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Development of Design Theory on the Tooth Arrangement and the threshing Drum for a Large–Sized and High–Speed Head–Feeding Combine

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This study was intended to develop the design theory of the threshing unit for a large–sized and a high–speed head–feeding combine. It may be applied for various combining capacities with different cutting widths and forward speeds.

Design factors in the theoretical development are: (1) dimensions of the threshing drum, (2) tooth approaching angle, (3) distance between the adjacent teeth on their spiral setting line, (4) number of spirals, and (5) total number of teeth on the drum.

A computer simulation program was developed to predict the proper dimensions for the threshing drum and tooth arrangement. A simulation for the prospective combine with varied capacities was also demonstrated. The parameters analyzed in the developed design theory were shown to be consistent with those of existing combines.

INTRODUCTION

A head–feeding combine is widely used in Japan and Korea as a grain harvester. In these days, there is a tendency that the combines have been changing into the wider cutting width and faster forward speed, to give a higher capacity. The threshing part of combines is the kernel part which consumes about one half the total combine energy and has a great influence to the performance of threshing, separation, chaffing, and grain loss (Carrol, T,. 1961). Because of its complexity of threshing phenomenon, the design of the threshing unit has been much dependent upon an experience rather than design theory (Ezaki, H,. 1972). However, the trend of high–capacity combines currently demanded requires appropriate justified design theory, This study was intended to develop a theoretical design method for the threshing unit of a head–feeding rice combine.

Derivation of the theoretical Equation about Tooth Arrangement

The dimension of threshing drum can be defined by its diameter and length. A figure of the developd drum is shown in Fig. 1. Threshing teeth are fixed to the drum, which are made of steel–wire in the shape of the inverted V or U letters. The tooth has a different shape, generally a lower and wider in the first part and higher and narrow in the last part. The teeth are arranged with spiral form and defined by approaching angle of arrangement–line, distance between teeth, which adjoin on the arrangement–line, and the interval with arrangement–line in the direction of circumference (C. J. Chung, etc., 1972).

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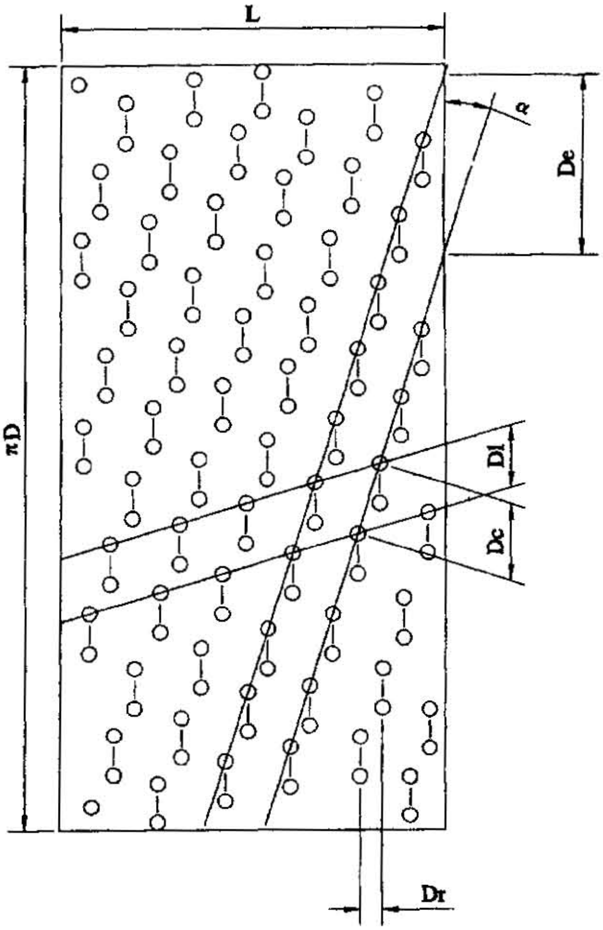


Fig. 1. Variable specification of threshing teeth arrangement

It is necessary to find an analytical relation among them, because these factors are all related with the threshing performance (C. J. Chung , etc., 1985; Quick, G. R., 1972).

Thickness of stems which pass the feeding chain

Let us denote the forward working speed as V_c (cm), number of rows cut by the cutter N_c, the interval between each plant bush row D_a (cm), cutting cross sectional area of each bush A_r (cm^2). The cutting cross sectional area of stems per unit time can be expressed as $\left(\frac{V_r}{D_a}\right) N_r A_r$. If we denote the feed chain speed as V_l, thickness of crops, which pass the feed chain without compression D_b, the crop's cross sectional area per unit time, which feed into the threshing unit by the feed chain, is $V_l D_b$. Above two values have to be the same. Therefore,

$$D_b = \frac{V_r N_r A_r}{D_a V_l} \tag{1}$$

Flail number of tooth

Suppose that threshing actions may occur by impact of threshing teeth to the crop head. The flail number, as the crops move as much as a unit length (1 cm) in the direction of axle of drum, are proportional to the total number of triangular teeth and the rpm of drum. Therefore, flail number of teeth per unit width to crops, which move through feed chain, is given as

$$\begin{aligned} N_i &= N_l (N_t - 3)\left(\frac{R}{60}\right)\left(\frac{1}{V_l}\right) \\ &= \frac{RN_l (N_t - 3)}{60V_l} \end{aligned} \tag{2}$$

Where, N_l =Number of teeth arrangement line

N_t =Number of teeth included in one arrangement line

R =Rotational speed of drum, rpm

Number of teeth on one arrangement line is equal to the length of arrangement line divided by length between teeth measured in the direction of the line, or

$$\begin{aligned} N_t &= \frac{L \sec(90^\circ - \alpha)}{D_r \sec(90^\circ - \alpha)} = \frac{L}{D_r} \\ &= \frac{L}{D_l \tan\alpha} \end{aligned} \tag{3}$$

Where, L = Length of drum (cm)

D_r = Lateral distance between adjacent teeth in the arrangement line (cm)

α = Approaching angle of arrangement line (deg.)

D_l = Interval of flail–line, which is the length of adjacent teeth in the direction of drum circumference.

Relation of feed chain speed to approach speed of arrangement–line

The approaching speed of the arrangement line to the crops threshed must be equal to the rotational speed of drum multiplied by approaching distance of arrangement line. Therefore, the speed ratio of feed chain to approach of arrangement line is given as

$$R_r = \frac{\pi D R \tan\alpha}{60 V_t} \tag{4}$$

Where, D=the effective diameter of drum (cm).

Theoretical equation of drum and tooth arrangement

Based on the above equation developed, it can be derived the dimension of the drum and design equation about threshing tooth. Giving feed chain speed V_t as in Equation (1), the approach angle of tooth arrangement line, α, is given as

$$\alpha = \tan^{-1} \frac{60 R_r V_c N_c A_r}{\pi R D D_a D_b} \tag{5}$$

If the Equation (2) rewrite about N_t and it is equated with Equation (3), then the length of drum L is given as,

$$L = D_l \tan\alpha \left(\frac{60 V_t N_r}{R N_l} + 3 \right) \tag{6}$$

Substituting V_t of Equation (1) in Equation(6), the length of drum is

$$L = D_l \tan\alpha \left(\frac{60 V_c N_c A_r N_r}{D_a D_b R N_l} + 3 \right) \tag{6'}$$

The length between adjacent two teeth in the direction of arrangement line is given,

$$D_c = \frac{D_l}{\cos\alpha} \tag{7}$$

The interval of arrangement–lines in the direction of drum's circumference, D_e, is the same value as the drum's circumference divided by the number of arrangement–line.

$$D_e = \frac{\pi D}{N_l} \tag{8}$$

ANALYSIS ON THE DRUM AND TOOTH ARRANGEMENT

In deriving the theoretical design equations of threshing drum and teeth arrangement, it was used many design factors and derived variables. To make use of the developed equation in design application, it is need to specify appropriate range of the design factors involved. For instance, Table 1 is a summary of actual values of the design factors measured for head–feeding rice combines having 2–, 3–, 4–rows of cutting width. Fig. 2 shows the developed figure of the threshing teeth arrangement of a 4–row combine.

There are many kinds of teeth as shown in Fig. 2. The teeth may be classified in low–triangular tooth (1), semi–circular tooth (2), double semi–circular tooth (3), low double triangular tooth (4), high double triangular tooth (5), triangular tooth(6), sorting plate (7). Dimensions characterizing the tooth shape are shown in Table 1.

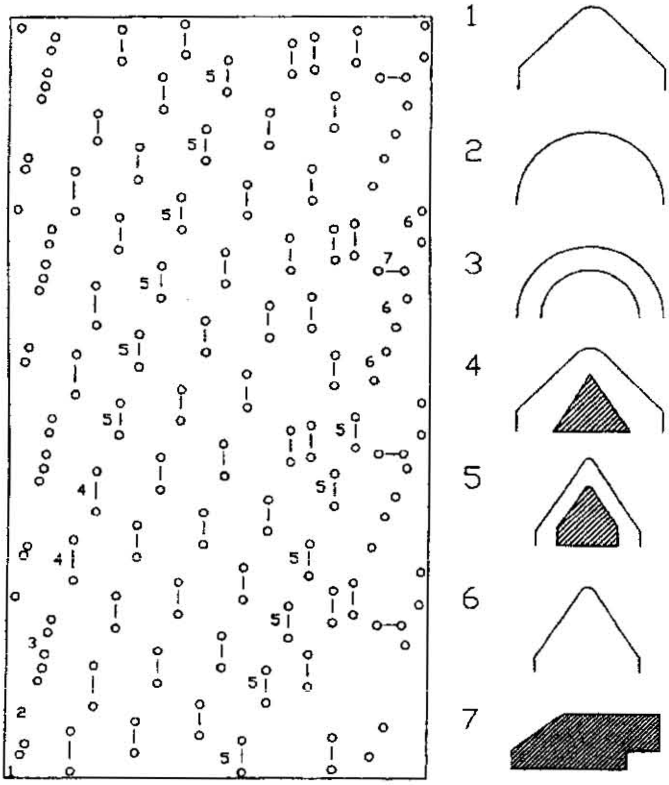


Fig. 2. Threshing teeth arrangement of 4-row head-feeding combine

DESIGN SIMULATION OF THRESHING DRUM AND THRESHING TEETH

Design for large-sized combine

It is attempted to design the threshing drum and teeth arrangement for a large-sized head-feeding combine by computer simulation using the design equations already developed and the analyzed variables of the threshing unit of the existing combine. With this method, the threshing unit for varied design factors can be easily designed. The values of variables, which were applied to illustrate the design simulation, are shown in Table 2. Fig. 3 shows the design simulation results for 4-, 6-, and 8-row head-feeding combines.

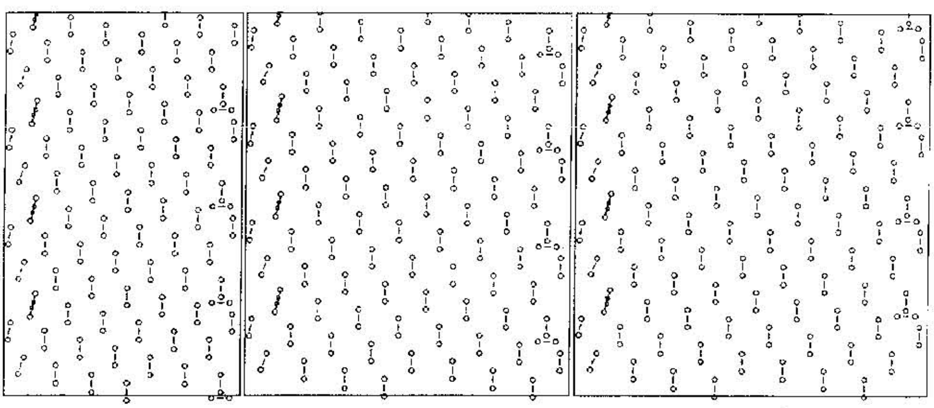
Design of small combine with a high speed

Existing 2- or 3-row self-feed combine was designed based of low forward speed (actually lower than 0.6 m/s). The design could be modified to catch up the trend of high

Table 1. Specification of threshing drum and teeth of the head-feeding combine

Size of combine		2-row	3-row	4-row
Diameter of drum (mm)		420	420	420
Length of drum (mm)		480	480	750
Rated rotational speed of drum		480	480	480
Thickness of drum (mm)		5.2	5.2	6.4
Height of tooth (mm)		68	68	68
Number of arrangement-line		4	4	4
Number of winding of arrangement-line		1.36	1.58	1.75
Number of tooth per arrangemen t-line	Low-triangular tooth[1)]	1	1	1
	Semi-circular tooth[1)]	1	1	1
	Double semi-circular tooth[1)]	1	1	1
	Double triangular tooth	10	12	14
	Triangular tooth	3	3	3
Total number of tooth		64	72	84[2)]
Speed of feed chain (m/s)		0.26	0.45	0.5
Travel speed of combine (m/s)		0.21-1.2 (6step)	0.28-1.57	<1.06

[1)] The tie-up angles of low-triangular tooth, semi-circular tooth, double semi-circular tooth are 10°, 20°, 13° respectively.
[2)] Add two triangular teeth in each two rows.



(a)4-row combine (b)6-row combine c)8-row combine

Fig. 3. Threshing teeth arrangement of large sized combine designed by the design theory developed in this study.

Table 2. Data used in computer simulation for designs of threshing teeth arranging of the large-sized head–feeding combine.

Design factor/Kind		4–row	6–row	8–row
Rotational speed of threshing drum	R (rpm)		480	
Diameter of threshing drum	D (cm)		42	
Distance between plant bushes	D_s (cm)		15	
Cross–sectional area of each plant bushes	A_r (cm^2)		4 π	
Number of arrangement lines	N_l		4	
Distance between impact lines	D_l (cm)		12	
Forward speed	V_t (cm/s)	100	110	120
Ratio of approaching speed of arrangement line to the speed of feed chain	R_r	6.9	6.5	6.0
Number of impact	N_i	11	11	11
Thickness of feeding stem	D_t (cm/s)	6.7	9.0	12.0

Table 3. Variables in the simulation of threshing unit design for higher forward speed.

Design factor/Kind		2–row		3–row	
		Existing value	Higher speed value	Existing value	Higher speed value
Rotational speed of threshing drum	R (rpm)		480		
Diameter of threshing drum	D (cm)		42		
Distance between plant bushes	D_s (cm)		15		
Cross–sectional area of each plant bushes	A_r (cm^2)		4 π		
Number of arrangement lines	N_r		4		
Distance between impact lines	D_l (cm)		12		
Forward speed	V_e (cm/s)	60	90	80	100
Ratio of approaching speed of arrangement line to the speed of feed chain	R_r	10.8	8.0	6.3	6.0
Number of impact	N_i	16	14	11	11
Thickness of feeding stem	D_b (cm/s)	3.9	4.5	4.5	5.5

speed to get more capacity of threshing. Such design to speed up the threshing unit will need to make it clear to optimize main variables from simulation of varying variables involved. Here we simulated applying data of main variables given from the Table 3 and showed the results in the Fig. 4.

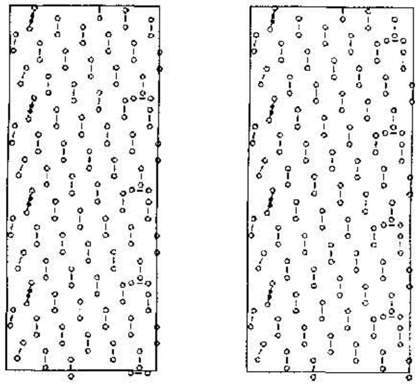


Fig. 4. Threshing teeth arrangement designed for higher forward speed

RESULTS AND CONCLUSIONS

The objective of this study is to develop a design theory for the threshing unit that can adopt the changes of working capacity due to the increment of cutting rows and/or forward speed. The main design factors of the threshing unit considered in this study were the number of threshing teeth, the approaching angle of the teeth, the distance between teeth on arrangement line, the speed of feed chain, the number of arrangement lines, and the total number of teeth.

The computer simulation program was developed to design threshing drum and to arrange threshing teeth by applying the developed equations. The design simulation showed that the design method developed here went along well with the design of existing combines, and thus the method could be used for developing a new design of head-feeding combine having a varied capacity.

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