보통 콤바인 급동의 소요동력 모델

Power Requirement Model for Combine Cylinders

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적 요

곡물을 수확하는데 필요로하는 동력의 상당부분이 탈곡부 급동에서 소요된다. 예취된 작물 전부가 탈곡부에 투입되는 콤바인의 경우 급동 소요동력이 전체 소요동력의 80%까지 되기도 하며, 축류식의 경우가 보통형인 경우보다 높은 급동 소요동력을 보인다. 수확된 곡물의 가치가 작업기의 동력비 및 운영비 보다 커야하므로, 급동 소요동력모델은 경제성을 고려한 콤바인의 설계 및 작동을 유도해 내는데 기본이 된다. 본 논문에서는 콤바인 급동의 소요동력을 예측하기 위해 탈곡현상에 기초를 둔 수학적 모델을 개발하였다. 급동에 부착된 라습바(rasp-bak)의 수, 수망과 급동의 간격, 수망의 길이, 공급물의 두께, 공급율, 급동회전속도 등의 변수들을 포함한 수식이 개발되었으며 급동의 크기에 의한 영향도 고려되었다. 개발된 모델은 측정된 자료와 잘 일치했으며 ($R^2=0.9$) 높은 신뢰도를 보였다.

Introduction

Combine cylinders consume the major part of the total power used to harvest grain. Measurements reported by Burrough (1954), Arnold and Lake percent of the total power required by the harvester. These data were collected before axial-flow combines were developed. With the axial-flow design, an even higher percentage of the total power should be due to the cylinder (rotor). Understanding the power consumption by the cylinder is, thus, a key to understanding total power requirements of a combine.

It is usually not economical to harvest all grain. The cost to thresh and separate the last small fraction of grain in the straw is usually greater than the value of the grain. Optimum harvest occurs when the value of grain harvested is larger than or equal to the cost to power and operate the machine. Obviously, improvement in modeling power consumption can lead to more optimum harvester design and operation.

Only limited work has been published on mathematical functions to describe power consumption. Dodds (1968) reported that power requirement is a linear function of feed rate ; however, some of the data collected by Arnold and Lake (1964) disagree with this relationship and indicate that power consumption can vary with feed rate squared for certain conditions. Arnold and Lake (1964) found that closed concaves consume more power than concaves with open grates. Power consumption also varies with concave length (Arnold and Lake, 1964). The objective of this paper is to develop a function to predict power consumption in combine cylinders as a function of the many variables that af-

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fect the system. The equation should also resolve the contradiction between the results of Dodds (1968) and Arnold and Lake (1964).

Model Development

The power, P, required by the threshing drum can be expressed as the summation of power to operate a machine with no material (P_0) and power to process material, p_p,

$$P = P_0 + P_p \quad (1)$$

The power to operate the machine with no material may vary with size and design of the machine, but it should be a constant or nearly a constant for a given machine. The power required to process material will vary with many variables and will be evaluated with three schemes.

Power to Process-Scheme 1

Work or energy can be expressed as pressure times a change in volume.
Power is energy per time. Power can, therefore, be expressed as pressure times the volume flow rate of material. Volume flow rate can be expressed as feed rate divided by material density (straw-grain particle density), which results in the following equation for power to process :

$$P = (P_r \rho)\ F_r \quad (2)$$

where P_r = pressure on material in machine,
ρ = density of material in machine, and
F_r = feed rate of material.

Equation 2 explains the data for power consumption reported by Kepner et al. (1982) for hay balers and provides insight to how certain variables will affect power consumption in combines. First, if pressure and density remain constant, then power consumption varies as a linear function of feed rate, which matches the results of Dodds (1968) and Arnold and Lake (1964) for constant material thickness. If material thickness is doubled, the pressure in the system should double. This relationship explains the results obtained by Arnold and Lake (1964) when feed rate was increased by increasing material thickness on a conveyor with constant speed. For this condition, data from Arnold and Lake (1964) followed the relationship that power varies with the square of feed rate.

Changing concave clearance should have the same effect as changing material thickness. Reducing concave clearance should increase pressure and increase power consumption. From this analysis, it can be concluded that the ratio of material thickness to concave clearance is an important dimensinoless variable. It can also be concluded that a final power equation should have the following form :

$$P_p = A_1\ (T_h/C)\ F_r \quad (3)$$

where A_1 = a coefficient that may vary with other variables not yet considered,
T_h = thickness of feed material, and
C = concave clearance.

Power to Process-Scheme 2

Work or energy can also be expressed as force times distance. Force is mass times acceleration ; therefore, work can be expressed as

$$W_k = (M\ \ a)\ L \quad (4)$$

where W_k = work performed to process the material, M = mass of material,

a = acceleration occurring in the system, and

L = length over which work is performed (length of concave)

Power is work per time and feed rate is mass per time. If both sides of equation 4 are divided by time, the following equation for power to process is obtained :

$$P_p = (F_r \ a) \ L \quad \cdots\cdots (5)$$

The linear relationship of feed rate in Equation 5 matches the linear relationship given in Equation 3. One additional variable is obtained ; power also varies with concave length. Equations 3 and 5 can be combined to obtain

$$P_p = A_2 \ L \ (T_h/C) \ F_r \quad \cdots\cdots (6)$$

where A_2 = a coefficient that, like A_1 may vary with other variables not yet considered.

Power to Process-Scheme 3

Power can also be expressed as force times velocity. With this relationship, power can be expressed as the product of impact force made by the cylinder on the material times the velocity of the cylinder.

$$P_p = F_i \ V \quad \cdots\cdots (7)$$

where F_i = impact force for a given material and constant feed rate, and

V = linear velocity of cylinder.

The velocity, V, can be expressed as the product of cylinder circumference and angular velocity ; therefore,

$$P_p = F_i \ \pi \ D \ W \quad \cdots\cdots (8)$$

The impact force only applies on the fraction of the cylinder in contact with the concave and the power must be multiplied by this fraction :

$$P_p = F_i \ \pi \ D \ W(L/(\pi D)) \quad \cdots\cdots (9)$$

Equation 9 reduces to

$$P_p = (F_i \ W) \ L \quad \cdots\cdots (10)$$

The impact force can be replaced with the force per cylinder bar, F_b times the number of bars N per revolution times revolutions per time, W, times time, T, required for material to pass through the system :

$$P_p = (F_b \ N \ W^2 \ T) \ L \quad \cdots\cdots (11)$$

The force per bar can also be expressed as the mass encountered per impact times the local acceleration :

$$P_p = (M \quad a_L \ L \ N \ W^2 \ T) \ L \quad \cdots\cdots (12)$$

If the right side is multiplied and divided by time in the system the following is obtained :

$$P_p = (M/T \quad a_L \ N \ W^2 \ T^2) \ L \quad \cdots\cdots (13)$$

The M/T term is proportional to feed rate ; therefore

$$P_p = A_3 \ a_L \ T^2 \ N \ W^2 \ L \ F_r \quad \cdots\cdots (14)$$

where A_3 = a coefficient. If the linear cylinder speed is held constant but diameter of the cylinder changed, W can be replaced with a constant C_1 divided by πD. This substitution results in the following equation :

$$P_p = A_3\ a_L\ T^2\ N(C_l/\pi\Delta)^2 L\ F_r \cdots\cdots\cdots\cdots (15)$$

It will be shown in a later section that Arnold's data matches Equation 15.

A general power to process equation can be obtained by superimposing Equations 6 and 14. The final equation is

$$P_p = A_4\ N(T_h/C)\ W^2\ L\ F_r \cdots\cdots\cdots\cdots\cdots\cdots (16)$$

where A_4 = a coefficient that incudes a_L and T_2

The final total power equation is

$$P = P_0 + A_4\ N\ (T_h/C)\ W^2\ L\ F_r \cdots\cdots (17)$$

Variable Feed Rate

Most combines have concaves with open grates. As grain is threshed and separated, the mass flow or feed rate decreases. Because of this process, cylinders with closed concaves typically require more power than cylinders with open concaves. Obviously the true power equation for cylinders is a non-linear function of concave length. The actual feed rate varies with the interaction of threshing and separation occurring along the length.

In simulation models where the grain removal from the straw is simulated as a function of concave length, Equation 17 can be applied for a small differential length of the concave. The total power can be obtained with a summation of power from all differential lengths.

The average internal feed rate also appears to be proportional to machine feed rate for cross-flow cylinders. Most cross-flow cylinders, for example, separate 60 to 80 percent of the grain from the straw. If the grain to straw ratio is unity, the mass flow leaving the cylinder will vary between (0.5+0.2*0.5) F_r and (0.5+0.4*0.5) F_r. If the average feed rate is the average of incoming and outgoing mass flow, then the average feed rate will vary between 0.80 F_r and 0.85 F_r. Less than a 5 percent error will occur if a constant of 0.82 is used and internal changes in feed rate are ignored Note, however, that a closed concave would result in approximately a 22 percent (100*0.18/0.82) increase in power. This amount closely matches the 25 percent reported by Arnold and Lake (1964).

Verification

Data from Arnold (1964) were used to verify the derived equation. The cylinder peripheral speed and the length of the concave used to collect this data were held constant. Equation 15 was combined with Equation 1 and tested. For the first evaluation, material thickness was constant. The fit of the feed rate and cylinder diameter relationship is shown in Figure 1. A comparison of measured and predicted values of mean power for constant stream thickness is shown in Figure 2. An R^2 of 0.901 was obtained, which was significant at the 99.9% probability level (alpha=0.001). This analysis provided evidence that the feed rate and cylinder diameter relationship in Equation 15 is valid.

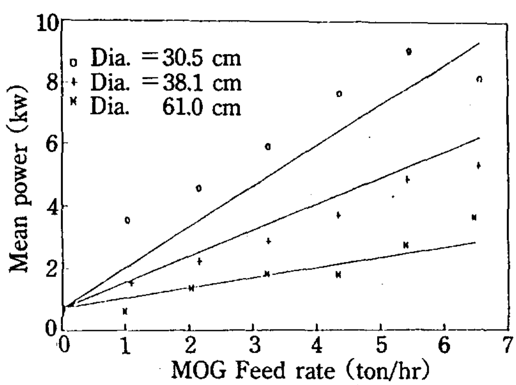

Figure 1. Relationship between feed rate at constant stream thickness and mean power.

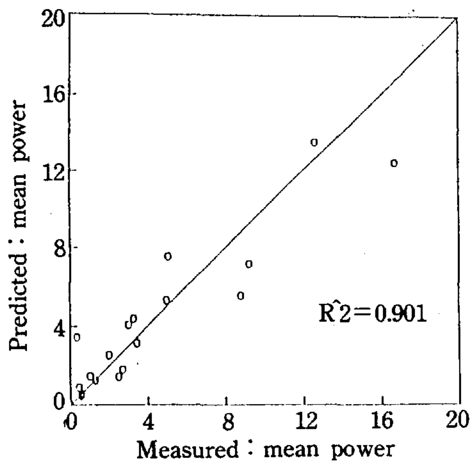

Figure 2. Comparison of measured and predicted values of mean power for constant stream thickness.

When feed rate is increased by increasing material thickness on a conveyor with constant speed, the thickness of the material can be expressed as :

$$T_h = F_r/(\rho☆W_d☆V) \cdots\cdots\cdots\cdots (18)$$

where ρ = bulk density of material,
W_d = material contact width on the concave surface, and
V = conveyor speed.

If the T_h in Equation 16 is replaced with the right side of Equation 18 and W is replaced with C_1 divided by πD, the following power equation is obtained.

$$P = P_0 + A_5\, N\, (I/C)\, (C_1/\pi D)^2\, F_r^2 \cdots\cdots (19)$$

where A_5 = a coefficient that incudes a_L, T^2, ρ, W_d and V.

The fit of Equation 19 with the data reported by Arnold (1964) is shown in Figure 3. Also a comparison of measured and predicted values of mean power for the data of constant stream

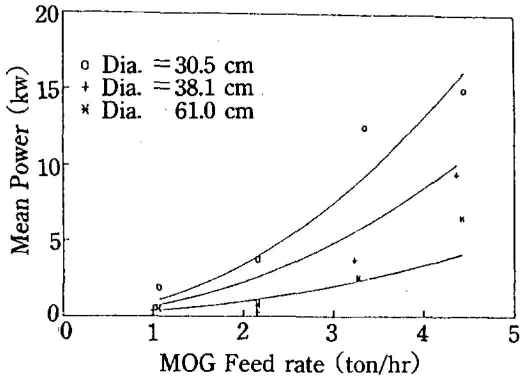

Figure 3. Relationship between feed rate at constant stream speed and mean power.

speed is shown in Figure 4. The derived function fit the measured data with an R^2 of 0.900 and had a value of 0.001 for alpha. The analysis verified that power varies with the square of feed rate when feed rate changes with thickness.

Not all variables in Equation 17 were tested. Three variables, F_r, T_h, and D^2 through W^2 were tested. All variables tested appear to be formulated correctly in Equation 17. It is assumed that the variables, N, C and L are also correct and it is concluded that Equation 17 is a valid power function to explain performance of com-

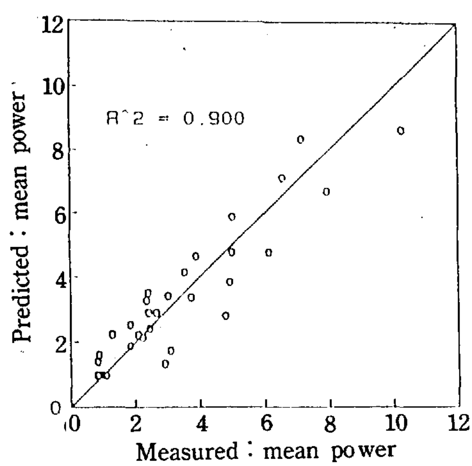

Figure 4. Comparison of measured and predicted values of mean power for constant stream speed.

bine cylinders.

Summary

Because combine cylinders account for up to 80 percent of the power requirements to harvest grain, it is important to have a reliable method to predict and analyze power consumption. An equation was derived to meet the prediction needs. The equation contains the variables number of bars on the cylinder, concave clearance, concave length, thickness of the feed material, feed rate, and cylinder speed. Indirectly, cylinder diameter was also considered. The derived equation was verified to be a reliable function for three of the variables and the equation was judged to be a reliable power prediction equation.

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