Measurement of the Stress State in the Lower Link of the Three-Point Hitch Mechanism

Vera Cerović, Dragan Milković(✉), Aleksandar Grbović, Saša Radulović, and Jovan Tanasković

Faculty of Mechanical Engineering, University of Belgrade, 11120 Belgrade, Serbia
verica.cerovic@gmail.com, dmilkovic@mas.bg.ac.rs

Abstract. Agricultural machines and their implements are subjected to dynamic loads during farm operations. Depending on the type of operation (e.g. lifting or plowing), lower links of the three-point hitch mechanism are exposed to stresses caused by combination of bending moments and axial forces. In this paper we analyzed influence of the soil resistance during plowing in the lower link and the possibility of its failure. The stresses were measured using strain gauges at locations with uniform stress distribution in order to enable more reliable comparison with finite element analysis (FEA). Recorded stresses vs. time were used for identifying mean stresses and amplitudes for different plowing depth and different tractor speeds. Due to the geometry of the lower links and their joints in the three-point hitch mechanism, during plowing and transferring soil resistance, links are loaded not only by axial forces but also by bending moment in the horizontal plane. Under some assumptions, FEA provided us to make relations between the measured stresses and the loads that caused them. Measured stresses show that links have significant safety margin relative to tractor installed power and soil resistance, which enables the possibility of their design optimization. Obtained results may also serve for further analyses of fatigue life prediction, measurement of the draft forces etc.

Keywords: Three-point hitch mechanism · Lower link · Stress state
Strain gauges · Finite element analysis

1 Introduction

Three-point hitch mechanism (TPH) is the most widely used way of connecting implements to the tractor (Fig. 1). Considering that it is extremely dynamically loaded, a substantial number of authors analyzed the possibilities of its improvement [1–3]. In this paper, the focus was on the lower link of TPH mechanism, and the first step of the analysis was to identify the stresses and the character of the loads that these elements transmit during plowing operation. Depending on the depth of plowing and the type of soil, forces needed to carry out this operation differ in a wide range. In this paper, we dealt with the first category link for low power tractors. Tractors with a power of less

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than 40 kW are widely used on smaller farms, and they have a significant share in the agricultural machinery market, with the tendency of increasing the number of units sold [4]. The largest investments, based on the Agrievolution Alliance data, in the past few years in this area are in the countries such as China and India.

Fig. 1. Three-point hitch mechanism (TPH) [5].

The analysis presented in this paper is based on the experimental measurements of the stresses using strain gauges during plowing operation. These values are compared to the results of finite element analysis (FEA) performed in order to determine the load intensity that caused these stresses. The measurements were made with one tractor-implement configuration, on the one soil type. Plowing is one of the most power demanding soil tillage operations. It is cutting and turning up and over the soil. Due to the small installed power of the tractor, the speed of movement was mostly limited by the depth of plowing and the resistance that tractor can overcome.

Fig. 2. Lower link of the TPH mechanism.

The tested link belongs to the first category of links, made by forging. It has holes for the pins and spherical joints at both ends. Lateral distance between the joints of the two links forming a pair on the implement side is greater than on the side closer to the tractor (Fig. 1). As a result, ends of the link, in the zone of the joints, are folded for about 6° relative to longitudinal axis of the lower link central part (Fig. 2). There are also kinematic methods for determining positions of all TPH elements [6].

2 Field Tests Preparation

Experimental measurements were performed with the IMT 539 Rakovica tractor in combination with the OLT OSIJEK PTO 2/25 plow (Fig. 3). The lower link of the support mechanism is equipped with strain gauges set and connected in the measuring bridges according to Fig. 4. The layout of the strain gauges was chosen to measure the stresses at locations with uniform stress distribution in order to enable more reliable comparison with FEA.

Fig. 3. Tractor-plow configuration.

For measurement of the stresses, strain gauges of type HBM KY31 120-3 were used (Fig. 4). Bending due to the eccentric effect of the axial force of the lower link is a consequence of link position when mounted on the tractor (Figs. 1 and 3). Due to the existence of a stabilizer that prevents the link from being tilted to the side, in addition to the axial force, there is also a force in the stabilizer, which additionally bends the lower link. Therefore, the bending moments are not only due to the geometry of the link and TPH mechanism, but also by the force in the stabilizer. One possible way of separating these influences is using blind signal separation (BSS) for recovering two or more sources that caused mixed recorded stress signal [7] or by defining analytical equations for establishing relations between the source forces and resulting stresses.

FEA confirmed that the stress state resulted from bending only due to geometry of TPH, differs in two measuring points. On the other side, considering the position of the strain gauges (the same position on the inner and outer side of the link), the relative deformation i.e. stresses caused by stabilizer are equal at both measuring points. One strain gauge is loaded by tensile and the other by the compressive strains. Each strain gauge is temperature compensated. They are connected with dummy gauge to form a Wheatstone's half-bridge. Installed link is shown in Fig. 5.

Fig. 4. Strain gauges position

Figure 6 shows complete measuring chain with used digital acquisition system (DAQ) type and laptop for data storing and visualization. Stresses were recorded at 600 Hz sampling rata and low pass filter 100 Hz was applied in order to eliminate high frequencies with low energy capability and to have clearer recorded signal.

Fig. 5. Lower link with applied strain gauges on the tractor

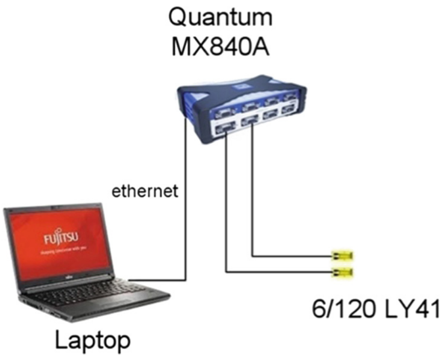

Fig. 6. Measuring chain

3 Measurement Results

Measurements in real conditions were performed on the soil of the category "chernozem" on the stubble after harvest of wheat. The test included measuring the stresses with different tractor speeds and different depths of the plowing.

The speed of the tractor was varied according to the available power in the range of 2 to 6 km/h, which could be achieved with the depth of plowing from 11 cm to 17 cm. (Table 1). Figures 7, 8 and 9 show recorded stresses vs. time for different regimes of plowing. Due to the change in the resistance of the plow, the stresses vary in a wide range. For the analysis and comparison, the measured mean stresses and amplitudes for the different depths of the plowing and the speed of the tractor's movement have been identified. Table 2 shows these values at relatively steady state. These data may serve for fatigue life analysis of the lower link using the stress-life method [3] or FEM based crack propagation method proposed in [8] and grounded on the stress intensity factors (SIFs) calculations. In the event of multiple damages, SIFs can be calculated either using extended finite element method (XFEM) or approximate method based on principle of superposition [9]. Therefore, stresses measured at lower link are necessary for fatigue life estimation as described in [3, 8, 9].

Table 1. Plowing regimes

Measurement no.	Tractor speed (km/h)	Plow depth (cm)
I	2	11
II	6	17
III	2	17

It can be seen that the stresses measured from the outside of the lower link and the inner side differ. This different comes from the link geometry and the load distribution. Therefore, the links are not quite axially loaded. There are also stresses caused by bending. The link forces are transmitted along the axis which connects the spherical joints at both ends of the links, and as a result, an additional bending of the link about approximately vertical axis occurs. Also, as explained, there exists an influence of the stabilizing chain, that prevents lateral movement during plowing. This bending appears on the span between sphere joint on the implement side and the stabilizer, as shown in Fig. 11.

Based on FEA, a relation between the stresses and forces in the lower link is established. The stress gradient in the measurement zone is small, so the possible inaccuracy of the strain gauges location does not affect the accuracy of the determination of the relative strains or the stresses at the measuring points.

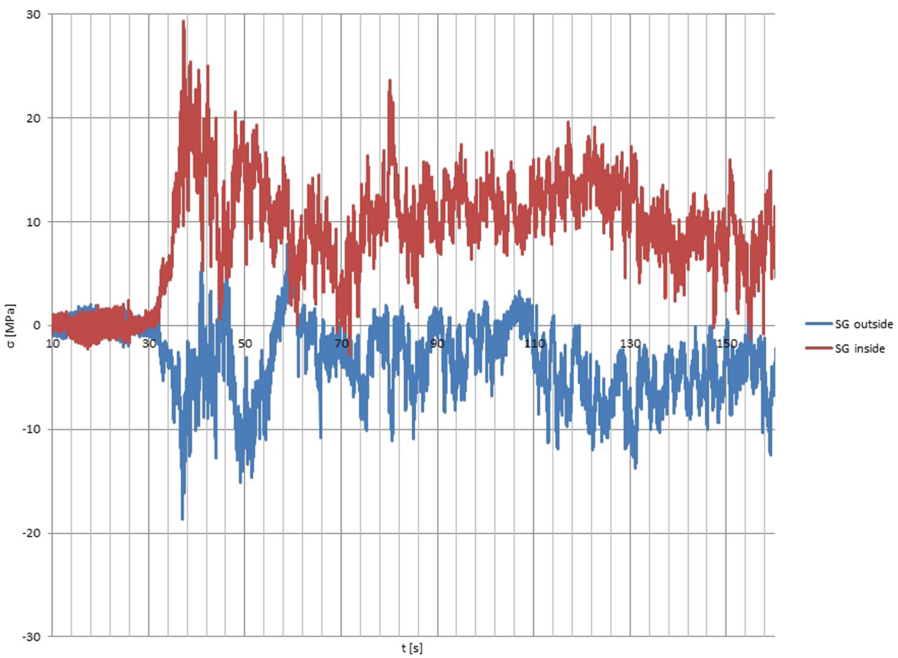

Fig. 7. Recorded stresses vs. time – measurement No. I

Figure 10 shows the finite element model for calculations and the results corresponding to measurement No. I. The maximum stress equals to 32.2 N/mm^2 appeared in the area near the sphere joint and the second critical zone is welded joint with stress equal to 25.7 N/mm^2.

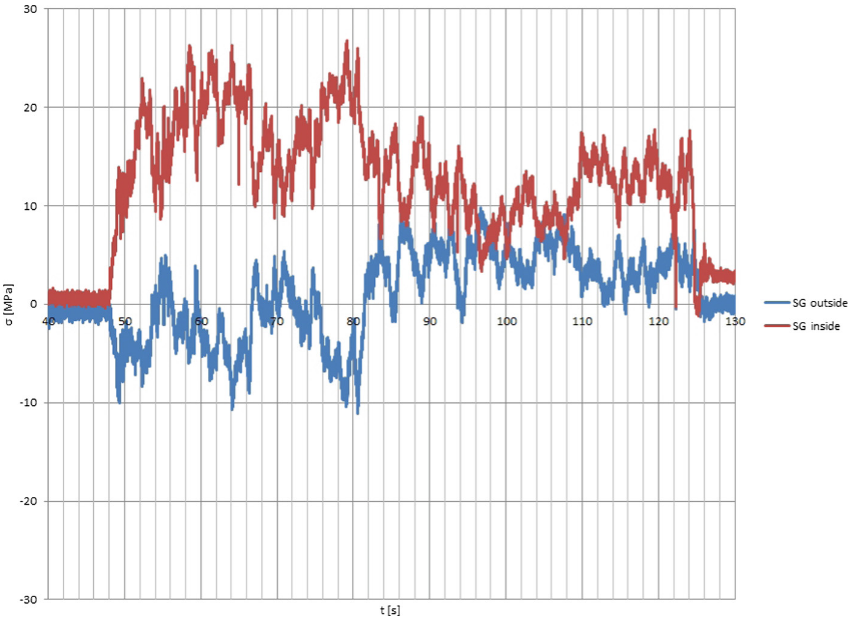

Fig. 8. Recorded stresses vs. time – measurement No. II

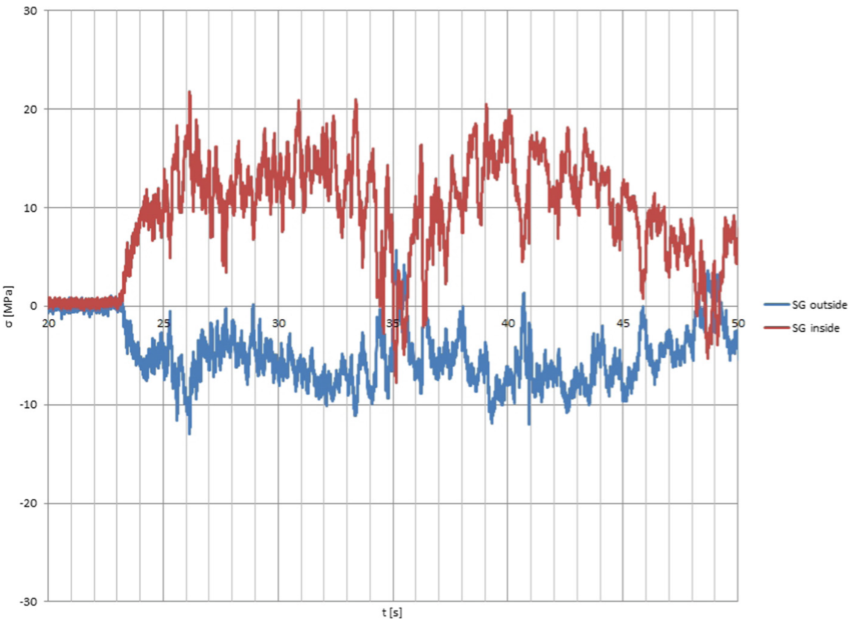

Fig. 9. Recorded stresses vs. time – measurement No. III

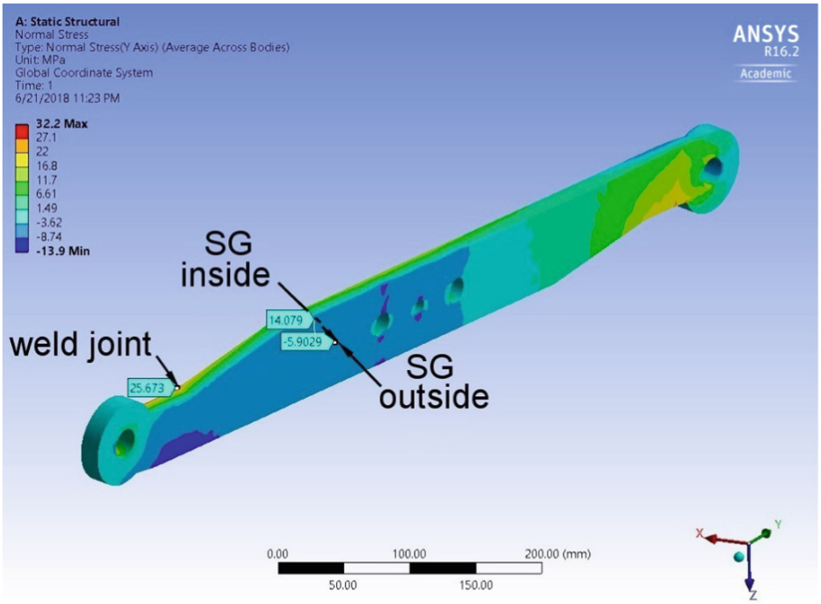

Fig. 10. FEA and obtained normal stresses during measurement No. I at the strain gauges position and at welded joint

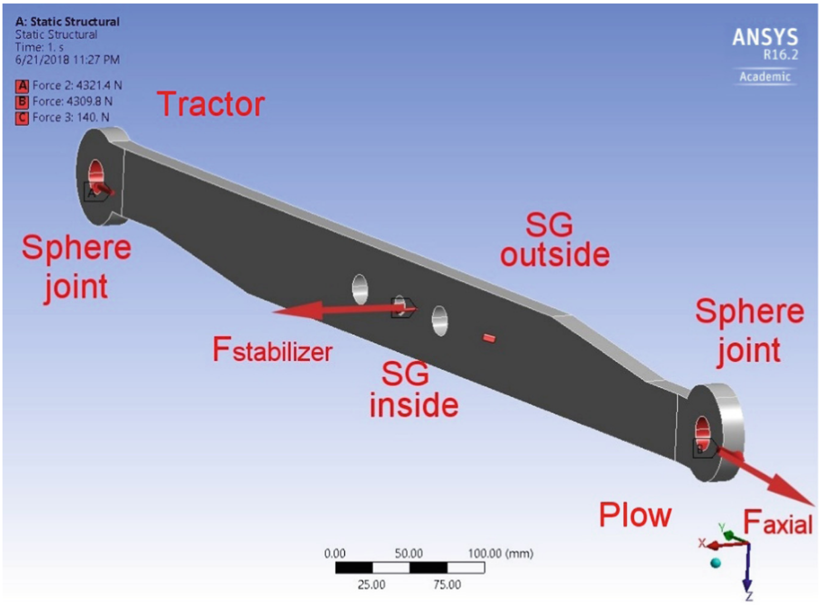

Fig. 11. Reconstructed forces based on the calculated stresses – measurement No. I

Recovered or reconstructed forces (Fig. 11) based on the FEA and relatively steady state measured stresses are shown in Table 2. An analysis of the influence of stabilizer force on the stress state was performed. It turns out that this force may not be neglected. The lower link is loaded by the superposition of axial force and the force in the stabilizer.

Table 2. Relations based on FEA between the measured stresses and forces that caused them

Measurement no.	Normal stresses σ [N/mm^2]			F_{axial} (kN)	$F_{stabilizer}$ (kN)
	SG location	SG inside	SG outside		
I	Mean value	14.1	−5.9	4.3	0.14
	Amplitude	5.5	2.5		
II	Mean value	19.9	−5.2	7.5	0.15
	Amplitude	6.5	5.2		
III	Mean value	11.6	−1.9	5.0	0.07
	Amplitude	3.8	3.6		

4 Conclusion

Measured stresses show that links are extremely variable loaded. The stresses depend on the resistance caused by tractor speed, plowing depth and the type of soil. Nevertheless, there is still significant safety margin, which enables the possibility of their design optimization. Obtained results may also serve for further analyses and measurements of the draft forces. The analysis shows that the forces in the stabilizer are not large, but they influence the obtained stresses at the positions of the strain gauges. Therefore, they cannot be neglected, and have to be measured along with forces in other elements of the THP mechanism. Measured stresses and amplitudes can be used for fatigue life predictions by some of the available methods and for identification of critical locations that occur under cyclic loads.

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