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FINITE ELEMENT ANALYSIS FOR VERTICAL MIXER-CHOPPER AUGER OF MIXER FEEDER WITH A CAPACITY OF 1.5 m^3

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ABSRACT

Optimizations in manufacture of agricultural machinery not only provide significant material savings, but also provide significant savings in energy requirements of drive units of these machines. In this study, chopper and mixer auger of self-propelled mixer feeder and spreader with a vertical auger and 1.5 m^3 capacity was optimized by using finite element method (FEM) of analysis. Auger design was performed with Solidworks software and stress analyses were performed with Static Analysis Module of the software. For auger tube analyses, St37 was selected as the material. Based on stress analysis results, auger tube dimensions were identified as 219 x 6 mm. The greatest stress (91.5 MPa) value was observed at bolted connections of the auger tube. Based on operational parameters for auger tube dimensions, safety coefficient was identified as 2.57.

1. Introduction

Livestock industry constitute the greatest meat and milk source for human nutrition. Livestock manure together with plant production and industrial waste materials significantly enrich soil organic matter content and allow high yield and sustainable agriculture. In addition, the industry supplies raw material to textile, leather and some other industries and provide significant contributions to national income and employment.

Among the European Union countries, France with a bovine inventory of 19 million has the first place in livestock industry of Europe and constitute about 21% of European production. Turkey with a bovine inventory of 14.2 million has the second place in Europe (TÜİK, 2017a). In Turkey, ovine milk production was 16.8 million tons in 2016 and bovine meat production was 1.015 million tons in 2015 (TÜİK, 2017b). For human nutrition, such numbers for milk and red meat are quite significant and both production sectors are critical sectors for the country economy. Number of animals per operation (enterprise – facility) is 4 and number of operations with a bovine inventory of 50 is 24 000 (İleri, 2018). Therefore, policies should be developed to promote livestock production activities of small-scale agricultural enterprises and agricultural machineries should also be developed to make production activities efficient and economic.

Feed mixtures are essential items of animal feeding. A homogeneous mixture allows animals to benefit from the feeds at maximum level. Number of mixer feeders and feed spreaders in machinery parks of agricultural enterprises are increasing in each year because of the investments made in livestock industry and the total number reached to 28 979 in the year 2016 (TÜİK, 2017b).

Mixer feeders and spreaders used in livestock industry are actuated by the tractors or electric motors. They have a feed mixing volume of between 0.75 – 20.0 m^3. Feed preparation cost is not economic when the capacity of tractor-actuated mixer feeders and spreaders are less than 4 m^3. However, considering the size and structure of agricultural enterprises of the country, there is a need for mixer feeders and spreader under this capacity. When these small size operations used such large capacity

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machines, their feed preparation costs increase and feed preparation becomes uneconomical. When the electric motor-actuated machines are used, problems are experienced in spreading because of cable connections. Also, 380 V electric supply system may not be available in the region where the livestock operation is located and such an unavailability limits the operation of electric motors. These machines are used fixed in a certain place, feed is poured to a single point and spread to feeders by using a secondary labor.

Mixer feeder and spreaders are manufactured in two different configurations as of single or double vertical augers and single or double horizontal augers. There are important differences in powertrain systems and main components (bucket or wagon, chopper augers) of the machines manufactured at different capacity and structures. Such differences then result in differences in manufacture or production costs of the machines. Together with developing technology for machine design and manufacture, computer-aided design (CAD) applications and static and dynamic analysis modules integrated into these application allowed user to do various analysis easily. Finite element analysis has also long been used in machine design.

Vegricht et al. (2007) reported mean standard deviation for horizontal auger mixer feeder as 33.7% and reported the value as 56.8% for vertical double auger mixer feeder and as 65.8% for vertical single auger mixer feeder. Yalçın et al. (2007) carried out study in livestock operations of Aegean Region with 4 m3 local-type (A), 8 m3 local-type (B) and 8 m3 imported-type (C) feed mixer and spreaders. Researchers determined mixing homogeneity following the loading of all feed materials and 2% trace element and reported average chopping length as 2.53 mm for machine A, 4.74 mm for machine B and 11.54 mm for machine C; reported variation coefficient of of trace element as 16.46% for machine A, 5.74% for machine B and 10.94% for machine, Akdeniz (2015) designed a self-propelled electric-driven feed mixer and spreader for small-size livestock operations and used CAD application for strength, stress and deformation analyses of chassis and fasteners. Taşer (2015) carried out a study with damaged planet gear transmission of R6 mixer feeder and reported cracks, fractures and corrosions over the gears because the gears were not able to bear the torque-induced stress-strains created through rotation of the shaft bearing augers of the mixer feeder during feed mixing operation. The researcher also investigated the damages over the gears and observed that damages were experienced over a section of gear width.

In this study, auger tube of a mixer feeder with vertical auger and 1.5 m^3 capacity was analyzed with finite element method. Analyses were used to determine auger tube dimensions based on stresses over the auger tube and blades, blade displacements and safety coefficient.

2. Materials and Methods

In this study, chopper and mixer auger of self-propelled mixer feeder and spreader with a vertical auger and 1.5 m^3 capacity designed to meet the needs of a small-scale livestock operation was analyzed by using finite elements analysis method. Some technical specifications for self-propelled machine are provided in Table 1.

Table 1
Technical specifications for auger design

Characteristics	Measures
Auger material	St 37
Position	Vertical
Step	340 mm
Auger diameter, bottom	950 mm
Auger diameter, top	540 mm
Auger height	700 mm

Power output of an electric motor used for locally manufactured feed mixer with the same capacity, same geometry and vertical position was used as the starting point. The power value of electric motor used in this machine was 7.5 kW and torque value was calculated with the following equation:

$$Ne = \frac{Md\ x\ n}{9550}$$

Ne : Power consumption of the auger (kW)
Md : Torque (Nm)
n : Auger rotation speed (min^{-1})

Since the maximum torque to which the mixing and chopper auger was exposed was determined as 1 500 Nm, auger rotation speed was calculated as 48 min^{-1} based on this torque value, motor rotation speed and transmission ratio. For auger tube, St 37 was selected as the material since it can be supplied from the markets easily at low cost. Material characteristics of the auger design are provided in Table 2.

Auger tube analysis was performed by using Solidworks static analysis module. Before the analysis, chopper and mixer auger was designed in 3-D and required analysis parameters were defined properly. Auger tube was connected to gear box of the machine with 4 M14 bolts and a flange. Bolted connections were used as fixed support in analysis. Support points and force vectors are presented in Figure 1. The specified torque was applied to bottom, top and side surfaces of the auger blades.

The finite element mesh was defined at high precision. Increasing mesh quality will clearly improve analysis results. Finite element mesh details are presented in Figure 2.

Table 2
St 37 Material Characteristics

St 37 Material Characteristics	Value	Unit
Modules of Elasticity	21 0000	N mm^{-2}
Poisson Ratio	0.28	-
Modulus of Rupture	79 000	N mm^{-2}
Mass Density	7 800	kg m^{-3}
Tensile Strength	360	N mm^{-2}
Yield Strength	235	N mm^{-2}

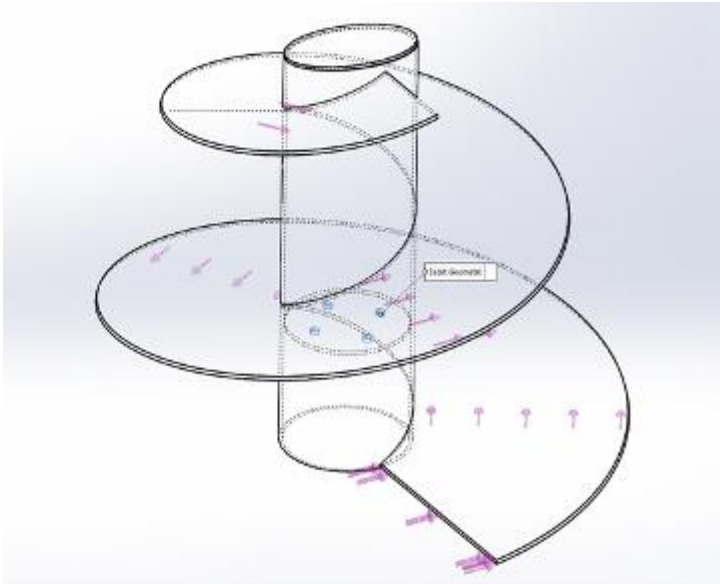

Figure 1
Fixed support points and force vectors of the auger

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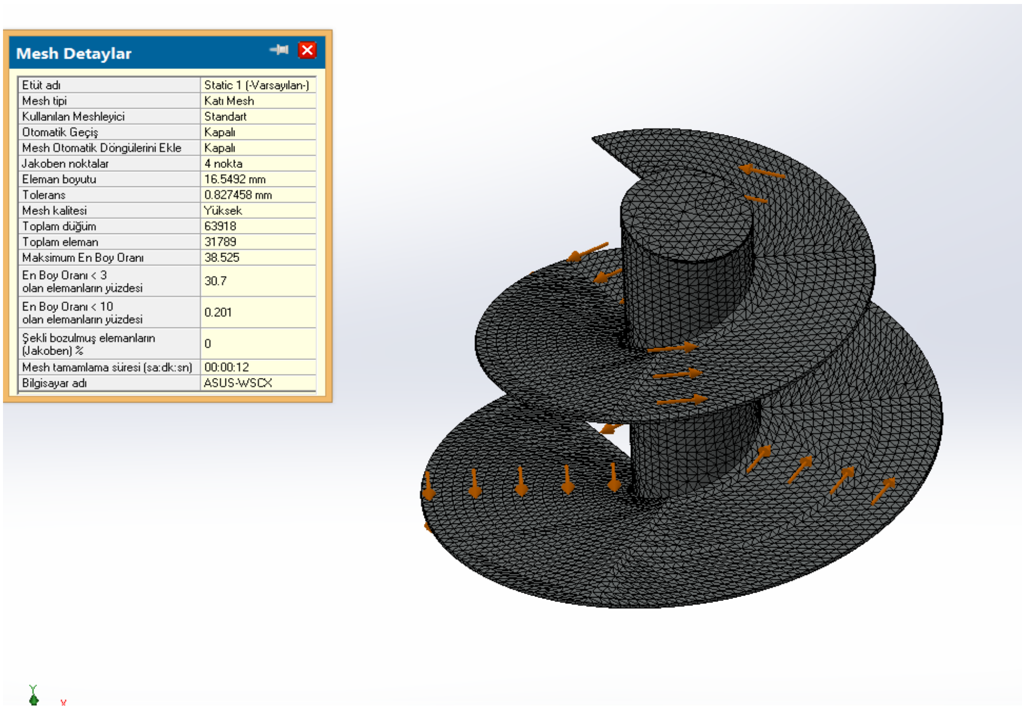

Figure 2
Finite element mesh details

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3. Results and Discussion

Static analyses revealed fixed support and force-induced stresses over auger tube, deformations over the material and safety coefficient. The greatest stress value was observed as 91.5 MPa at bolted connections of the auger (Figure 3).

Blades were welded to auger tube. The stress values at these welded sections reached to 50 MPa. Such a value indicated the significance of weld quality along the blade-tube joint line (Figure 4).

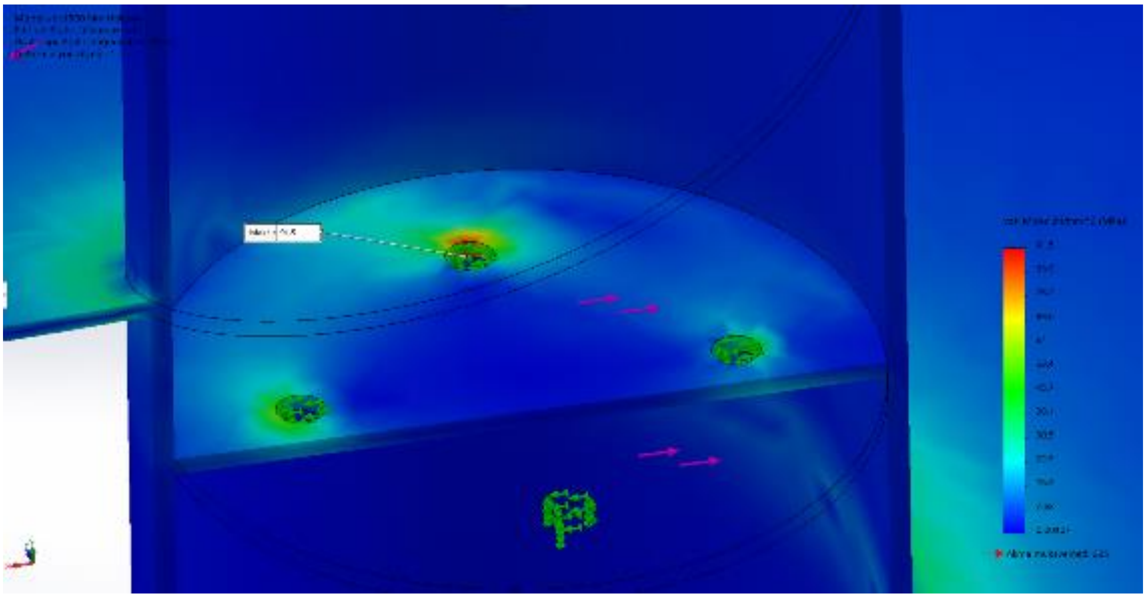

Figure 3
Stresses observed at bolted connections

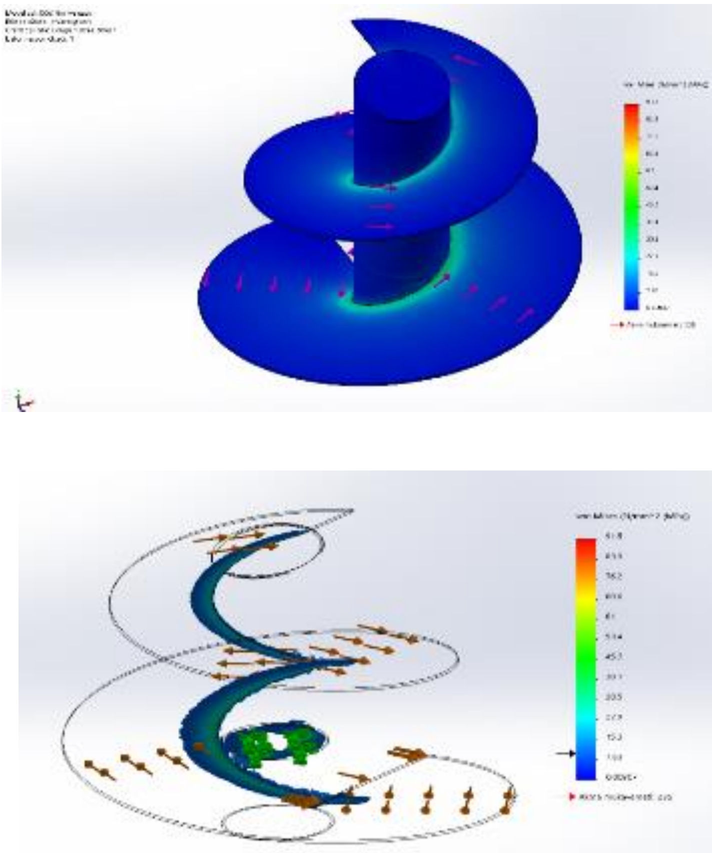

Figure 4
Stresses along the blade-tube joint line

Maximum deformation of auger tube was measured as about 1.0 mm. This deformation was observed at blade edges (Figure 5). Such a deformation was resulted from the forces exerted by mixed and chopped feed material over the blade surfaces.

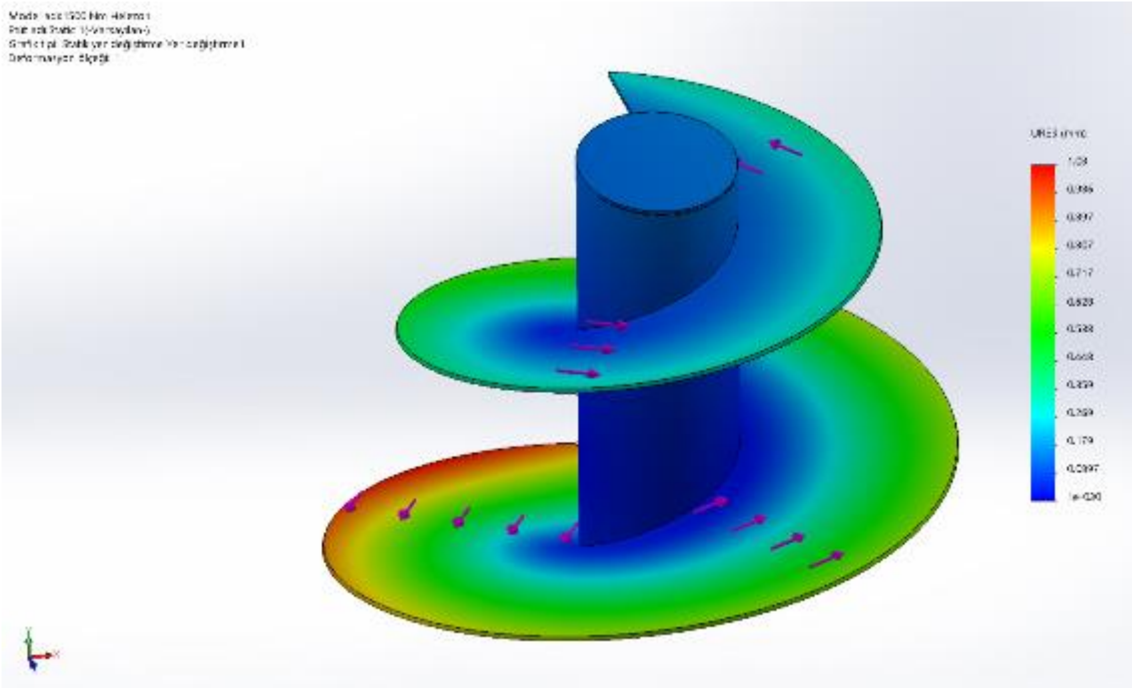

Figure 5

Deformation color indicator

Based on auger geometry and quality of St37 material, auger tube dimensions were determined as 210 x 6 mm. Considering the bolted fixed support points and applied torque value, the safety coefficient of auger tube was identified as 2.57 (Figure 6).

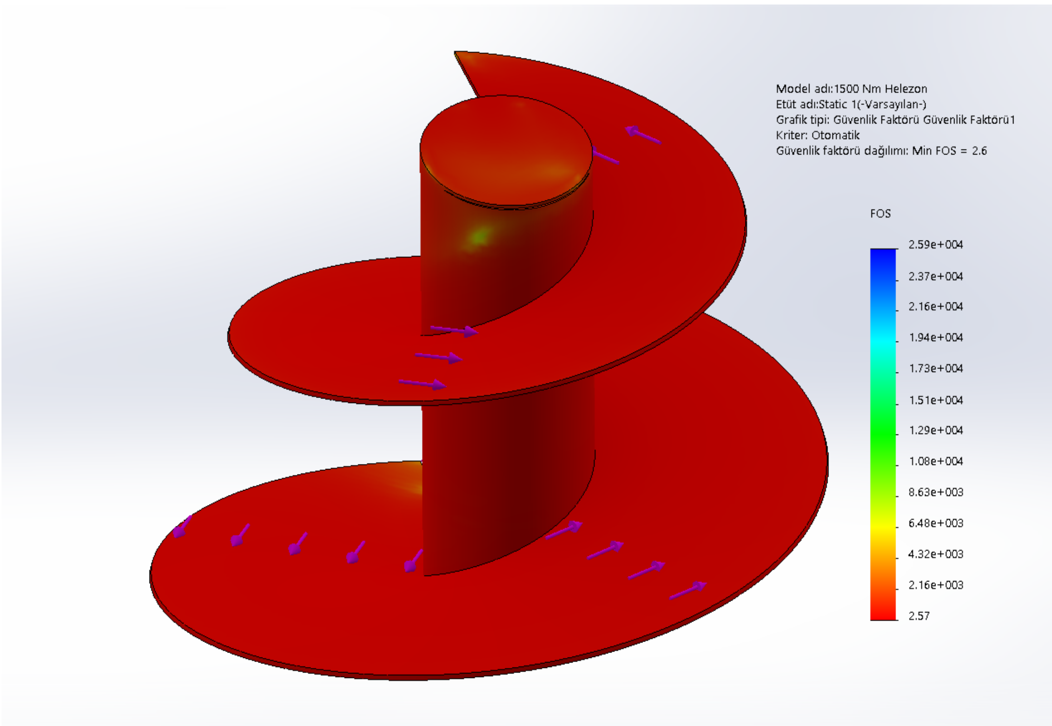

Figure 6.
Safety coefficient

4. Conclusion

Although 3-D design software are increasingly used in agricultural machinery manufacturing industry of Turkey, analysis-dominated designs are still insufficient. Mostly reverse engineering practices and trial-error methods are used in manufactures and such a case clearly indicate the significance of analysis software. Relevant analyses will allow optimum design of machines, especially of agricultural machinery. The significance of such analyses in improving competitive conditions of agricultural machinery manufacturing industry in national and international markets is indisputable.

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