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Performance Evaluation of 65 HP Transmission System of a Tractor

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Abstract – The basic design of a tractor has remained the same for a number of years. Constant efforts are being made to improve the performance and bring down the cost of producing a tractor. The transmission system of a tractor comprises of two main assemblies, the housings which form the chassis and the gears, shafts etc. which form the gear train. The concern of using the chassis of a tractor designed for handling a certain magnitude of loads in a tractor which will encounter much higher operating load, for any chance of failure of chassis as well as the parts of transmission system such as gears, shafts and bearings have been discussed. The present work provides a critical analysis of the chassis transmission system of 65 HP tractor and concludes that the same chassis and transmission system can be used as specified for 50 HP tractor.

Index Terms – Tractor, transmission system, stress analysis and transmission loss.

1. INTRODUCTION

The word "tractor" comes from the word "traction" as it pulls a load. The tractor is designed to provide high torque at low speeds, which enables it to pull heavy objects. A tractor not only finds its application in the field of agriculture, but it serves in some commercial areas like running compressor, laser leveler applications, haulage operation in sand mining, driving an alternator through PTO (power take off) shaft, loader applications and so on. It can be easily said that higher horse power tractors (60 HP plus) are taking over the commercial sector by proving there worth [1]. One of the key components of a vehicle is its chassis. Chassis decides the basic shape of a vehicle as it denotes the basic frame of a vehicle. It also holds all the crucial components of a vehicle [2].

The chassis of a tractor is a single unit formed by connecting the clutch housing, the gearbox, the differential and the axle tubes. The chassis should be designed to withstand shocks, twists and other stresses during its life cycle. In other words, we can say that the chassis should be designed to carry maximum loads under dynamic and static condition safely [3]. A balance between adequate bending stiffness along with strength for better handling characteristics needs to be achieved while designing a chassis. The chassis is subjected to numerous degrees of intensities of stress and fluctuating loads of combined bending and torsion [4]. Hence it becomes important to analyze the chassis design before putting it to use. The gear train suffers transmission losses which needs to be evaluated in order to reduce losses and make the gear train more efficient.

2. RELATED WORK

Experimental studies have been conducted by various researchers to study the dynamics of tractor. The housings of the tractor chassis were subjected to different static as well as dynamic forces in different studies, so as to observe the stresses developed and identify points of failure. Majority of work has been done on independent housings rather than on the whole chassis. Some of the work has been highlighted below:

- Structure analysis of Rear Axle Housing
- Finite element analysis of trolley axle
- Design analysis of Gearbox
- Vibration transfer in chassis
- Chassis load case and boundary conditions

2.1. Structure analysis of Rear Axle Housing

The studies [5,6,7] show force transferred on the rear axle of the tractor and the usual points of failure in an axle tube. Some solutions to improve the design have also been discussed.

2.2. Finite element analysis of Trolley Axle

The loads encountered by the axle of a loaded trolley have also been studied and studies have been conducted to reduce its weight and deflections under load [8].

2.3. Design analysis of Gearbox

Earlier work [9,10] also show the deflections due to external loads and internal forces occurring due to motion of tractor and shafts and gears respectively. It has been observed that majority of failures occur in the clutch housing.

2.4 Vibration transfer in Chassis

Vibrations cause fatigue loading in the chassis and studies [11] have been conducted to measure its values and reduce it. Thus, reducing the chances of fatigue failure.

2.5 Chassis: Load and boundary conditions

The boundary conditions play major role while analysis. Technique [12] to determine the boundary conditions and calculations to determine loads have also been highlighted in this study.

3. PROPOSED MODELLING

A systematic approach was utilized for conducting the study [13]. The proposed methodology for research has been given in the flow chart in figure 1.

Study of performance parameters of transmission system of a tractor

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Modelling of chassis assembly

↓

Estimating forces on the chassis

↓

Finite element analysis of the Chassis

↓

Generation of transmission system layout

↓

Performance evaluation of the transmission system

FIG 1. METHODOLOGY

3.1 Study of performance parameters of transmission system of a tractor

Gear trains are used for transmitting power from a driving unit to a driven unit, often with a change of speed. The output from the gear train can have a higher or a lower speed, depending on the requirements of the driven unit.

Power loss in the gear train results from viscous friction of lubricants, sliding friction between the meshing teeth and losses of energy due to vibration and noise, among other causes. Therefore, the power supplied to the gear train is always greater than the power delivered to the driven unit. Following power loss factors have been incorporated:

(i) Gear set losses

With the type of gear set being used, the efficiency losses may vary between major or minor. 0.5% to 3% loss is expected while using spur, helical and bevel gears. Losses up to 5% is experienced when a face gear is used. A few types like crossed helical, cylindrical worms and double enveloping worm experience losses between 5% to 50%, 10% to 50% and 2% to 50% respectively.

(ii) Seal losses

Seals are used for creating a barrier between the gearbox and the outside world and to prevent lubricants from leaking out. There is no impact on the efficiency of the gearbox when static seals are used between members of a gearbox. Dynamic seals come in contact with the rotating members and hence impact the efficiency. Efficiency is lost in form of friction and heat generated when shafts rotate between stationary seals. To reduce losses due to friction, lubrication is used. Different seal types lead to different amounts of losses due to resistance to rotating of shaft.

(iii) Bearing losses

There are many types and styles of bearings available. Roller bearing that do not have seals are the most efficient out of all the types available. A roller bearing provides the liberty to add numerous types of seals to it, but this results in addition of drag and lowering the gearbox efficiency. Many type of viscous greases are available to improve the efficiency of the bearing. Some other types of bearings available include iron bushing, moulded plastic bushing and powdered metal bronze.

(iv) Lubrication

Grease or oil is used to lubricate gearboxes. Various types of grease and oils are available bearing qualities such as: high temperature, extreme pressures, water resistance, corrosion protection, etc. Viscosity of a lubricant plays a major in increasing or decreasing the efficiency of a gearbox. Increase in viscosity occurs due to decreasing temperatures, thereby resistance increases within the gearbox. The opposite is also true, viscosity decreases with increase in temperature. Churning action is a result of addition of too much lubrication into the gearbox whereas inadequate lubrication will result in wearing of gears.

The power required to drive a gearbox is directly affected by gear set, seal, bearing and lubrication. A larger motor is needed to drive a gear system and overcome losses, it leads to increase in cost. Gear set losses are predicted on the basis of gearbox type being designed. The tough part is to determine the seal, bearing and lubrication loss. When designing a high load capacity gearbox, these losses may be neglected. But when designing a smaller gearbox, the losses become considerably high. Therefore, testing a gearbox especially at extreme temperatures become important so as to minimize losses.

3.2 Modelling of chassis assembly

The chassis that forms the backbone of a tractor and is one of the major component of a transmission system, was modelled using the software named SOLIDWORKS 2017. The part modeler was used to create various housings like clutch housing, gearbox housing, differential housing, brake housing and the axle tube housing. The assembly module was used to create the assembly by constraining the housings with respect to each other. Figure 2 shows the clutch housing, figure 3 shows the gearbox housing, figure 4 shows the differential housing, figure 5 shows the brake housing and figure 6 shows the axle tube housing.

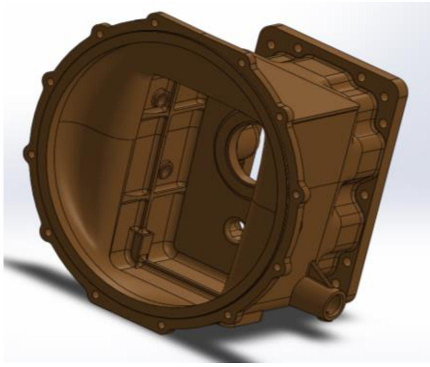


FIG 2. CLUTCH HOUSING

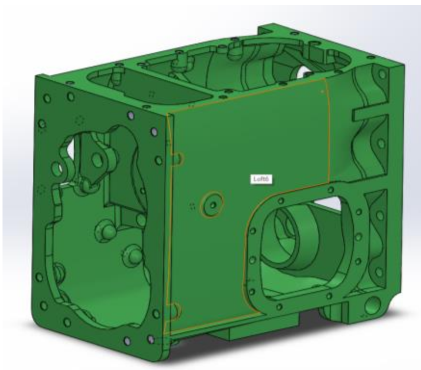


FIG 3. GEARBOX HOUSING

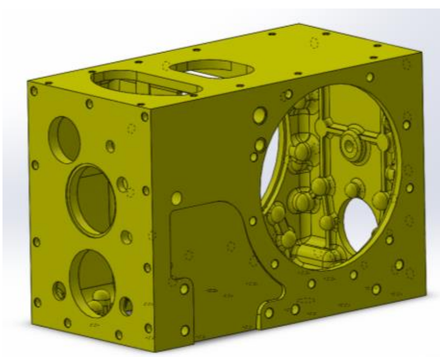


FIG 4. DIFFERENTIAL HOUSING

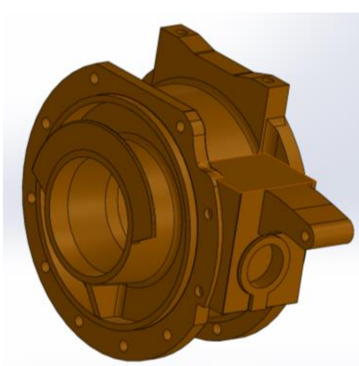


FIG 5. LEFT BRAKE HOUSING

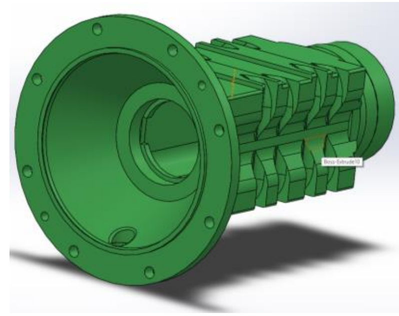


FIG 6. RIGHT AXLE TUBE

The assembly module was used to create the assembly by constraining the housings with respect to each other. Figure 7 shows the final assembled chassis in SOLIDWORKS assembly module.

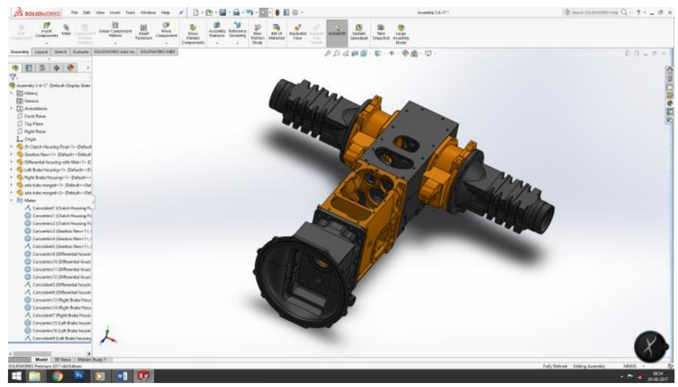


FIG 7. THE FINAL ASSEMBLY

3.3 Estimating forces on the chassis

During tillage operations in field, the chassis encounters mainly two types of forces, one is from the implement used and the other is the reaction force on the wheels due to self-weight.

The data in terms of draft force produced; collected by various researchers through experiments [14, 15, 16, 17, 18, 19, 20 and 21] are shown in table 1. It is clear from the data that the maximum draft force produced is in case of Mould Board plough (MB plough). Thus for analysis purpose a force equal to 17000 N was applied on the chassis.

Table 1. Draft force requirement of various implements

Sr. No	Implement	Draft Force (Newton's)
1.	Mould Board Plough	16300
2.	Chisel Plough	15410
3.	Disc Harrow	1800
4.	Field Cultivator	3490

The reaction forces estimated through mathematical formulas for 65 HP tractors has been shown. The wheel base and the weight of the existing 50 HP tractor was known but for finding the weight and wheel base increments in 65 HP tractor a study was conducted and data was collected to know the specifications of all 65 HP tractors in market. A comparative study was prepared, Table 2 shows the data for weight and average weight increment from 50 to 65 HP which was used for calculating various forces. Table 3 shows the data for wheelbase and average wheelbase increment from 50 to 65 HP which was used for the calculations.

A 65 HP tractor was considered as standing on plane surface, the forces acting on it have been highlighted in figure 8.

TABLE 2. WEIGHT OF EXISTING MODELS OF TRACTORS

Sr.No	Brand (Company)	Weight of 50 HP tractor (kg)	Weight of 65 HP tractor (kg)	Increment (kg)
1.	Indo farm	2035	2390	355
2.	John Deere	1870	2290	420
3.	Swaraj	2170	2330	160
4.	New Holland	2055	2405	350
			Average Increment	321.25

Table 3. WHEELBASE OF EXISTING MODELS OF TRACTORS

Sr.no	Brand (Company)	Wheel base of 50 HP tractor (mm)	Wheel base of 65 HP tractor (mm)	Increment (mm)
1.	Indo farm	3610	3810	200
2.	John Deere	3430	3535	105
3.	Swaraj	3420	3590	170
4.	New Holland	3045	3279	234
			Average Increment	177.25

Variables Considered

Wheel Base of 65 HP tractor (X) = 2107 mm. (considering average increment of 177 mm from table 3)

Weight of 65 HP tractor = 2500 kg. (considering average increment of 300 kg from table 2)

X_r - The distance of center of gravity from the center of rear wheel.

X_f - The distance of center of gravity from the center of rear wheel.

W_f - is the reaction force on front wheel.

W_r - is the reaction force on rear wheel.

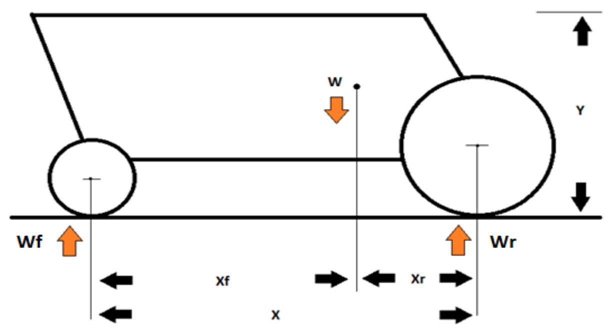


FIG 8. LINE DIAGRAM OF TRACTOR ON PLANE SURFACE

Calculations

$X_r = (W_f \text{ x } X) / W$ (Assuming X_r = 30% of X)

$0.30 \text{ x} = (W_f \text{ x } X) / W$

W_f = 750 kg.

It is known that the total weight is equal to the sum of the reaction forces on the front and rear wheel.

$W = W_f + W_r$

$2500 = 750 + W_r$

W_r = 1750 kg.

Reaction force on front axle

Total reaction force on front wheels = 750 x 9.81 = 7357.5 N

Reaction force on each front wheel = 7357.5 / 2 = 3678.75 N

Reaction force on rear axle

Total reaction force on rear wheels = 1750 x 9.8 = 17167.5 N

Reaction force on each rear wheel = 17167.5 / 2 = 8583.75 N

3.4 Finite element analysis of the Chassis

The aim of the analysis was to observe the deformations and stresses induced in the chassis of a tractor when a Mould Board plough was attached to the tractor and used for tillage operations. Hence a benchmark was set for the existing chassis design (50 HP) and then the same chassis was subjected to loads encountered by a 65 HP tractor during its service life which gave the evaluative results to determine the points of failure.

Analysis of operating conditions

For analyzing the benchmarked design under implements used with 65 HP tractor, a force equal to 8583.75 N was applied on both the rear axle ends and a pulling force of 17 kN acting on the link point was considered. The top of the engine was made fixed for the analysis. The material of the housings was taken as FG 250 using ANSYS 15.0 software

Screenshot in figure 9 shows the deformation that occurred in the chassis and figure 10 shows the maximum deformation that was observed at the ends of the rear axle. The value of deformation at link point was observed to be 1.40 mm and at the differential rear wall, it was found to be 1.25 mm.

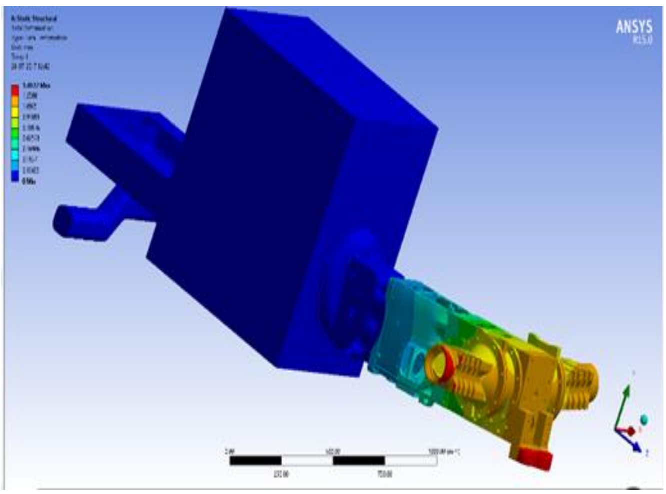


FIG 9. TOTAL DEFORMATION UNDER IMPLEMENT LOADS

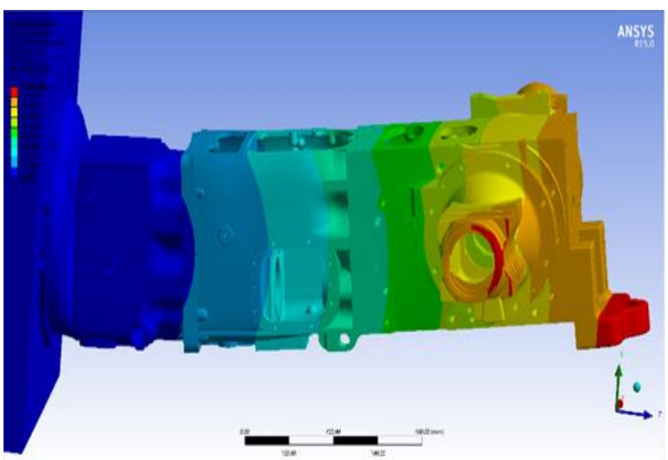


FIG 10. TOTAL DEFORMATION UNDER IMPLEMENT LOADS (MAGNIFIED)

Under the same conditions, figure 11 shows the stress distribution in the overall chassis. Figure 12 shows the clutch housing where maximum stress of 141.04 MPa was observed which is highlighted by red color in the same screenshot.

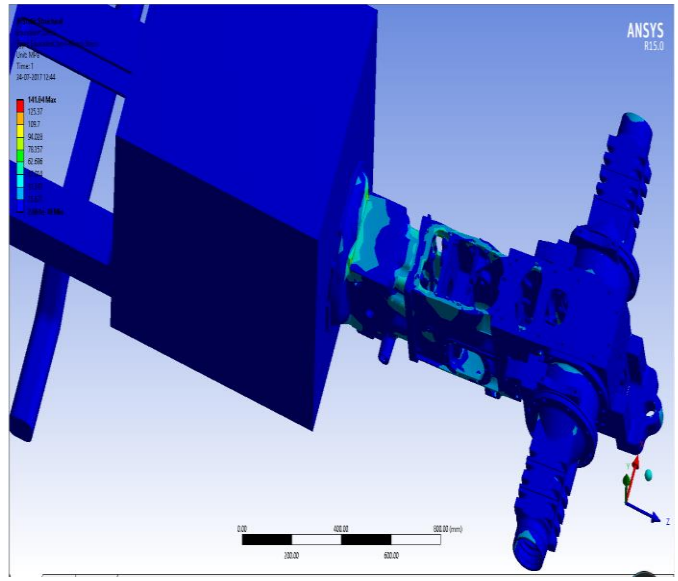


FIG 11. EQUIVALENT STRESS OF 65 HP TRACTOR UNDER IMPLEMENT LOADS

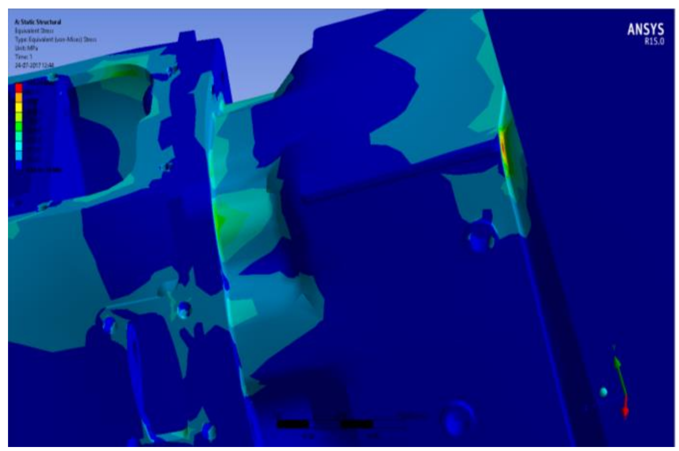
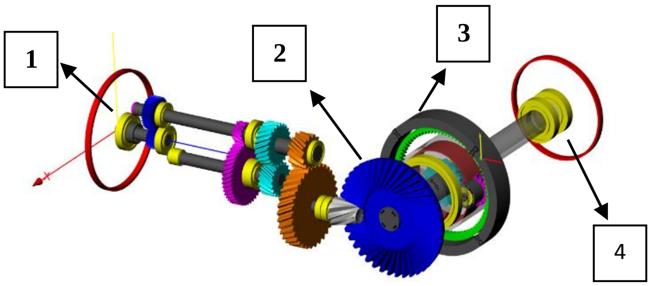


FIG 12. STRESS CONCENTRATION ZONE IN CLUTCH HOUSING UNDER IMPLEMENT LOADS

Similarly, the analysis for benchmarking of 50 HP design was performed. In this case, maximum deformation of 1.27 mm was seen at the ends of the rear axle and the maximum stress of 124.85 MPa was induced in the trumpet of the chassis.

3.5 Generation of transmission system layout

In the present work, KISSsoft 17 helped in designing and developing the transmission line. The model representing the gears interconnected (when 1st gear of the tractor transmission is engaged) was modelled and considered for analysis because first gear delivers maximum torque through the system. KISSsoft calculated the loads and moment encountered by the gears, bearing and shafts when an input of 65 HP was provided to the transmission system, it also helped to determine the power losses. Figure 13 shows the final gear train prepared for evaluation.



Labelling description

1 - Input coupling (representing the flywheel)

2 - Crown gear

3 – Epicyclic gear system

4 – Output coupling (representing the wheel)

FIG 13. FINAL LAYOUT OF GEAR TRAIN

3.6 Performance evaluation of the transmission system

The existing gear drive was modelled with the specifications and then benchmarking as well as evaluation was done for the system. A comparative study of overall transmission losses was prepared, considering a case where 50 HP transmission system was used with a 65 HP engine. The common aspects to both the cases were that the system was considered to be air cooled through conduction via the housing walls and the system partially submerged in oil. Only the input in terms of torque and power varies in both the cases. Figure 14 shows the setup used in analysis.

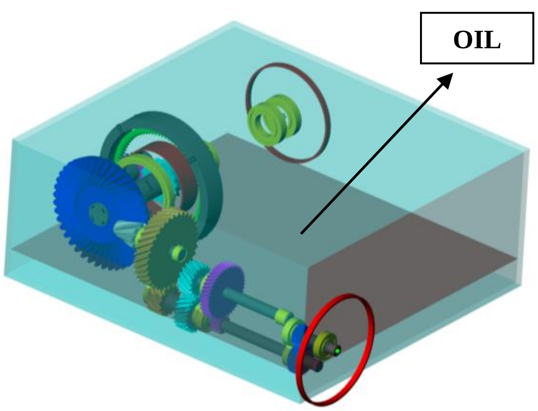


FIG 14. GEARBOX LAYOUT

Case I: Analysis of transmission losses for 50 HP tractor

For evaluating the losses in the existing design and to set a benchmark, the analysis was conducted with the input provided at the input coupling which replicates the clutch of a tractor. Figure 15 shows the input given.

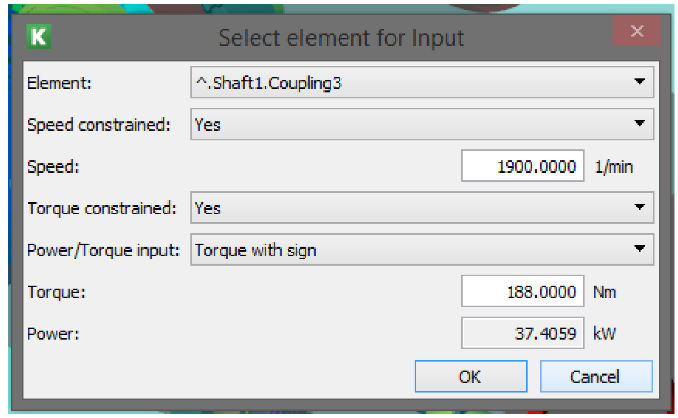


FIG 15. INPUT PARAMETER FOR 50 HP

Figure 17 shows the performance report generated by the software for 50 HP input.

Case II: Analysis of transmission losses for 65 HP tractor

To calculate the losses in the existing design and to evaluate it when used with a 65 HP engine the analysis for performance evaluation was performed and the input was given at the input coupling as shown in figure 16.

Figure 18 shows the performance report generated by the software for 65 HP input.

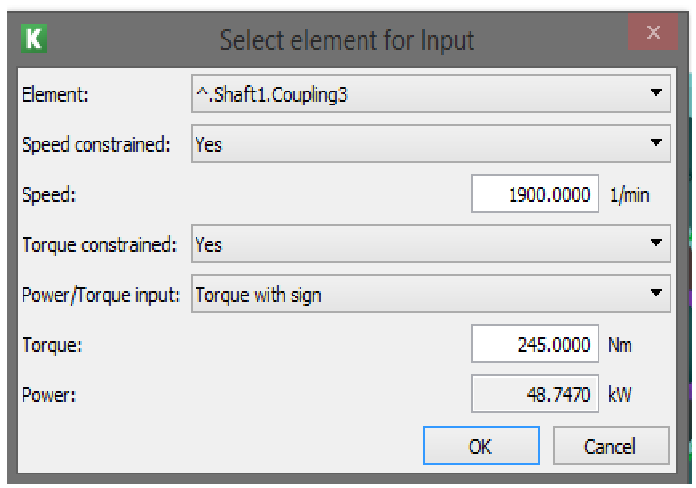


FIG 16. INPUT PARAMETER FOR 65 HP

4. RESULTS AND DISCUSSION

The outcome of the analysis performed under forces during tillage operation have been shown and discussed in detail. The percentage increment in the values of deformation and stress induced have been shown and on basis of factor of safety calculated for 50 and 65 HP cases, the chassis design has been declared safe for use. The transmission losses have also been highlighted for 50 and 65 HP case and percentage loss has been evaluated.

FIG 18. PERFORMANCE REPORT FOR 65 HP

Efficiency | Losses | kSys3DView

	A	B	C	D	E
1	**CALCULATION SETUP**				
2	Requested Result	Efficiency		Units	W
3	Calculation Method	ISO TR 14179-2		Contact Analysis	No
4					
5	Housing	Settings	Ventilation	Lubrication	Oil Cooler
6					
7	**SPECIFIC FUNCTIONS**				
8	Reset		Consistent		Report
9					
10	**RESULTS SUMMARY**				
11	Power Input [W]	37405.9		Efficiency (total) [%]	88.62
12	Power Output [W]	33150.1		Efficiency (gear mesh) [%]	94.72
13	Power Losses [W]	4255.8		No Req. Result	0
14					
15	**LOSSES AND DISSIPATIONS**				
16	**Heat Generated**	Correction Factors		**Heat Dissipated**	Correction Factors
17	Gear Churning Losses PVZ0 [W]	273		Housing [W]	0
18	Gear Meshing Losses PVZ [W]	1975.4		Foundations [W]	0
19	Bearing Losses PVL+PVL0 [W]	2007.4		Input/Output Shafts [W]	0
20	Seal Losses PVD (+rest PVD0) [W]	0		Oil Cooler [W]	0
21	Total Power Losses [W]	4255.8		Total Dissipation [W]	0

FIG 17. PERFORMANCE REPORT FOR 50 HP

Efficiency | Losses | kSys3DView

	A	B	C	D	E
1	**CALCULATION SETUP**				
2	Requested Result	Efficiency		Units	W
3	Calculation Method	ISO TR 14179-2		Contact Analysis	No
4					
5	Housing	Settings	Ventilation	Lubrication	Oil Cooler
6					
7	**SPECIFIC FUNCTIONS**				
8	Reset		Consistent		Report
9					
10	**RESULTS SUMMARY**				
11	Power Input [W]	48747		Efficiency (total) [%]	87.95
12	Power Output [W]	42872.4		Efficiency (gear mesh) [%]	94.52
13	Power Losses [W]	5874.6		No Req. Result	0
14					
15	**LOSSES AND DISSIPATIONS**				
16	**Heat Generated**	Correction Factors		**Heat Dissipated**	Correction Factors
17	Gear Churning Losses PVZ0 [W]	260.6		Housing [W]	0
18	Gear Meshing Losses PVZ [W]	2670		Foundations [W]	0
19	Bearing Losses PVL+PVL0 [W]	2944		Input/Output Shafts [W]	0
20	Seal Losses PVD (+rest PVD0) [W]	0		Oil Cooler [W]	0
21	Total Power Losses [W]	5874.6		Total Dissipation [W]	0

4.1 Analysis under loads

Table 4 shows a comparison of deformation, stress induced and factor of safety in the chassis between the benchmarked design (50 HP) and the same design under the load of 65 HP.

TABLE 4. COMPARATIVE STUDY OF ANALYSIS UNDER LOADS DUE TO MB PLOUGH

Sr. No	Parameter	50 HP tractor	65 HP tractor	Percentage Change
1.	Max. Deformation (mm)	1.27	1.40	10.23
2.	Max. Stress Induced (MPa)	124.85	141.04	12.96
3.	Factor of safety	2	1.77	11.5

4.2 Analysis of gear-train

For evaluating the losses in the existing design and to set a benchmark, the analysis was conducted with the input provided at the input coupling which replicates the clutch of a tractor.

Table 5 highlights the results obtained when input of 65 HP was given to the transmission system layout created on KISS-SOFT. Figure 19 shows graphical representation of the losses that occurred in the transmission system. It was seen that there was an overall loss of 5874.6 W loss which comprised of gear churning loss of 260.6 W, gear meshing loss of 2670 W and the maximum loss is due to bearing loss of 2944 W.

TABLE 5. PERFORMANCE EVALUATION OF TRACTOR

Sr. No	Parameter	Value
1.	Input power (W)	48747
2.	Output power (W)	42872.4
3.	Power Loss (W)	
	a. Gear churning loss	260.6
	b. Gear meshing loss	2670
	c. Bearing loss	2944
	d. Seal loss	0
	Total power loss (W)	5874.6

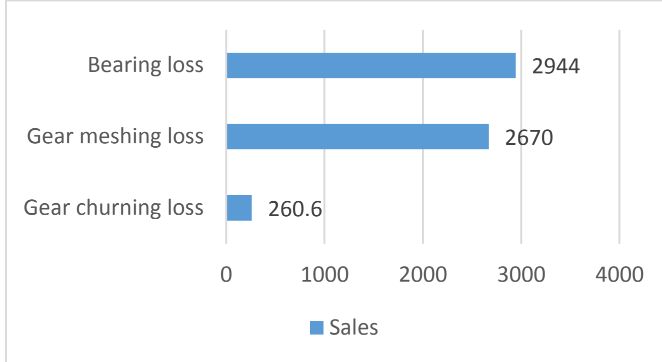


FIG 19. GRAPHICAL REPRESENTATION OF TRANSMISSION LOSSES IN 65 HP

A comparative study in table 6 highlights the losses in the transmission when used with 65 HP engine as compared to the benchmarking results.

TABLE 6. TOTAL LOSS COMPARISON

	50 HP (BENCHMARKING)	65 HP (EVALUATING)
Input (W)	37405.9	48747
Output (W)	33150.1	42872.4
Total loss (W)	4255.8	5874.6

Figure 20 brings out the graphical representation of difference between total losses that were observed in the transmission system.

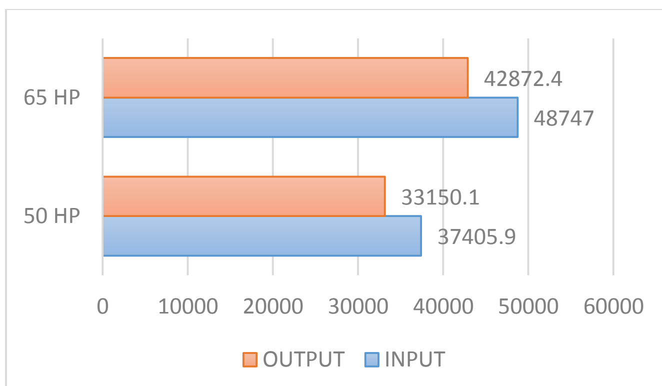


FIG 20. GRAPHICAL REPRESENTATION OF TOTAL LOSS BETWEEN 50 AND 65 HP TRANSMISSION SYSTEM

After analyzing the two cases, it was clear that if the transmission system of 50 HP tractor is used for 65 HP tractor then there will not be huge difference in losses of the two when compared hence, the transmission system needs no modifications as far as the losses are concerned.

There was 11.37% loss in 50 HP tractor and 12.05 % loss in the same system with 65 HP input. The difference comes out to be 0.68 % which is very less hence the system can be used as it is in the new tractor design. But due consideration must be given to bearing life and gear life before implementing this design with a higher HP engine.

5. CONCLUSIONS

The bench marked design was tested for higher HP engine. Initially the existing design was tested under different loading cases for which it was designed. The stresses induced and the deformation that occurred provided a standard to begin with. In the second step, the same design was tested for the new loading case. The stresses induced and the deformation values gave base to determine the safety of the design. When these values were compared with the benchmarked values following conclusions are drawn:

- When the chassis was analyzed for forces produced while using MB Plough, it was observed that a maximum deformation of 1.40 mm occurred at axle ends and a maximum stress of 141.04 MPa was induced in the trumpet of clutch housing.
- The factor of safety remains above 1 and hence the chassis of 50 HP tractor is safe to be used with 65 HP tractor also.
- The transmission system showed a total loss of 4255.8 W and 5874.6 W when 50 HP and 65 HP engines were considered to be providing input at the flywheel respectively.
- In both the cases of transmission system, bearing losses were found to be maximum and gear churning losses to be minimum.
- While comparing the losses of 50 HP with 65 HP there was an increment of 0.68% in 65 HP transmission which is very small.

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