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RESEARCH PAPER

Computer simulation for predicting tractor engine overloading for tillage operations

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ABSTRACT

The primary purpose of agricultural tractors, especially those in the middle to high power range, is to perform field work. Tractor manufacturer needs prediction of tractor field performance data in the tractor design stage itself so that they can optimize the transmission with the engine to give better performance. Engine speed prediction model was developed using Budni tractor test data. Developed engine speed prediction model for 10 engine model was compared with actual data of engine speed, it was found that for all engine models R^2 (co-efficient of determination) between predicted and actual engine speed was greater than 0.98. So developed empirical equations can be used in software for predicting engine speed. The field experiments were conducted using a tractor with three different implements *viz.,* 3-bottom mould board plough, 11-tyne cultivator and offset disc harrow. For each operation, the performance parameters such as draft, slip, depth, engine speed and fuel consumption were measured at different combinations of gear and throttle positions. Software in visual basic was developed to predict tractor engine overloading (engine speed drop) for field operations (MB plough, cultivator and disc harrow). The developed software was validated using field data collected in Kanchipuram, Tamil Nadu. For field operation with 2 WD tractor equipped with bias-ply tires and attached with cultivator the deviation of software predicted engine speed (rpm) drop was -16.47 to 26.92 per cent and for draft was -11.07 to 4.65 per cent. For field test with offset disc harrow the deviation of software predicted engine speed (rpm) drop was -17.44 to 15.38 per cent and for draft was -10.98 to 4.76 per cent. For field operation with MB Plough the deviation of software predicted engine speed (rpm) drop was 18.48 to 21.52 per cent and for draft -12.01 to -3.75 per cent.

KEY WORDS : Tractor engine overloading, Engine speed prediction model, Visual basic, Engine overloading

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INTRODUCTION

Average farm power availability in India has increased from about 0.30 kW/ha in 1960-61 to about 2.02 kW/ha in 2013-14 (Singh *et al*., 2014). India is the largest producer of the tractors in the world. Indian tractor industry, which was in its nascent stage in 1961-62 with annual production of 881 tractors, is now the largest producer in the world with annual production of 6.96 lakh units in 2013-14 (Singh *et al*., 2014).

Optimum engine speed is major parameter which governs the tractor's performance (Schrock *et al.,* 1986 and Scarlett, 1993). Marketing survey done on tractor industry reveals that, customers does not prefer more drop in engine speed during field and road operation. Keeping this in mind it is imperative for tractor manufacturer to evaluate any prototype tractor for this parameter (Engine speed drop).

The manufacturer would like to get data in the design stage itself to ensure his new product will perform equal or better than benchmark models of his own brand or that of competitor. In realty for doing such benchmarking trial one has to wait for development of prototype and go to the field for trials. If there is any optimization based on feedback of benchmarking trial, manufacturer has to go once again to complete the cycle of design change, development and evaluation. This is very tedious, expensive and time consuming process. Computer simulation for same work can ease the job. Thus, keeping in view the above problem study was undertaken with objectives:

– To develop empirical equations for predicting engine speed at different engine torque by using Budni tractor testing data.
– To develop software for predicting tractor engine overloading (engine speed drop) and determine the optimum gear and engine speed setting combination for different tillage operations.
– To validate the developed software using field experiment data.

EXPERIMENTAL PROCEDURE

Performance characteristics of diesel engine of the test tractor :

The Budni test report data for 10 selected tractors for software development were used to analyze the performance of the tractor engine. The graphs were plotted for engine torque and engine power at different speeds. By using the data obtained from the report, empirical equations for engine speed were developed in terms of engine speed at zero torque and engine torque. The developed empirical equations were used in computer simulation for getting the actual engine speed at different engine torque.

Simulation of tractor, engine, implement combination performance :

A software is developed in visual basic 6.0 language (Al-Hamed and Al-Janobi, 2001). The programme can predict the engine speed drop for different field operations, the optimum gear and speed selection for particular field operations. The input parameters needed for running the software and output parameters are given in Table A.

Table A : Input and output parameters in software

Sr No.	Category	List of parameters
1.	Tractor related parameters	Static weight, C.G. location, wheel base, tyre sizes, tractor power, speeds in different gear at rated rpm etc.
2.	Implement related parameters	Type of implement, size, weight, C.G. location, depth of operation etc.
3.	Soil related parameters	Soil type, soil cone index and land slope
4.	Output parameters	Engine torque, engine speed drop, draft, optimum gear and speed combination, actual forward speed, matching size of implement, weight transfer, fuel consumption.

Fig. A : Output screen of softrware

The programme starts with screen having options like engine, tractor model selection, implement selection and implement specifications like width, center of gravity location, static weight etc. The programme is feed with tractor specification database containing information such as tractor type, make and model, tractor power at rated engine speed and engine rpm corresponding to maximum torque, engine to driving wheel speed reduction, static weight distribution, wheel base, hitch point location, CG location etc. The tire database contains tire type (radial or bias-ply) and parameters such as tire size, section width, overall diameter, static loaded radius. Operating parameters like engine speed setting, gear selection, soil type, depth of operation, land slope have also to be given. Output screen is as shown in Fig. A.

Validation of developed software using field experiment data :

The field tests were carried out in Kanchipuram. The soil type was clay loam soil. The tillage implements were operated at an average cone index of 1425, 1050 and 850 kPa for MB Plough, cultivator and disc harrow, respectively. The tractor was operated with different implements at varying depths for different throttle positions. For each combination of implement, depth, tractor gear and throttle position, the performance data such as draft, engine speed, slip and fuel consumption was measured.

The tensile and bending forces experienced by the lower links and compressive forces by the top link were sensed by the strain gauges of each 120 Ω and 2.6 gauge factor mounted on the links (Bandy *et al.*, 1986). A fabricated proving ring attached to the top link was used to measure the compressive force acting on the link during tillage operations (Godwin and Dogherty, 2007). Vertical angles of lower links, depth of operation were sensed by rotary potentiometers. A Data Acquisition System (DATATAKER) was used to record these parameters (Grogan, 1987). Knowing the forces acting on both lower links and top link and the angles made by these links in horizontal and vertical planes, the draft of the implement was computed using the following expression:

$$\text{Draft} = A\cos\theta\cos\varphi + B\cos\theta\sin\varphi - C\cos\alpha\cos\gamma \quad .....(1)$$

where,

A = tensile force in lower links; B = bending force in lower links; C = compression force in top link; θ = angle of lower link in horizontal plane; α = vertical angle of top link; φ = angle of lower link in vertical plane; γ = horizontal angle of top link (this angle was assumed as zero due to hitching characteristics of linkages with implement).

The slip was calculated by measuring the actual speed in the field and the theoretical speed on a concrete surface in the same gear and throttle position. The fuel consumption was measured using a measuring cylinder as an auxiliary tank (Grisso *et al.*, 2003).

The main aim of carrying out field tests was to collect data related engine speed drop and compare those with software predicted results. A Massey Ferguson, 2WD tractor (38 kW maximum PTO power) with three different implements *viz.*, 3 bottom MB plough, 11 tyne cultivator and 14 disc, disc harrow were used for the field experiments.

Engine speed measurement :

Proximity switch was used for measuring the engine speed. Frequency signals from proximity switch were converted into voltage signals using frequency to voltage converter. For calibration of engine speed, actual engine speed of engine was measured by tachometer and corresponding voltage output was recorded in DATATAKER. For measuring engine speed in dynamic condition a proximity switch was mounted over the pulley hub, which drives radiator fan which was having two sensing points *i.e.* two holes.

Recording unit :

The outputs of all wheatstone bridges, potentiometer circuits and proximity switch were stored in DATATAKER. It was powered with 12V DC battery of the tractor.

Field preparation :

Approximately 18 acre land was available for field testing. The field was having sub plots each sub plot was having at least 50m length. These sub plots were used for measuring the draft of tillage implements, engine speed drop and fuel consumption of tractor at different depths, gears and at different engine speed setting for each implement (Wismer, 1972). Before starting the experiments, the data on cone index was collected in each plot.

Test procedure :

Before each test, cone index of soil was measured and the Null adjustments of the wheatstone bridges were made keeping the tractor and implement on a level ground. Similarly, before start of the tractor engine, the initial readings of the potentiometer circuit channel were noted down. During the test run of 50m, the variables recorded were tensile force, bending force, compressive force, angle made by the links, depth of tillage, engine speed setting. All the data were set at a frequency of 5 Hz in each channel of DATATAKER (Al-Janobi, 2000). Each test was replicated thrice.

While operating the tractor with implement, the initial potentiometer reading was noted down by keeping the implement on the ground level. Similarly the potentiometer reading was recorded when the implement was engaged at a particular depth of operation. From the calibration curve, the total height of lower link hitch point from the ground level was calculated before and after engaged into the soil. Finally the depth of operation was calculated by taking the difference of heights of lower link hitch point before engagement of the implement and after engagement of implement into the soil from the ground level.

The distance covered for 10 revolutions of the drive wheel of the tractor without engaging the implement into the soil was measured at particular throttle and gear settings on hard soil condition. After engaging the implement into the soil, tractor was operated at same engine speed setting and gear settings throughout the test run. The distance travelled and time taken for 10 revolutions of driving wheel for each case was measured to calculate the slip of driving wheel and speed of operation of the tractor. Similar procedure was followed for all other tests in each gear and engine speed setting.

All the experiments were conducted at constant inflation pressure (front tire 2.2 kg/cm^2, rear tire 1.1 kg/cm^2).

Similar procedure was followed for all the implements at each gear, engine speed setting and depth of operation.

EXPERIMENTAL FINDINGS AND ANALYSIS

The analysis of Budni tractor testing data is done for predicting engine speed at different torque and at different throttle position.

Development of mathematical model for engine speed :

The variation of engine torque and speed for engine model (A) are given in Fig. 1. These data were obtained from the Budni test report. Using Polymath Professional software, mathematical models (Eq. 1 and 2) were developed for

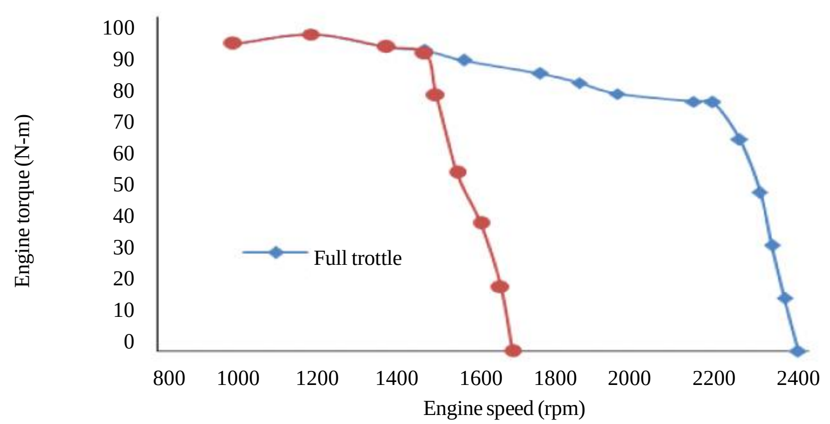

Fig. 1 : Performance curves of engine model (A) based on Budni report

engine speed in terms of engine torque and engine speed at zero torque (Harris and Pearce, 1990).

Empirical equation for governor line :

$$N = (a_0+a_1T+a_2T^2)+(a_3+a_4T+a_5T^2)Z \quad ....(1)$$

Empirical equation for full fuel line :

$$N = b_0+b_1T+b_2T^2+b_3T^3 \quad ....(2)$$

where, T = torque for governor lines, N-m; Z= speed at zero torque, rpm; N= speed at a particular load, rpm.

Validation of developed engine speed prediction model :

The developed engine speed prediction models eq. (1) and (2) were validated by using Budni tractor test data. The per cent deviation in engine speed predicted by developed models from the actual fuel data from Budni tractor test reports are given in Table 1 at various per cent load. The data indicate that the new developed equations are found to predict the engine speed varies only by -0.88 to 1.27 per cent at full fuel line, prediction varies by -0.82 to 0.93 per cent at part throttle and prediction varies by -0.67 to 0.52 per cent at full throttle governor line.

Validation of developed software :

The developed software was validated using field data collected in Kanchipuram. The results are discussed as follows:

Field performance test :

The comparison between the experimental and predicted results of field operation is given in Tables 2 to 10. The

Table 1 : Comparison between actual and predicted engine speed for engine model A

Governor line			Full fuel line		
Actual ES rpm	Predicted ES rpm	Variation, %	Actual ES rpm	Predicted ES rpm	Variation, %
2472	2470	0.08	2250	2239	0.49
2436	2442	-0.25	2200	2205	-0.23
2403	2406	-0.12	2000	2011	-0.55
2372	2361	0.46	1900	1886	0.74
2320	2308	0.52	1800	1791	0.50
2250	2265	-0.67	1600	1614	-0.88
	Part throttle line		1500	1481	1.27
1728	1733	-0.29	1400	1409	-0.64
1697	1687	0.59	1200	1191	0.75
1645	1638	0.43			
1583	1596	-0.82			
1528	1528	0.00			
1500	1486	0.93			

Table 2 : Comparison between experimental and predicted results of cultivator, depth=15 cm

Gear	ES set, rpm	Predicted rpm drop	Observed rpm drop	Variation, %	Predicted draft, kg	Observed draft, kg	Variation, %
L4	1800	136	124	-9.68	879	802	-9.64
	2000	132	117	-12.8	904	827	-9.36
	FLY UP	128	148	13.51	954	879	-8.93
H1	1800	183	174	-5.17	934	841	-11.0
	2000	189	177	-6.78	964	885	-9.01
	FLY UP	498	472	-5.51	1037	945	-9.82
H2	1800	Engine stall	Engine stall	-	Engine stall	Engine stall	-

Table 3 : Comparison between experimental and predicted results of cultivator, depth=12 cm

Gear	ES set rpm	Predicted rpm drop	Observed rpm drop	Variation, %	Predicted draft, kg	Observed draft, kg	Variation, %
L4	1800	112	98	-14.80	708	643	-10.11
	2000	106	116	8.59	728	689	-5.66
	FLY UP	94	123	23.58	769	803	4.23
H1	1800	149	147	-1.48	753	711	-5.91
	2000	148	134	-10.91	778	758	-2.64
	FLY UP	153	180	14.83	840	881	4.65
H2	1800	Engine stall	533	-	Engine stall	915	-

Table 4 : Comparison between experimental and predicted results of cultivator, depth=8 cm

Gear	ES set rpm	Predicted rpm drop	Observed rpm drop	Variation, %	Predicted draft, kg	Observed draft, kg	Variation, %
L4	1800	82	75	-9.33	475	438	-8.45
	2000	73	71	-2.82	490	461	-6.29
	FLY UP	57	78	26.92	518	474	-9.28
H1	1800	106	93	-13.98	507	468	-8.33
	2000	99	85	-16.47	524	483	-8.49
	FLY UP	84	97	13.4	567	515	-10.10
H2	1800	178	159	-11.95	581	531	-9.42
	2000	186	165	-12.73	606	553	-9.58
	FLY UP	502	480	-4.58	668	614	-8.79

Table 5 : Comparison between experimental and predicted results of offset disc harrow, depth=15cm

Gear	ES set rpm	Predicted rpm drop	Observed rpm drop	Variation, %	Predicted draft, kg	Observed draft, kg	Variation, %
L4	1800	121	110	-10.00	746	715	-4.34
	2000	115	103	-11.65	765	739	-3.52
	FLY UP	104	121	14.09	804	760	-5.79
H1	1800	160	144	-11.11	788	747	-5.49
	2000	161	149	-8.05	812	769	-5.59
	FLY UP	165	174	5.17	875	819	-6.84
H2	1800	Engine stall	459		Engine stall	812	

Table 6 : Comparison between experimental and predicted results of offset disc harrow, depth=12cm

Gear	ES set rpm	Predicted rpm drop	Observed rpm drop	Variation, %	Predicted draft, kg	Observed draft, kg	Variation, %
L4	1800	101	86	-17.44	599	545	-9.91
	2000	93	88	-5.68	615	568	-8.27
	FLY UP	77	91	15.38	647	583	-10.98
H1	1800	132	114	-15.79	634	581	-9.12
	2000	127	109	-16.91	654	601	-8.82
	FLY UP	121	127	4.72	701	635	-10.39
H2	1800	Engine stall	167		Engine stall	662	

Table 7 : Comparison between experimental and predicted results of offset disc harrow, depth=8cm

Gear	ES set rpm	Predicted rpm drop	Observed rpm drop	Variation, %	Predicted draft, kg	Observed draft, kg	Variation, %
L4	1800	75	81	7.41	401	421	4.76
	2000	67	71	5.63	412	426	3.24
	FLY UP	49	55	10.91	434	456	4.75
H1	1800	96	103	6.80	425	430	1.24
	2000	88	79	-11.39	439	460	4.56
	FLY UP	70	66	-6.06	472	467	-1.07
H2	1800	157	139	-12.95	482	463	-4.10
	2000	159	144	-10.42	502	484	-3.77
	FLY UP	169	151	-11.92	549	512	-7.23

Table 8 : Comparison between experimental and predicted results of MB plough, depth=30 cm

Gear	ES set rpm	Predicted rpm drop	Observed rpm drop	Variation, %	Predicted draft, kg	Observed draft, kg	Variation, %
L2	1600	109	92	-18.48	1517	1403	-8.13
	1800	99	89	-11.24	1530	1426	-7.29
	2000	91	109	16.51	1544	1458	-5.90
L3	1600	623	545	-14.31	1624	1489	-9.07
	1800	272	315	13.65	1661	1601	-3.75

Table 9 : Comparison between experimental and predicted results of MB plough, depth=25 cm

Gear	ES set, rpm	Predicted Rpm drop	Observed rpm drop	Variation, %	Predicted draft, kg	Observed draft, kg	Variation, %
L2	1600	94	83	-13.25	1270	1177	-7.90
	1800	85	81	-4.94	1282	1198	-7.01
	2000	76	91	16.48	1296	1212	-6.93
L3	1600	171	153	-11.76	1375	1279	-7.51
	1800	172	159	-8.18	1412	1316	-7.29
	2000	176	165	-6.67	1453	1381	-5.21

Table 10 : Comparison between experimental and predicted results of MB plough, depth=20 cm

Gear	ES set rpm	Predicted rpm drop	Observed rpm drop	Variation, %	Predicted draft, kg	Observed draft, kg	Variation, %
L2	1600	80	74	-8.11	1020	939	-8.63
	1800	71	68	-4.41	1030	947	-8.76
	2000	62	79	21.52	1042	968	-7.64
L3	1600	144	125	-15.20	1113	1053	-5.70
	1800	140	130	-7.69	1147	1074	-6.80
	2000	138	132	-4.55	1185	1108	-6.95
L4	1600	180	166	-8.43	1177	1085	-8.48
	1800	187	175	-6.86	1226	1119	-9.56
	2000	339	297	-14.14	1278	1141	-12.01

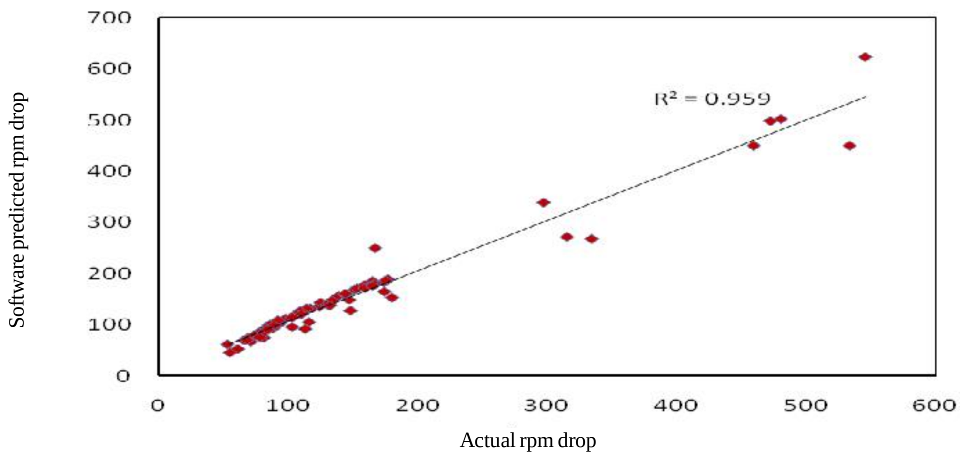

Fig. 2 : Comparison of actual and predicted rpm drop

data indicate that, the deviation of software predicted engine speed (rpm) drop was -16.47 to 26.92 per cent for cultivator, -17.44 to 15.38 for offset disc harrow and -18.48 to 21.52 for MB plough operation when compared with experimental results. Similarly, the deviation of software predicted draft was -11.07 to 4.65 per cent for cultivator, -10.98 to 4.76 for offset disc harrow and -12.01 to -3.75 for MB plough operation when compared with experimental results.

Software predicted rpm drop and actual rpm drop are compared in Fig. 2. It was found that R^2 (co-efficient of determination) between predicted and actual engine speed drop was 0.959. It was observed that engine speed drop increased with increase in depth of operation because of increase in draft. Engine speed drop increased when tractor was operated at higher gear because at higher gear, speed of operation is higher so draft is higher. Also at higher gear available axle torque is less compared to lower gear due to reduction in available axle torque as torque gets divided by gear ratio from engine to wheel. It was observed that engine speed drop at 1600 rpm engine speed setting is higher than that of at 1800 rpm engine speed setting, because as engine speed decreases governor regulation decreases. So at 1600 rpm engine speed setting same torque is achieved at higher rpm drop than that at 1800 rpm engine speed setting provided engine is operating along governor line. If engine operates along full fuel line then engine speed drop at 1600 rpm engine speed setting is lesser than that of at 1800 rpm engine speed setting, because at higher engine speed forward velocity of tractor increases and so draft requirement increases.

Conclusion :

The present study conducted led to the following major conclusions.

–Developed engine speed prediction model for 10 engine model was compared with actual data of engine speed, it was found that for all engine models R^2 (co-efficient of determination) between predicted and actual engine speed was greater than 0.98. So developed empirical equations can be used in software for predicting engine speed.

–For field operation with 2 WD tractor equipped with bias-ply tire and attached with cultivator the deviation of software predicted engine speed (rpm) drop was -16.47 to 26.92 per cent when compared with observed engine speed drop and the deviation of software predicted draft was -11.07 to 4.65 per cent when compared with observed draft.

–For field operation with 2 WD tractor equipped with bias-ply tire and attached with offset disc harrow the deviation of software predicted engine speed (rpm) drop was -17.44 to 15.38 per cent when compared with observed engine speed drop and the deviation of software predicted draft was -10.98 to 4.76 per cent when compared with observed draft.

–For field operation with 2 WD tractor equipped with bias-ply and attached with MB Plough the deviation of software predicted engine speed (rpm) drop was -18.48 to 21.52 per cent when compared with observed engine speed drop and the deviation of software predicted draft was -12.01 to -3.75 per cent when compared with observed draft.

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