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MODAL ANALYSIS OF FIELD SPRAYER BOOM DESIGN FOR DIFFERENT MATERIALS

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Abstract

During spraying, vibrations of sprayer booms, which take place because of unevenness of soil and tractor velocity, affect the success of spraying. When vibrations increase, this situation cause disruption of spraying pattern and leaf coverage. Thus, the yield of agricultural product drops. Manufacturers desire durable field sprayer boom during the spraying operation. To do this, they manufacture various suspension systems to damp vibrations. Beside vibration, weight of the field sprayer boom is very important. Most manufacturers start to use aluminum due to its lightness and corrosion resistance reasons. In this study, for the same field sprayer boom design, materials of mild steel and aluminum are compared via modal analysis with finite element analysis in a CAD Program. According to results of modal analysis field sprayer boom which made of mild steel has 7.4 Hz natural frequency under its own weight that applied from own center of gravity. And also same field sprayer boom which made of aluminum has 8.15 Hz natural frequency under its own weight from own center of gravity. The costs, weights, and manufacturability of materials are also compared.

Key words: *modal analysis, field sprayer boom, material selection for field sprayer boom, manufacturability.*

INTRODUCTION

Field sprayer boom is one of most used and manufactured plant protection machines in Turkey. Day by day, these machines are developed by researchers, manufacturers, also farmers. During the application, due to tractor velocity and soil unevenness, field sprayer boom vibrations occur. To damp these vibrations; dampers, springs, piston-cylinder with cushioning are also used. However, in Turkey, most of manufacturers do not study on damping the vibrations, they only try to reduce boom weight. To do this some manufacturers prefer aluminum because of lightness and corrosion resistance against pesticides. However, vibration effects of aluminum also must be searched. Kennes et al. (1998) investigated a tractor mounted field sprayer with a spray arm width of 12 m by the finite element method. The vibrations from the field were observed at a frequency of 0.3 Hz and 3 Hz. Vibration amplitude was also 2 cm in width. Nielsen and Sorensen (1998) investigated the suspension of an active field sprayer boom in their work. They made active and passive suspensions for simulation and compared the results. The passive suspension system consists of a construction itself and a spring that acts as a damping damper. A hydraulic piston and a spring are also installed for the active suspension. According to results, field sprayer boom must include both active and passive suspension systems.
Borchert and Schmidt (2015) studied on the characterization of the horizontal axis motion of tractor mounted field sprayers in their work. After the mathematical model of the field sprayer boom was discovered, this mathematical model was analyzed in Matlab /Simulink program. They also operated the related field sprayer boom on a vibration machine at 0-3 Hz and measured the working amplitude. Then observed data was a standard deviation of 1.4% between the maximum amplitude and the actual amplitude given by the Matlab program.
Koç (2017) solved the structural analysis of a field sprayer with a field sprayer boom width of 21 m in his work with finite element method. For the same geometric design but different materials (aluminium and steel) were used.

According to fatigue analysis results, it is understood that aluminum material is better than mild steel.
Aim of this study, is to study modal analysis of a field sprayer boom for same geometric design but different in materials (mild steel St 37 vs. 6061 aluminum) by the aid of finite element method. By this way, for same geometrical design aluminum and steel field sprayer booms' vibration characteristics are compared. Beside this result, manufacturing costs of both materials are determined and compared with each other.

MATERIALS AND METHODS

Modal analysis is used to determine vibration characteristic of a body under a load. Modal Analysis can be applied both Mathematically and Experimentally also in 3D CAD programs. General vibration characteristic of a system can be defined as below:

$$m\ddot{x} + c\dot{x} + kx = F$$

One of mostly manufactured field sprayer boom's construction is determined. The field sprayer boom has no damping element on it. Therefore, mathematical defining of undamped free vibration system can be as below:

$$m\ddot{x} + kx = 0$$

To solve the differential equation, $C\ and\ s$ as coefficient of differential equation and x is function of t (Rao, 2004).

$$x(t) = Ce^{st}$$

From here:

$$Ce^{st}(ms^2 + k) = 0 \quad \text{and} \quad Ce^{st} \neq 0$$

$$(ms^2 + k) = 0$$

$$s_{1,2} = \pm\sqrt{-\frac{k}{m}} = \pm i\omega_n \text{ (rad/s)}$$

$$\omega_n = 2\pi f_n$$

In modal analysis with finite element method, general mathematical defining of a field sprayer boom can be defined as above.

To apply modal analysis in CAD program, firstly one side of boom (for easily resolving the problem) with 16 m width field sprayer was measured geometrically. Then modelled and assembled in 3D CAD program Autodesk Inventor 2017 (Figure 1). In field sprayer boom 40*40*3 rectangular profiles are used (both in aluminum and mild steel). After modelling, both materials mild steel and aluminum 6061 were chosen for analysis.

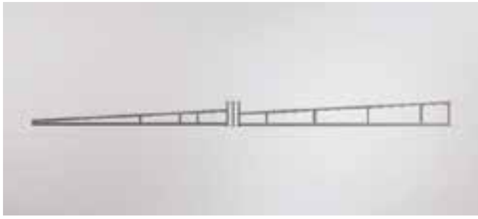

Figure 1. Modelling of field sprayer boom geometrically

Aluminum 6061 and mild steel is applied to geometric design, and then weights are calculated as shown in Table 1.

Table 1. Weights of different materials for same geometric design

Properties	Aluminum Boom	Mild Steel Boom
Weight (kg)	13,164	38,274
First Section Weight (kg)	5,672	16,492
Second Section Weight (kg)	7,492	21,782

After modelling and assembling field sprayer booms the Autodesk Inventor 2017, in stress analysis module. For analysis, modal analysis is chosen and then fixed points are marked which are joint of second section.
The weights (shown Table 1) are converted to loads and applied from each centre of gravity of each boom section.
In this study, only vertical forces are evaluated. Because horizontal inertial forces changes during a time period also field sprayer booms' construction are designed to resist vertical forces.
After meshing, simulating and solving are started and results are compared. Beside the modal analysis results, manufacturing costs are also calculated and compared. In region, manufacturing costs are as below.

Table 2. Costs of raw materials and manufacturing

Properties	Aluminum	Mild Steel
Raw material cost ($/kg)	3,75	0,625
Manufacturing cost ($/kg)	1,5	1,25

RESULTS AND DISCUSSIONS

Manufacturability Evaluation of Different Materials

According to results of weight and manufacturing costs, total costs of aluminum boom and mild steel boom are calculated as Table 3. Total manufacturing costs of aluminum is higher than steel. As known, thermal expansion coefficient of aluminum is higher than steel. Because of that reason, it is difficult welding of aluminum. Excessive heat can cause welding distortion whether cooler blocks is not used. Therefore, the difficulty of a process increase, cost of process of the manufacturing also increases.

Table 3. Costs of raw materials and manufacturing in region

Properties	Aluminum	Mild Steel
Raw material cost ($/kg)	3,75	0,625
Manufacturing cost ($/kg)	5,75	1,25
Total weight (kg)	13,164	38,274
Total cost ($/kg)	125,058	71,76375

Aluminum has better corrosion resistance than mild steel. Manufacturers use steel joints for aluminum field sprayer boom, because of hardness differences joints can enlarge holes of aluminum plates, which are located end of second section.

Modal Analysis Evaluation

In Figures 2 and 3, modal analysis results of mild steel and aluminum are shown.

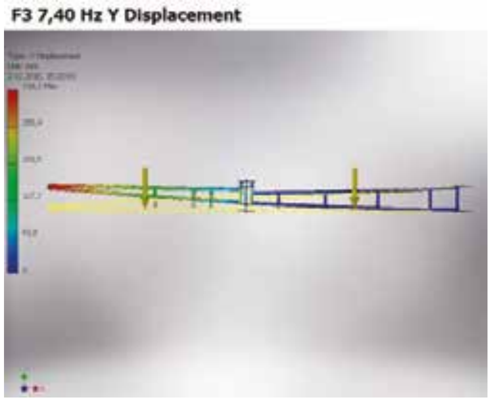

Figure 2. Modal Analysis Results of mild steel

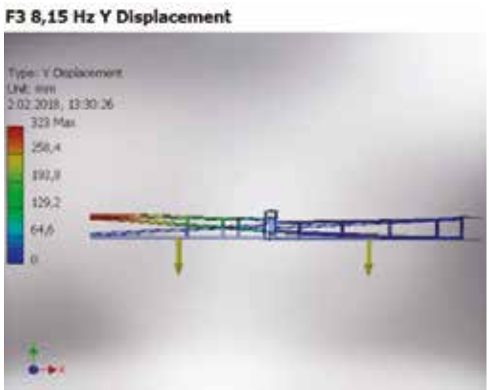

Figure 3. Modal Analysis Results of aluminum

According to results; mild steel has 7,40 Hz natural frequency under own load. Beside this, mild steel has 8,15 Hz natural frequency as shown in Table 4.

Table 4. Costs of raw materials and manufacturing

Properties	Aluminum	Mild Steel
Natural Frequency (Hz)	8,15	7,4
Total Weigh of Boom (kg)	13,164	38,274
Total Load (N)	129.138	375.467

Under own loads booms natural frequency differs. Although mild steel field sprayer is heavier than aluminum field sprayer boom, natural frequency of mild steel field sprayer boom is lower than natural frequency of alumium field sprayer boom which means under own load mild steel field sprayer vibrates less than aluminum field sprayer boom. Therefore spray pattern of pesticide that applied from mild steel field sprayer boom is better than aluminum field sprayer boom.

CONCLUSIONS

According to the results of the modal analysis of two different materials, it is understood that aluminum boom (8,15 Hz) can vibrate more than steel boom (7,4 Hz) under their own loads. Beside the vibration characteristics of these booms, manufacturing costs are also important. As in results, cost of steel boom is approximately half of the aluminum boom. However, it is not easy to weld aluminum boom because of high thermal expansion, heat transfer coefficient and low melting temperatures. For connecting two sections with each other, steel pins are used. Because of hardness difference (for steel pin and aluminum boom), it is not proper to use these materials together. Whether aluminum booms are preferred for manufacturing spraying booms, vibrating damping elements must be used to damp excess vibrations.

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