The wide research of the life fatigue prediction of multipurpose agricultural carrier steel frames in Slovakia was done in Slovak Agricultural Testing and Research Centre. Applying the stress gauges for recording the deformation of the steel structure allowed designing the more efficient frames (*Sestak, 2002*). The agricultural machines parts that are influenced to the cyclic loading are still under the intensive research. Not only agricultural machines parts but also the heavy trucks parts are the object of the research. The prediction of life fatigue of front axle of heavy truck was done in system Ansys® (*Zhang et al. 2016*). The all agricultural steel components that are transmitting the loading or power are in most cases welded. From this reason is necessary to determine the life fatigue of welded joints and its residual stress (*Maddox, 1991; Niemi, 1995; Cui et.al. 2019*). The time-domain approach was defined in the form 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 (*Anzai, 1995; Aykan, 2005*). The determination of vibrations of structure and measurements with strain gauges needs more sensors. In many cases the location on frame of strain gauges are complicated due the irregular shape of structure. The best way is the using the acceleration gauge to determine the frame acceleration in certain direction. Determination the additional stress of structures from vibrations applying the basic dynamics relationship is very useful method. The main objective of this research was to study the relationship between additional stresses on building induced by vibrations, vibration nature and building dynamic characteristics. The designed models maximum stresses were measured due to each vibration load (*Hashad, 2015*). Assessment of life fatigue in agricultural universal transporters from operation vibration was investigated by many authors. The three motion parameters (displacement, velocity, and acceleration) describing a shock spectrum, velocity is the parameter of greatest interest from the viewpoint of damage potential. This is because the maximum stresses in a structure subjected to a dynamic load typically are due to the responses of the normal modes of the structure, that is, the responses at natural frequencies (see Chap. 21). At any given natural frequency, stress is proportional to the modal (relative) response velocity. Specifically,

$$\sigma_{\max} = C.v_{\max}.\sqrt{\rho.E}\ , \tag{1}$$

where : σ_{max} is maximum modal stress, v_{max} is – maximum modal velocity, ρ is mass density of the structural material, E is modulus of elasticity, C - Constant of proportionality dependent upon the geometry of the structure (often assumed for complex equipment to be 4 < C < 8 (*Piersol & Bateman et.all, 2010*). The Rain Flow Cycle (RFC) was analysed and reviewed by many authors. Definition of this method from mathematical point of view was done. The method presented by (*Rychlik, 1987*) 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. Algorithm of RFC was also analysed by (*Schluter, 1991; Baek, 2008*). Practical application of RFC in fatigue life prediction was published by many authors. The application of Palmgren-Miner rule in fracture mechanics was realized by (*Chen et al., 2011*) The Palmgren–Miner rule can be used for fatigue life predictions, if and only if, the damage development rate can be presented as a product of the functions of stress (strain) amplitude and current amount of damage (*Todinov, 2001*).

MATERIALS AND METHODS

Measurement object

Object for measurement was a plough Kuhn Vari-Master 183 depicted on Figure 1. The basic parameters of plough are listed in the Table 1. (*www.khun.com*). Measurement on plough was realized on deep plow. The plowed ground was planar without rough parts. The plough was mounted on tractor John Dere 8220.

Tab. 1 Properties of plough

Parameter		m	kg	pieces
Manufacturer	Kuhn			
Type	Vari Master 183			
Mass (m_P)			2840	
Distance between bodies		0.96		
Bodies				6
l_{ef}		5.76		
Beam ($a \times a \times t$)		0,180x0,180x0,008		

Fig.1 Plough Pottinger

Fig. 2 Detail of sensor location

Fig.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

The measured vibration data were transformed to the stress data set. We cannot use the mentioned method by Piersol et. because we have a time depend acceleration. We assume that the behaviour of the plough mounted on the three point linkage is similar like behaviour of the cantilever beam. For this reason we used 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:

- 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.

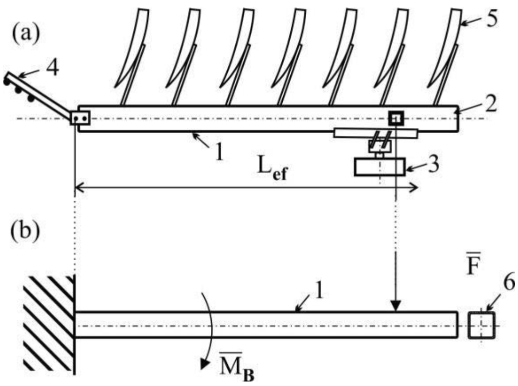


Fig. 4 Plough and its model

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 equation for calculating stress we use d the equation 2.

$$\sigma_{(i)} = \frac{m_p.l_{ef}}{W}.a_{(i)} \qquad (2)$$

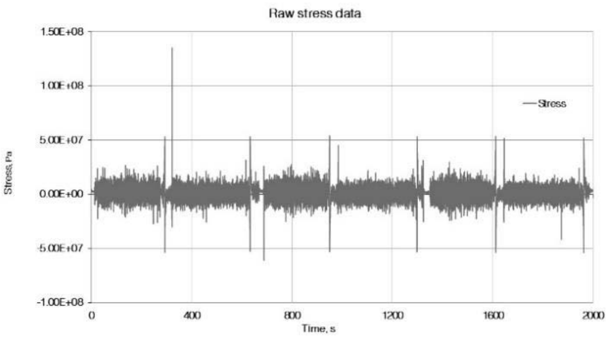
RESULTS AND DISCUSSION

From the experimental measurement we got the technical function of the acceleration in z-axis direction. Based on equations (2) we got the raw data of the stress, depicted in the figure 5 and 6. The raw accelerations data was filtered with Butterworth maximally flat magnitude filter, see Equations (3)

$$B_n(s) = \prod_{k=1}^{\frac{n}{2}} \left[s^2 - 2.s.\cos\left(\frac{2k+n-1}{2n}.\pi\right) + 1 \right], n = even \qquad (3)$$

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

$n-$ order of filter



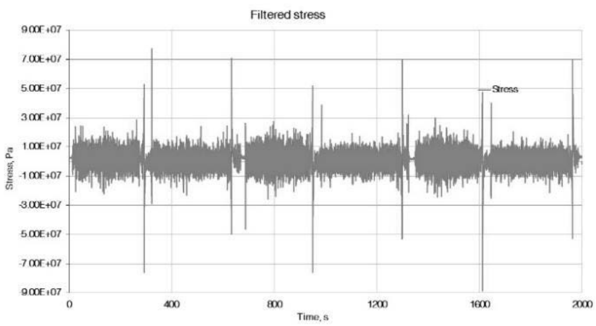
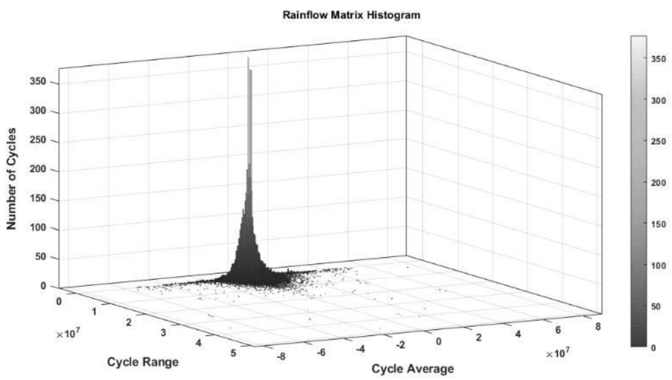


Fig.5 Stress raw data **Fig.6** Filtered stress data

Applying the rain flow method on the filtered stress data we got the rain-flow matrix histogram. The matrix is depicted in the figure 7. The rain-flow matrix was solved with the Matlab® system which is available for academics through the Slovak Centre of Scientific and Technical Information (*http://www.cvtisr.sk/*). The stress and cycles chart is depicted in the figure 8.



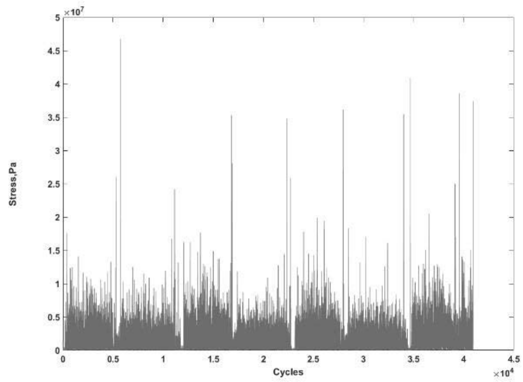


Fig.7 Rain-flow matrix **Fig.8** Stress-cycles chart

From rain-flow analysis we got the values which are necessary for the life fatigue calculation. The range counts and statistical values are in the table 2.

Tab. 2 Rain-flow counting results

Stress	Pa
Min	-8.841604021544859e+07
Max	.694699408809440e+07
Mean	1.055257081702104e+06
Median	1.141895561065718e+06
Deviation	6.420929987293424e+06
Range	1.653630343035430e+08

CONCLUSIONS

The unusual method of beam stress determination was presented. The operating environment was an agricultural ground, where plough supported on the tractor performed the agro-technical operation. The vibrations of the plough were measured and the acceleration was transformed to the acting force. The similar method to determine the steel frame stress was published by *Hashad (2015).* The designed mathematical model is very simply and utilizing it's we should on the easiest way determine the potential damage of the beam. But the Palmgren-Miner rule must by applied. For application of Palmgren-Miner rule must by the set of the stress data counted by rain-flow counting algorithm as published by *Harral (1987), Anzai (1992)* and *Sestak (2002).* The results published by *Harral (1987)* was the stress deviation in range 5 to 26 MPa and solved standard stress deviation calculated by us was up to 6,421 MPa. Also the maximum stress counted by Harral was 177 MPa and maximum stress solved by us was 88 MPa in absolute value .These results are very significant and proving our methodology. The similar algorithm of rain-flow counting method and application of Palmgren-Miner rule are published by *Todinov (2001)* and *Piersol and Paez (2010).* The typical shape of stress histogram of rain-flow counting algorithm was created. From the analysis we get the peaks of stress and the cycles ranges which are the significant properties of the analysis. As denoted by *Cui et al. (2019)* the fatigue life prediction model is based on the elastic fracture mechanics. The our model is also based on the mechanics of the elastic isotropic bodies. For the shorter publication space, we didn't publish the results from application of Palmgren-Miner rule. To validate the presented method must be carried out the experimental measurement with stress gauge.

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