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Taguchi Approach on Stress-Displacement Analyses of the Mounted Type Chassis Used in Agricultural Sprayer Machine

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Abstract: The optimum design for effective and economical use of agricultural sprayer machinery is becoming increasingly important. In order to reduce weight of agricultural sprayer machinery, safe designing has been continuously developed on chassis and sprayer boom by related engineers. The purpose of study aim is to determine how much boom and tank weights the mounted type chassis can carry. By the way, the stress strain analyses of the developed mounted type chassis design for agricultural sprayer machine were carried out with finite elements analyses (FEA) after doing related literature survey. The Taguchi orthogonal array design (L16, 2^4) for eight FEA is done. After doing FEA according to Taguchi experimental design, von-Mises stress and shear stress together with displacements on mounted type chassis were obtained. As a result, the effect of the weights of pesticide tank and sprayer boom on stresses and displacement determined. The effect on equivalent von-Mises stress of pesticide tank and boom weights obtained as 5.89% and 87.38% sequentially from variance analyses. Moreover, the boom width, tank capacity and safety factor on the developed chassis were predicted via FEA before manufacturing.

Tarımsal İlaçlama Makinelerinde Kullanılan Asılır Tip Şaside Gerilme ve Yerdeğiştirme Analizi Üzerine Taguchi Yaklaşımı

Anahtar Kelimeler
Tarımsal ilaçlama makinesi,
Asılır tip şasi,
Gerilme ve yer değiştirme analizi

Öz: Tarımsal ilaçlama makinelerinin performanslı ve ekonomik kullanımı için optimum tasarımın önemi giderek artmaktadır. Bu bağlamda, konuyla ilgili mühendisler tarımsal ilaçlama makinelerinin ağırlığını azaltmak için şasi ve ilaç püskürtücü kanatların emniyetli tasarımını geliştirmeye devam etmektedirler. Bu çalışmanın amacı, yeni asılır tip şasinin taşıyabileceği tarımsal ilaç püskürtücü ve ilaç deposu ağırlıklarını belirmektir. Bu bağlamda, gerekli literatür araştırmasından sonra asılır tip tarımsal ilaçlama makinesinin şasisi için statik gerilme-yer değiştirme analizi sonlu elemanlar yöntemi kullanılarak gerçekleştirilmiştir. Sistematik sonlu elemanlar analizi için Taguchi ortogonal dizin deney tasarımı (L16, 2^4) yapılmış ve neticede geliştirilen asılır tip şaside oluşan bileşke gerilme ve kayma gerilmesi ile birlikte yer değiştirme değerleri elde edilmiştir. Varyans analizinden, püskürtücü ve ilaç tankı ağırlıklarının bileşke gerilme üzerine etkisi sırasıyla 87.38% ve 5.89% elde edilmiştir. Sonlu elemanlar analizleri sonucunda, imalat öncesi ilaç püskürtücü kanadın ve ilaç tank ağırlıklarının gerilme ve yer değiştirme üzerine etkisi ve püskürtücü kanat genişliği, ilaç tank kapasitesi ve güvenlik faktörü tahmin edilmiştir.

1. INTRODUCTION

Today agricultural machine and its equipment sector has turned into a unique sector rather than a sub-branch of machinery sector. Agricultural spraying machine is one of the agricultural machines affecting agricultural yield. Moreover, with the adaptation of the automation and controlling systems to the agricultural spraying machine, the conventional spraying machines have been transformed into high value-added technology. For example; Akgül et al [1] developed the GPS aided proportional controller unit used in agricultural spraying. In their study, they declared that the amount of pesticide per unit agricultural area with low margin error and commercialization of this technology. Ilıca and Boz [2] developed an agricultural nozzle-height control test system using a permanent magnet tubular linear synchronous motor. They experimentally tested this control system that the developed system keeps the distance between differently sized plants and the nozzle at the set point with minimum error. It was mentioned in another study [3] that the automatic boom control systems were developed to check dynamic and static behaviour of spray boom and its suspension. Besides, it was reported [4] that the artificial intelligent and image processing technologies started to be used to detect and separate weeds from plants and also autonomous agricultural aircraft spraying system in the pesticide control. The opportunity to improve the control of the suspended center frame and boom system has dramatically increased using the hydraulic cylinders, spring-damper systems, sensor instrumentation and programmable controllers increase the potential for better management and control of a suspended boom system [5].

The sprayer boom system has four main mechanical components: the fixed center frame, suspended center frame, right and left boom wing. Agricultural spraying quality depends on a stability these mechanical components together with operation and land conditions, control and suspension systems. All mechanical components, suspended and control systems are assembled to the chassis of sprayer. Researcher and engineer have interested to understand a stability and stress-strains behaviours of mechanical components in agricultural sprayer machine in order to develop new suspension and control systems [6-12]. For example, Erdoğan et al [6], an increase in sprayer boom length caused increasing the stress on the connection of boom elements due to wing beat and cross displacements obtained from finite element analyses for sprayer boom. Therefore, they preferred to support the boom with swing bearing and chain link to sprayer chassis and center section in the booms wider than 15 meter. Miles 2018 [13] reported that it is important to control the boom height due to maintaining problem a level boom as when driving over uneven terrain with a wider boom and at faster speeds. Also, the related manufacturer started to manufacture agricultural spraying machining having larger pesticide tank, wider booms, faster drive and more acres spraying [13] to meet consumer demands and to improve this technology. Therefore, various boom and frame designs have been developed to control the boom height in the sector. For example, in one study [14] emphasized that the stability and level of the boom greatly depend on the chassis and suspension of the sprayer to maintain the optimum nozzle height. There are different methods to mount the boom to allow the boom rotate around pivot location on the machine chassis. These are known as rigid, fixed, pendulum, trapeze, inverted trapeze, and a combination of pendulum and trapeze of boom center designs. It is claimed that the fixed boom center mounted chassis may be useful to carry extra load on the boom and to attach some auto height-control system study [14]. Another study gives information on the structural analyses result about transport chassis of sprayer machine that safety factor calculated as between 0.33 and 1.34. [15]. Koç 2015 [16] studied on the structural analyses of field sprayer boom that he emphasized using aluminium for active boom suspension system for field sprayer boom produced more favourable structural results than steel.
In this study, the main aim is to investigate stress and displacement analyses in mounted type chassis of agricultural sprayer machinery by static finite elements analyses (FEA) before manufacturing. FEA sets were planned to simulate real condition by Taguchi orthogonal array design (L16 2^4). Total eight FEA were realized by using ANSYS programme under different loads occurred with different the pesticide tank capacities and sprayer boom length. After doing literature survey, the mounted type chassis construction were designed to carry the fixed boom center with Solid program and then were transferred to ANSYS structural analyses, and also material constant and other finite elements modelling arrangement such as element type, element size, support type and locations, the calculated all loads and its locations. After 16 trials of FEA analyses, von-Mises stress, shear stress and displacement results for each FEA trial were obtained and then these results were used to analyze of Taguchi to predict the stress and displacements consecration in the chassis at the design stage. According to FEA results and Taguchi analyses, important information for design and manufacturing to mounted chassis were obtained.

2. MATERIAL AND METHOD

The mounted type chasses was modelled in real size which can be seen in Figure 1. Figure 1a shows the front left side view of chasses including upper and lower connecting points, points of mass. Mass points are the surfaces where the spraying tank is placed and carries the tank. Chassis is mounted with upper and lower connection point on the tractor suspension arms. After modelling the chasses, the optimum and homogeneous meshing were carried out which was given in Figure 1c. FEA were conducted with Ansys program after reviewing structural analyses workings, and also the meshing was realized by selection quadrilateral triangle elements in optimum condition.

The mesh sizes, which will negligible affect the stress and strain results, was determined as 8 mm. To improve the mesh quality, standard mechanical and high smooting modes on automatic method used. The steel material of St37 for the mounted chassis was selected. Afterwards, the homogenous mesh structure was obtained by preliminary preparing of finite elements which was given in Figure 1c.

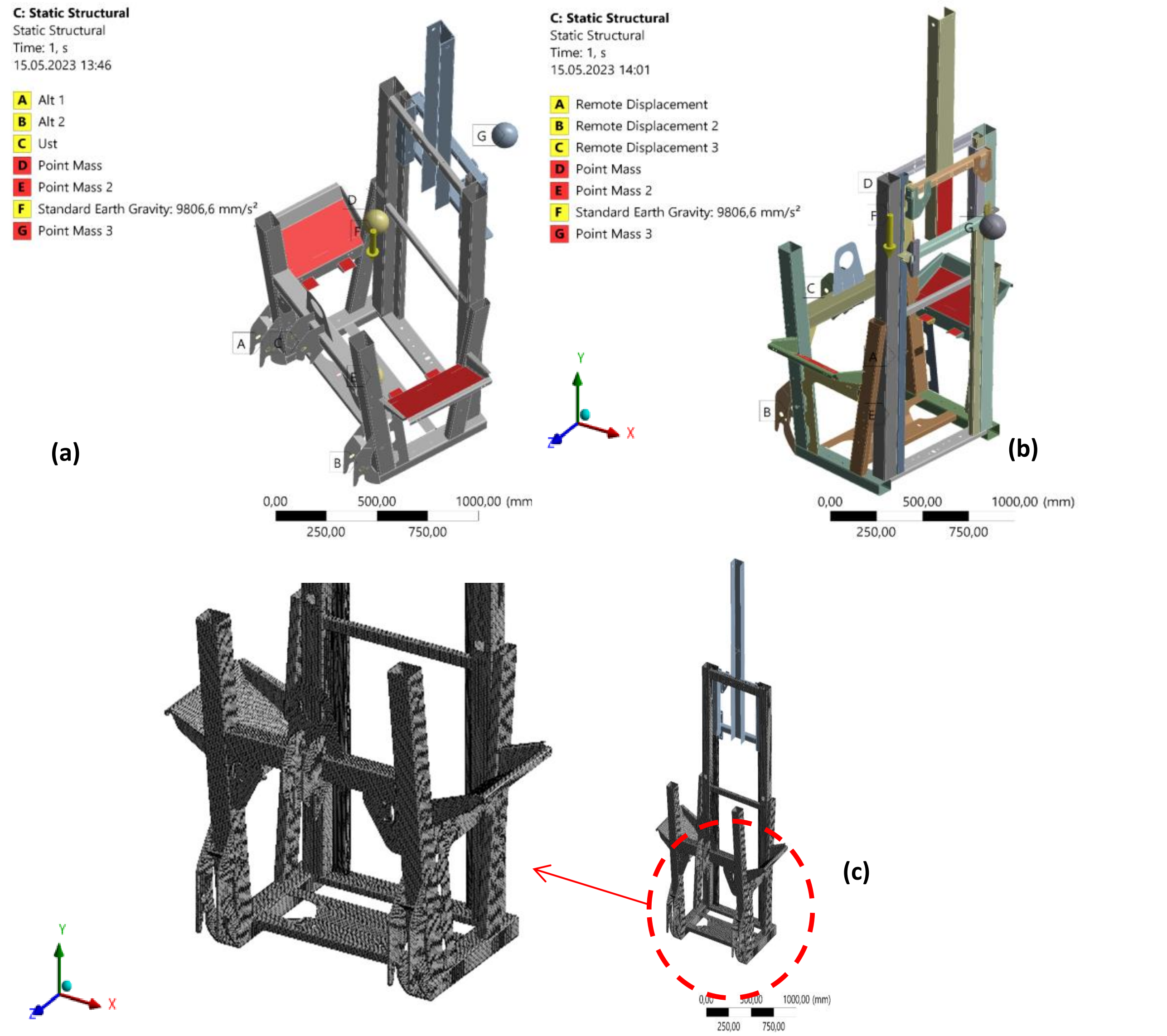

Figure 1. a) Front left side view of the mounted chasses, b) Back right side view of it, c) Mesh structure.

Total elements of 135064 elements and nodes of 137855 were produced after doing FEA of spraying machine with mounted chassis. Later, the cylindrical support was applied to the lower and upper connection points of chassis model. FEA was systematically done with L16 (2^4) Taguchi orthogonal array design (Table 1).

Tank and boom construction weights, which may be possible mounting to the chassis, have been determined by taking into account the application information. Taguchi orthogonal array design is a practical method to determine the effect of main input parameters on target outputs of analyse and experiment research, to determine the sub-level of main input variables.

Table 1. Taguchi orthogonal array design for FEA, input variables and levels.

Input Variables	Force (kgf)	Levels			
	STW (kgf)	1200	1500	2400	3000
	SBW (kgf)	450	600	900	1200
FEA Trials					
FEA No	**STW (kgf)**	**SBW (kgf)**			
1	1200	450			
2	1200	600			
3	1200	900			
4	1200	1200			
5	1500	450			
6	1500	600			
7	1500	900			
8	1500	1200			
9	2400	450			
10	2400	600			
11	2400	900			
12	2400	1200			
13	3000	450			
14	3000	600			
15	3000	900			
16	3000	1200			

It is well known that traditional experiment and analyze design plan is time-consuming and cause the high costs and complexity while determining the cause-effect relationship [17].In the Taguchi orthogonal design, two input parameters of spraying tank weight (STW) with levels of 1200, 1500, 2400, 3000 kgf and sprayer boom weight (SBW) with levels of 450, 600, 900, 1200 kgf were selected. Spraying tank weigh is the full weight with pesticide. Boom weights of 450, 600, 900, 1200 kgf vary with length of 12, 16, 20, 24 m, respectively. Thereby, the pesticide capacity and spraying width of the mounted chassis planned to be manufacture have been determined. As can be seen Table 1, total 16 analyses were conducted to determining the effect of input variables on output variables of von-Mises stress, shear stress and displacements for the mounted spraying machine chassis. According to Table 1, Taguchi analyse was performed by using the stress and displacement values obtained from FEA. The relationship between input variables with stress and displacement on sprayer chassis tried to determine.

3. RESULTS

After doing FEA, the total 80 values about shear stress, von-Mises stress and displacement results for each FEA trial were obtained. Firstly, the screen samples of stresses and displacements distributions were given in Figure 2 for the obtained minimum loading condition of 1st and 16th trials, respectively. According to 1st FEA results which was conducted under 450 kgf of boom weight and 12 m of its width and 1200 kgf of pesticide tank weight; 178.44 MPa of maximum von-Mises stress, 58.87 MPa of shear stress and 7.6727 mm of total displacement were occurred on the chassis construction, respectively.

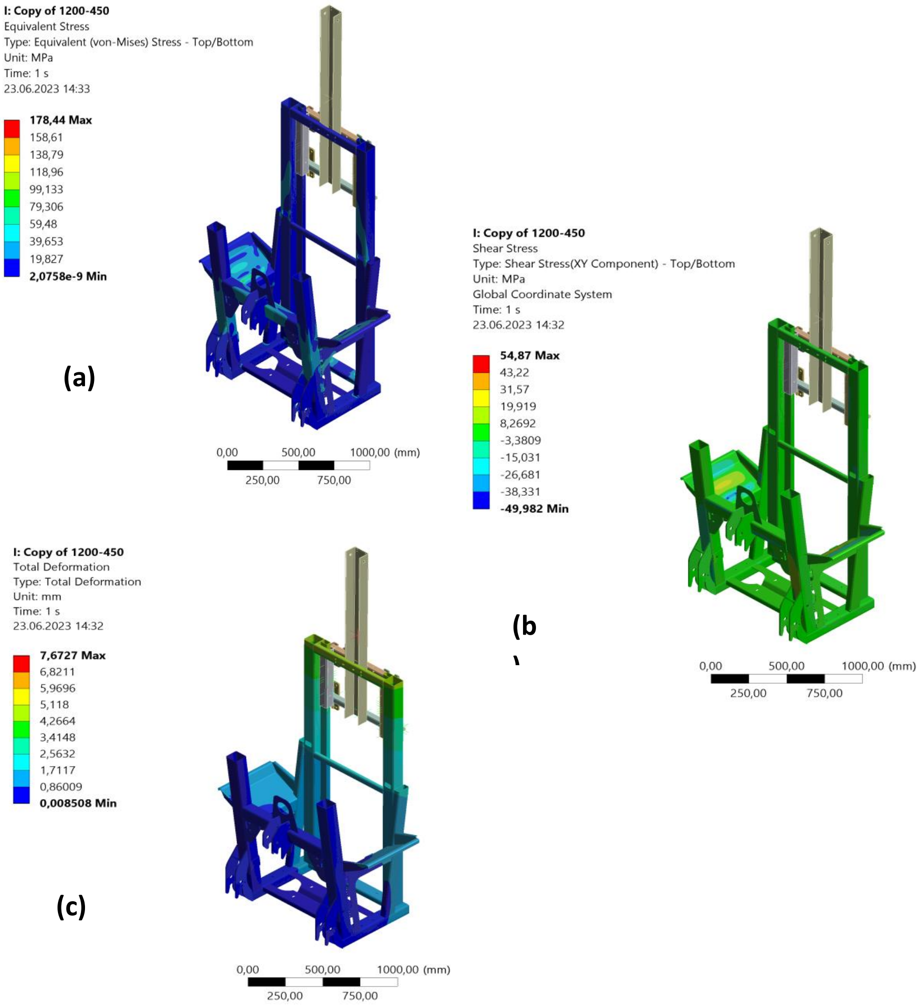

Figure 2. FEA result screens for minimum loading condition (1st FEA).

While the stresses concentrated on surfaces where the pesticide tank is placed, displacements occurred in vertical profile close to the sliding mechanism that adjusts the spraying level. In this situation, Taguchi analyse is performed to determine the effect of pesticide tank and boom weights on stress and displacement. The contributions values on equivalent von-Mises stress of pesticide tank and boom weights obtained as 87.38% and 5.89% sequentially from variance analyses realized using results of FEA analyses (Table 2). The effect of sprayer boom weight on von-Mises stress is seen more and this can be understood from the P-values of 0.0002 and 0.114770, respectively. R-Sq values of 93.26%, error of 6.74%, R-Sq (adj) of 88.77 and R-Sq (pred.) of 78.71% were obtained from variance analyses which are within the acceptable values [18]. As can be seen in Figure 3, the sprayer boom weight is more effective than pesticide tank weight in the Taguchi analyses by adopting “smaller is better”. The reason interpreted that sprayer boom caused especially bending stress together with shear stress on the chassis of sprayer machine since the boom is mounted behind the chassis. Mises stresses relatively increased with increasing from 450 kgf to 600 kgf, on the other hand, the boom weight above 600 kgf increased von-Mises stresses dramatically.

Table 2. The contributions values on equivalent von-Mises stress of pesticide tank and boom weights.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Pesticide Tank Weight (kgf)	3	11185	5.89%	11185	3728	2.62	0.11470
Sprayer Boom Weight (kgf)	3	165989	87.38%	165989	55330	38.92	0.00002
Error	9	12796	6.74%	12796	1422		
Total	15	189970	100.00%				

This state can be seen in Figure 3a. 1200 kgf and 1500 kgf of pesticide tank weight caused smiliar von-Mises stress values, and also the pesticide tank weight above 1500 kgf relatively increased. Thereby, the boom widht and boom weight to be monted on the agricaltural spraying machine should be evaluated more in terms of safe chassis design and rigidty.

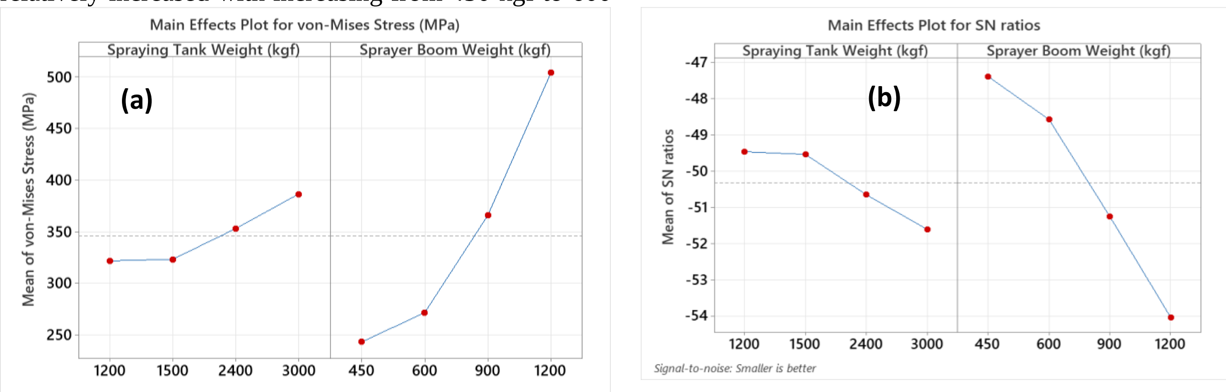

Figure 3. The curves of main effect and SN ratios for von-Mises stresses.

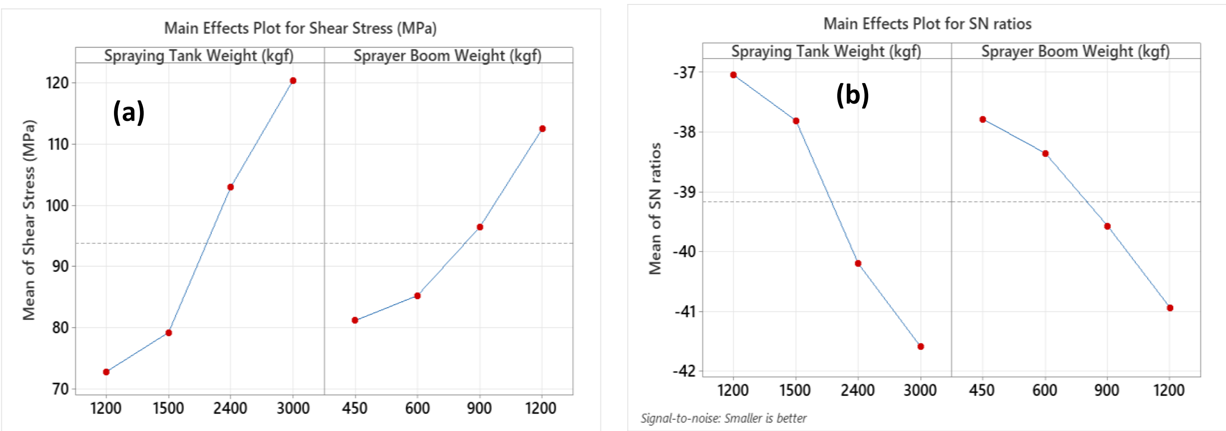

Figure 4. The curves of main effect and SN ratios for shear stresses obtained from Taguchi analyses.

Figure 4 shows the main effect and SN curves for shear stress occured on the chassis obtained from FEA analyses. In contrast to the von-Mises stress situation, the pesticide spraying tank weight is more effective on shear stresses. Because, sprayer thank is mounted on the chassis of agricultural sprayer. The shear stresses increased and bending stresses less than the effect of boom due to loading on the chassis. The shear stress increased dramatically when more than 1500 kgf of spraying tank is placed on the chassis. As similar, the boom weight above 600 kgf increased dramatically shear stresses. The effect of main input parameters on displacement of chassis is shown in Figure 5. According to Figure 5, sprayer boom weight has more influence on displacement of chassis. The effect of pesticide spraying tank weight between 1200 kgf and 2400 kgf on displacement of chassis is almost the same, and also, after loading 2400 kgf, the displacement tends to increase. On the other hand, in case of increasing the sprayer boom weight depending on its width, chassis displacement dramatically increase.

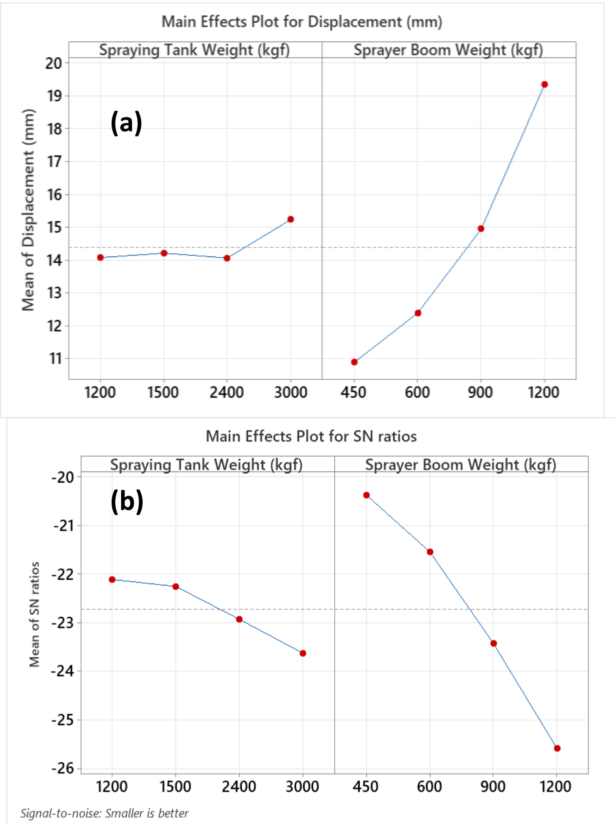

Figure 5. The main effect and SN ratio of main input parameters on displacement of chassis.

As can be seen in Figure 6, the lowest displacements (7.6727 mm and 7.9685 mm) of chassis were respectively obtained from 1st and 5th FEA trials, which are 1200 kgf of tank weight, 450 kgf of boom weight and 1500 kgf of tank weight, 450 kgf of boom weight, respectively. The highest displacement values of 22.862 mm and 22.857 mm occurred in 4th and 8th of FEA trials, which are 1200 kgf of tank weight, 1200 kgf of boom weight and 1500 kgf of tank weight, 1200 kgf of boom weight, respectively. Indeed, the displacement values in sprayer chassis are found to be between 8 mm and 16 mm.

The combined effect of two input parameters on von-Mises stress, shear stress and displacement can be seen in Figure 7. When 600 kfg of sprayer boom and around 2200 kgf of tank capacity is mounted on the sprayer chassis, the obtained von-Mises stresses was found to be lower than the yield strengt (around 230 MPa) of chassis materials St37 steel which can be seen in Figure 7a. The chassis construction has been forced with around 80 MPa of shear stress under same loading for 600 kfg of sprayer boom and around 2200 kgf of tank capacity. Over these loads caused the stresses above yield strenght (YS) of sprayer chassis. Figure 8 shows stresses for 16 FEA trials and in can be interpretted the safety factor of sprayer chassis.

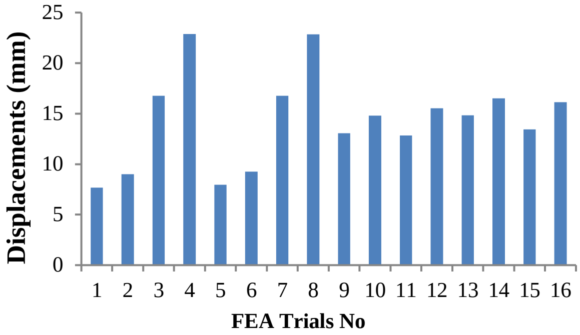

Figure 6. Displacement values in sprayer chassis for 16th FEA trials.

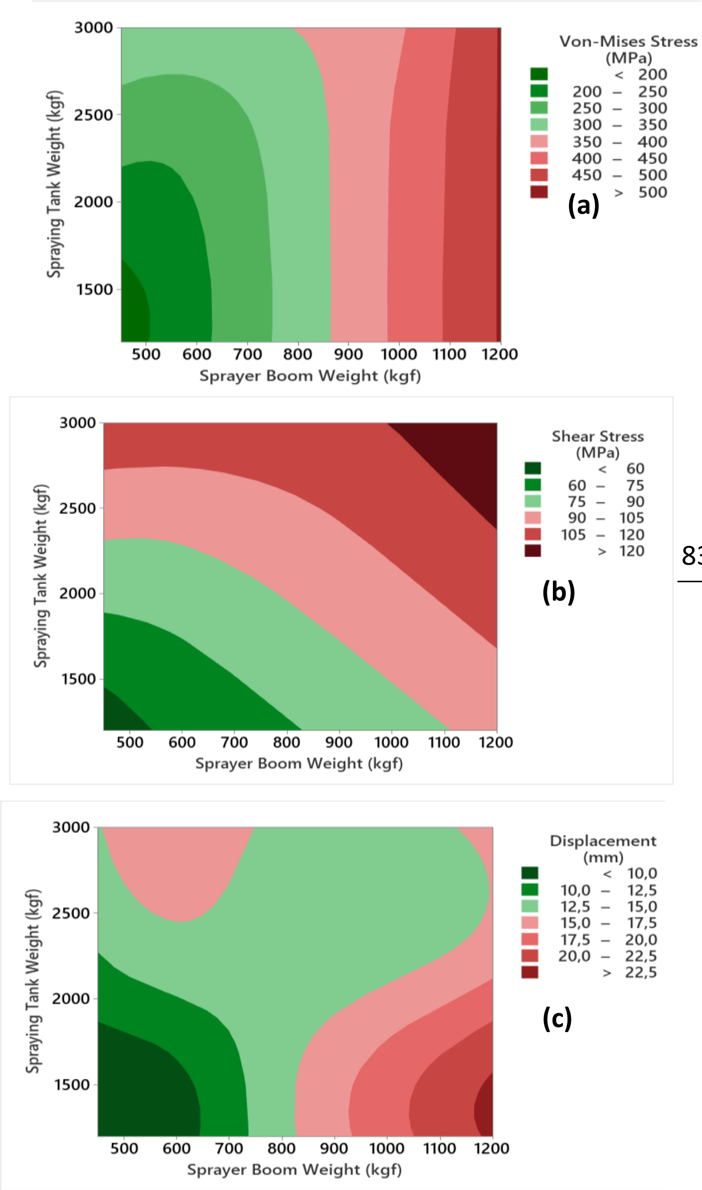

Figure 7. The combined effect of two input parameters on von-Mises stress (a), shear stress (b) and displacement (c).

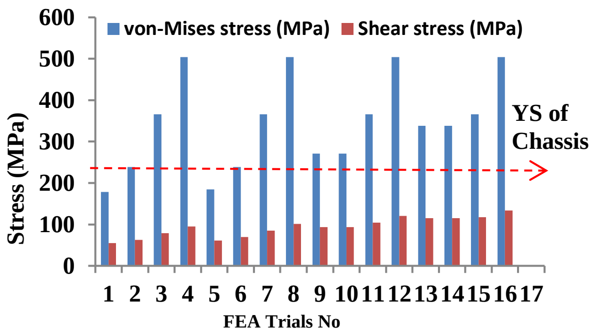

Figure 8. Von-Mises stress and shear stress values obtained from FEA of sprayer chassis.

4. CONCLUSION

In this study, which was performed to estimate the stress-displacement occurring in the designed mounted type agricultural spraying machine chassis before manufacturing, the following results were obtained:

- Firstly, safe the pesticide tank capacity and sprayer boom width of new one designed mounted type spraying chassis is determined by obtained FEA. The lowest displacements (7.6727 mm and 7.9685 mm) of chassis are respectively obtained from 1st and 5th FEA trials, which are 1200 kgf of tank weight, 450 kgf of boom weight and 1500 kgf of tank weight, 450 kgf of boom weight, respectively.
- While the stresses concentrated on surfaces where the pesticide tank is placed, displacements occurred in vertical profile close to the sliding mechanism that adjusts the spraying level.
- The effect on equivalent von-Mises stress of pesticide tank and boom weights obtained as 5.89% and 87.38% sequentially from variance analyses. The combined effect of sprayer boom and sprayer tank weights has the most influence on shear stress in sprayer chassis, secondly von-Mises stress and finally displacement values.
- Finally, the safety factors for new design of mounted type agricultural spraying machine chassis has been determined as 1.35 and 1.3 from 1st and 5th of finite elements analyses according to the obtained maximum von-Mises stress. It is alleged that the value of required safety factor of $1.3-1.35$ was adopted as a mean value from the range of factors for very accurate calculations, uniform material and fine design [19].

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