Application of ecological design based on innovative method in baling device

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Abstract. China’s ecological environment is deteriorating, with excessive use of energy and materials, inconvenient disassembly and single function, which are manifested in silage equipment. To this end, the ecological design based on the innovative method was briefly described. Then the frame of the baling device in the silage equipment was taken as an example. The ecological design process based on the innovative method was applied to solve the ecological problem of excessive use of the material. It enables the baling device to improve the ecological performance while satisfying the function. Finally, through the functional analysis and ecological analysis of the frame, the feasibility of applying the method to silage machinery is also verified. This also provides an effective way for the ecological improvement of silage equipment.

1. Introduction
China's industrial development is increasingly constrained by resources and the environment. While developing the economy, people have to face increasingly serious resource and environmental problems [1]. In this environmental context, the market competition is fierce. So designers need more logical and operational innovative methods to guide the green and effective development of products. Products achieve innovation while saving design cycles and avoiding negative pitfalls [2]. More and more experts and scholars combined TRIZ theory and ecological design into the conceptual design stage of products. Liu, J.N. of Hunan University applied driving innovative and ecological design of product development by utilizing TRIZ tools to solve poor serviceability of garbage collection devices [3]; Gu, X.J. of Zhejiang University applied product ecological design method integrating TRIZ to achieve the weight reduction of friction plates [4]; Liu, Z.F. of Hefei University of Technology applied a green innovative design method based on TRIZ and case-based reasoning to improve the disassembly of dishwashing [5]. This ecological problem also exists in silage equipment, so the ecological design based on innovative methods is introduced into the design process of silage equipment. Ecological design is to add environmental factors to the design considerations. TRIZ theory provides a more logical and operational guidance for the design process. The ecological design based on TRIZ is to integrate ecological design with TRIZ. It enables the product to improve the ecological performance and save the design cycle while satisfying the function.

2. Ecological design based on innovative method
Ecological design is based on traditional design, taking environmental factors into consideration. First, through the observation and interview, the functions of the products were decomposed. The weights of each function were obtained in the form of questionnaires. The system with large functional
requirements was selected for ecological optimization. Second, 7 of the World Business Council for Sustainable Development (WBCSD) were proposed. Based on the eco-efficiency factors (represented by A, B, C, D, E, F and G) [6], the triangular fuzzy number was used to judge its importance. The eco-efficiency factor with the highest weight was preferentially improved. Combining ecological demand with TRIZ engineering parameter mapping, ecological problems were transformed into engineering problems. Then TRIZ theory problem solving tools were used to solve problems [7]. The initial plan was obtained. Next, the related parameters were calculated and determined. Finally, the obtained preliminary plan and the pre-improvement plan were compared and analyzed to verify whether the ecological performance was improved while products met function [8]. The specific process of ecological design based on innovative method was shown in Figure 1. It mainly included six parts: functional requirements, ecological needs, problem solving, preliminary plan, parameter determination and program evaluation.

3. Ecological design of the baling device

3.1. Overall design of the baling device

The existing silage equipment had problems such as low work efficiency, high manufacturing cost, and serious nutrient loss during straw collection. Therefore, small and medium-sized modular backpack crop harvesting silage equipment that realized straw cutting, crushing, bundling and coating was developed. The layout scheme of the silage equipment was shown in Figure 2. It was mainly composed of a header device, a power device, a baling device, a telescopic device, a lifting device and a coating device.
The baling device occupies a central position in the silage equipment and is a bridge connecting the header device and the coating device. The overall scheme of the baling device was as shown in Figure 3. It was composed of a transmission system, an opening mechanism, a frame, a binding room, a rope feeding mechanism, a cutting rope mechanism and so on.

3.2. Ecological design of the baling device

Although the existing baling device satisfies the functional requirements, it still has disadvantages such as bulkiness, detachability and unreasonable resource utilization. In response to the existing problems, the ecological design of the baling device can improve the ecological performance while realizing the functional demand.

3.2.1. Functional requirements. The ecological design of the product is to improve the existing ecological problems under the premise of ensuring the functions of various institutions. The function of the baling device was obtained through observation and interview, and the baling device was decomposed by the system function [9], as shown in Figure 4. After the function was decomposed, the function weights of each system were obtained in the form of questionnaires. As shown in Figure 5, the rope cutting system, the collecting and conveying mechanism and the frame with high weight were selected to analyze the ecological problems. This article took a frame as an example.

Figure 2. Layout of silage equipment.

Figure 3. Baling device.

Figure 4. Function structure decomposition of the baling device.
3.2.2. Ecological needs. Although the system was decomposed, there may be multiple ecological problems per subsystem. If you analyze each ecological problem, the operation was cumbersome and unnecessary. Two industry experts were invited to judge the ecological efficiency factors of the rack —P1 and P2. The fuzzy mathematics method [10] was used to make the "fuzziness" problem clear. The importance of each eco-efficiency factor was obtained. The most important ecological issue was chosen to improve.

\[
P_j = \begin{bmatrix}
    A & B & C & D & E & F & G \\
    A & - & u_4 & u_5 & u_6 & u_7 & u_8 \\
    B & u_4 & - & u_1 & u_3 & u_4 & u_5 \\
    C & u_5 & u_2 & - & u_2 & u_3 & u_4 \\
    D & u_6 & u_3 & u_4 & - & u_1 & u_2 \\
    E & u_7 & u_4 & u_5 & u_6 & - & u_4 \\
    F & u_8 & u_6 & u_7 & u_8 & u_1 & - \\
    G & - & u_2 & u_3 & u_4 & u_5 & u_6 \\
\end{bmatrix}
\]

\[
MP = \begin{bmatrix}
    (0,0.0) & (6.78, 7.885) & (6.78, 7.885) & (6.78, 7.885) & (6.78, 7.885) & (6.78, 7.885) & (6.78, 7.885) \\
    (2.34, 4.56) & (4.56, 4.56) & (4.56, 4.56) & (4.56, 4.56) & (4.56, 4.56) & (4.56, 4.56) & (4.56, 4.56) \\
    (1.5, 2.3) & (0.0, 0.0) & (2.34, 4.56) & (4.56, 4.56) & (4.56, 4.56) & (4.56, 4.56) & (4.56, 4.56) \\
    (2.34, 4.56) & (6.78, 8.785) & (0.0, 0.0) & (7.885, 3.45) & (3.45, 6.78) & (6.78, 6.78) & (0.0, 0.0) \\
    (1.12, 1.12) & (4.56, 4.56) & (1.523, 1.523) & (0.0, 0.0) & (2.34, 2.34) & (2.34, 2.34) & (2.34, 2.34) \\
    (3.45, 4.56) & (6.78, 6.78) & (5.67, 5.67) & (6.78, 6.78) & (0.0, 0.0) & (6.78, 6.78) & (0.0, 0.0) \\
    (3.45, 4.56) & (5.67, 5.67) & (2.34, 2.34) & (4.56, 4.56) & (2.34, 2.34) & (4.56, 4.56) & (2.34, 2.34) \\
\end{bmatrix}
\]

\[
m_1, m_2, m_3, m_4, m_5, m_6, m_7, n \text{ and } n \text{ were obtained for obtaining } w_f=(0.2242, 0.2087, 0.1939),
\]

\[
w_e=(0.1515, 0.1602, 0.1551), w_f=(0.0939, 0.1019, 0.1102), w_e=(0.1697, 0.1650, 0.1612), w_f=(0.0697, 0.0728, 0.0857), w_e=(0.1818, 0.1748, 0.1714), w_f=(0.1091, 0.1165, 0.1224). \text{ They were respectively brought into the formula (1) for obtaining a clear result. The importance of each eco-efficiency factor was obtained, as shown in Table 1.}
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\[
w \langle I, b, r \rangle \rightarrow w = \frac{l+2b+r}{4}
\]

Table 1. Ecological efficiency factor importance of the frame.

| Ecological efficiency factor | A   | B   | C   | D   | E   | F   | G   |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|
| Importance                  | 0.2089 | 0.1568 | 0.1020 | 0.1652 | 0.0753 | 0.1757 | 0.1161 |

It can be seen from Table 1 that the eco-efficiency factor A, the material density of products and services, was the most important. So it was preferred to improve A. Through the static analysis of the original frame, it was found that the maximum equivalent stress of the original frame was 54.312MPa<157MPa (the allowable stress of Q235). This illustrated that the structure had more surplus and a larger space for weight reduction. From the working conditions and cost considerations of the equipment, the lightweight design was used to improve the ecological efficiency A. The TRIZ engineering parameters corresponding to the lightweighting were 23 and 26, which corresponded to
the mapping relationship between ecological demand and TRIZ engineering parameters. According to the number of ecological requirements corresponding to the engineering parameters, the engineering parameters 26 that correspond to more ecological needs was selected. Engineering parameter 26 is the quantity of matter or thing: the number of materials, components and subsystems can be changed partially or completely, temporarily or permanently.

3.2.3. Problem Solving. Through ecological analysis, the frame can reduce the amount of material. But the reduction in material usage will affect the strength, stiffness and vibration performance of the frame. After the actual problem was transformed into a model problem, the above problem becomed that the reliability of the frame deteriorated. This problem belonged to the technical conflict problem. The contradiction matrix was queried [11] and the corresponding invention principle was obtained, as shown in Table 2.

| Deteriorating parameters | Improved parameters | Reliability |
|--------------------------|---------------------|-------------|
| 26 Quantity of matter or thing | 18, 3, 28, 40       |             |

After analyzing the invention principle 3, turn the uniform structure of an object or environment into uneven or make different parts of the object perform different functions, was adopted.

3.2.4. Initial plan and parameter determination. According to the invention principle of local mass, it was decided to adjust the thickness of the left and right side plates which had a great influence on the total mass. Preliminary adjustment size was obtained after multiple analysis and adjustment, as shown in Table 3. The ribs were added where the vibration was large, as shown in Figure 6.

Table 3. Thickness size of main parts before and after adjustment.

| Components               | Left front side panel | Right front side panel | Left rear side panel | Right rear side panel |
|--------------------------|-----------------------|------------------------|----------------------|-----------------------|
| Pre-adjustment thickness | 4mm                   | 4mm                    | 4mm                  | 4mm                   |
| Adjusted thickness       | 3mm                   | 3mm                    | 3mm                  | 3mm                   |

3.2.5. Program evaluation. (1) Static analysis: The strain cloud map and equivalent stress cloud map of the initially adjusted frame were shown in Figure 7 and Figure 8 respectively. The maximum equivalent stress was 72.742 MPa, which was still much less than the allowable limit of the material.

(2) Modal analysis: Each step natural frequency of the adjusted model was relatively large. Moreover, the excitation frequency of the motor was farther than 15Hz when the baling device was used alone. So resonance is less likely to occur. It can be seen from Figure 9 that the amplitude of the adjusted model was small. The vibration distribution of the adjusted model was also relatively uniform. So the stability was better.
(3) Quality analysis: In Solidworks software, 4 components before and after adjustment were added materials. Then the quality analysis was performed. The quality comparison was shown in Table 4. From the table, the total mass can be reduced by 7.812kg. The rack had four reinforcing ribs whose total mass was 1.48kg. Therefore, The quality of the whole frame was 6.322kg less than that before adjustment.

| Mechanism         | Left front side panel | Right front side panel | Left rear side panel | Right rear side panel |
|--------------------|------------------------|-------------------------|----------------------|-----------------------|
| Pre-adjustment     | 10.073kg               | 10.073kg                | 5.55kg               | 5.55kg                |
| Adjusted quality   | 7.555kg                | 7.555kg                 | 4.162kg              | 4.162kg               |

Through static analysis, modal analysis and mass analysis, the adjusted model not only satisfies the static demand, but also avoids the resonance phenomenon. The quality was reduced by 6.322kg. Therefore, the adjusted model reduced the material density of the rack. In other words, the eco-efficiency factor A was improved.

4. Another section of your paper
(1) Ecological design based on innovative methods is introduced into the design process of silage equipment. Its design process is constantly being improved during the application process. It provides theoretical guidance for the green and effective development of silage equipment.

(2) By comparing and analyzing the performance parameters and ecological elements of the frame before and after improving, it is verified that the material density of the frame is reduced. It is also verified that the ecological design based on the innovative method has effectively improved the baling device.

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