Design and strength analysis of a fertilizing and soil covering vehicle

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Abstract: In this paper, a kind of fertilizing and soil covering vehicle is designed with compact structure, easy control and substituting manual work to conduct the operations including fertilizing and soil covering. In accordance with movement, structure and loading feature of fertilizing and soil covering vehicle, parametric modeling is carried out for the frame part of this fertilizing and soil covering vehicle to define boundary conditions such as load, constraint, etc. when the frame is under the working condition of normal full load. ANSYS software is used to produce finite element model of frame, and to analyze and solve the model, so as to obtain stress and stain variation diagram of each part of frame under working condition of normal full load. The calculation result shows that: the structure of frame is able to meet the strength requirement, and the maximum value of stress is located at joint between frame and external hinge, which should be appropriately improved in thickening way. In addition, a larger deformation occurring at damper on lower part of hopper may be reduced by adding rib plate at damper on lower part of hopper. The research result of this paper provides the theoretical basis for the design of frame of fertilizing and soil covering vehicle, which has deep theoretical significance and application value.

1 Introduction

For long time, the farming in China was seriously dependent upon manual operation. The example is that manual furrowing, fertilizing, soil filling was required during deeply applying fertilizer by hand. This method does not only waste time and energy with high labor intensity and low working efficiency, is but also difficult to control the fertilizing amount and easy to form waste, so is not able to meet the requirement of modern farming.
With the mechanization and scale development of agricultural production, the problems including low working efficiency of manual operation, more waste formed during furrowing fertilizing and low fertilizer efficiency during farming are required to solve rapidly. Based on the combination with theoretical analysis and experimental test, a kind of fertilizing and soil covering vehicle with design and research diversification, broader application range and higher technological content is capable of conducting continuous operations including furrowing, fertilizing, and so on instead of manual work. This research trend has become a focused issue attracting agricultural machine researchers [1~6].

Finite element method is an approximate value analysis method used to solve complicated issues during engineering analysis. Simplification of mechanical model based on frame structure and load-carrying capacity feature of fertilizing and soil covering vehicle, and finite element analysis conducted by ANSYS[8] is an effective method for assessment of structural rationality, and provides technical base for combination with experimental test and taking improvement measures in the future [9~11].

In this paper, we make parametric modeling for frame part of a kind of fertilizing and soil covering vehicle to guide parametric model into finite element analysis software ANSYS workbench, so as to carry out finite element analysis to this model and obtain stress and strain distribution diagram of frame structure. In accordance with finite element result, frame structure and connecting styles of each part are improved, and the frame has been designed in lightweight way using scheme of size optimization. The research result of this paper, offering theoretical foundation for design and lightweight of frame, indicates high theoretical significance and application value.

2 The entirety structure design of the fertilizing and Soil Covering vehicle

In this paper, a kind of fertilizing and soil covering vehicle is designed with compact structure, easy control and substituting manual work to conduct the operations including fertilizing and soil covering, which is conducive to solve problems such as low efficiency of manual work, heavy waste during furrowing and fertilizing, low fertilizer efficiency, etc. during farming. The main structure is shown in Fig. 1.

1. Hopper of fertilizer tank; 2. Fertilizer tank support; 3. Base plate support; 4. Hinge connecting with wheel; 5. Hinge connecting with tractor; 6. Chain wheel assembly; 7. Fertilizer sprayer; 8. Fertilizer conveying belt; 9. Feed opening; 10. Wheel; 11. Soil covering unit

Fig. 1: A sketch map of the overall structure of furrowing and fertilizing vehicle

Technical proposal used by a kind of fertilizing and soil covering vehicle is that: hopper of
fertilizer tank is mounted on fertilizer tank support, fertilizer tank support is mounted on base plate support, base plate is connected with plate spring by hinge, plate spring is mounted with wheel, and wheel contacts with ground, and is used to support the overall weight of furrowing, fertilizing and soil covering vehicle, and is treated as the main movement carrier.

Chain wheel assembly is mounted on base plate support, with the function of transmitting the rotation of wheel shaft to fertilizer sprayer at lower of fertilizer tank by chain, so as to rotate fertilizer sprayer to output fertilizer from fertilizer tank and drop it on fertilizer conveying belt. Fertilizer conveying belt is mounted on base plate support, and move leftward or rightward to convey fertilizer to feed opening. With the effect of gravity, fertilizer drops into farming furrow through feed opening. Soil covering unit is used to cover the soil on fertilizer.

3 Finite element analysis model of frame

3.1 Establishment of model

During establishing three-dimensional model for frame of a kind of fertilizing and soil covering vehicle, the close matching of model and practice is not only considered, the feasibility of model calculation is also considered. According to accuracy principle of frame structure and design calculation model, parametrical model is partly simplified when establishing the model, and geometric features less impacting on mechanics property analysis result of overall frame, such as some holes, chamfers, bending, etc. in initial model of frame are required to simplify.

The frame model of fertilizing and soil covering vehicle established in ansys is shown in Fig. 2. The frame of fertilizing and soil covering vehicle is of space beam structure which is welded with square steel tubes, rectangular steel tubes and steel plates, with structural steel material ($7.84 \times 10^3$Kg/m$^3$, elasticity modulus $E=2.068 \times 10^5$MPa, Poisson’s ratio $\mu=0.3$).

3.2 Handling of load and working conditions constraint

As shown in Fig. 2, the load borne by this frame mainly come from gravity applied by full-load hopper of fertilizer tank, which presents as concentrated load perpendicular to frame plane. When load of hopper of fertilizer tank is full, the load is 2000kg, which is expressed as Load A IN ANSYS model.

In Fig. 2, part 4 means the hinge connecting with wheel support, through which fertilizing and soil covering vehicle connects with wheel to pass the load of full-load hopper of fertilizer tank to ground.
Part 5 means the hinge connecting with tractor, through which fertilizing and soil covering vehicle connects with tractor to pull fertilizing and soil covering vehicle forward by tractor. In this paper, part 4 and part 5 are set as fixed constraints, which is indicated as constraint B~F in ansys model.

In addition, before establishing model, dimensioning system of all input data is required to unify. Material property is homogeneous and isotropic.

3.3 Grid partition

In this paper, finite element analysis model established for the frame of a kind of fertilizing and soil covering vehicle is used to analyze the strength of this frame, and conduct lightweight design on this basis. In the frame, fertilizer tank support and base plate support, as the main carrier and load passing mechanism, are required to be selectively analyzed with respect with strain. Therefore in ANSYS, solid element is selected to model for frame of a kind of fertilizing and soil covering vehicle, hexahedral element is selected to conduct precise partition on fertilizer support and base plate support, and tetrahedron element is selected to conduct partition on other secondary element, in order to save calculation resource.

For grid partition, method of 8-node linear solid hybridization element (C3D8H) is used with grid seed density 0.05m. The size of established model is same as solid size, and established material is same as solid material which is structure steel.

According to this method, there are totally 2869740 nodes and 15645026 elements formed, as shown in Fig. 3.
4 Analysis result

Fig. 4: Stress distribution cloud chart

Based on the static load calculation of ANSYS program, equivalent stress distribution cloud chart of frame is obtained as shown in Fig. 4. The maximum stress point shown in figure is located at joint between frame and external hinge with a stress up to 50MPa, so this position should be improved in thickening way. The stress at joint between fertilizer tank hopper and fertilizer tank support is concentrated, which should be considered. Because of $\sigma_{\text{max}}=50\text{MPa} < [\sigma][12]$, the maximum stress is less than permissible stress of material and meets the strength requirement.

Fig. 5: Strain distribution cloud chart

As shown in Fig. 5, under the condition of full-load fertilizer tank hopper, there is a tiny frame deformation by force, and the maximum deformation point is located at lowest point of fertilizer hopper with a maximum value 2.8 mm. If prevention of more deformation at damper on lower part of hopper is required, it is suggested to add rib at damper on lower part of hopper.

5 Structure improvement scheme

In accordance with finite element analysis result of frame and stress and strain distribution diagram under full-load fertilizer tank hopper, the maximum deformation position is found at lower part of fertilizer tank hopper. When fertilizer sprayer outputs fertilizer, the larger deformation occurring at damper on lower part of fertilizer tank hopper may result in that the fertilizer is sprayed outside of fertilizer conveying belt, which may cause waste and contamination to tools. Therefore, to avoid this situation, left part and right part at middle of lower damper of fertilizer tank hopper are each welded...
with two rib plates 5mm thick. Contrast diagram for structure improvement is shown in Fig. 6.

![Contrast between initial and improved structure](image)

**a) Before improvement**  
**b) After improvement**  

Fig. 6: Contrast between initial and improved structure

After improvement of lower structure of fertilizer tank hopper of fertilizing and soil covering vehicle, the maximum deformation does not occurring at lower part of fertilizer tank hopper any more, but at upper part of hopper, with the value 1mm, and the maximum deformation of lower damper of hopper is 0.5mm. The strain chart after improvement of lower structure of fertilizer tank hopper is shown in Fig. 7.

![Cloud map of strain distribution after improving the structure of hopper](image)

Fig. 7: Cloud map of strain distribution after improving the structure of hopper

### 6 Conclusion

1) In this paper, a kind of fertilizing and soil covering vehicle is designed with diversification, broad application range, high technological content and substituting manual work to conduct the continuous operations including furrowing, fertilizing and soil covering, which is conducive to solve problems such as low efficiency of manual work, heavy waste during furrowing and fertilizing, low fertilizer efficiency, etc. during farming.

2) Under condition of full-load fertilizer tank hopper, the maximum stress of frame is less than permissible stress of material and meets the strength requirement. The point with maximum stress is located at joint between frame and external hinge with the value up to 50MPa, but still less than permissible stress, so it meets strength requirement, and this position should be improved in thickening way. The stress at joint between fertilizer tank hopper and fertilizer tank support is more concentrated and should be considered.
3) In accordance with finite analysis result, the lower structure of fertilizer tank hopper of fertilizing and soil covering vehicle is improved to reduce the maximum deformation of lower damper of fertilizer tank hopper from 2.8mm to 0.5mm, so as to avoid the possibility of spraying fertilizer outside of fertilizer conveying belt during fertilizer sprayer outputting fertilizer.

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