

Design Process of a Low Cost Tractor

Christina Popa, and Dorina Ionescu

Abstract— The concept of a South African tractor is not new but due to import options, there was never a known / well established South African brand. Due to the shrinkage of the South African mechanical manufacturing industry by nearly 40 % in the last years, a successful tractor design and manufacturing will contribute toward the much needed job creation.

Due to its complexity the project is a combination of outsourced components and newly designed parts. The integration of design establishes the layout of the tractor with the aid of virtual 3D solid modelling. The design aim is to produce a tractor able to provide adequate power for an existing Grader machine at a lower cost than the actual market offers for similar power rating tractors.

Keywords— Mechanical design, cost, selection, modeling

I. INTRODUCTION

THE rural road upgrades in South Africa and in general on the African continent it is considered to be the key to poverty relief and growth of rural areas. Roads for Africa, a project initiated by Terragrader (Pty) Ltd under a Public-Private Partnership, is formulated to achieve fast track empowerment, job creation and poverty relief. The program is aimed at poor and unemployed semi-skilled/unskilled women from rural areas that will receive training, full equipment and all logistical needs in order to start refurbishing rural roads. Furthermore the equipment is to be locally manufactured at a lower cost than imported machinery, therefore boosting local manufacturing industry and create more jobs.

At present, a multifunctional grader machine have been designed and produced, that will mechanically refurbish existing earth roads or create new such roads in rural or informal areas in South Africa. The grader machine is not autonomous hence a tractor with adequate power needs to tow it. Research shows that the agricultural sector in South Africa depends mainly on imported machinery. The prices of imported tractors according to AGRIFACTS [1] were in 2012 between R7070 and R 9400 per kW power, making them expensive for the project consequently the decision was to design a low cost tractor that can be locally assembled.

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II. DESIGN PROCESS

A. Background research

The design process started with the background search on tractors that showed a brief history and classification of tractors in terms of uses or in terms of power delivered. The research revealed that there is a great variety of designs specific to the task required to perform and sometimes to the industry. Tractors are used on farms for farming operations like plowing, tilling, planting, harvesting, insecticide spraying, etc. or transport of farming products. Specially designed tractors are used in orchards and vineyards and also in forestry. Apart for the agricultural applications, tractors are used in constructions and mining industries. It was found that IITA (International Institute of Tropical Agriculture) classifieds tractors into six main types [2].

B. Design Requirements and Constrains

The general design requirements have been established as follows:

- The main function of the tractor is to provide traction means and hydraulic power for Terragrader machine hence deliver the required power as well as be equipped with an hydraulic power system;
- The tractor should be versatile such as, when not towing the Terragrader, it must be able to be used as an agricultural tractor for farming activities (i.e. consider a three-point hitch at the rear for attachment of agricultural implements);
- The machine should be simple in design therefore easy to run and maintain by semiskilled operators. That implies no electronic controlled components and basic controlled board.
- The machine will be built as a combination of ready to use, off the shelf components and locally manufactured parts that are assembled locally.
- The cost must be at least 20% less than a tractor sold on South African market with the same engine power rating.
- The machine must conform to safety regulations and road regulations, i.e. to be fitted with brakes and ROPS as well as all mirrors, lights and signals.

The design constrains have been summarized as follows:

- Low cost of components, assembly of the machine, service and maintenance;
- Robustness and simplicity of design;
- Ease of operation and maintenance;
- Good reliability.

C. Tractor Configuration

The selected configuration is a full time four wheel drive

with the engine situated longitudinally in front of the driver's seat coupled with the clutch. A coupling shaft will connect the clutch to the transfer case from where drive shafts will transfer power to the front and rear final drives via differential units build in the axles.

D. Engine Selection

With the general layout configuration established, the next step in design was to select the engine. Between a petrol engine and a diesel engine, the later will be selected considering that the majority of agricultural machinery are powered by diesel engines due to the fact that they are easier to maintain and repair, deliver more power at low speed and have a strong and sturdy construction, hence a longer life. Other consideration for the engine selection was engine power requirements. The Terragrader designer conducted research in order to quantify the mechanical power from the pulling force required for the scarifying, grading and stabilization operations. The towing capacity and the power of the tractor was recommended to be 52750 N and 123 kW (167 hp) respectively [3]. In conclusion, the tractor engine power has to be between 120 kW (163 hp) and 125 kW (170 hp). Investigation shows that naturally aspirated engines are available for up to 90 kW (122 hp) power. To achieve higher power all engines are turbocharged, hence naturally aspirated will not be considered as criteria for selection.

The summarized selection criteria for the engine: a cost effective diesel engine, turbocharged, with 120 to 125 kW power (163-170 hp). After thorough research, a few diesel engines for agricultural purposes have been selected from a long list of diesel engines manufacturers as shown in Table I. Many brands were excluded for either not being suitable for the purpose or, like Kubota and CaseID, having lower power range than required.

TABLE I
SELECTED DIESEL ENGINES

	Manufacturer	Model	Displacement [l]	Peak power [kW/hp]	Peak torque [Nm]	Aspiration type	Price Excl. VAT	Notes
1.	Fiat Powertrain Technologies	N45ENT	4.5	104/141 @2200rpm	608 @1600rpm	TAA	R 67 450	Excludes radiator PTO optional
2.	Fiat Powertrain Technologies	N67MNT	6.7	129/175 @2200rpm	770 @1250rpm	TAA	R 78 340	Excludes radiator PTO optional
3.	John Deere	6068T	6.8	127/170 @2500rpm	606Nm @1200rpm	Turbo	R 129 000	Includes: radiator, cooling fan
4.	John Deere	4045H	4.5	115-129/154-173 @2400	645 @1500rpm	Turbo	R 123 123	Includes: radiator, cooling fan
5.	Cummins	85.9 6BTA5.9C 165		123/165 @ 2200rpm	675 @1500rpm	Turbo	R 91 500	Excludes radiator and delivery Radiator price R15000; total R106 500

A decision matrix have been formulated for the above engines in terms of power requirements, cost, engine complexity and technical support availability as shown in Table II.

TABLE II
ENGINE SELECTION DECISIO MATRIX

	FPT N45 ENT	FPT N67 MNT	John Deere 6068TF250	John Deere 4045H	Cummins 6BTA5.9C 165
Power requirements (kW)	104	129	127	115-129	123
Cost (ZAR) excl.VAT	67450	78340	109000	103123	91500
Engine complexity	Tier 3	Tier 3	Tier 1	Tier 1	Tier 2
Tier/Aspiration	TAA	TAA	Turbo	Turbo	Turbo
Technical support availability	2	2	3	3	2
TOTAL	9	13	12	11	11

The scores shown are from 9 to 13 with the lowest for FPT N45 ENT engine, while the highest score is recorded by FPT N67MNT as heaving suitable power, good price, good technical support and level of complexity. Therefore this engine is selected for the application.

E. Clutch Selection

A dry clutch is selected since has no service requirements and is less expensive for which the calculated maximum disk diameter is 205 mm (8.07 in). From the engine specifications, the engine flywheel side is 292.1 mm (11.5 in).

Clutches that have been considered are:

- Twin disk SP 211P3, with max input torque of 1235 Nm (910 lb-ft), SAE 3 housing, 2 plate and organic facing.
- Eaton SOLO self-adjust medium duty clutch, 109500-10(3ST), 3 Super Traps, 2 discs DCF-CO-LR dampened, ceramic facing, coaxial.

Both of the above clutches are available in the local market however, in consultation with the engine supplier specialist, the Twin disk SP 211 was recommended as a better match for the engine.

F. Transmission Selection

In selecting a transmission, the following criteria should be addressed:

- Power matching and efficiency
- Ease of operation and reliability
- Low maintenance cost
- Ease of maintenance and repair
- Installation dimensions and weight
- Cost

Research shows that transmissions for tractors available on the market are assemblies of transmission, differential, rear axle and other components of the driven axle into one unit called transaxle. That provides a compact arrangement of all the systems in one place and eliminates the drive shaft from transmission to the driven axle in 2WD vehicle. From a general design point of view this is a desirable option because not only it reduces the process of sourcing and selecting each and every component while having to ensure the compliance of one with another but it also takes care of the system torsional compatibility. As seen in Fig.1, the transaxle cast casing provides the rigid frame on which the cabin and seat are mounted.

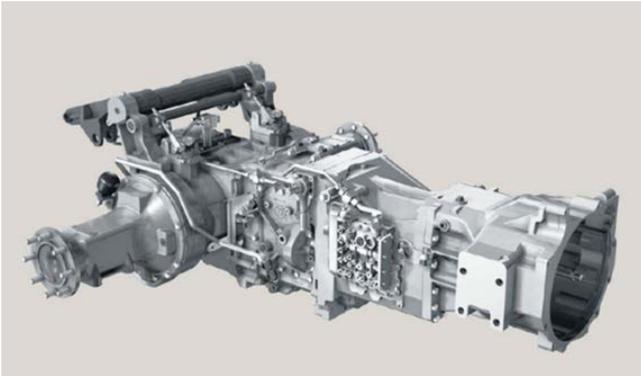


Fig. 1 ZF Synchronmesh Transmission T500 –T600 series

Against the design criteria specified above, such transaxle is expected to be highly reliable and to have a more strict maintenance schedule. The cost of a transaxle may be slightly higher than the price of every component sourced and purchased separately. Apart for regular maintenance no repairs can be done on the site since it is so compact and almost half of the vehicle has to be disassembled in order to get to the defective part of the

A number of six transmissions have been short-listed from companies like John Deere, ZF, Twin Disk and Eaton and the most suitable transmission is the ZF T-7000series transmission which is a complete transaxle that comprises of transmission, rear differential axle, and transfer case for 4WD, rear PTO and 3 point hitch for agricultural implements. In consultation with the Technical specialist from ZF South Africa, the T-7232 powershift transmission from the T-7000 series have been selected.

G. Axles and Tires Selection

Requirement for the front axle is to match the rear axle and to be steerable. A matching steering axle have to be selected from the same manufacturer. The available steering axles from ZF are:

- The AS-3000 Agrosteer series,
- The new series, ZF- Terrasteer.

The recommended one by ZF technical consultant is the Agrosteer series as more suitable for the application and cost effective from which AS-3050 have been selected.

A size range for the rear tires are recommended by the transaxle manufacturer and based on that a 20.8R42 is selected. This is a radial tire with a 528 mm (20.8 in) side wall, 1936 mm (76.2 in) outside diameter and 8190 kg (19630 lbs) static recommended load.

The matching front tires selected are 18.4R30 with 1545 mm (608.3 in) outside diameter, 467.36 mm (18.4 in) width and 467 mm side wall.

H. Integration of Design

After selecting the major parts, in order to prepare the layout of the tractor, each of the major components have been modeled individually using Autodesk Inventor 2012 as the 3D Solid modeling package. The models include major dimensions and accurate position of the mounting/assembly points. No fine details have been included since it is considered time consuming and irrelevant for the purpose of

establishing the layout. Fig. 2 shows the individual models of the transaxle, steering axle and the engine.

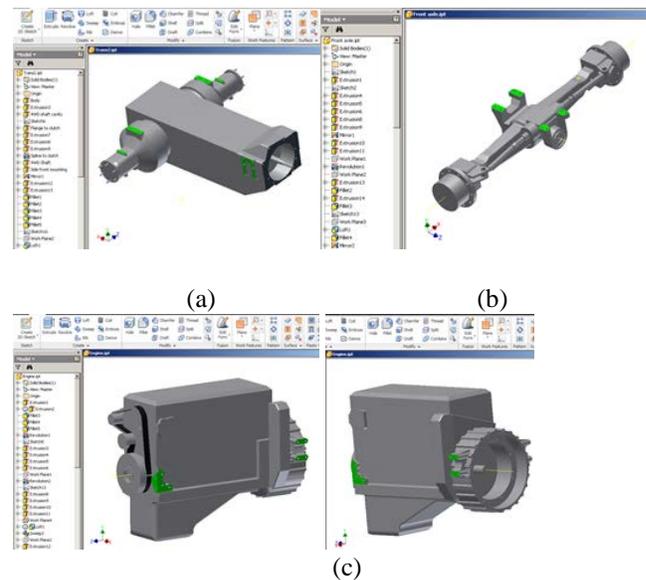


Fig. 2 3D Models of: (a) Transaxle, (b) Steering Axle, (c) Engine

The layout of the tractor is created in Inventor assembly environment. Firstly the transaxle, clutch and engine are assembled together using created work axes and planes and Mate, Insert and Angle constrains to align them up. Their common horizontal axis (longitudinal axis) is the assembly Z axis, the transversal axis is the assembly X axis remaining that the vertical axis is the assembly Y axis.

In order to determine the position of the front axle on Y direction, the wheels and tires have been modeled and assembled on both rear and front axle.

The front suspension have been designed as a three link type with a swivel bracket that has a pivot point and on each side, mountings for the shock absorbers as shown in Fig. 3.

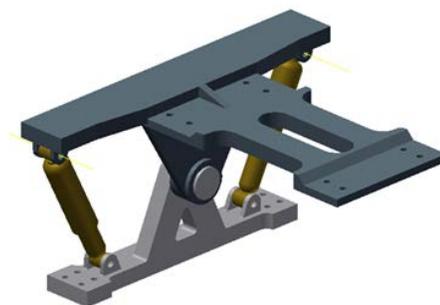


Fig. 3 3D Models of the front suspension assembly

Although the transmission, clutch and engine are connected there must be a structure that supports the engine and the front axle and that is a frame that needs to be custom designed to this application. The idea for the frame is to create it from steel plate with welded and/or bolted sections. The frame should have cross members and brackets to match the engine mounting points. The approach used is to use the created layout and start from the transmission mounting points with the

first panel. This panel will also provide mounting brackets for the rear of the engine. Between the left and right panel a cross member is designed with brackets on the middle to fix the gear box attached to the transaxle.

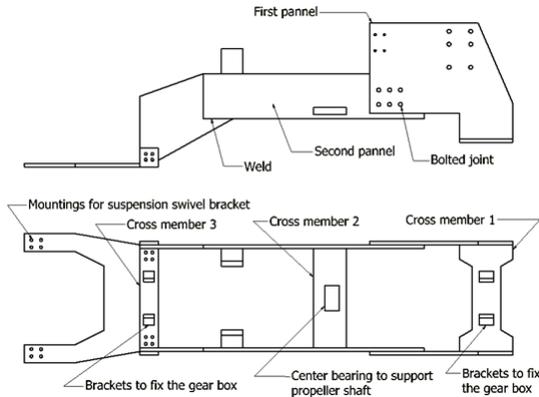


Fig. 4 Frame design

The second panel is bolted into the first one and has welded brackets on the inside for the front side of the engine mounting. The proposed design of the frame is shown in Fig. 4. The center bearing on Cross member 2 does not form part of the frame. It is inserted in the drawing to show the location of it and that it is going to be fixed on that particular cross member. The material for the frame is Weldox 700 that is a general structural steel with 700 MPa yield strength

As the integration of the main components have been completed, the final layout of the model is shown in Fig. 5 and overall dimensions summarized in Table III.

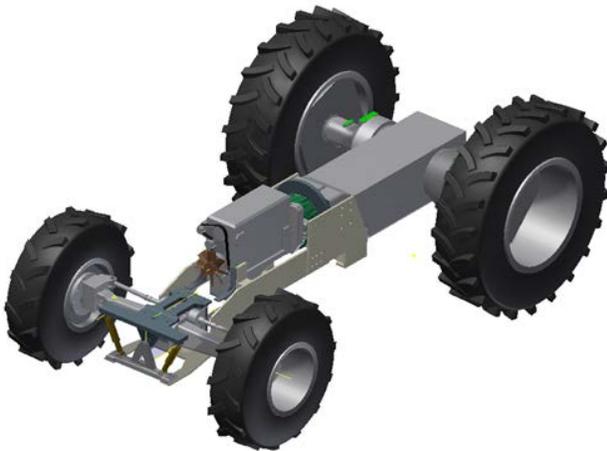


Fig. 4 3D model of the tractor

TABLE III
Overall Dimensions Of The Tractor

Length tire center to tire	3283
Front width – center of the	2231
Rear width – center of the	2303
Overall length	4863
Overall width	2831

III. COST ANALYSIS

The aim was to design a tractor that is cost effective therefore to have a lower price as compared with the already existing tractors on the market. The cost analysis used the prices from quotations obtained at the time (2012) except the frame and the suspension system that have been estimated. There are some other costs not included like the cabin, the seat and the control board. Also the assembly man/hours of the whole machine have not been included as it is difficult to estimate how long takes the assembly process for the prototype. If a 30% is added to the above total to cover for all the unaccounted costs, the price of the prototype will then be R 607 500.00 excl. VAT or R 692 550 inclusive VAT.

IV. PRICE COMPARISON

The price for tractors with approximate same power rating extracted from AGRIFACTS [1] are shown in Table IV where the less expensive tractor is a Massey Ferguson that can be purchased for R 991 773 (VAT inclusive). Its price is approximately R 299 223 higher than the price of the designed tractor and that represents a considerable price difference. The difference will be actually even greater because, when mass producing the machine, the cost will be 10 to 15% lower since a better price is offered for buying more components at the time as compared with a single one and the assembly line is already set up and running at lower costs than for the prototype.

TABLE IV
IMPORTED TRACTOR PRICES

Tractor make and model	Engine power (Kw)	Inclusive Price	Price Excl. VAT
John Deere	110	R 1 181 854	R 1 036 714
Massey Ferguson	123	R 991 773	R 869 976
McCormick	123	R 1 079 808	R 947 200
New Holland	124	R 998 925	R 876 250
Valtra	125	R 1 052 886	R 923 584

V. CONCLUSIONS

This work proves that a tractor of a medium power rating can be assembled locally with off the shelf parts and assembly components available on the local market. The selected components are manufactured by well-known companies, are new and highly reliable. That gives assurance of good quality and sturdiness of the whole machine. Although the components are not low priced, the cost of the entire machine, as shown above, it is considerably lower (30%) than to purchase for example a new Massey Ferguson or New Holland tractor.

REFERENCES

- [1] Information on - <http://www.agfacts.co.za/tractorprices.htm>;
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