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PRELIMINARY STUDY ON AN AUTOMATIC PROPELLANT SYSTEM FOR IMPROVING TRACTIVE PERFORMANCE OF TRACTOR

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ABSTRACT

This paper presents the design of an automatic propellant system model in order to improving tractive performance of tractor. The theoretical basis of automatic control, the characteristics and function of the system, and the kinematic analysis are also discussed.

Key Word: Computer, Propellant set, Slip, Performance, Tractor, Soil

INTRODUCTION

When a tractor works in agricultural fields, it often meets some difficult conditions, such as soft soil, deep sinkage, high slip, etc.. It results in low efficiency, high fuel consumption.

The performance of tractor could be improved in the following ways by some researchers. For example, Dawson et al. (1985) and Lasoen et al. (1987) respectively designed a device that can change the air pressure of tractor tires in the cab during farm working in order to raise the tractive performance and reduce the soil compaction. Clark et al. (1986) developed an automatic tractor ballast system to simplify changing of vertical load distribution between the tractor axles. Ballast in the form of liquid was pumped between tanks located on the front and rear of the tractor. Self et al. (1987) designed an instrument to control tractor dynamic load ratio from the cab. Their objective was to raise the tractor performance by means of applying rational dynamic load on tractor. In 1988, Welsh Agricultural College (U.K) designed the "gripwheels" with retractable traction aid bolted to the outside of the rear tractor wheels. They can be hydraulically engaged and disengaged based on the soil condition by the operator. However, all these systems are some automatic assistant set for raising tractive efficiency of tractor.

The purpose of this preliminary study is to design a set of automatic model to improve the tractive performance of a tractor. This model system could be used as an assistant propellant device automatically when the actual slip is higher than the given value in order to raise the tractive efficiency.

CONTROL SLIP AS THEORETICAL BASIS

According to dimensional analysis (Freitag, 1966), the performance of a tire wheel depends on soil condition (such as friction angle ϕ, cohesion c, specific weight γ, etc.), tire parameters (for example diameter d, section width b, section height h and deflection δ) and system condition (dynamic load W, translational velocity V, slip S, tire-soil friction μ, etc.). For simplifying the study, a relation of the parameters function was developed as Eq. (1) (Wismer and Luth, 1973):

$$R/W,\ F/W,\ Q/(r_oW) = f\,(S,\ C_n,\ b/d,\ r_o/d) \qquad (1)$$

Which:

R/W : coefficient of rolling resistance;
F/W : coefficient of traction; F: traction force;
$Q/(r_oW)$: coefficient of torque;
S : tire slip;
$C_n=C_Ibd/W$: tire numeric;
C_I : soil cone index;
r_o : rolling radius of tire.

They developed a traction equation (cf. Eq. (2)):

$$F/W = 0.75\,(1 - \exp(-0.3C_nS)) - (1.2/C_n + 0.04) \qquad (2)$$

$$F_T=(blc + W\tan\phi)(1-K/(Sl)+K/(Sl)(\exp(-Sl/K)) \qquad (3)$$

Equation (3) is a world known formula to calculate the traction force with respect to slip (S), soil (c, ϕ) and and wheel parameters (b, l, K) for tractor on dryland and also paddy field soil (Shao, 1988).

Hong (1990) has studied on this subject for many years and some idea was presented in his Ph.D Thesis dissertation.

For an automatic system to raise the tractive performance of a tractor, it is necessary to select a control index while the system is on working. The soil parameters as indices in the above equation are too much and too difficult to measure while working. But the slip of tractor is easy to measure, and it is a practical index to measure the tractive performance of a tractor. So we take the control slip as the basic index for our assistant propellant system.

The general definition of tractor slip is as Eq. (4):

$$S = 100\% \, (V_t - V_r)/V_t \tag{4}$$

which:

S : tractor slip (%);
V_t : theoretical speed;
V_r : real speed.

The generation of slip is unavoidable. When tractor is working, we take the slip as the basic parameter of the interaction between tractor and soil. The slip has an optimal value zone to give higher tractive efficiency. Increased tractive efficiency not only reduce the direct operating costs, but also improve corp yields through reduced soil compaction.

TEST MODEL DESIGN

For the preliminary study, a test model has been designed. It is composed of three parts (cf. Fig. 1):

(1). a tractor model;
(2). an assistant propellant device;
(3). a single chip microcomputer control system.

Tractor Model

There are two rear driving wheels and a front driven wheel on little tractor model (cf. Fig. 1). This tractor is driven by electric motors which the rotative velocity is reduced by means of two pair of worm gear. It has forward and return travelling direction by means of simply switching to give clockwise or counterclockwise rotation of his motors.

Assistant Propellant Device

The assistant propellant device is composed of an electric motor and a linking mechanism with driving disc crank, oscillating pole (L_1 and L_2) and a guiding slide. Their simplified form of linking mechanism is presented in figure 2. The electric motor is controlled by the single chip microcomputer.This device is in reality an oscillating and guiding pole link mechanism. There are a crank r, an oscillating pole and guiding part B (cf. Fig. 2). While the crank r rotates around O_1, the oscillates pole slides in the guiding part and the oscillating pole oscillates around O_2. When the crank r is perpendicular to the oscillating pole, O_1A_1 and O_2A_2 are the limit positions of the oscillating pole. Angle β is the angle of these two limit positions. According to figure 2, there will be a relation shown as Eq. (5):

$$\sin(\beta/2) = r/D = 1/\lambda \qquad (\lambda = D/r) \tag{5}$$

On figure 2, the time which the oscillating pole oscillates from O_2A_2 to O_2A_1 is shorter than that from O_2A_1 to O_2A_2. While the crank r runs with uniform velocity, the speed of the oscillating pole is variable with a character of rapid return. The rate of this two speed is as Eq. (6):

$$k = \varphi_2/\varphi_1 = (180°+\theta)/(180°-\theta) \tag{6}$$

According to the geometric relation of the figure 2, the related expression between angular velocity of oscillating pole $\omega 1$, that of crank ω and their structure parameters is as Eq. (7):

$$\omega_1/\omega = (1+\lambda\cos\omega t)/(1+\lambda^2+2\lambda\cos\omega t) \tag{7}$$

Taking O_1A_0 as starting position, the effect of value λ on ω_1/ω and ωt is presented in the figure 3. This figure shows the following characters:

(a). curves vary symmetrically;

(b). the less the value λ, the more violent the variation ω_1 of return stroke, the more the maximum value ω_1, and inversely there is a tranquil variation;

(c). if the value λ is rather small, the size of the device can be reduced. The oscillating angle of the pole becomes larger, but the value ω_1 of return stroke varies violently. It is suitable while the value λ is somewhat larger than 2. A reasonable device for approaching an uniform motion in working stroke and having a rather more speed in return stroke is designed.

In figure 4, supposing C is the center of oscillating pole, the speed of the assistant propellant device is as following Eq. (8):

$$V_h = \omega_1(L_1 + L_2)\cos\alpha \tag{8}$$

L_2 is a constant value. L_1, ω_1 and α are function of time t. The V_h is a variational speed. The displacement J of propellant device may be calculated by the following equation (9). It is clear that the optimum J means to have better traction action.

$$J = \int V_h \, d(\omega t) \tag{9}$$

According to figure 4, this equation of moving is influenced by its slip S:

$$X = J(1 - S) - (L_1 + L_2)\sin\alpha \tag{10}$$

$$Y = (L_1 + L_2)\cos\alpha \tag{11}$$

Single Chip Microcomputer Control System

Based on the control principle above, a single chip microcomputer control system has been developed. The figure 5 shows the bloc diagram of the hardware system. The sensor 1 is a dynamo driven by rear wheel shaft for measuring the theoretical speed. The sensor 2 is also a dynamo driven by front wheel for measuring real speed. The measuring principle of this sensor is that the generating voltage is proportionally to the speed.

The software of the control system has been programmed in assemble language in accordance with the MCS-51 instruction and the processing, then written into EPROM.

SYSTEM FUNCTION

Before measuring and controlling system working, a given value of slip (Sg) should be inputted by keyboard. At the same time, two sensors (1 and 2, cf. Fig. 5) measure respectively the theoretical speed (V_t) and real speed (V_r), and the microcomputer calculates actual slip (S_a). While the actual slip is equal or higher than the given slip value, the microcomputer controls the working of the electric motor of assistant propellant device. When the system stop its working, it must conform to the following two conditions: (a) $S_a < S_g$ and (b) the assistant propellant device goes back to up position. The second condition is sensitized by a sensor of switch (cf. Fig. 1). The flow chart of this system is presented on figure 6.

CONCLUSIONS

Based on this preliminary study, the following conclusions can be drawn:

(1). It's suitable and convenient to take the tractor slip as the controlling base of microcomputer in the automatic system for improving tractive performance of tractor.

(2). A single chip microcomputer used as collecting informations and controlling the assistant propellant is suitable. In an EPROM, it can be written plural programs (if it has enough capacity). According to the necessity, the program can be loaded or the EPROM can be replaced.

(3). The assistant propellant system is good enough to give an extra tractive force to normal and give better work. It's interesting to note that it's better the rotative velocity of crank (ω) can be automatically changed. We are now to study continuously on its practical application.

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FIGURES

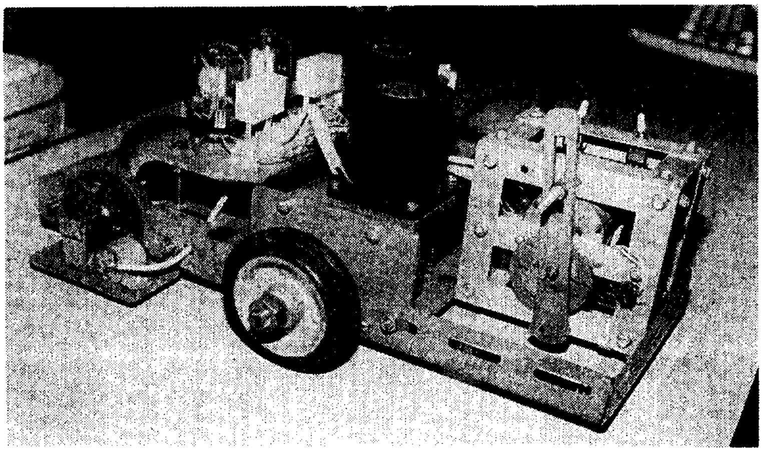

Figure 1. PHOTOGRAPH OF THE TEST MODEL

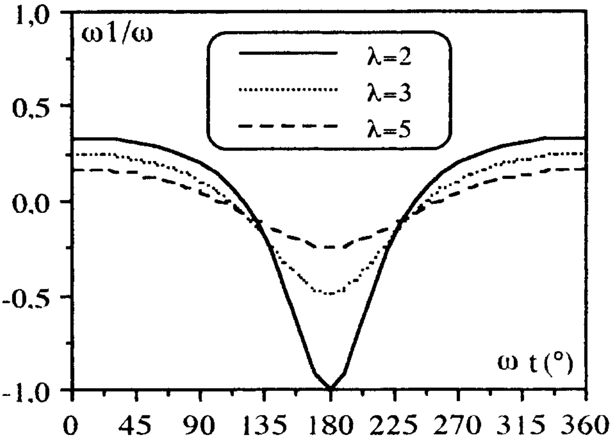

Figure 3. EFFET OF (ω_1/ω) ON ANGULAR VELOCITY UNDER DIFFERENT VALUE

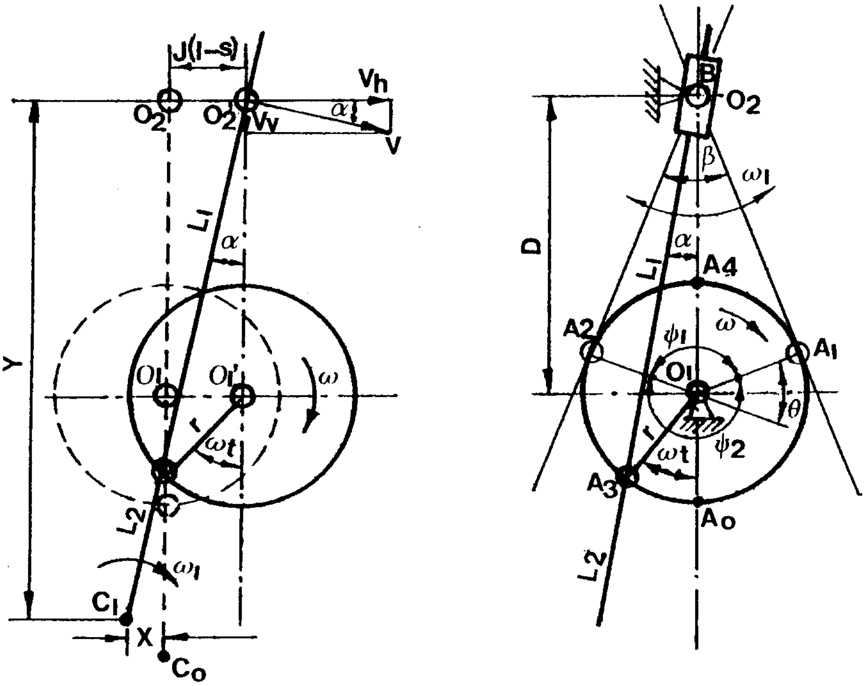

Figure 2

Figure 4

Figure 2 and 4. KINEMATIC ANALYSIS ON THE ASSISTANT PROPELLANT LINK DEVICE

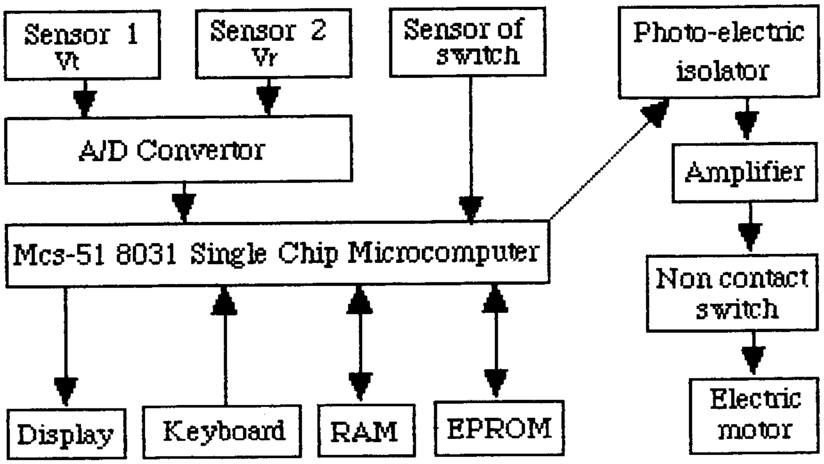

Figure 5. BLOC DIAGRAM OF THE HARDWARE SYSTEM

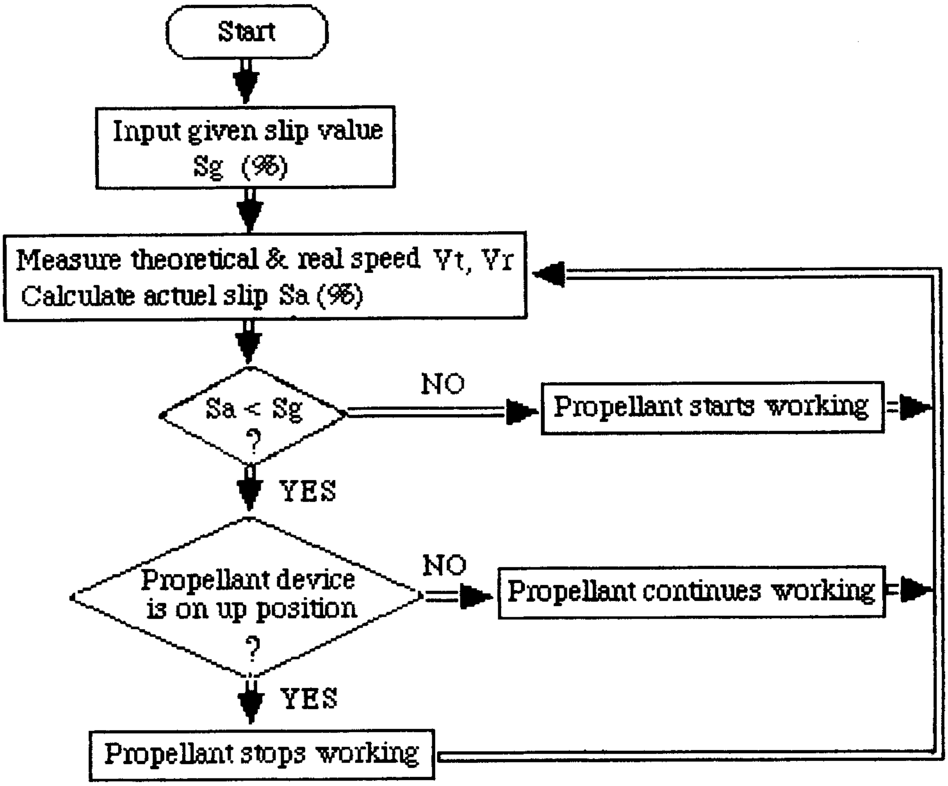

Figure 6. FLOW CHART OF THE FUNCTION ON PROPELLANT SYSTEM