Potential Performance Characteristics for Different Types of Tractors: Two-Wheel-Drive Tractor, Four-Wheel-Drive Tractors and Crawler Tractors

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Abstract. The paper addresses a very important criterion for the evaluation of the tractive and economical performances of agricultural tractors, namely the potential performance characteristics, which represents the drawbar power curve depending on the drawbar pull. At a large scale, this curve coincides with the tractive efficiency of the tractor taking account of the drawbar pull. We herein present the mathematical modelling of the potential performance characteristics which is particularized for three types of tractors: two-wheel-drive tractor, four-wheel-drive tractor and caterpillar tractors. The mathematical modeling has a high degree of generalization: the final mathematical functions comprise only dimensionless parameters. Related graphs are subsequently presented and the three types of tractors are comparatively analyzed taking into account the tractive and economical performances. Considering the potential performance characteristics, we put forward proposals for an accurate design of a tractor transmission when establishing the number and structure of gears.

Keywords: Tractor · Performance characteristics · Tractive efficiency

1 Introduction

1.1 A Subsection Sample

The potential performance characteristics of the tractor is named the curve $P_t = f(F_t)$, that is to say the drawbar power P_t depending on the drawbar pull F_t. This name is given on account of the fact that the potential performance characteristics may be obtained only under ideal operating conditions: constant engine load and continuous (progressive) adjustment of the travel speed considering the drawbar pull.

At a different scale, the curve of the potential performance characteristics coincides with the curve of the tractive efficiency depending on the drawbar pull: $\eta_t = f(F_t)$. There are three categories of efficiencies in agricultural tractors, i.e. overall efficiency, tractive efficiency, and conventional tractive efficiency. These categories are framed by taking into account the stable condition under which the tractor is operated on horizontal ground, that is to say v = constant. At the next stage the three categories of efficiencies are analytically defined [1, 3]:

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The overall efficiency is defined by the ratio.

$$\eta = \frac{P_t + \eta_p P_{pp}}{P_e},$$

where P_t – the drawbar power of the tractor; η_p – efficiency of power take-off transmission, P_e – actual engine power.

The tractive efficiency is defined by the ratio

$$\eta_t = \frac{P_t}{P_e - P_{pp}},$$

and the third category of efficiency, namely *the conventional tractive efficiency*, is described by the following ratio

$$\eta_{t\,conv.} = \frac{P_t}{P_n},$$

where P_n is the nominal power engine.

Provided the power take-off does not function, the overall tractor efficiency is equal to its tractive efficiency: $\eta = \eta_t$.

This paper has considered the tractor to operate without power take-off. In this case,

$$\eta_t = \frac{P_t}{P_e} = \frac{\eta_{tr} P_t}{P_m} = \eta_{tr} \frac{v}{v_t} \cdot \frac{F_t}{F_m} = \eta_{tr} \eta_\delta \eta_r, \quad (1)$$

where: $\eta_{tr} = P_m/P_e$ – overall transmission efficiency (in case of crawler tractors it also includes the efficiency $\eta_s = 0.95\ldots0.97$ of the active branches of the two tracks); P_m – power at the driven wheels; P_e – actual engine power; $\eta_\delta = v/v_t = 1 - \delta$, slip efficiency; v – actual speed of the tractor; v_t – theoretical speed of the tractor; δ – tractor slip; $\eta_r = F_t/F_m$ – efficiency of motion; F_t – drawbar pull; F_m – tractive effort, $F_m = F_t + R_r$; $R_r = fG$ – rolling resistance; f – rolling resistance coefficient; G – operating weight of the tractor.

2 Mathematical Modelling of the Potential Performance Characteristics for Three Types of Tractors: 4 × 2 Tractors, 4 × 4 Tractors and Crawler Tractors

The tractive efficiency of the tractor is determined with the relation (1) that is successively transformed into

$$\eta_t = \eta_{tr}(1 - \delta)\left(1 - \frac{R_r}{F_m}\right) = \eta_{tr}(1 - \delta)\left(1 - \frac{fG}{F_t + fG}\right). \quad (2)$$

We use the relation (2) to draw the tractive efficiency curve taking account of the drawbar pull F_t; this curve actually represents the potential performance characteristics of the tractor $\eta_t = f(F_t)$. This characteristic assesses the similitude degree between an actual performance characteristic and an ideal one. Expressing the tractive efficiency η_t by considering only dimensionless parameters has considerable theoretical and practical advantages in terms of increasing the degree of generality of the relation, that is to say the relation applies to a wide range of tractors.

Thus, the last parenthesis in relation (2), which represents the efficiency of motion η_r, is successively written as follows:

$$1 - \frac{fG}{F_t + fG} = 1 - \frac{f}{\frac{F_t}{G} + f} = 1 - \frac{f}{\frac{F_t}{G_a}\lambda_m + f} = \frac{1}{1 + \frac{f}{\lambda_m \varphi_t}}. \tag{3}$$

We have expressed above the operating weight according to the load on the driven wheels G_a, namely: $G = G_a/\lambda_m$ and we have used the definition relation of the specific drawbar pull: $\varphi_t = F_t/G_a$. Thus, relation (2) becomes:

$$\eta_t = \frac{\eta_{tr}(1 - \delta)}{1 + \frac{f}{\lambda_m \varphi_t}}. \tag{4}$$

Relation (4) is subsequently particularized for each type of tractor.

4 × 2 Wheeled Tractors. Using the relation (4), the potential performance characteristic is obtained by drawing the graph of the curve $\eta_t = f(\varphi_t)$, equivalent to $\eta_t = f(F_t/G_a)$. For the performance calculation, the coefficient of the load on the driven wheels is λ_m = 0.75…0.8 (in idle position λ_m = 0.6…0.65). The calculation accuracy required in order to analytically determine the tractor's performance highly depends on a modelling of the tractor-soil interaction that is as precise as possible, that is to say a calculation of the slip δ as precise as possible. In case of wheeled tractors, very good results are obtained with the following relation [1–3]:

$$\delta = \frac{A\varphi_m - B\varphi_m^2}{C - \varphi_m}; \quad A = \frac{3m\varphi}{4}; \quad B = \frac{m}{2}; \quad C = \varphi + \frac{m\varphi^2}{4}; \quad \varphi = \varphi_{m\,\max}. \tag{5}$$

In this relation $\varphi_m = \varphi_t + \frac{f}{\lambda_m}$, and m – angular coefficient of the line on the linear variation of the slip: $\delta = m\varphi_m$, when $0 \le \varphi_m \le 0.5\varphi$.

Figure 1 presents the graph of function (4), $\eta_{t1} = f(\varphi_t)$, for 4 × 2 tractors, to which the graph of the slip function $\delta_1 = f(\varphi_t)$ has been added.

4 × 4 Wheeled Tractors. For this type of tractors the mathematical modelling of the potential performance characteristics is identical to that of 4 × 2 tractors, but in this case λ_m = 1.

In Fig. 2 we present the graph of function (4), $\eta_{t2} = f(\varphi_t)$), where λ_m = 1, for 4 × 4 tractors, to which the graph of the slip function $\delta_2 = f(\varphi_t)$) has been added.

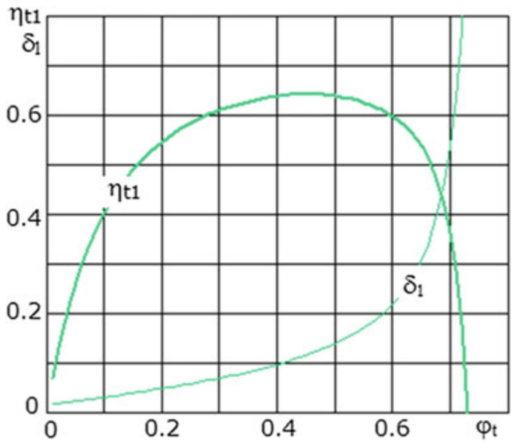

Fig. 1. η_{t1} and δ_1 dependency taking account of φ_t.

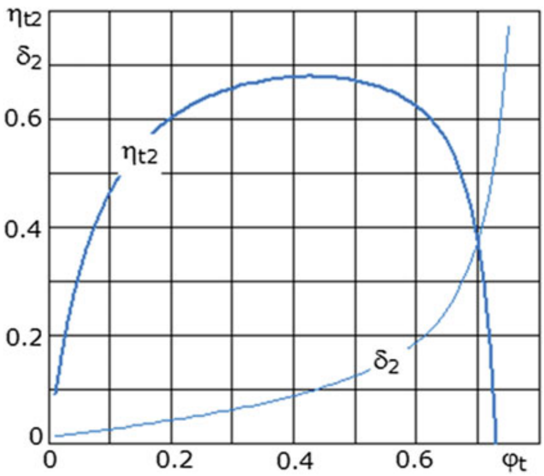

Fig. 2. η_{t2} and δ_2 dependency taking account of φ_t.

Crawler Tractors. For crawler tractors the mathematical modelling of the potential performance characteristics is similar to that applied for 4 × 4 tractors; $\lambda_m = 1$ in this case as well, but the mathematical modelling of slip is different. A fair number of specialist papers recommend the following function for the mathematical modelling of slip for crawler tractors. This mathematical modelling is also used in papers [1, 3]:

$$\delta_3 = \frac{0.0333\varphi_t}{1 - 1.377\varphi_t^2}. \tag{6}$$

In the last relation $0 \leq \varphi_t \leq 0.84$, which corresponds to slip $0 \leq \delta_3 \leq 1$.

Figure 3 presents the graph of function (4), $\eta_{t3} = f(\varphi_t)$, for crawler tractors where $\lambda_m = 1$, to which the graph of the slip function $\delta_3 = f(\varphi_t)$ has been added, using relation (6) in this case.

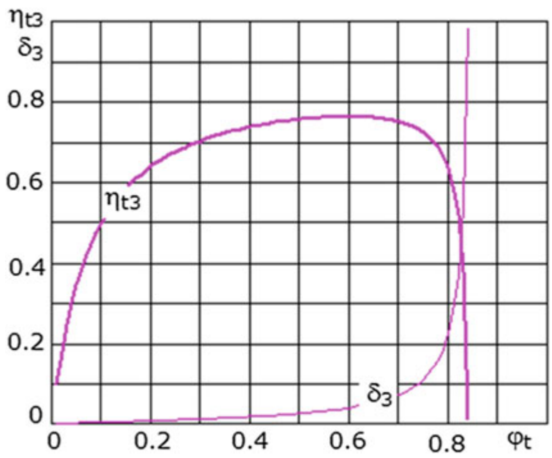

Fig. 3. η_{t3} and δ_3 dependency taking account of φ_t.

3 Conclusions

The conclusions include a comparative analysis of the potential performance characteristics for the three types of tractors.

Figure 4 presents the curves $\eta_t = f(\varphi_t)$ and $\delta = f(\varphi_t)$ for all the tractors comparatively analysed, corresponding to tractors operation on stubble field. As mentioned above, these curves represent, at a different scale, the potential performance characteristics for the tractors under analysis. In order to highlight the significant influence of slip upon the curves η_t, Fig. 4 also shows the curves $\delta = f(\varphi_t)$.

By comparing the three curves η_t in Fig. 4, the following conclusions arise:

- Crawler tractors have a higher tractive efficiency as compared to wheeled tractors;
- Taking the crawler tractors, the maximum value of tractive efficiency is placed to the region of high drawbar pull;
- Taking the crawler tractors, the efficiency η_{t3} is optimum within a wide range of drawbar powers;
- In the case analysed (operation of tractors on stubble field) the maximum value of tractive efficiencies is: $\eta_{t1\,\max} = 0.642$; $\eta_{t2\,\max} = 0.679$; $\eta_{t3\,\max} = 0.763$;
- Tractors should be operated in a region of maximum tractive efficiency.

By analysing the form of the potential performance characteristics, we make out another important conclusion that is of great use to designing tractor transmission. To be more precise, when the number and the structure of gears are established the region

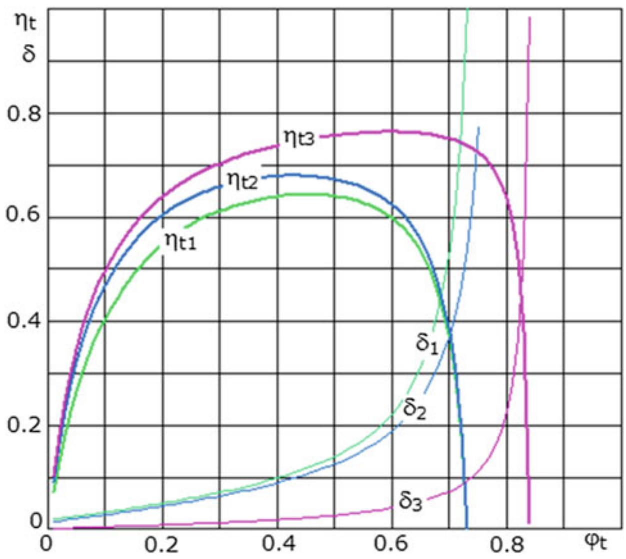

Fig. 4. η_t and δ dependency taking account of φ_t for all types of tractors

of drawbar pulls, where the tractor will operate more economically, should be considered. This conforms to the region of maximum tractive efficiency.

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