Design Optimization of Bullock Cart Yoke

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Abstract. Since from ancient times weight of bullock cart is concentrated on the neck of the bullock reducing its efficiency. This paper presents various design of the yoke structure for the cart and its analysis whose aim is to reduce the stress acting on the single point i.e. on the neck of the bullock. The stress needs to be distributed over the entire body of the bullock instead of concentrating only on the neck. This paper gives an idea of how the stress is distributed on the bullock and the deflection of the yoke corresponding to the load. The design iterative process is based on the presently used bullock cart yoke structure. This paper also includes the design concepts which provide cushioning at the contact of the wooden frame to the bullock. The best design is then selected based on the structural behaviour for particular boundary and loading conditions. The modelling is done in SOLIDWORKS 2017 software and simulated/analysed using ANSYS 18.2 software.

1. Introduction

The design of the bullock cart has not been given much importance in the last few decades considering the loads that are loaded on to the cart which are quiet beyond the capacity of the bullock. These carts were developed in the ancient times and are still used today as a mode of transporting goods, people etc., because they are less expensive than the commercial or passenger vehicles. The bullock carts are basically of two types on the basis of number of bullocks i.e. single bull driven and double bull driven. The bullock cart consists of two wheels which are usually bigger in diameter. The payload carrier is the one on which the major load is put on. The payload carrier is then connected to a V-shaped wooden frame usually used in double bull driven that is in turn connected to the yoke. The yoke is a circular cross-sectional member that transforms the entire load from the payload carrier to the neck of the bullock. Traditionally, all the bullock cart yokes are made of neem wood. The yoke being a solid cylindrical member has a centre loading from the payload carrier. The V-shaped wooden frame is sometimes tilted w.r.t. pull axis in some of the carts which induces more stress at the point of contact i.e. at the neck. The point of contact of wooden yoke on the skin of the bullock involves tissue wear and also neck swelling with addition of higher payloads.

With the material taken into consideration the neem wood is perfect as considered with the overall parameters i.e. the environmental factors, financial factors, physical and chemical properties. Since, the loads that are loaded on the payload carrier is not a factor that can be controlled, redesigning the entire yoke structure must be considered. Thus, the material is taken as neem wood and the design of the entire yoke structure including the connecting wooden frame must be optimized. The design optimized in this case is for double bull driven.
2. Structure of yoke

With some of the yokes being optimized to c-cross sections, it serves the purpose of higher strength to weight ratio but converting it to I cross section increases effectiveness in reducing stress and allows frame for inserting cushioning material. The point of contact of the yoke and neck must be of semi-circular geometry including the cushioning material so as to provide smooth contact [1]. There are many materials from which the structure of the yoke can be constructed such as teak wood, MMC’s, neem wood, FRP’s etc. Selection of wood is considered as the best material to have met customer demands [2].

The optimum value of thickness of the yoke must be in range of 12-24mm in order to meet design requirements. The distance between the pull axis of the yoke and the payload carrier must be at same height w.r.t ground i.e. if cart is inclined about the pull axis, the reaction of the yoke will be in upward direction hence inducing more stress on the neck through the harness. The above-mentioned case is highly effective when applied in conditions of gradient surfaces [3]. The cushioning material must be of higher shock resistance so as to have smooth contact between yoke and neck.

2.1. Present yoke structure

Here the term yoke structure constitutes both the yoke and the V-shaped wooden frame. This yoke structure shown in the below figure.1 lags in many of the factors that lead to the reduction of performance of the bullock. Getting to the point of contact, the structure imposes rough contact to the neck. The front part of the yoke is provided with four holes in order to have harness attached to it. The harness play an important role in controlling the direction and motion of the bullock. It is the basic parameter and is being carried out in all the three designs. This yoke structure is of circular cross section and the connecting wooden frame is of rectangular cross section.

![Figure 1. Regular yoke design.](image)

2.2. First iterative yoke structure

The structure in the figure 2. is proposed to overcome the effects occurred at the contact and also reduce the stress induced by changing the circular cross section to I-section which has higher strength and lesser stress induced. The material used are neem wood for the wooden structure and silicone rubber for cushioning purpose. A semi-circular slot is produced at the contact point of yoke in order to attach the cushioning material. To ensure distributed loading, the connecting V-shape is replaced by two long horizontal semi-circular bars which will lie on the entire back of the bullock and also has the provision of attaching the cushioning material.

The vertical bar is designed in such a way that it can be attached to the payload carrier through the nuts and bolts. This is done to ensure that there will be no elevation difference between the entire yoke structure and payload carrier. The square pockets in the front are the space provided for the hump of the bullock.
2.3. Second iterative yoke structure

In order to ensure radial movement of the front part of the yoke, it is required to have revolute joint as a part of assembly which is shown in figure 3. Hence, the entire structure mentioned in figure 2 is taken into topology optimization and then redesigned for the best possible structure. In the below figure 3. The space between the yoke and the horizontal bar is provided for the hump of the bullock and the radial movement of the front structure enables ease of movement whenever change of direction is required.

3. Methodology

The above-mentioned structures are analyzed for equivalent stress (von-Mises) and total deformation for the material neem wood and silicone rubber [4]. The properties are mentioned in the below table 1. The joining of neem wood with silicone rubber can be done by adhesives or by some mechanical means.

| Description            | Neem wood     | Silicone rubber |
|------------------------|---------------|-----------------|
| Young’s Modulus        | 11294Mpa      | 50Mpa           |
| Density                | 750kg/m³      | 1.03kg/m³       |
| Ultimate tensile strength | 34.2Mpa      | 5.5Mpa          |
| Poison ratio           | 0.35          | 0.49            |
3.1. Boundary and loading conditions for regular yoke
The fixed supports are below the payload carrier and thus it is fixed at both the ends[5]. It is assumed that V-shaped wooden frame is distributed with equal loads on either sides. The magnitude of force is 1600N on either sides as shown in figure 4. The frictional contact between the neck and the cushioning material of the bullock is negligible[6].

![Figure 4. Boundary conditions for regular yoke.](image)

3.2. Boundary and loading conditions for first iterative yoke design
Here the loads are equivalent to the regular yoke but varies in the assignment of fixed ends which has direct contact from the payload carrier, fixed through mechanical joints. Each vertical column has got four sites as shown in figure 5[7,8] that can be taken and attached to the payload carrier with some extensions to it.

![Figure 5. Boundary conditions for second iterative design.](image)

4. Equivalent stress in yoke structure
The stress analysis shows that the stress induced in the regular yoke is 23.358MPa[9-15] which is evident from figure 6, while that of the iterative yoke has 22.3MPa[16-18]. The main point is that the major portion of the load is concentrated on the back of the bullock as shown in figure 7. The stress distribution is uniform in second iterative structure.
4.1. Rejection criteria first iterative yoke design
The first iterative structure does have a stress value of 18.08MPa[19-21] shown in fig.10 which is less than compared to the other two structures but the front part of the yoke is restricted in radial direction which is not preferred as it does not allow the body movement of the bullock. Hence, it is rejected.

While in the second iterative design radial movement is provided at the centre of the yoke.

4.2. Total deformation in yoke structures
The deformation as evident from the figure 9. and figure 10. is minimum in the second iterative yoke structure and quite larger in the regular yoke which is equivalent to 78mm[22,23]. The normal yoke do not have any cushioning material due to which direct contact is attained and tissue wear, rough contacts summing to uncomfortable zone arrives in normal yoke. But the above mentioned situation is encountered by placing cushioning material at the contacts which is present in second iterative yoke. The deformation in both the design is quite similar to a cantilever beam which is fixed near the payload carrier and free at the yoke side. Hence the deformation is maximum at the yoke side which in turn signifies that the yoke deflects 78mm downwards in the regular yoke which is shown in figure 11. and 27mm in the iterative structure.
5. Conclusion

From the above-mentioned analysis, it is quite clear that the yoke has been optimized in order to have its load entirely distributed on the body. The regular yoke has got a stress value nearer to second iterative yoke but the deformation in regular yoke is way too high which makes the second iterative yoke structure more efficient. Hence The second iterative yoke yields better results in concentrating the load over the entire body instead of a single point and also avoids rough contacts by providing cushioning effects.

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