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Development of Computer Software for Design of 16+4 Speed Gearbox for Tractor and Practical Validation

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Research Article

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ABSTRACT

Indian tractor industry is now the largest in the world in number of unit production with an average of more than 2 lakhs unit production per year. Export market of tractor is also increasing on an average 30-40% rate. At present most of the tractor models produced in India has (6+2) or (8+2) speed gear box. But it is already proven that more number of speed options can reduce fuel consumption and can increase possibility of power-load matching. To meet the requirement of market demand and better performance, a new “16 forward + 4 reverse” speed gearbox, is required to be designed and developed. To automate the highly technical and time consuming design procedure, a software has been developed by using Visual Basic 6.0 language. Up-shift analysis is very important for efficient gearbox design. During design up-shift spectrum has been kept as even as possible. Slip torque and duty cycle concepts has been introduced for engineering optimization of the gearbox parameters. Introduction of slip torque and duty cycle concept reduced face width of different gears from 9 to 34 %. Stress analysis shows that in all the cases design bending and contact stress are within 10% than the corresponding induced stress values. With the result of the developed software, a prototype of new gearbox has been developed. Haulage testing was carried out with the new prototype. The new prototype resulted in 8.6 % reduction in total fuel consumption for 10 km run on level road as with the new prototype better matching of load vs. pull was possible.

Keywords: 16 speed gearbox, tractor, up-shift, performance analysis;

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1. INTRODUCTION

India holds fourth position in world for total number of tractor in use after USA, Japan and Italy (Anonymous, 2004). At present India is the largest producer of tractor in number of unit sale. India produces mainly 20 - 65 hp range tractors which are suitable for domestic small Indian farms (Mondal and Rao, 2005; Edwards, 2002). Presently there are more than 2 million tractors, which effectively control 41.4 million ha (28.95% of cultivated area). The current need is for about 2.75 million additional tractors: 1.25 million for additional power and about 1.5 million for replacement. The average annual demand will be about 3.43 lakh tractors over the next 8 years. By 2010, the tractor population needs to be increased to 4.13 million tractors (Anonymous, 2006). Export market of tractor is also increasing on an average 30-40% rate. Export market includes developed countries like USA, different European countries to third world countries like Bangladesh, Sri Lanka etc. The tractor industries are always under pressure to produce fuel efficient and comparatively inexpensive tractors to match the socioeconomic capabilities of the Indian farmers. One of the trends, as an answer to this problem, is the design of an efficient tractor transmission system. Most of the tractor models produced in India has (6+2) or (8+2) speed gear box. It is already well known that more number of speed options can reduce the fuel consumption and can increase possibility of power-load matching (Mondal et al., 2007). In view of the above argument, the objective of the present investigation is to design and develop a computer software to design a“16 forward+4 reverse” speed gearbox and subsequent practical validation.

2. MATERIALS AND METHODS

2.1 GEAR SPACING DESIGN

Designing effectively entails disciplined methodology in the treatment and analysis of information. The operators appreciate having speed selection suited to the load, the job, or the implement being used, in order to maximize vehicle productivity (Browning, 1978). Gear spacing decision considers factors of cost, efficiency and complexity. Percent upshift is an important criterion for gear spacing. It is given as

$$\% \text{ Upshift} = \{(\text{speed in Gear}_2 / \text{speed in gear}_1) - 1\} \times 100 \quad (1)$$

An extensive survey with 29 models of Indian tractors was carried out to know the percent upshift value. This knowledge bank was created to finalize the speed and upshift value of new transmission system. 30-40 hp segment consists 57% and greater than 40 hp segment consists 21% of Indian tractor market. It was found that most of the transmission systems of Indian tractors have high as well as irregular upshift value, which is not desirable. A low and regular upshift value is an essential part for proper design of transmission system. 2.5 and 30 kmph were selected as the target lower and upper limit speed for the new transmission system. The gearbox has to be designed for 39 hp engine, which was having 2000 rated rpm and the peak torque of engine was 15.2 kg-m.

2.2 SOFTWARE DESIGN

To automate the tedious gearbox design job one software, namely "16 speed Gearbox Designer Software" **(**16 speed GBDS) was developed using Visual Basic 6.0. This software has two modules, namely 'gearbox design part' and 'gear design part' (Mondal, 2004).

2.2.1 Module I: Gearbox design part is used for analysis of upshift, calculation of theoretical speeds and practical speeds, finalization of gear reduction ratios at different stages etc. Gear design part is used to calculate different design parameters of gear like fatigue life, contact ratio, bending and contact stress and different gear dimensions etc. By using this part of 16 speed GBDS all the upshift values, intermediate speeds and gear reduction ratios were calculated. Gearbox design part was developed step by step. First from different manual inputs like required lowest speed (ls) and highest speed (hs), first constant reduction (fcr), second constant reduction (scr), engine rpm (erpm), high-low reduction (hlr), crown wheel pinion reduction (cwpr), bull gear reduction (bgr) and rolling radius of tire (rrt) are entered. Then from these values theoretical upshift (us) value was calculated. In the second step on basis of theoretical upshift value, all theoretical speeds (tspeed 1-16) were calculated. In the third step practical gear reduction ratios (fgrr, sgrr, tgrr, fogrr) were calculated on the basis of theoretical speeds. In the fourth step practical speeds (wspeed 1-16) and practical upshift (us 1-15) values were calculated on the basis of realistic gear reduction ratios, calculated in the third step. Algorithm for module-I of 16 speed GBDS has been given in Fig. 1.

2.2.2 Module II: Proper design of gears is very complex job. It involves torque calculation, stress analysis, gear life calculation, face width calculation, gear geometry calculation etc. All these works require lot of man-hour. 'Gear design part' of 16 speed GBDS was designed to do all these previously mentioned jobs.

2.3 GEARBOX PROTOTYPE

A gearbox prototype was developed by using the newly designed gears and shafts and selected bearings. Centre shift pattern has been used for regular gear shifting and high low selection. One special right hand side shift arrangement was developed to shift between first constant reduction and second constant reduction (Mondal, 2004).

2.4 PERFORMANCE TESTING OF NEW GEARBOX

The newly developed gearbox prototype was tested for haulage operation, most common operation done by Indian tractors, with a single axle trailer having 10 ton payload. Before testing regular checking of the vehicle like lubrication oil level, radiator water level etc. have been checked. Pressure of front and rear tire were kept 2.2 and 1.1 kg cm^{-2}, respectively. During the test application of clutch and brake were avoided as much as possible. For the first trial the tractor was operated with regular (8+2) speed gearbox. And second trial was made with the newly developed (16+4) speed gearbox. In both the cases the tractor was operated for 10 km distance on a level tarmacdam road. Indian standards were followed to measure the actual speed of the vehicle during testing.

Fig. 1 Flowchart of 'gearbox design part' of 16 speed GBDS

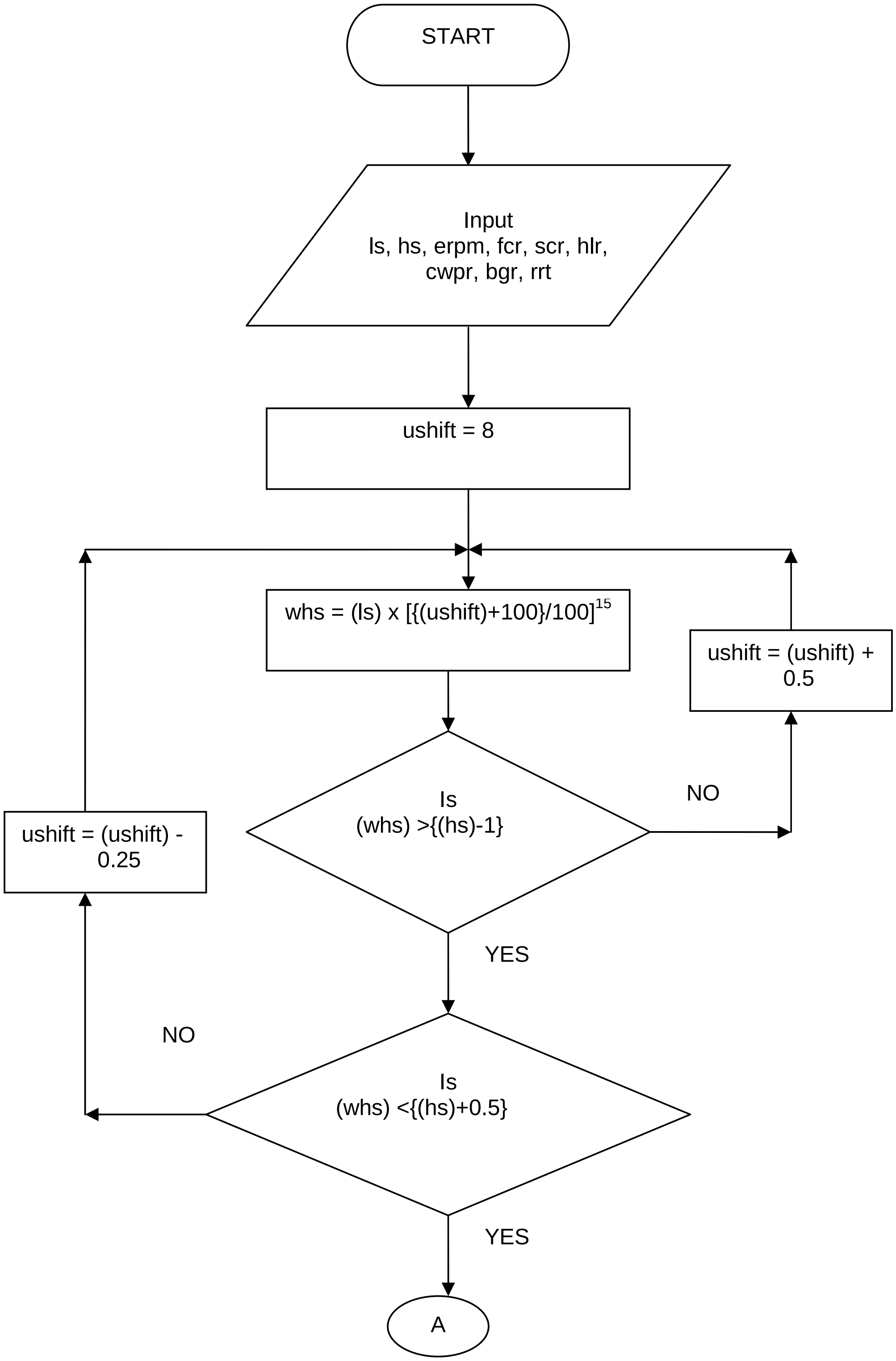


Fig. 1 Contd.

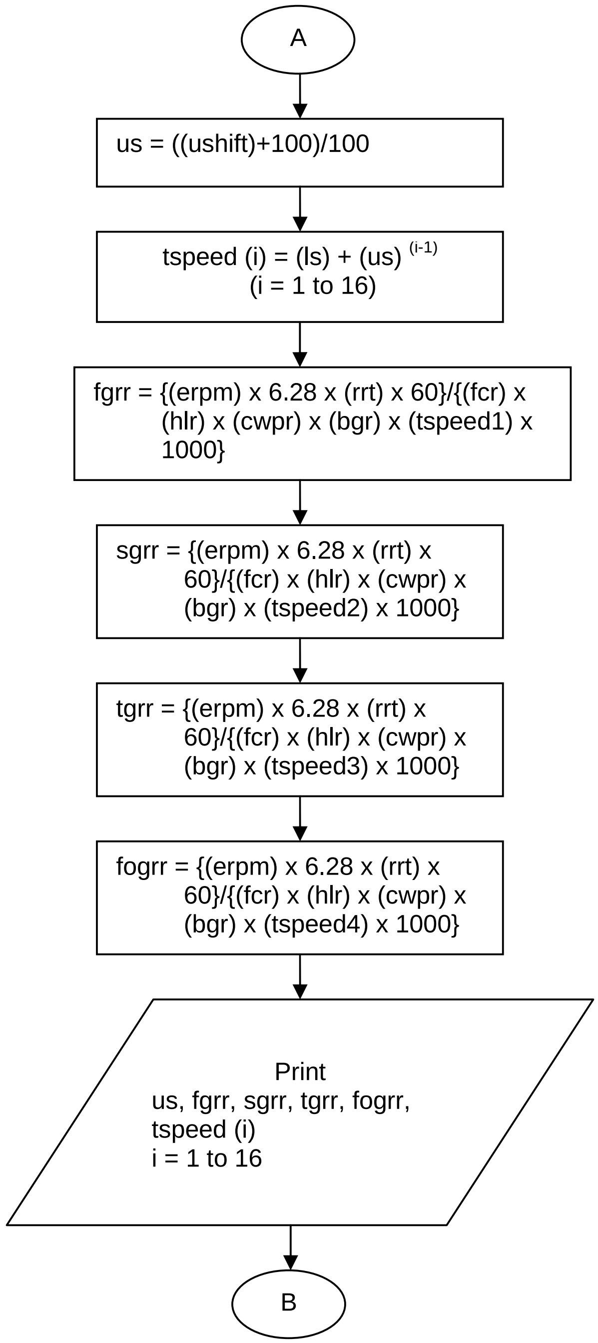

A
us = ((ushift)+100)/100
tspeed (i) = (ls) + (us) (i-1)
(i = 1 to 16)
fgrr = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (hlr) x (cwpr) x (bgr) x (tspeed1) x 1000}
sgrr = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (hlr) x (cwpr) x (bgr) x (tspeed2) x 1000}
tgrr = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (hlr) x (cwpr) x (bgr) x (tspeed3) x 1000}
fogrr = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (hlr) x (cwpr) x (bgr) x (tspeed4) x 1000}
Print
us, fgrr, sgrr, tgrr, fogrr,
tspeed (i)
i = 1 to 16
B

Fig. 1 Contd.

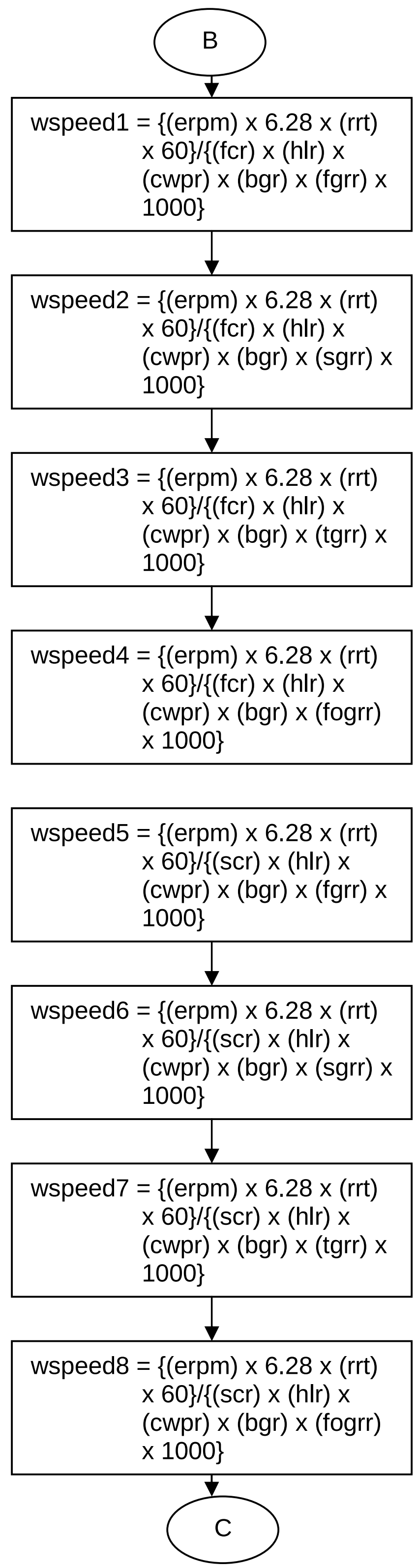

B
wspeed1 = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (hlr) x (cwpr) x (bgr) x (fgrr) x 1000}
wspeed2 = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (hlr) x (cwpr) x (bgr) x (sgrr) x 1000}
wspeed3 = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (hlr) x (cwpr) x (bgr) x (tgrr) x 1000}
wspeed4 = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (hlr) x (cwpr) x (bgr) x (fogrr) x 1000}
wspeed5 = {(erpm) x 6.28 x (rrt) x 60}/{(scr) x (hlr) x (cwpr) x (bgr) x (fgrr) x 1000}
wspeed6 = {(erpm) x 6.28 x (rrt) x 60}/{(scr) x (hlr) x (cwpr) x (bgr) x (sgrr) x 1000}
wspeed7 = {(erpm) x 6.28 x (rrt) x 60}/{(scr) x (hlr) x (cwpr) x (bgr) x (tgrr) x 1000}
wspeed8 = {(erpm) x 6.28 x (rrt) x 60}/{(scr) x (hlr) x (cwpr) x (bgr) x (fogrr) x 1000}
C

Fig. 1 Contd.

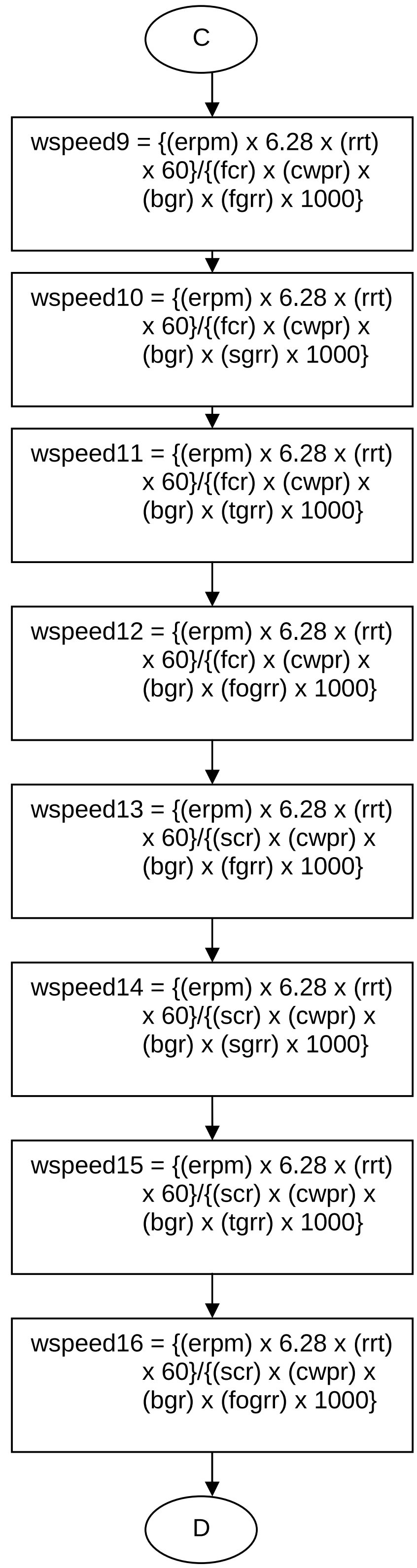
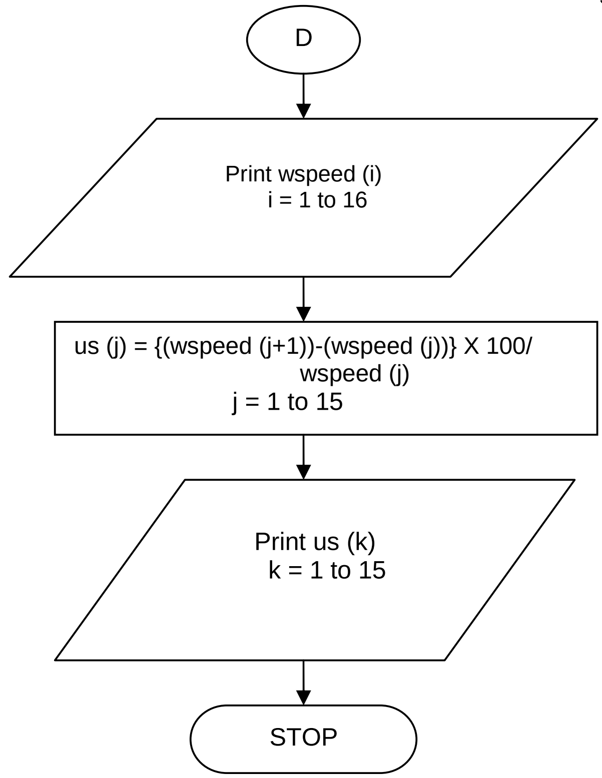

C
wspeed9 = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (cwpr) x (bgr) x (fgrr) x 1000}
wspeed10 = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (cwpr) x (bgr) x (sgrr) x 1000}
wspeed11 = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (cwpr) x (bgr) x (tgrr) x 1000}
wspeed12 = {(erpm) x 6.28 x (rrt) x 60}/{(fcr) x (cwpr) x (bgr) x (fogrr) x 1000}
wspeed13 = {(erpm) x 6.28 x (rrt) x 60}/{(scr) x (cwpr) x (bgr) x (fgrr) x 1000}
wspeed14 = {(erpm) x 6.28 x (rrt) x 60}/{(scr) x (cwpr) x (bgr) x (sgrr) x 1000}
wspeed15 = {(erpm) x 6.28 x (rrt) x 60}/{(scr) x (cwpr) x (bgr) x (tgrr) x 1000}
wspeed16 = {(erpm) x 6.28 x (rrt) x 60}/{(scr) x (cwpr) x (bgr) x (fogrr) x 1000}
D

Fig. 1 (Contd.).



Twenty five meter distance was marked in the road and tractor was operated in that marked region with load. Time required for covering that distance was recorded and vehicle speed for both the trials were determined. Fuel consumption was measured with the help of a fuel circuit measuring setup (Fig. 2).

The fuel supply line was connected to the filter from the tank instead of original fuel tank. The tank was filled to a certain level before the field operation and the fuel flow from the tank to injector was disconnected. The tractor was then operated in the road with the trailer. The additional fuel tank was filled to that certain level by measuring cylinder and the amount of fuel consumed in the operation was subsequently found out. For both the trials the engine speed were kept at 2000 rpm. Three replications were carried out for each set of trial to minimize error level.

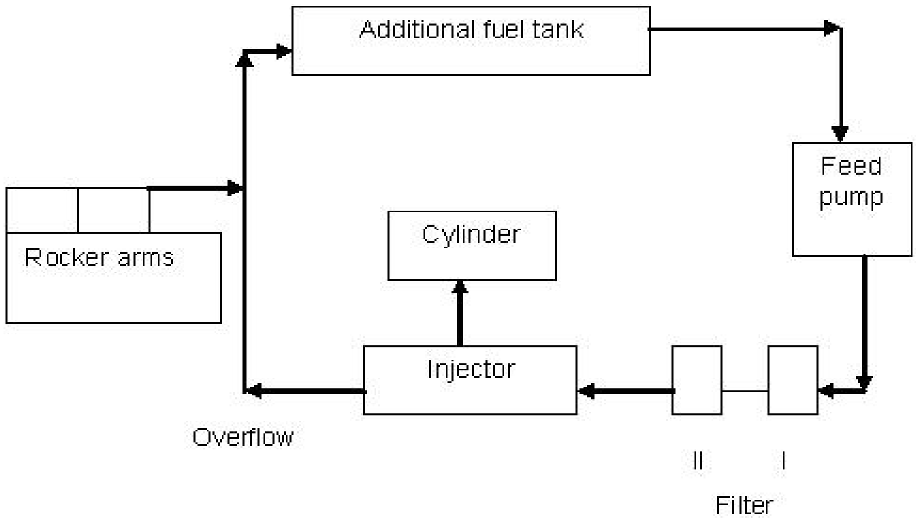


Fig. 2 Block diagram of fuel measuring arrangement

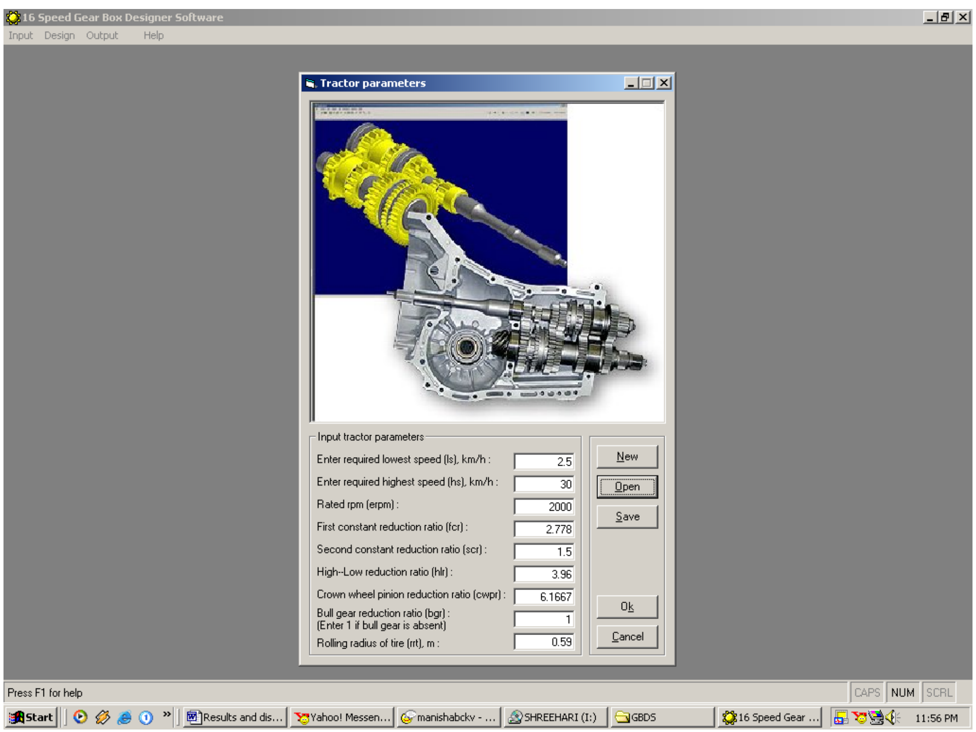


Fig. 3 Tractor parameter input window

3. RESULTS AND DISCUSSION

3.1 16 SPEED GBDS

Input window of gearbox design part has the options of entering different parameters like required lowest speed and highest speed, first constant reduction, second constant reduction, engine rpm, high-low reduction, crown wheel pinion reduction, bull gear reduction and rolling radius of tire (Fig. 3).

From these values theoretical upshift value, all theoretical speeds, practical gear reduction ratios (fgrr, sgrr, tgrr, fogrr) practical upshift values were calculated (Fig. 4). So the designer can have complete understanding of the vehicle speed from this portion. Hence, this portion of the software empowers the designer with gearbox performance prediction capability. After finalizing the gearbox parameters user should go to gear design part.

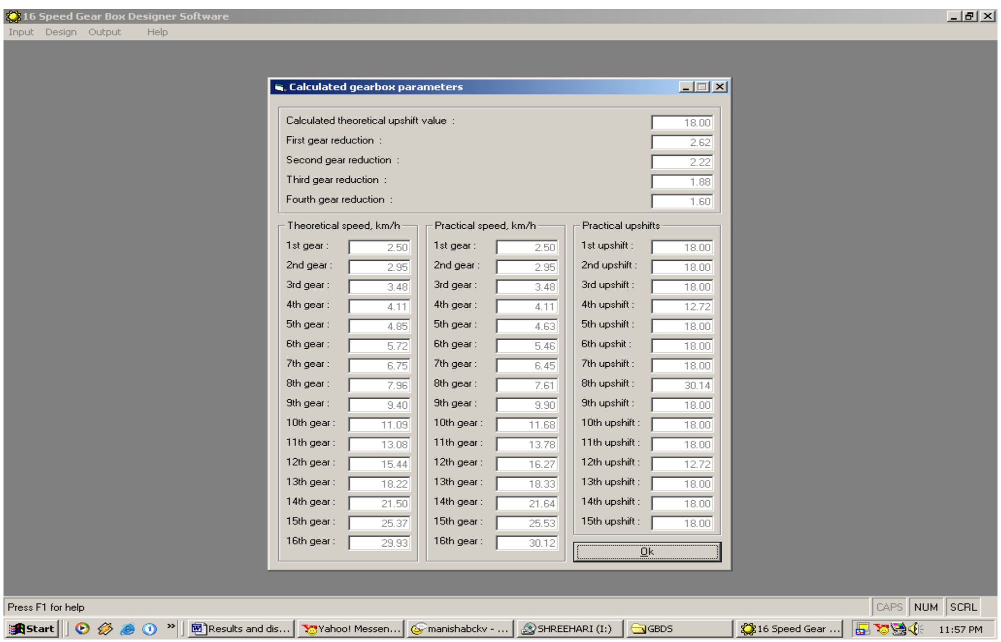


Fig. 4 Gearbox parameter output window

Fig. 5 gives the picture of gear parameter input window. Here user will manually enter the values of different gear parameters or can use the values of a previous example by clicking on 'Open' button. First different manual inputs like pinion teeth number, gear teeth number, theoretical pressure angle, selected centre distance, initial face width, prime mover torque, slip torque, number of mating gear, rpm, predicted life from duty cycle are entered. After entering the values user can save these values to use in future.

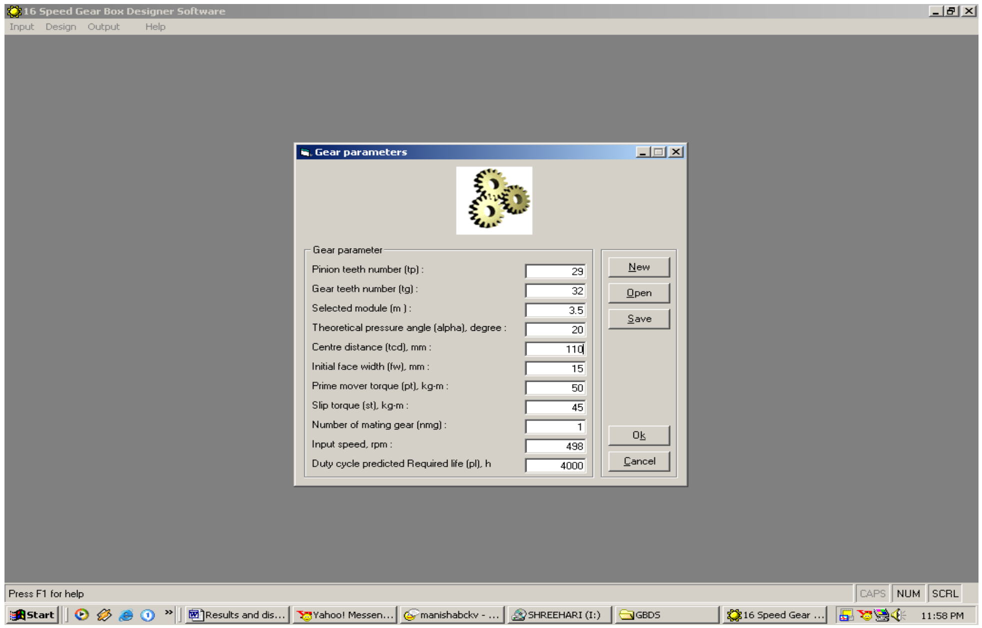


Fig. 5 Gear parameter input window

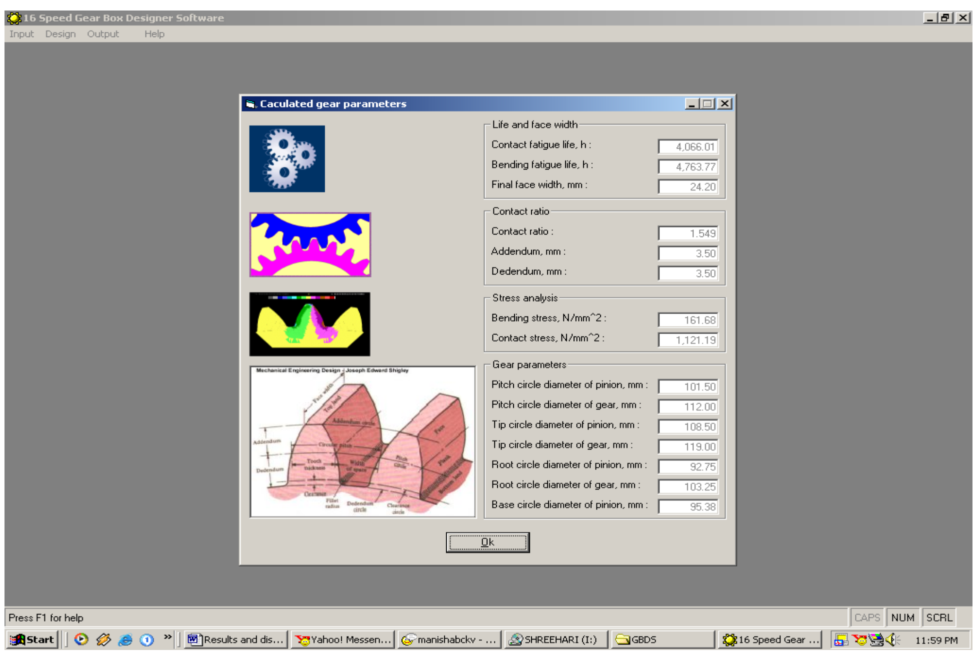


Fig. 6 Gear parameter output window

Fig. 6 gives the gear parameter output window. Contact and bending fatigue life, contact ratio, contact and bending stress and different dimensions of new gear are shown in this window. Still picture, movie (.avi file) etc. has been added to help the user to understand complicated gear parameters. Therefore this portion of the software helps the designer to have a hold on complex gear geometry and performance parameters.

3.2 SPEED SPECTRUM OF NEW GEARBOX

The target lower limit and upper limit of speeds were 2.5 kmph to 30 kmph, which were decided from the experience of the extensive survey made with 29 models of Indian tractors. The new speeds of the transmission system are available from Fig. 7. It is clear from the speed spectrum that this new transmission system can provide 8 speeds within the field speed limit (2.5 -8 kmph). This will be extremely helpful for operator to select nearly exact speed to match the implement's pull requirement. This will help not only to reduce operating sfc (specific fuel consumption) but also to reduce total operating time by selecting higher speed, resulting reduction in total fuel consumption.

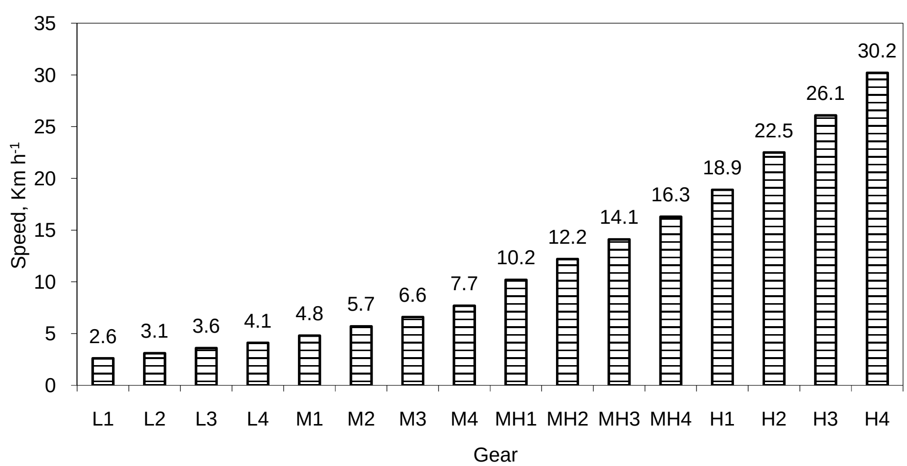


Fig. 7 Speed spectrum of newly designed transmission system

3.3 UPSHIFT SPECTRUM

The target upshift was 20% to make the new transmission system comparable with European and US tractors (Browning, 1978). This target upshift was kept in mind when speeds were finalized. Fig. 8 gives the upshift spectrum of the new transmission system. It clearly shows that all the upshift values (except M4-MH1) are within 20%, making it comparable with European as well as US market.

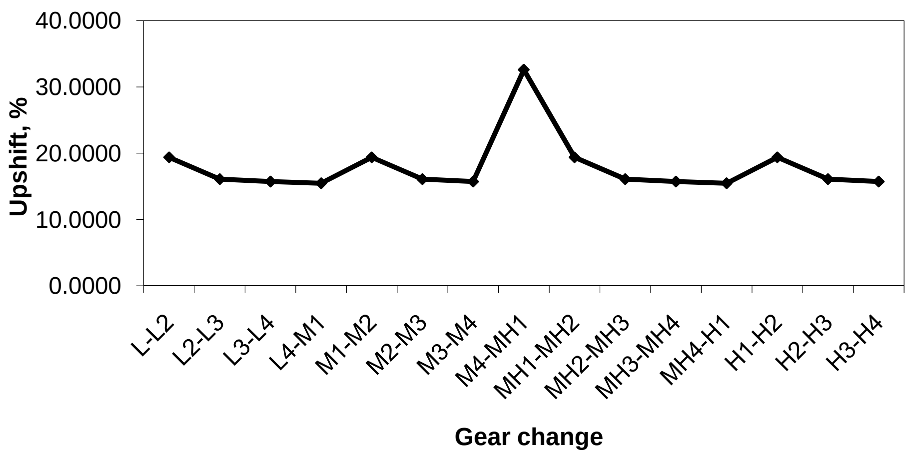


Fig. 8 Upshift spectrum of new transmission system

3.4 STRESS ANALYSIS OF NEWLY DESIGNED GEARS

Stress analysis has been done by 16 speed GBDS after finalizing the gear ratios. Bending stress and contact stress analysis has been carried out keeping in mind that induced stresses in both the cases should not be more than design stresses. Fig. 9 gives the result of stress analysis.

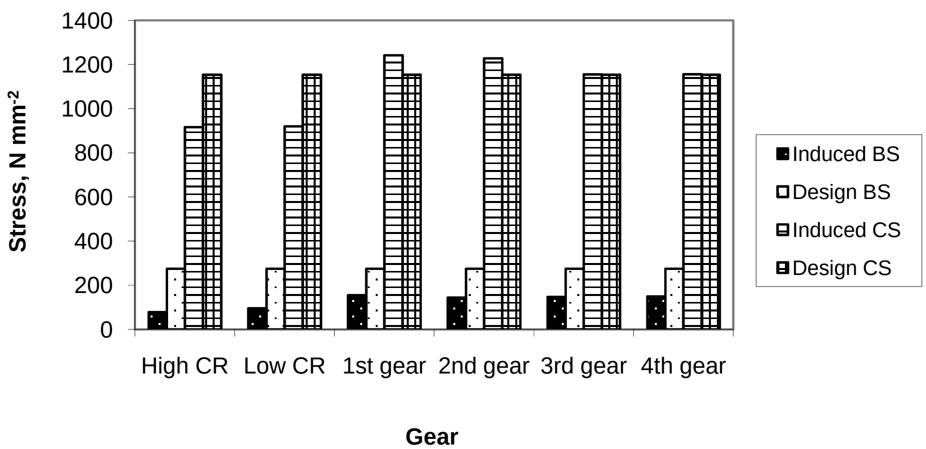


Fig. 9 Stress analysis results of newly designed pinions

Stress analysis shows that in all the cases design bending and contact stress are less or within 10% than the corresponding induced stress values, which is a common practice in gear industry. This indicates that design of all the pinions are safe from bending stress as well as contact stress point of view. As both the gear and pinion are made of same material (SAE 8620), so only pinions are analyzed for stress. Because always pinions experience more stress than gears. As slip torque values for 1st, 2nd and 3rd gear were less than the corresponding prime mover torque values, slip torque was used for design of these gears. Introduction of slip torque and duty cycle concept reduced 9 to 34 % of face width of these gears, which is available from Table 1. Cumulative life of the new gearbox also satisfied 10,000 hour for these new face widths.

Table 1. Advantage of application of slip torque and duty cycle concept

Gear	Face width, mm (PMT*)	Face width, mm (ST*)	Reduction in face width, %	Life, hr	Total life, hr
High constant reduction	24.5#			5247.8	10382.1
Low constant Reduction	13#			5134.3	
1st gear	33.5	22#	34	2036.3	10170.9
2nd gear	26.5	20.6#	22	2024.9	
3rd gear	27.5	25#	9	3059.3	
4th gear	24#			3050.4	

** PMT-prime mover torque, ST- slip torque; # Selected face width*

3.4.1 Haulage Performance

Haulage test result of new prototype was presented in Table 2. The first trial the maximum possible gear was high 2nd and the corresponding vehicle speed was 20.5 km h^{-1} and for the second trial the maximum possible gear was high 2nd, but here speed was 22.5 km h^{-1}. Results shown are the average of three replications. The new prototype resulted in 8.7 % reduction in total fuel consumption for 10 km run on level road as with the new prototype better matching of load vs pull was possible.

Table 2. Comparative haulage performance of new gear box with regular gear box

Trial	Type of gear box	Engine speed, rpm	Selected gear	Load on trailer, ton	Total Fuel Consumpt -ion, L	Reduction of fuel consumption
I	8+2 speed	2000	High 3rd	10.0	4.18	8.61 %
II	16+4 speed	2000	High 3rd	10.0	3.82	

4. CONCLUSION

1. To automate the tedious gearbox design process an unique software, “16 speed GBDS” has been developed by using Visual Basic 6.0 language. The window based interactive software was extremely user-friendly.
2. Upshift, slip torque and duty cycle concepts has been introduced for engineering optimization of the gearbox parameters. Introduction of slip torque and duty cycle concept reduced face width of different gears from 9 to 34 %.
3. Stress analysis shows that in all the cases design bending and contact stress are within 10% than the corresponding induced stress values.
4. Haulage testing resulted in 8.6 % reduction in total fuel consumption for 10 km run on level road.

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