Development of a Model Stress Equation for the Steyr Tractor Lift System

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ABSTRACT

The construction of the Steyr tractor three-point lift system enhances its sideways swing both at work and during implement transportation especially on farm roads. These sideway swings produce impact stresses and have led to failures of some parts of the lift system such as the stabilizer bracket (sule, 2007). Stress development on machine parts especially agricultural machines and tractors during their operations can not be avoided. Otmianowski, (1983) stated that all agricultural machines that work on the farm are exposed to the dynamic effect of undulating terrain as well as rolling friction on both loose soil and bed-like farmland. These and other factors all contribute to the development of stress on the agricultural machine elements which may either lead to breakdowns or failures of some parts. The knowledge of the origins and nature of these stresses are important if they must be eliminated or reduced. In this paper, a model equation is developed from the first principles showing factors affecting stress development on the Steyr tractor stabilizers and brackets. The equation shows that the total stress existing on the bracket is a function of the mass (m) of the three-point linkage system with the coupled implement, the length of slot (s) and the speed (v) of swing as well as the ploughing resistance (P). The total stress existing on the bracket showed that, as m, s and P increase, the total stress σ_T increases.

Keywords: Speed, stress, energy, swing, brackets, stabilizers, Nigeria

1. INTRODUCTION

Stress (σ) is defined as the effect of force or load acting on a unit area of a body. Mathematically stress is defined as:

$$\text{Stress, } \sigma = \frac{P}{A}\left[N/m^2\right] \quad \text{-------------------- (1)}$$

where:
P = force or load acting on a body.

A = cross sectional area of the body

Apart from tensile and compressive stresses, other types of destructive stresses include creep, fatigue and shock or impact stress.

Creep is a slowly progressing, permanent deformation that results from steady force acting on a material. The gradual loosening of bolts, sagging of long span cables, and the deformation of components of machines and engines are all noticeable examples of creep.

Kelly (2007) defined fatigue as the progressive, localised, and permanent structural damage that occurs when a material is subjected to cyclic or fluctuating strains at nominal stresses that have maximum values less than (often much less than) the static yield strength of the material. The resulting stress may be below the ultimate tensile stress, or even the yield stress of the material, yet still cause catastrophic failure. Khurmi and Gupta (2002) stated that machine parts are sometimes subjected to loads with impact, thus producing impact stress. A mechanical or physical shock is a sudden acceleration or deceleration caused by impact (Kelly, 2007).

When designing machine parts, it is desirable to keep the stress lower than the maximum or ultimate stress at which failure of the material takes place. This stress is known as the working stress, design stress, safe or allowable stress. Ultimate stress is defined as the largest stress obtained by dividing the largest value of the load reached in an experiment by the original cross-sectional area.

The draught of agricultural implements which is an important parameter in the determination of stress varies widely under different conditions and are affected by such factors as the soil type and condition, ploughing speed, plough type, plough shape, friction characteristics of the soil-engaging surfaces, share sharpness and shape, depth of ploughing, width of furrow slice, type of attachments, and adjustment of the tool and attachments. A great deal of work has been done in evaluating these various factors and investigating possible means for reducing draught. Mathematical methods and models have been developed by researchers for predicting draught (Reece, 1965; Stafford, 1984). Draught of agricultural implements has been studied by many researchers (Oni et al., 1992; Shirin et al., 1993; Fielke, 1996; Kushwaha and Linke, 1996; McKyes and Maswaure, 1997; Onwualu and Watts, 1998; Al-Suhaibani and Al-Janobi,1997; Manian et al., 2000; Shrestha et al., 2001; Gratton et al., 2003; McLaughlin and Campbell, 2004; Mamman and Oni, 2005; Manuwa and Ademosun, 2007). The construction of the Steyr tractor three-point lift system enhances its sideways swing both at work and during implement transportation especially on farm roads. According to Mijinyawa and Adetunji (2005), 61.8% of the farmers in Oyo and Osun states of Nigeria have access to only untarred roads and that farm roads were found to be very deplorable. These bad roads that favour sideway swings produce impact stresses and have led to failures of some parts of the lift system such as the stabilizer bracket (sule, 2007). This failure is in the form of breakages of either the pin or the bracket at the right hand side of the lift system which sometimes leads to the damage of the axle and may lead to the replacement of the entire axle. In order to avoid, eliminate or reduce the destructive tendencies of impact or shock stress on the Steyr tractor three-point lift system, this study is carried out to determine the factors that affect the development of shock (impact) stress. It is important to know these factors in order to handle them effectively to reduce or eliminate the frequent failures of this system experienced by the users of Steyr tractors in the region of the authors.

2. THE STEYR TRACTOR THREE-POINT HITCH STRESS SYSTEM

Machine parts are subjected to various forces which may be due to either energy transmitted by the weight of machine, frictional resistances, inertia of reciprocating parts, or change of temperature as well as lack of balance of moving parts (Khurmi and Gupta, 2002). The different forces acting on a machine part produce various types of stresses. Even though the stress experienced on the Steyr tractor bracket has the nature of both fatigue and shock (impact), the latter is more pronounced. This is because the brackets experience impacts from the mounted implements on the swinging three-point linkage system during transportation and during ploughing when the implements strike an object on the farm.

When the Steyr tractor is in motion, the three-point hitch of mass (m) is found to swing left and right. The swinging movements of this mass of body hits the brackets through the stabilizer shafts thus producing shocks (impact stresses) on the bracket. When the tractor is at work, the draught resistance also acts on the bracket (Sule, 2007).

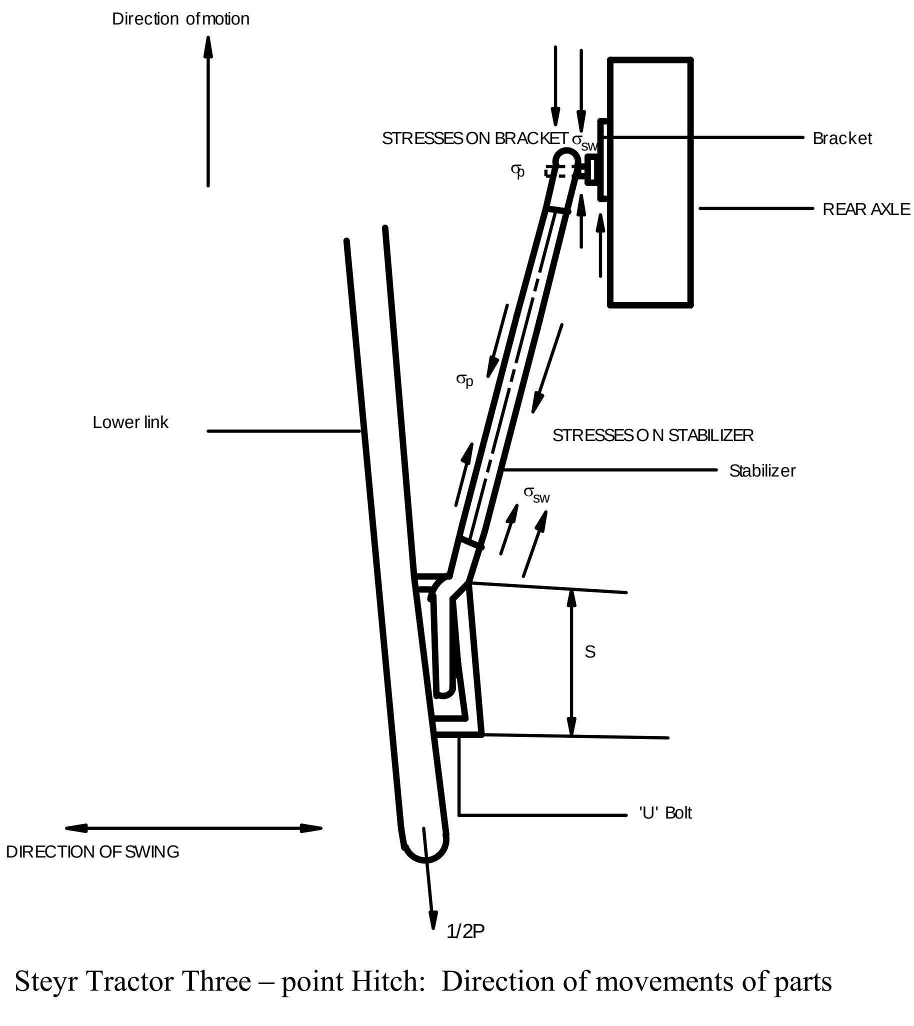


Figure 1. Steyr Tractor Three – point Hitch: Direction of movements of parts

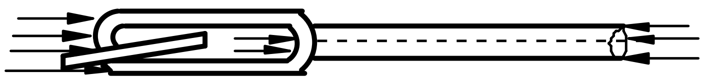
The total stress σ_T on the bracket of Figure 1can be represented as

$\sigma_T = \sigma_{sw} + \sigma_p$

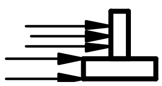
where:

σ_{sw} = stress from sideway thrust due to sideways swinging (also due to undulating field)
σ_p = stress due to draught of ploughing
σ_{sw} tends to produce impact stress on the bracket.
Assumption: The effect of up and down movements of the weight of the implement on the stress of the bracket is negligible because the stabilizer linking the bracket does not carry the weight of implement. The weight of implement is carried by the lower and upper links. The pin – bracket connection also allows for free up and down movements.

The impact stress produced can be expressed thus;
Consider that the mass of the three point linkage system including that of the hitched implement moves through the distance, s, in hitting the bracket as it swings in the shown direction in Figure 1 while Figures 2a and b show the stressed parts of the hitch system.



a Stressed Stabilizer



b Stressed Bracket

Figure 2 Stressed Areas

In calculating the impact stress σ_i produced, let
A = Cross sectional area of the bracket (m^2)
E = Young's modulus of the bracket material (N/m^2)
l = length of the bracket (m)
δl = Deformation of the bracket (m)
p = Force (N)-the impact load that produces the deformation δl
$\sigma_i = \sigma_{sw}$ (N/m^2) = Stress induced on the bracket due to the application of impact (shock) load
s = distance through which the load moves (m)
According to Khurmi and Gupta (2002), energy gained by the body (the bracket) Δ_1 in the form of strain energy is given as:

$$\Delta_1 = \frac{1}{2} \times p \times \delta l \ [J]$$

The energy lost Δ_2 by the swinging body of the three point hitch plus the plough attached to it is given as:

$$\Delta_2 = \frac{1}{2} m v^2 .$$

Where:
m = mass of the three point linkage with the implement [kg]
v = velocity of swing [m/s]
Equating the two energies,

$$\frac{1}{2}\times \mathrm{p}\times \delta \mathrm{l} = \frac{1}{2}mv^2 .\ \therefore \mathrm{p}\ \times\ \delta \mathrm{l} = mv^2 \quad \text{---------------------------- (2)}$$

Then from
p = σ_i x A and

$$\delta l = \frac{\sigma_i \times l}{E}$$

Substituting for δl and p in equation 2 gives

$$\therefore\ \sigma_i \times\ A \times \frac{\sigma_i \times l}{E} = mv^2$$

$$\therefore \frac{\sigma_i{}^2 \times l \text{ x } A}{E} = mv^2$$

Therefore, $\sigma_i{}^2 = \dfrac{Emv^2}{Al}$ ------------------------------ (3)

Velocity,v is defined as

$$v = \frac{s}{t}$$

where:
s is the distance moved by the body (in this case $s \leq$ length of the slot and *t* is the time taken to move from one point of the slot to another.)
Therefore, substituting for v in equation 3,

$$\sigma_i = \sqrt{\frac{Ems^2}{t^2 Al}} \quad (\mathrm{N/m^2}) \quad \text{-------------------------------- (4)}$$

From the above, it can be seen that with increase in distance (*s*) through which the load moves, the impact stress increases.

To determine the value of the stress due to the draught of ploughing, σ_p, the magnitude of the force acting on the bracket must first be determined. According to Barger *et al* (1963), the line of force (draught) of ploughing passes between the lower links and the center link of the tractor. It can therefore be said that this force (draught) is shared equally by the lower links as shown in Figure 3.

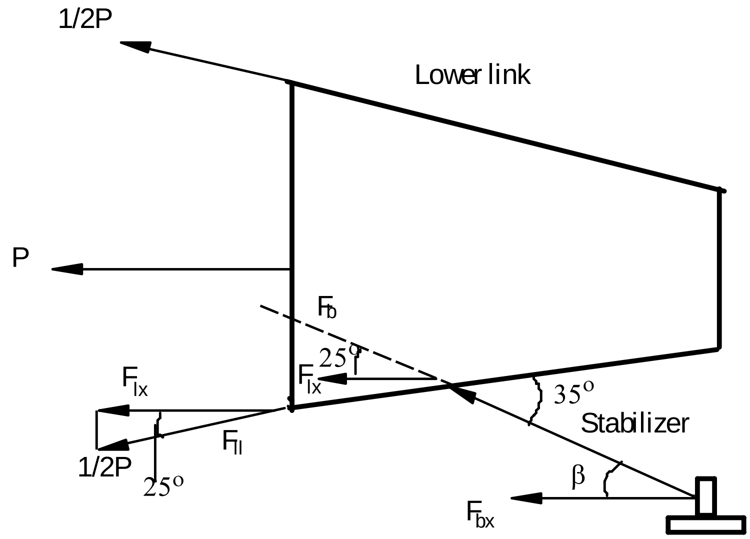


Figure 3. Forces Acting on the Lower Links and the Stabilizer

When the coupled implement with the three point linkage is at rest as in Figure 3, the horizontal component of the force on the lower link,
$F_{lx} = 1/2PCos25^0$.

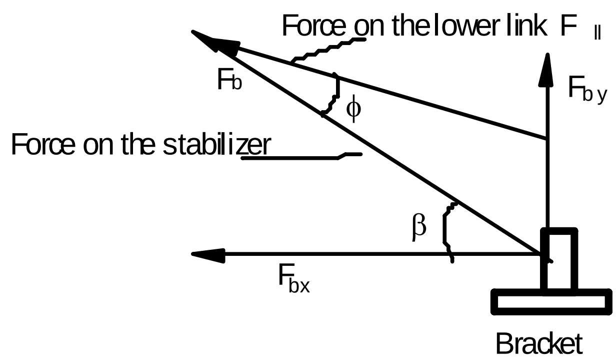


Figure 4. Resolutions of Forces in Figure 3

To determine the force acting along the length of the stabilizer, the force, F_{lx} is resolved on it to give F_b.(Fig. 3). At the time when maximum force is acting on the stabilizer shaft as in Figure 4, $\phi = 25^0$, $\beta = 35^0$ the force on the stabilizer shaft is

$$F_b = \frac{F_{lx}}{Cos25^0} = \frac{1/2PCos25^o}{Cos25^0}$$

and the force that brings about the shearing of the bracket,

$$F_{bx} = F_b \text{ x } Cos\,\beta = \frac{1/2PCos25^o}{Cos25^0} x\ Cos\beta = 0.41P$$

The angles Φ and β were directly measured using a protractor.
$F_{bx} = F = 0.41P$ and the stress due to the draught of ploughing, $\sigma p = 0.41P/A$
The total stress on the bracket $\sigma_{T} = \sigma_{sw} + \sigma_p$
Therefore:

$$\sigma_T = \sigma_{sw} + \sigma_p = \sqrt{\frac{Ems^2}{t^2Al}} + 0.41P/A \quad \text{----------------------------------(5)}$$

From equation 5, it can be seen that as the mass of the three - point hitch system (plus the attached implement) and the draught resistance (P) increase, the total stress increases.

3. CONCLUSION

The total stress existing on the bracket as given in equation (5) shows that as s and P increase, the total stress σ_T increases.

Force/draught of ploughing, P is given as kab [N] and it is influenced by the following component factors:

k = Soil unit resistance [N/m^2]

a = depth of ploughing [m]

b = width of ploughing [m]

In the same way, as time, t, taken to move from one point of the slot to another increases, the impact stress decreases. In other words, as the speed of swinging of the stabilizer is reduced, the impact (shock) stress is reduced thereby reducing the total stress.

4. RECOMMENDATION

In order to minimize the impact stress on the Steyr tractor brackets, it is recommended that the speed of swing of the lift system be reduced and if possible be eliminated. This can be achieved by reducing the length of the slot, s.

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