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Structural analysis of the weeding attaching frame of robotic paddy weeder using finite element analysis

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Abstract
Structural analysis of weeder attached frame of robotic paddy weeder using finitie element analysis in terms of Von Misses stress, displacement, and safety factor was conducted in Solid work simulation using finite element analysis at Dr NTR College of Agricultural Engineering, Bapatla. SolidWorks 2018 software was used for the development of 3 D model for weeding frame. AISI 1010 was the material utilized in the construction of the weeder frame for attaching rotsry weeder in this study. Based on the mentioned description of the analysis, the goal of this study was to use SolidWorks 2018 software and the finite element analysis method to examine the weeder frame construction. The minimum value of the safety factor was one of the references used as a gauge of a design's safety. Engineers frequently utilize an object's safety factor as a reference metric when determining how much stress it can withstand. This study's results include Von Mises stress, displacement, and safety factor for determining the material's capacity to sustain dynamic loads and shock loads. When designed load of 1471 N applied on weeder holding frame as per design calculation, lowest value of von Mises stress 0.107 N/m^2 was observed at the weeder center shaft whereas highest von misses stress of $10.80x10^7$ N/m^2 was observed at the end of frame attached to main driving shaft which required bearing for bearing dynamic loads. Max deformation of 4.537 mm was observed at the end of frame attached to main driving shaft and minimum was observed at centre shaft of weeder. Due to large deformation at the edge and maximum von Mises stress, bearing support provided for controlling twisting and dynamic loads. The factor of safety was observed as 1.6 which suited for carrying dynamic loads. The weeder support system developed was suitable for carrying static and dynamic loads of weeding system.

Keywords: Rotary weeder, weeder frame, stress analysis, finite element analysis, von mises stress, displacement, and safety factor

Introduction
Rice (*Oryza sativa* L.) is India's prominent crop, and is the staple food for most of the Indians. India has the world's largest area under rice cultivation and is one of the largest producers of white rice, accounting for 20 percent of global production. Even though many improved technologies have been introduced in paddy cultivation, still management of weed is a major concern in paddy cultivation which competes for sunlight, space and nutrients with the main crop and directly responsible for reduction in crop yields due to 10 to 25% weeds and 35 to 45% in direct sowing paddy (Yaduraju 2012) [24]. The common type of weeds which affects yield is *Cyperus difformis, Marselia quadrifoli, Echinochloa crusgalli etc.,* (Yaduraju, 2012) [24]. Different manufactures, industries and scientists have developed different types of weeders for both dry and wet land paddy conditions using improved equipment like hand hoe, finger & cono weeders, animal, power tiller and self-propelled weeders for weeding in paddy fields. Major constraints in using above weeders are Chocking of mud, High risk of maneuverability, high cost of operation and tedious operation.to overcome above problems and identified research gap, an remote controlled paddy weeder was developed at Dr NTR College of Agricultural Engineering, Bapatla using differential chassis, triangular track wheels, drive system, weeding system and operating system.
Weeding system of machine consists of weeding elements, mounting structure and chain and sprocket for providing as per design calculations,2 rotary weeding elements were attached to shaft through bearings and 10x20 MS angular having length of 400 mm.

Plate 1: Weeding system of developed machine

Each rotary weeding element was attached to driving shaft through 2no. of angular which are attached MS L-angular having dimensions of 50x50 mm at a distance of 150 mm between each end, both rotary weeding elements were fixed to shaft having diameter of 19.5 mm and length of 800 mm. The pillow block bearings having 19.5 mm inner diameter were used for fixing weeding elements on to the drive shaft. The drive shaft was fixed to chassis frame with pillow block bearings which were fixed on the 50x50 mm GI square boom projected from chassis having length of 200 mm. The chain drive was provided from rotary shaft to the weeding element hub with 12.25 mm pitch chain and 12 teeth sprockets.

Prior to manufacture the machine, a design must be created using computer design technology (CAD/CAM). This technology can reduce major expenses associated with design flaws (Chirende, Li, and Vheremu 2019; Cekus *et al*., 2019) [9, 6]. Design optimization can reduce manufacturing errors and can lengthen the product's service life (Vegad and Yadav, 2018) [20]. Technology-based design optimization has been used by cutting-edge businesses working in mechanics and other types of structures. (Gheorghe *et al*., 2018) [15]. Software like SolidWorks and ANSYS (AlShammari and Al-Waily, 2018; AlShammari and Abdullah, 2018) [1, 2] uses finite element analysis techniques as an efficient tool to discover solutions to challenging problems and can solve many engineering difficulties effectively (AlShammari *et al*., 2020) [1].

The finite element approach used to tackle a variety of issues, including issues with structural analysis, buckling (buckling), and vibration analysis. Structural analysis was the finite element analysis technique that was most widely employed. The term "structure" in this context refers to mechanical, aeronautical, and naval structures as well as buildings and bridges. The static structural analysis ignores the effects of inertia and damping while accounting for displacements, stresses, strains, and forces on the structure as a result of loading. Solid models of the differential chasis, frame for mounting all components were prepared in solid work software. Each of these part assembly models were analyzed for maximum stress and deformation using a FEA software in solid work analysis module.

The material choice and frame design must be based on the maximum value of working stress, analysis of the stresses occurring on a structure is crucial. Based on the findings of the uniaxial tensile test, the von Mises stress is utilized to forecast the yield of materials subjected to complicate loading (Suprapto and Wibawa, 2021) [25]. But where the stress received in high magnitude results in breakage of the chassis. Therefore, the dimension and strength of the weeder frame developed in such a way that even at ultimate stress, the chassis was expected to withstand and perform well. To prevent a failure and establish operability of the tool design, considering safety factor is necessary.

Materials and Methods

SolidWorks 2018 [4] software was used for the development of 3 D model of weeding system. AISI 1010 was the material utilized in the construction of the frame for attaching 2no.of weeders in this study. It was chosen because it was heat and corrosion-resistant. The overview of the parameters used in the simulation is shown in Table 1. For analysis, the data in the table will be entered into the solid work analysis module.

Table 1: Simulation parameters of materials

Description Value	Name
Material	Steel for weeder MS iron for triangular track and frame
Model type	Isotropic
Yield strength	1.7 x 108 Nm^{-2}
Tensile strength	4.85 x 108 Nm^{-2}
Elastic modulus	2x1011 Nm^{-2}
Poison's ratio	0.265
Mass density	8.027 kgm^{-2}
Shear modulus	8.2 x 1010 Nm^{-2}
Thermal expansion	1.65 x 10^{-5} /Kelvin
Load on rotary weeder	176 N

Mesh simulation modelling

Mesh has an impact on computational modelling utilizing the Finite Element Analysis (FEA) technique. In a simulation, mesh was a process that has a high level of complexity (Sosnowski *et al.*, 2018) [26]. Mesh results have a significant impact on the simulation's convergence outcomes. The simulation may fail as a result of an error made during creating the mesh, which means that mesh generation process must be reperformed, which was time-consuming. The findings are more accurate with smaller meshes, but the simulation procedure takes longer.

Table 2: Mesh distribution information

Mesh type	Tetrahedral
Mesher used	Curvature
Maximum element	2.69609 cm
Minimum element	0.539218 cm
Mesh quality	Draft
Total nodes	7808
Total elements	25599
Maximum aspect ratio	2.558,3
Percentage aspect ratio<3	91.6%
Percentage aspect ratio>10	0.43%

Hexahedral mesh, polyhedral mesh, and tetrahedral mesh are some of the mesh types utilized in computational fluid dynamics (CFD) simulation. The tetrahedral mesh was employed in this study because it was more effective for simulating stress distributions and CFD simulations are frequently used in irregular geometries (Chen *et al.*, 2021) [7]. The information on the mesh distribution used in this investigation is shown in Table 2. Calculations utilizing the finite element approach must be performed using a computer due to many equations involved. This approach was cost and time efficient while also ensuring the accuracy of the results. The fundamental idea behind the finite element approach was to discretize an item into a finite number of parts. This section takes the shape of a triangle, with each element being a linear quadrilateral connected by a node (node) as shown in Fig.1.

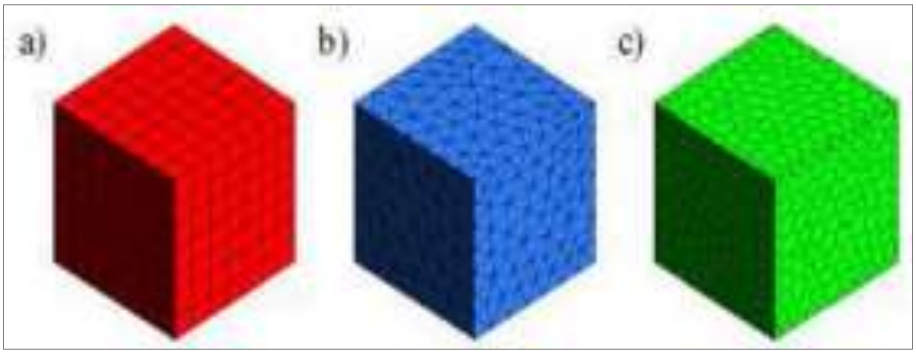

Fig 1: a) Hexahedral mesh b) tetrahedral mesh and c) polyhedral mesh on finite element method.

Based on the mentioned description of the analysis, the goal of this study was to use SolidWorks 2018 [4] software and the finite element analysis method to examine the differential chassis frame construction. The minimum value of the safety factor was one of the references used as a gauge of a design's safety. Engineers frequently utilize an object's safety factor as a reference metric when determining how much stress it can withstand (Wang *et al.*, 2019) [21]. This study's results include Von Mises stress, displacement, and safety factor for determining the material's capacity to sustain dynamic loads and shock loads.

Von Misses stress, displacement, and safety factor are among the simulation outcome parameters. The following equation was used to calculate theoretically the value of strain and stress and equation 1 was used for estimating factor of safety value.

$$\begin{cases}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{zz}\end{cases} = \frac{E}{(1+v)(1-2v)}\begin{cases}(1+v)\varepsilon_x + v\varepsilon_y + v\varepsilon_z\\ v\varepsilon_x + (1-v)\varepsilon_y + v\varepsilon_z\\ v\varepsilon_x + v\varepsilon_y + (1-v)\varepsilon_z\end{cases} \quad (1)$$

Where σ is stress, ε is strain, **v** is poison ratio and E is modulus young of material. The following equation can be used to calculate the safety factor's value,

$$SF = \frac{\sigma_{max}}{\sigma_{max\ material}} \quad (2)$$

Where,
SF is a safety factor, σ_{max} is allowable material stress and σmax material is stress on the material.

Results and Discussions

The structural and stress analysis of weeding frame was conducted using finite element analysis to understand the stress zones, elongation and safety of factor for improving the structural strength of frame for attaching weeder.

The differential chassis which was supported by triangular track wheels, supporting frame for engine, gearboxes and weeding system. In order to understand the suitability to loading conditions, von mises stress, deformation and factor of safety were analyzed using Finite element analysis on 3 D diagram of differential chassis with meshed diagram as shown in Fig 2.

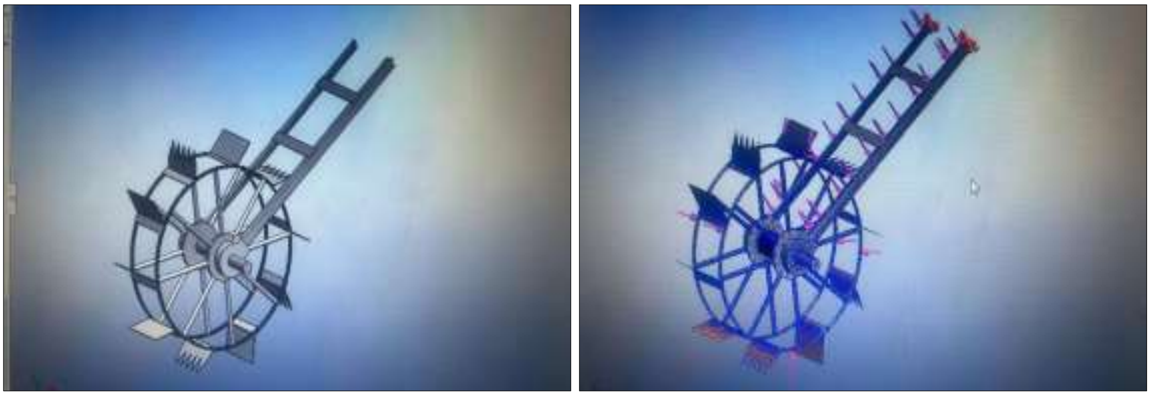

Fig 2: 3-D model of weeder frame with mesh generation

Von mises stress

The material choice and frame design must be based on the maximum value of working stress, analysis of the stresses occurring on a structure is crucial. Based on the findings of the uniaxial tensile test, the von Mises stress is utilized to forecast the yield of materials subjected to complicated loading (Suprapto and Wibawa, 2021) [25]. The Von Mises stress determines whether a material will be safe or fail (Karmankar, 2017) [27]. If the stress value exceeds the material strength, von Mises can fail (Hutton D. V., 2003) [7].

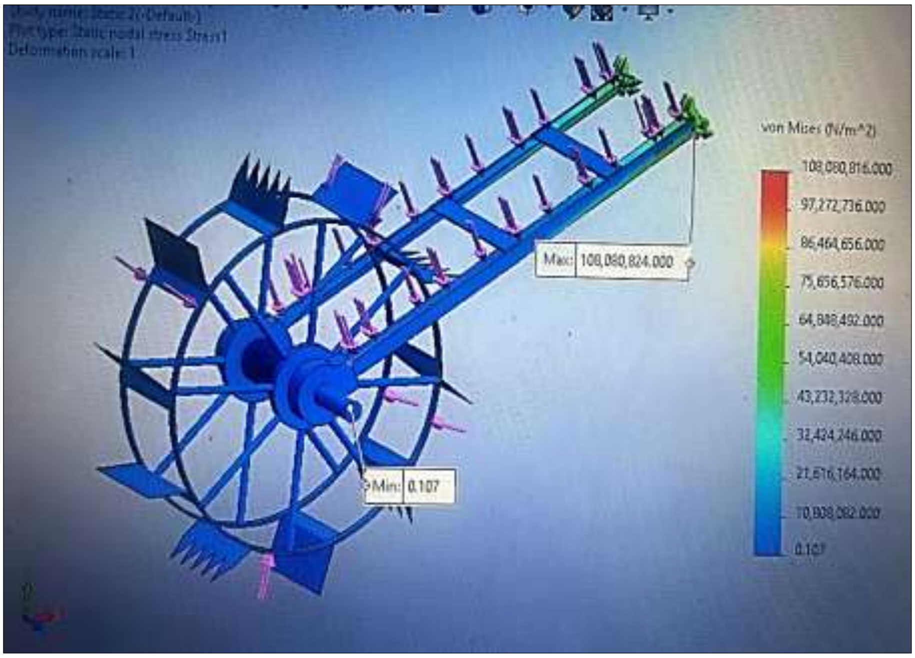

Fig 3: Von mises stress distribution over differential chassis

It was observed that, the red portion in the figures represents high levels of stress deformation, while the yellow and green represents moderate level and blue mark represent low level of stress deformation. It demonstrated how the stress is spread equally throughout the differential chassis. When designed load of 1471 N applied on weeder holding frame as per design calculation, lowest value of von Mises stress 0.107 N/m^2 was observed at the weeder center shaft whereas highest von misses stress of $10.80x10^7$ N/m^2 was observed at the end of frame attached to main driving shaft which required bearing for bearing dynamic loads.

Deformation of differential chassis

Deformation is a physical alteration to an object brought on by a load or force. Elastic deformation and plastic deformation are the two categories into which deformation is further separated (Juvinall, 2011) [28]. When an object undergoes elastic deformation, which is a physical change brought on by a force or load, it will revert to its original shape (Juvinall, 1967). Naturally, elastic deformation is used while developing tools since the maximum stress is constrained below the yield strength (K. Z. V. Dobrovolsky, 1973) [11]. The displacement over the differential chassis frame when applied rated load of 1471 N is shown in Fig.4.

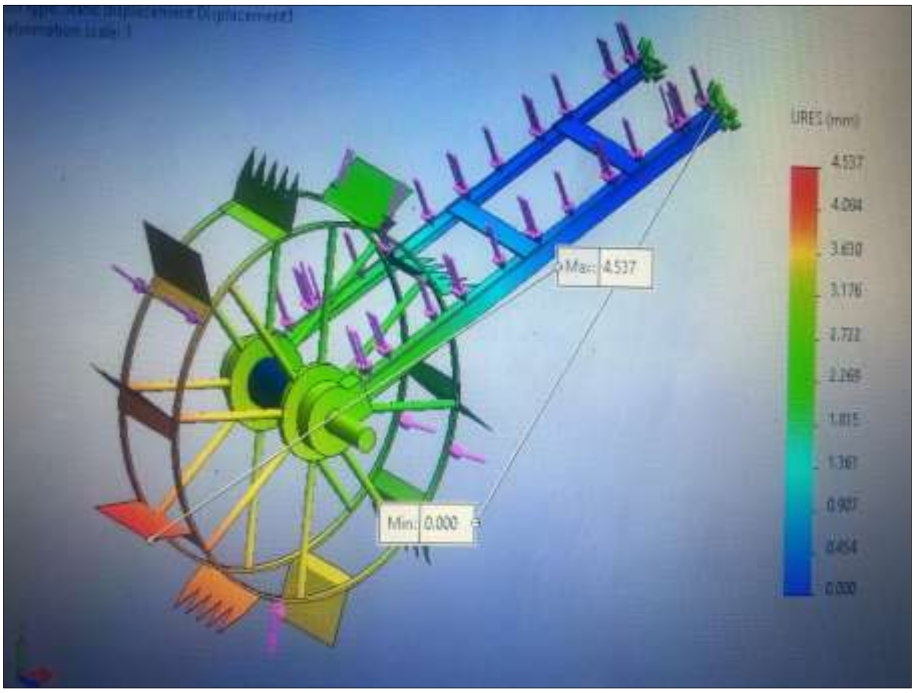

Fig 4. Deformation distribution over attachment frame of weeder

From the fig. 4 it was observed that, Max deformation of 4.537 mm was observed at the end of frame attached to main driving shaft and minimum was observed at centre shaft of weeder. Due to large deformation at the edge.

Factor of Safety

When performing stress testing on a model of an object, one of the parameters used as a reference is the safety factor (Wang *et al*. 2019) [21]. To prevent a failure and establish operability of the tool design, considering safety factor is necessary. The review procedure uses the safety factor, which ensures the proposed design is secure and serves as a gauge for an element's strength (Wibawa *et al*., 2020) [22].

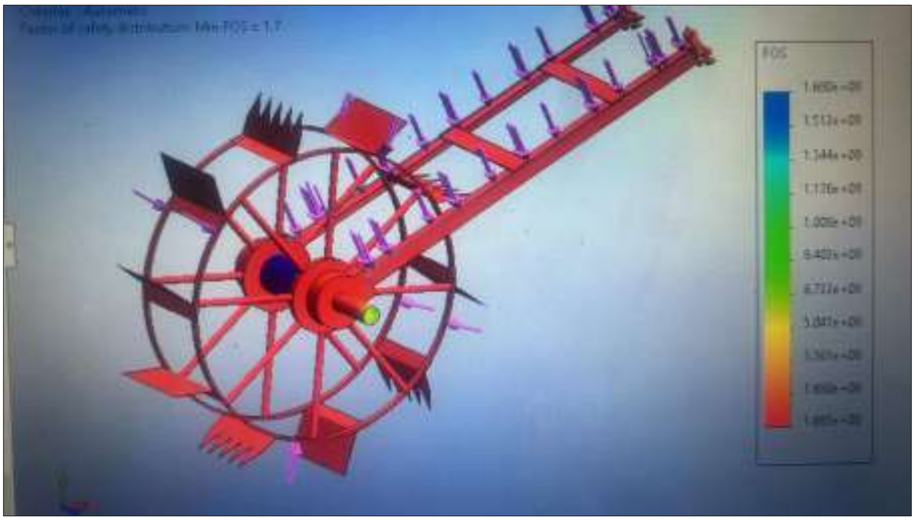

Fig 5: Factor of safety diagram of finite element analysis

The factor of safety was observed as 1.6 which suited for carrying dynamic loads (K. Z. V. Dobrovolsky, 1973) [11]. Hence the support system developed was suitable for carrying static and dynamic loads of weeding system.

Conclusions

When designed load of 1471 N applied on weeder holding frame as per design calculation, lowest value of von Mises stress 0.107 N/m^2 was observed at the weeder center shaft whereas highest von misses stress of 10.80×10^7 N/m^2 was observed at the end of frame attached to main driving shaft which required bearing for bearing dynamic loads. Max deformation of 4.537 mm was observed at the end of frame attached to main driving shaft and minimum was observed at centre shaft of weeder. Due to large deformation at the edge and maximum von Mises stress, bearing support provided for controlling twisting and dynamic loads. The factor of safety was observed as 1.6 which suited for carrying dynamic loads. Hence the support system selected was suitable for carrying static and dynamic loads of weeding system.

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