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COMPUTER SIMULATION OF TRACTOR PERFORMANCE WITH REGARD TO ENERGY SAVING AND POLLUTION REDUCING

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ABSTRACT

A study on optimum operation performances of power efficiency, economy and exhaust emissions for a tractor was conducted. A mathematical model of multiple degree polynomial equation was applied to establish the function of solid multiple parameter curves for specific fuel consumption (ge), carbon monoxide (CO), hydrocarbons (HC) and carbonaceous smoke (Rb). The optimum operation theorems for economy operation indicated by ge and for exhaust emissions described by Co, HC and Rb were obtained from analytical method and performance test data. The optimum operation theorems could exhibit optimum operation working points, curves, and regions.

The optimum matching relations of engine speed and transmission parameters were analyzed by using computer simulation methods in accordance with the tractor specifications, actual farm working conditions in a typical drawbar pull work such as plowing, the optimum operation objective functions, the ideal transmission ratio, practical gear shifting positions and practical travel speed of the tractor TN55 medel.

The results of the analyses indicated clearly that the optimum power efficient operation, energy saving and pollution reducing would be realized if the tractor would be operated according to the optimum operating methods.

Key words. optimum operation, tractor engine, fuel saving, exhaust pollution

INTRODUCTION

Energy crisis and environmental pollution are serious worldwide problems which greatly affect economic and social development. A great deal of wastes and emissions are removed to natural environment as long as the most events on the earth consume a large quantity of energy and natural resources. In order to looking for substantial solutions of the problems, some protecting actions were proposed and discussed in many nations (Nishizaki, et al. 1993).

Tractor is a very important power unit in agricultural production but it consumes a great deal of diesel fuel and emits a lot of harmful gases that pollute environment. Therefore, a research on the fuel economy and emission of pollutant gases for a tractor is a significant work. In this research work, the characteristics and optimization of tractor performance in a typical farm work such as plowing were studied with regard to energy saving and pollution reducing by using computer simulation technology.

The objective of this study was to develop an optimum operation methodology depending on working load conditions for a tractor with diesel engine. In particular, the followings were investigated in details.

1. To establish a mathematical model for expressing engine performances such as specific fuel consumption (ge), exhaust emission including carbon monoxide (CO), hydrocarbon (HC) and carbon smoke (Rb).
2. To derive the optimum operation theorems of engine performances and to establish the equations of optimum power efficiency, economy and exhaust emission operations.

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3. To analyze tractive efficiency of a tractor on drawbar pull work such as plowing .

4 . To optimize the matching relations of transmission ratio, gear shifting positions and tractor travel speeds according to the optimum operation theorems.

MATHEMATICAL MODEL

A curved surface fitting method was used to establish the mathematical model of multiple parameter curves of a diesel engine. Multiple parameter curves consist of a group of curves showing the dependence of one or more constant parameters with two other variable parameters .

In a general saying, economical parameters represented by specific fuel consumption ge and exhaust emission parameters including CO, HC and Rb can be expressed as a function of engine speed and engine torque, respectively. So the mathematical model of multiple parameter curves of an automobile engine (He, 1988) can be utilized to obtain the function of engine speed and engine torque for a tractor engine as followings.

$$Z=\sum_{j=1}^{s}\sum_{i=0}^{j} A\left[\frac{1}{2}(j+1)(j+2)-j+1+i\right]Me^{i}\left(\frac{n_e}{r}\right)^{j-i} \qquad [1]$$

Where, Z represent functions such as the parameters of specific fuel consumption ge/200 (g/km h), carbon monoxide CO (100 x %), hydrocarbon HC (ppm) and carbon smoke Rb in Bosch measuring. Me is engine torque, 1/100 (Nm). ne is engine speed (rpm). r are proportional constants of engine speed which valued of 1000, 800, 800 and 1000 for ge, CO, HC and Rb, respectively. S is degree of the model. A are the coefficients to be determined from experimental test data.

The equation above also can be defined as a matrix equation with stochastic errors to obtain the coefficients by a curved surface fitting method with the least squares technique using computer programming. The equation can be given by

$$\begin{pmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_N \end{pmatrix} = \begin{pmatrix} 1 & M_{e1}n_{e1}/r & \cdots & M_{e1}^{s}M_{e1}^{s-1}n_{e1}/r & \cdots & (n_{e1}/r)^{s} \\ 1 & M_{e2}n_{e2}/r & \cdots & M_{e2}^{s}M_{e2}^{s-1}n_{e2}/r & \cdots & (n_{e2}/r)^{s} \\ \vdots & \vdots & & \vdots & & \vdots \\ 1 & M_{eN}n_{eN}/r & \cdots & M_{eN}^{s}M_{eN}^{s-1}n_{eN}/r & \cdots & (n_{eN}/r)^{s} \end{pmatrix} \times \begin{pmatrix} a_0 \\ a_1 \\ \vdots \\ a_{k-1} \end{pmatrix} + \begin{pmatrix} e_1 \\ e_2 \\ \vdots \\ e_N \end{pmatrix} \qquad [2]$$

Where, $\{Z_1,Z_2...Z_N\}$ are the values of ge, CO, HC and Rb to be fiited. $\{a_0,a_1... a_{k-1}\}$ are coefficients to be determined. $\{e_1,e_2...e_N\}$ are stochastic errors. N is sampling number of experimental test points.

The experimental data of the performance test for 4115TD diesel engine were applied in order to calculate the coefficients in above equation. The results is shown in Table 1. In the Table, R are the curved surface fitting correlation coefficients.

Substituting these coefficients into the equations of the mathematical model, the multiple parameters curves for ge, CO, HC and Rb as a function of engine speed (ne) and engine torque (Me) would be obtained, respectively.

OPTIMUM OPERATION THEOREMS

In three dimensional coordinate, specific fuel consumption ge, exhaust emissions including CO, HC, and Rb are functions of engine speed and engine power which could be calculated from engine torque in multiple parameters curves as described as above. Thus the most optimum operation regions surely are existent in the working area, namely, the lowest regions are existent in the curved surface of the solid multiple parameters curves. It is the key point that the lowest regions would be found and utilized for farm operations. Zou et al. (1986) obtained the optimum operation curves of specific fuel consumption for a single sylinder diesel engine by using computer graghics.

In order to analyze it more precisely, the optimum operation theorems of a farm engine were defined as three ways: first one was the optimum efficient power performance, Second one was the optimum economical operation performance and third one was the optimum exhaust emissions operation performance.

The optimum efficient power performance theorem can be obtained at the nearly regions of the rated working point which located at the rated speed and rated power. The optimum economical operation performance theorem can be expressed by the optimum specific fuel consumption ge, and the optimum exhaust emissions operation performance theorem can be expressed by the united description of CO, HC and Rb. All of ge, CO, HC and Rb can be obtained from the multiple parameter curves. They are described as functions of engine speed and engine power as following equations.

$$\begin{aligned} ge&=G(ne,Ne) \\ CO&=C(ne,Ne) \\ HC&=H(ne,Ne) \\ Rb&=R(ne,Ne) \end{aligned} \qquad [3]$$

Arranging them to following form:

$$Z=Z(ne,Ne) \qquad [4]$$

Where, G, C, H and R represent functions of ne and Ne,respectively.

In the above equations, ge, CO, HC and Rb would become a function of ne only for a given constant power level. Assuming ge, CO, HC and Rb is a single continuous function of ne, the minimum ge, CO, HC and Rb at a given constant power level can be found by differentiating equation [4] with respect to ne and setting the derivative equal to zero.

$$\frac{dN_e}{dn_e}=\frac{\partial Z\ (n_e, N_e)}{\partial n_e} \Big/ \frac{\partial Z\ (n_e, N_e)}{\partial N_e} \qquad [5]$$

For a given engine power, the function Z is minimum if equation [5] holds. Furthermore, if Z is kept minimum values based on equation [5], and Ne varied along 0 to 100 % of the maximum power. ne would become a function of Ne with the minimum values of Z.

That means there is the minimum value of Z for every power level along 0 to 100 % of the maximum power level at different engine speed. The minimum value point of Z will form a single line which would express the optimum operation theorems.

The equation can ben given by following relation.

$$ne=F(Ne), \qquad \text{when } Z=Z_{min} \qquad [6]$$

The above equation is called the optimum operation theorems for a tractor engine.

For the Model 4115TD diesel engine, the optimum operation theorems were obtained (Zou et al. 1992) by synthetic analysis with theoretical method and performance test data using computer programs, and they were described as following equations and shown in Fig. 1.

$$\begin{aligned} &\text{When } ge=ge_{min}, && ne=922.29-10.31Ne+o.65Ne^2. && R=95.7\ \% \\ &HC=HC_{min}, && ne=1439.48+4.1Ne-1.08Ne^2+0.02Ne^3, && R=67\ \% \\ &CO=CO_{min}, && ne=791.41+42.47Ne-0.63Ne^2, && R=98\ \% \\ &Rb=Rb_{min}, && ne=796.06+55.3Ne-0.95Ne^2, && R=91.45\ \% \end{aligned} \qquad [7]$$

Where, R are correlation coefficients.

In the Figure, star mark points are the measured working points in performance tests. Solid lines crossing the star marks are power performance curves, dotted regions are the lowest areas of thege, HC, CO and Rb performances, and the dotted bold lines are the optimum operation curves exhibited the optimum operation theorems.

COMPUTER SIMULATIONS OF TRACTOR PERFORMANCE

Computer simulation technology is used to analyze dynamic constructs and functions of a system. In this study, in order to realize the optimum operations of a farm tractor, the optimization of matching relations of transmission system ratio and tractor travel speed were carried out by computer simulation when the tractor performing a typical farm work such as plowing with a variety of work loading levels.

1. Parameter Analysis

The specific parameters of the transmission system of the tractor TN55 with a diesel engine 4115TD model are shown in Table 1. Table 2 shows work loading levels of the tractor mounted a plow set BUT in plowing which were obtained by the Department of Agriculture Engineering of ShengYang Agricultural University.

The power balancing equation of the tractor in plowing can be expressed by:

$$Ne = Nm + Ns + Nf + Nt \qquad [8]$$

where, Ne, Nm, Ns, Nf and Nt are engine power, the friction power loss in transmission system, the power loss in slip resistances, the power loss in motion resistances and the drawbar pull power, respectively. An alternative expression above equation can be found as following:

$$Nt = Ne\ ETAt = Ne\ ETAm\ ETAs\ ETAf \qquad [9]$$

where, ETAt, ETAm, ETAs and ETAf are efficiencies of traction, the transmission system, slips and motion resistances, respectively. The drawbar pull power can be expressed by

$$Nt = Pt\ V \qquad [10]$$

where, Pt is tractive resistances and V is the tractor travel speed. Assuming both of PT and V are known, Ne will be obtained with the values of ETAm, ETAs and ETAf which were found by other further analysis (Souza and Milanez, 1991).

2. Simulation Procedures

After the preparations of the parameters analysis above, the computer simulation of the tractor performance could be conducted. The simulation flow chart is shown in Fig. 2.

Firstly, the specifications and dimension parameters of the tractor, the optimum objective functions of the tractor engine described at equations [7], the transmission system ratio and the work loading levels were input to computer. The tractive efficiency was calculated, and the drawbar pull power and the engine effective power were obtained sequentially.

Then, the objective working points of engine optimum operation indicated by Et, ge, Hc, Co and Re at the optimum operation curves for the given work loading levels were determined. The optimum operation objective working points at the given work loading levels is shown in Fig. 3. The bold points represent the objective working points on the optimum operation curves. The objective working points expressed that the engine speed was a function of engine power requested from the given work loading levels. That means engine speed can be adjusted by speed adjusting lever and transmission ratio for achieving the optimum operations.

Here, if the tractor operates at such these objective working points, that the engine would be operated at the most optimum conditions. Therefore, the ideal transmission ratio of the tractor at both of the conditions of the optimum objective engine speed points and maintaining travel speed have to be found. The condition of maintaining travel speed means that the transmission ratio have to changed in order to guarantee the tractor performing farm works normally.

3. Travel Speed Analysis

The ideal transmission ratio could not always be shifted and practical used by the tractor because it may be limited from the mechanical constructs of a gear transmission system. The practical transmission ratio or gear shifting positions for practical use have to be selected from the specifications of the transmission system of the tractor.

The calculating method of the ideal transmission ratio can be obtained by following equation.

$$I(i)=0.377\ rd\ n(i)/V(i) \qquad [11]$$

where, I(i) are ideal transmission ratio, n(i) are engine speeds according to the objective engine speed points on the optimum operation curves. V(i) are travel speeds at a normal operation. i are 1...5 for Et, ge, HC, CO and Rb respectively. rd is the effective radius of rear wheels of the tractor.

When i=1, n(1) and V(1) are the rated engine speed at rated power point and travel speed, respectively. V(1) can be obtained from the correlations between the work loading levels and travel speeds (Niu, 1992).

The practical gear shifting positions of the nearest to the ideal transmission ratio were found from the specifications and the dimension parameters of the tractor. The ratio at the positions are the practical transmission ratio. That means if the tractor operates at the practical transmission ratio, the optimum operation which is nearest to the ideal one would be achieved. While the practical gear shifting position were selected, the practical travel speed of the tractor in plowing were calculated depending on different objective functions. The calculating equation can be given by:

$$Vt(i)=0.377\ rd\ n(i)/IB(i) \qquad [12]$$

where, Vt(i) are practical travel speed at the optimum operation conditions. IB(i) are practical transmission ratio according to the practical gear shifting positions.

As described as above analytical method, a computer simulation program was developed to calculate the travel speed. The simulation results for tractor TN55 operated at different objective functions are shown in Table 3.

From the results, a good conformity can be found between the practical travel speed at the optimum operation conditions which ranging 4.48 to 5.65 km/hr and the normal travel speed without optimum operation performed at 5 km/hr.

CONCLUSIONS AND DISCUSSIONS

A theoretical analysis with experiment data were conducted by using computer simulation methodology for the optimum operation of a tractor depending on the different objective functions such as the optimum efficient power, economical, and exhaust emission performances. A multiple degree polynomial mathematical model was established to express the multiple parameters performances. The multiple parameter curves were analyzed and fitted as a curved surface function of engine speed and engine power. The least squares technique was employed to determine the constants of the curved surface fitting equation.

The objective operation theorems were obtained from the mathematical model and experimental data for different goals. Applying the objective operation theorems to a typical drawbar pull work such as plowing with different work loading levels, the practical gear shifting position achieving the optimum operation condition were selected. The simulation results showed a sufficient utilization.

However, the ideal optimum operation could not be obtained at a gear transmission system because the gear shifting positions were usually limited by the mechanical constructs. And the optimum efficient power, economical and exhaust emission performances were not so conformable that the most optimum operation for all objective functions was difficult to realize at the same time. So the different optimum operation have to be performed at different objective functions.(see Fig. 3). If the work loading levels and engine speed were in a constant, the ranging High-1 to High-3 of the practical gear shifting position shown in Table 3 were not so wide that the synthetic optimum efficient power, specific fuel consumption, exhaust emissions HC, CO, and Rb were realized together at a certain level.

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TABLES AND FIGURES

Table 1. The specifications of transmission system of TN55 tractor.

Series No.	Shift-position	Gear-ratio	Transmission-ratio
1	Low-1	41.16	296.89
2	Low-2	11.51	241.29
3	Low-3	9.06	180.96
4	Low-4	5.51	115.51
5	Low-5	4.03	81.41
6	High-1	3.07	61.37
7	High-2	2.49	52.31
8	High-3	1.96	41.18
9	High-4	1.19	25.05
10	High-5	0.87	18.37
11	Back-1	18.88	395.88
12	Back-2	4.09	85.83

Table 2. Work loading levels of TN55 tractor in plowing.

Load-mode	Load-value(kg)	Value-rate	Load-frequency	Adding up
1	1266	1	2896	2896
2	1203	0.95	7651	10550
3	1076	0.85	239876	250426
4	918	0.725	598309	818735
5	728	0.575	145135	993870
6	538	0.425	4936	998806
7	348	0.275	896	999702
8	158	0.125	298	1000000

* This data were measured with the conditions of sandy loam soil and BUT-35 mounted plow at 5 km/hr drawn speed, and by Agricultural Engineering Department of Shenyang Agricultural University, China

Table 3. Simulation results of the optimum operation for TN55 tractor.

Load mode (kg)	Objective function	Objective speed of engine (rpm)	Ideal transmission ratio	Practice shift position	Practice transmission ratio	Practice plowing speed(km/hr)
158	Et	1524.50	43.83	High-3	41.18	9.54
158	ge	882.88	43.51	High-3	41.18	5.63
158	HC	1411.62	72.77	High-1	64.37	5.85
158	CO	1010.57	53.84	High-2	52.31	5.13
158	Rb	1114.77	57.48	High-2	52.31	5.49
318	Et	1524.50	44.34	High-3	41.18	9.65
318	ge	883.57	48.08	High-3	41.18	5.59
318	HC	1387.31	71.30	High-1	64.37	5.54
318	CO	1141.74	59.64	High-1	64.37	4.62
318	Rb	1240.31	84.88	High-1	64.37	5.92
538	Et	1524.50	43.83	High-3	41.18	9.42
538	ge	898.23	45.69	High-3	41.18	5.55
538	HC	1329.33	67.62	High-1	64.37	5.25
538	CO	1234.90	62.82	High-1	64.37	4.88
538	Rb	1352.43	88.80	High-1	64.37	5.34
728	Et	1524.50	43.97	High-3	41.18	9.13
728	ge	930.07	45.87	High-3	41.18	5.57
728	HC	1298.45	64.04	High-1	64.37	4.97
728	CO	1319.81	65.09	High-1	64.37	5.08
728	Rb	1450.07	71.51	High-1	64.37	5.55
918	Et	1524.50	45.94	High-3	41.18	8.72
918	ge	986.83	48.50	High-3	41.18	5.65
918	HC	1275.97	60.13	High-1	64.37	4.67
918	CO	1397.12	65.81	High-1	64.37	5.11
918	Rb	1532.00	72.19	High-1	64.37	5.81
1076	Et	1524.50	47.43	High-2	52.31	8.43
1076	ge	1071.17	47.25	High-2	52.31	4.52
1076	HC	1267.07	55.90	High-2	52.31	5.34
1076	CO	1456.21	64.24	High-1	61.37	4.99
1076	Rb	1584.48	69.90	High-1	64.37	5.43
1203	Et	1524.50	42.65	High-3	41.18	7.34
1203	ge	1210.80	48.04	High-2	52.31	4.59
1203	HC	1277.70	50.69	High-2	52.31	4.85
1203	CO	1490.36	59.37	High-1	64.37	4.61
1203	Rb	1599.67	63.46	High-1	64.37	4.93
1266	Et	1524.50	38.54	High-3	41.18	6.64
1266	ge	1302.30	48.84	High-2	52.31	4.67
1266	HC	1306.28	46.83	High-2	52.31	4.48
1266	CO	1501.07	53.82	High-2	52.31	5.14
1266	Rb	1567.93	58.22	High-2	52.31	5.37

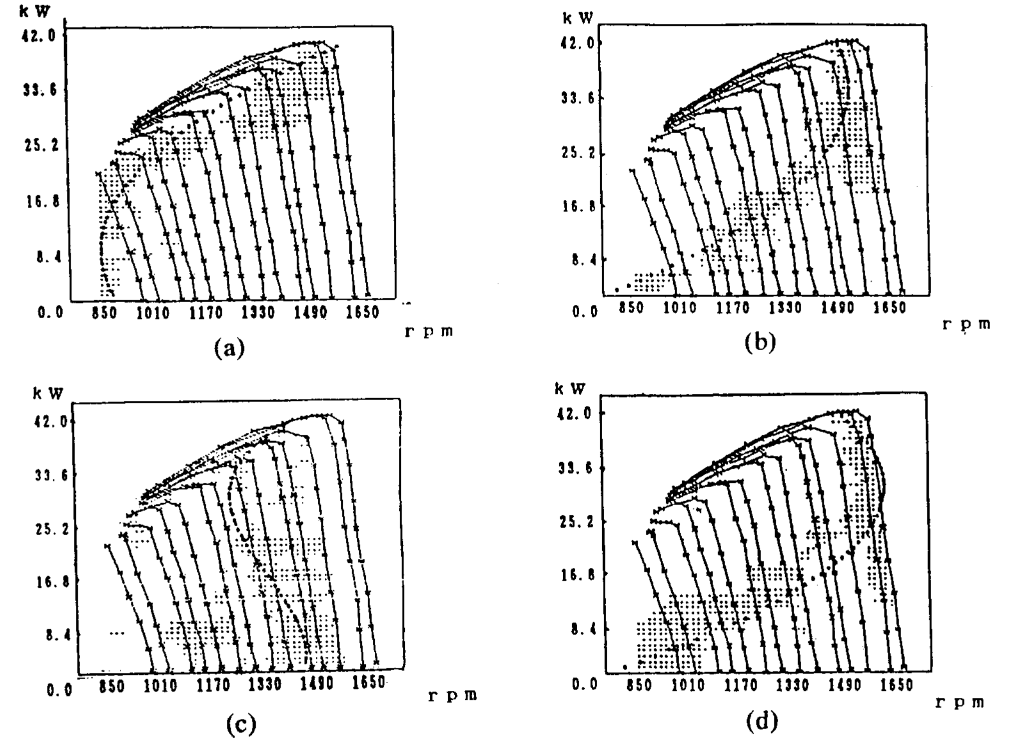

Fig. 1 The optimum operation theorems of specific fuel consumption ge (a), carbon monoxide CO (b), hydrocarbons HC (c) and carbonaceous smoke Rb (d) for a tractor engine.

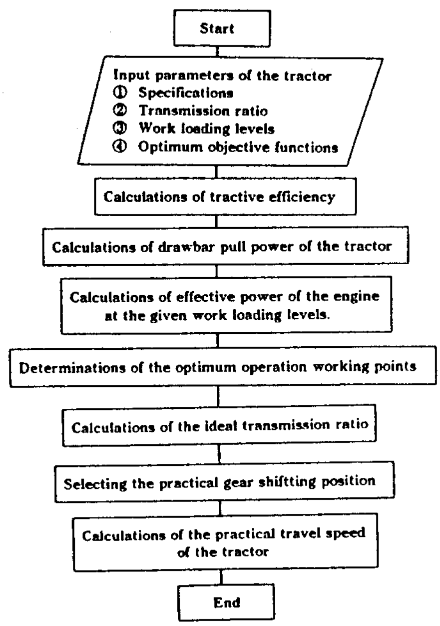

Fig. 2 The flow chart of computer simulation.

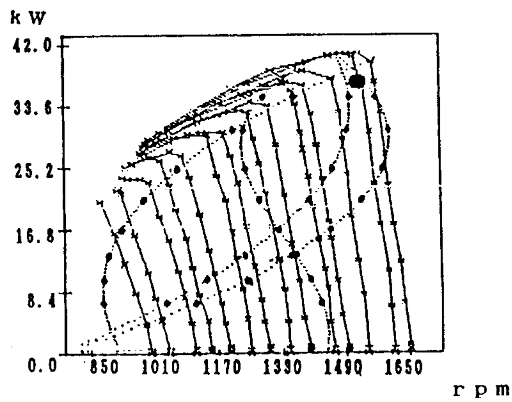

Fig. 3 The optimum operation objective working points.