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Original Article

Design factors affecting losses and power consumption of an axial flow corn shelling unit

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Abstract

The objective of this research was to study the design factors of the axial-flow corn shelling unit affecting losses and power consumption. The shelling unit was 0.90 m long with a diameter towards the end of the peg tooth of 0.30 m. Design factors comprised of five levels of peg tooth clearance (PC), 25.4, 50.8, 76.2, 101.6, and 127.0 mm, five levels of concave rod clearance (CR), 15, 20, 25, 30, and 35 mm, and five levels of concave clearance (CC), 10, 15, 20, 25, and 30 mm. The experiments were conducted based on response surface methodology and central composite design. The results of this study show that PC, CR, and CC were found to have significant impact on the shelling unit loss and power consumption, but not on grain breakage. Increase in PC and CC or decrease in CR had a trend to increase shelling unit loss. Increase in PC, CR, and CC resulted in less power consumption. Empirical models were constructed based on multiple linear models to define the behavior of the shelling unit loss and power consumption, with R^2 of 0.92 and 0.72, respectively.

Keywords: corn shelling unit, peg tooth clearance, concave rod clearance, concave clearance, shelling loss

1. Introduction

Corn is an economically important crop of Thailand and very important for Thai animal feed industry, there are approximately 1.2 million ha in Thailand, with an average yield of 4.4 tons per ha and a total production of over 5.3 million tons (OAE, 2012). Presently, corn shelling is generally done using the corn shelling machine. The use of axial flow threshers should be modified in some parts (Tongsawatwong *et al.*, 2003). The principle of the axial flow shelling unit is suitable for Thailand and Asian countries' conditions (Singhal and Thierstein, 1987; Chuan-udom, 2011).

Kunjara *et al.* (1998) conducted an experiment on a sheller with rasp bar sheller and peg-tooth sheller. The both sheller are highly efficient (99%), shelling unit loss and grain breakage was less than 1.5%. Nevertheless, a limitation of the rasp bar sheller was that in the long run the residual broken corn remained on the concave, thus reducing the amount of grains passing the concave. The power consumption and shelling drum speed of the peg-teeth sheller were double of that of the rasp bar sheller. Both corn shellers were not corn husker sheller. Changrua (1999) developed an axial flow shelling unit of corn husker sheller. Efficiency was rather high, but shelling capacity was not good. Corn ears also remained a short time in the shelling unit resulting in less shelling than it should be.

The Department of Agriculture (1996) improved and developed a shelling unit for corn husker sheller. This shelling unit was modified from a wheat threshing unit. Efficiency was relatively high, but grain breakage was also high. An axial flow rice thresher was also modified for shelling corn. This machine had a high threshing efficiency and cleaning effi-

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ciency, with little grain breakage. The axial flow rice thresher had been adjusted to shell corns because it was easy to modify it, economical, and provided the advantages for the axial flow rice thresher (Chuan-udom, 2013). Moreover, the axial flow shelling unit principle is suitable for Thailand and Asian countries' condition (Chuan-udom, 2011; Singhal and Thierstein, 1987). The threshing unit feature of Thai axial flow rice combine harvester had low threshing unit losses when harvesting Chainat 1 rice variety. The results indicated that the concave rod clearance (RC) had the most effect on the threshing unit loss (TL), followed by the side concave clearance (SC), concave clearance (CC), and upper concave clearance (UC), respectively. The number of spike teeth (NT) or peg tooth clearance (PT), rotor diameter (RD) and height of spike teeth (HT) showed relatively low losses by the threshing units (Chuan-udom and Chinsuwan, 2012). Influencing of threshing unit design of axial flow rice combine harvesters on threshing unit loss when harvesting Thai Hommali rice were depended on the number of spike teeth (NT) or peg tooth clearance (PT), which affected losses most, followed by the side concave clearance (SC), upper concave clearance (UC) and concave clearance (CC). The concave rod clearance (RC), rotor diameter (RD) and height of spike teeth (HT) showed relatively low losses (Chuan-udom and Chinsuwan, 2011).

Modifying of the axial flow threshers for shelling corn, the threshing unit was the most important component affecting the thresher's capacity (Chuan-udom, 2013). This research was aimed to study the effects of design factors of the axial flow corn shelling unit on losses and power consumption.

2. Materials and Methods

2.1 Corn shelling unit

This study was conducted using an axial flow corn shelling unit, provided by the Agricultural Research Development Agency (Public Organization) (Figure 1). The shelling unit was 0.90 m long, with a diameter towards the end of the peg tooth of 0.30 m, with controllable rotor speed. There was a power measuring device shown in Figure 2. The axial flow corn shelling unit was a spike-tooth cylinder. The concave part under the cylinder was made of curved steel bar. The guide vane inclination could be adjusted. Conveyor belt could be controlled for different feed rate of the materials into the shelling unit.

2.2 Materials and condition

The corn samples used in this study was Pioneer B-80 variety. The moisture contents of grains, husks, and cobs were 12.35 15.16 and 15.56 %wb, respectively. The rotor peripheral speed was 9.64 m/s (400 rpm) and corn feed rate was 1,500 kg/h. The experiments were performed in a laboratory in Khon Kaen University.

2.3 Independent factors

The important design factors that affected losses and power consumption of an axial flow corn shelling unit were comprised of PC, CR, and CC, as shown in Table 1. Since there were many factors and different levels of factors, the factorial experiment design required a great quantity of materials and experimental units. Thus, the central composite design (CCD) design was applied, as shown in Table 2, for it allowed reduction of the quantity of materials and time for testing (Berger and Maurer, 2002).

2.4 Testing method

Each test used 10 kg of corn; the corn was fed into the inlet of the shelling unit by conveyor belt. The samples taken from husks and cobs outlet was screened until only corn grain remained and the grains were weighted. This was

Figure 1. Corn Shelling Unit

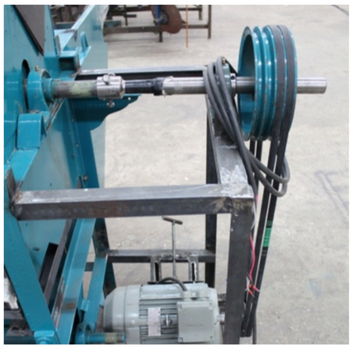

Figure 2. Power measuring device

Table 1. Independent factors and their level.

Factors	Level 1 (-2)	Level 2 (-1)	Level 3 (0)	Level 4 (1)	Level 5 (2)
PC (mm)	25.4	50.8	76.2	101.6	127.0
CR (mm)	15	20	25	30	35
CC (mm)	10	15	20	25	30

Table 2. Experiment units according to CCD for losses and power consumption of an axial flow corn shelling unit.

Expt. no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
PC, mm	-2	-1	-1	-1	-1	0	0	0	0	+1	+1	+1	+1	+2	0	0	0
CR, mm	0	-1	-1	+1	+1	-2	+2	0	0	-1	-1	+1	+1	0	0	0	0
CC, mm	0	-1	+1	-1	+1	0	0	-2	+2	-1	+1	-1	+1	0	0	0	0

considered as the shelling unit loss (TL). To obtain the percentage of grain breakage (GB), two kilograms of samples were randomly taken from the chute, GB was separated by hand and the weight of GB was recorded. In this experiment, the torque transducer with strain gage (KFG-2-350-D2-11L1M3R) was used. Torque meter was installed on the cylinder shaft for determination of torque requirement and power consumption (P).

2.5 Data analysis

Figure 3 shows the different clearances of shelling unit (PC, CR, and CC). These clearances affected amount of TL, GB and P. The multiple linear models were developed to analyze the effects of the parameters on the losses and power consumption based on the response surface method (RSM) and central composite design (CCD). The effects of each parameter on the coefficients of determination (R^2) were determined by using Design Expert® Version 7.

2.6 Indicator values

The indicator values consisted of TL, GB and P were computed based on the procedure for evaluation of corn shellers (RNAM, 1995). The indicators found from the study were as follows: Shelling unit loss (TL) – the ratio of grain-on-ear weight and grain weight discharged from output to grain weight collected under threshing mesh after cleaning, from Equation 1:

$$TL = [B / (A+B)] \times 100 \quad (1)$$

where TL is the shelling unit loss (%), A is the weight of shelled grain (whole and damaged grain) per unit time collected at the main grain outlet (in g), B is the weight of shelled and un-shelled grain per unit time collected at husks and cobs outlet per unit time (in g). **Grain breakage (GB)** – ratio of broken grain weight after shelling to weight of grains sampled from the chute beneath shelling mesh, see Equation 3:

$$GB = (E/C) \times 100 \quad (2)$$

where GB is the grain breakage (%), E is the weight or quantity of grain breakage collected at the main grain outlet (in g), C is the random weight of threshed grain (whole and damage grain) per unit time collected at the main grain outlet (in g).

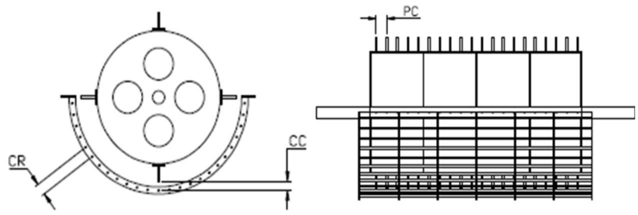

Figure 3. Clearances of shelling unit feature

Power consumption (P) – calculated from the value obtained from torque gauging from Equation 2:

$$P = (T \times n \times 2\pi) / 60 \quad (3)$$

where P is the power consumption (Watt), T is the electrics motor torque (N-m), and n is the rotor speed (rpm).

3. Results and Discussion

The effects of peg tooth clearance (PC), concave rod clearance (CR), and concave clearance (CC) on shelling unit losses (TL), grain breakage (GB) and power consumption (P) are shown in Table 3.

The data shown in Table 3 were used in the analysis of variance for regression equation of design factors affecting TL, GB, and P. Following are the results:

3.1 Effects of PC, CR and CC on TL

The analysis of optimal model of the design factors affecting the shelling unit loss is shown in Table 4. Sequential model sum of squares select the highest order polynomial where the additional term are significant and the model is not aliased. Model summary statistics focuses on the model maximizing the adjusted R^2 and the predicted R^2 (Saikeaw and Chillapat, 2006). The results indicate that a linear model was found to have significant and maximizing adjusted R^2 and predicted R^2.

Table 5 shows the analysis of variance design factors affecting the shelling unit loss. The results indicate that PC, CR, and CC significantly affected the shelling unit loss, with P-values < 0.05. The regression equation determined the effect of design factors on shelling unit loss as shown in Equation 4 with a R^2 value of 0.92.

$$TL = 2.76 + 0.03PC - 0.20CR + 0.10CC \quad (4)$$

Table 3. Effects of PC, CR and CC on TL, GB and P.

Expt. no.	PC, mm	CR, mm	CC, mm	Shelling unit losses (TL) (%)	Grain breakage (GB)(%)	Power consumption (P)(watts)
1	-2	0	0	1.20	0.38	1507.25
2	-1	-1	-1	4.02	0.41	1304.97
3	-1	-1	+1	5.43	0.42	1125.20
4	-1	+1	-1	1.39	0.33	1237.54
5	-1	+1	+1	3.18	0.34	1192.59
6	0	-2	0	14.06	0.36	1237.54
7	0	+2	0	2.04	0.39	1012.79
8	0	0	-2	1.64	0.41	1462.30
9	0	0	+2	9.68	0.37	922.89
10	+1	-1	-1	4.69	0.37	1147.60
11	+1	-1	+1	7.78	0.35	1147.60
12	+1	+1	-1	2.49	0.34	1057.74
13	+1	+1	+1	4.75	0.40	1035.27
14	+2	0	0	9.89	0.40	900.41
15	0	0	0	5.28	0.40	1080.22
16	0	0	0	5.01	0.41	1102.70
17	0	0	0	4.73	0.45	1012.80

Table 4. Analysis of optimal model of design factors affecting of shelling unit loss by using CCD.

Source	Sum of Squares	df	Mean Square	F -Value	p-value Prob >F	
Sequential Model Sum of Squares						
Mean vs Total	447.70	1	447.70			
Linear vs Mean	144.07	3	48.02	12.54	0.0004	Suggested
2FI vs Linear	0.62	3	0.21	0.042	0.9879	
Quadratic vs 2FI	10.37	3	3.46	0.62	0.6221	
Cubic vs Quadratic	24.35	4	6.09	1.26	0.4413	Aliased
Residual	14.45	3	4.82			
Total	641.55	17	37.74			
Source	**Std. Dev.**	**R^2**	**Adjusted R^2**	**Predicted R^2**	**PRESS**	
Model Summary Statistics						
Linear	1.96	0.7432	0.6839	0.4971	97.50	Suggested
2FI	2.22	0.7464	0.5942	-0.0083	195.47	
QuadraticCubic	2.352.19	0.79980.9255	0.54250.6024	-0.6460-14.8479	319.083072.21	Aliased

Table 5. Analysis of variance design factors affecting shelling unit loss.

Source	Sum of Squares	df	Mean Square	F -Value	p-value Prob >F	
Model	144.07	3	48.02	12.54	0.0004	significant
PC	33.26	1	33.26	8.68	0.0113	
CR	72.89	1	72.89	19.03	0.0008	
CC	37.92	1	37.92	10.35990	0.0077	
Residual	49.79	13	3.83			
Lack of Fit	49.64	11	4.51	58.81	0.0168	significant
Pure Error	0.15	2	0.077			
Correlation Total	193.86	16				

From Equation 4, the response surface plot of shelling unit loss (TL) showing the effect of PC, CR and CC can be generated (Figures 4, 5, and 6).

Figure 4 and 5 show that increasing the concave rod clearance (CR) tended to reduce the shelling unit loss. This correlates to research by Norris and Wall (1986), i.e., when the concave rod clearance (CR) increased, shelled grain ease through the concave, thus decreasing the shelling unit loss (Chinsuwan *et al.*, 2003; Chuan-udom, 2013). An increase in peg tooth clearance (PC) meant a fewer numbers of spike teeth thus decreased the impact of beating, making more grain separated from the cobs, hence, lowering the shelling unit loss (TL) (Waingwisad *et al.*, 2011; Chuan-udom and Chinsuwan, 2012) as shown in Figure 4 and 6. From Figure 5 and 6, increasing in concave clearance (CC) tended to increase shelling unit loss because of the reduction in shelling (Joshi and Singh, 1980; Petkevicius *et al.*, 2008; Rostami *et al.*, 2009; Chuan-udom, 2013).

3.2 Effects of PC, CR and CC on GB

Table 6 analysis of optimal model of design factors affecting grain breakage. The results indicated that PC, CR and CC did not affect grain breakage.

3.3 Effects of PC, CR and CC on P

Analysis of optimal model of design factors affecting power consumption is shown in Table 7. The results indicated that a linear model was found to have significant and maximizing adjusted R^2 and predicted R^2.

From Table 8, the results of analysis of variance design factors affecting power consumption indicated that PC and CR significantly affected power consumption with P-values < 0.05, whereas CC did not statistically affect the shelling unit losses (p-value > 0.05). The regression equation determined the effect of design factors on power consumption as shown in Equation 5 with R^2 value of 0.70.

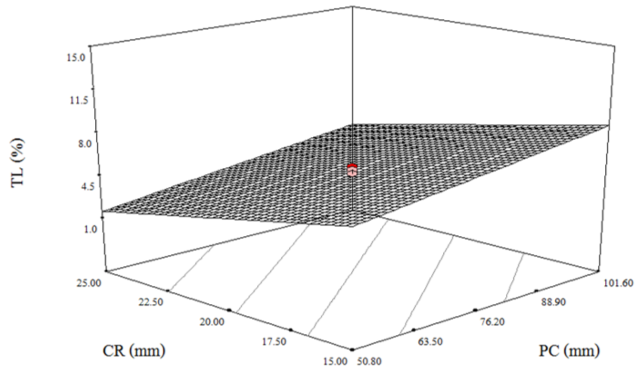

Figure 4. Response surface plot of shelling unit loss (TL) showing the effect of peg tooth clearance (PC) and concave rod clearance (CR), when concave clearance (CC) was 25 mm.

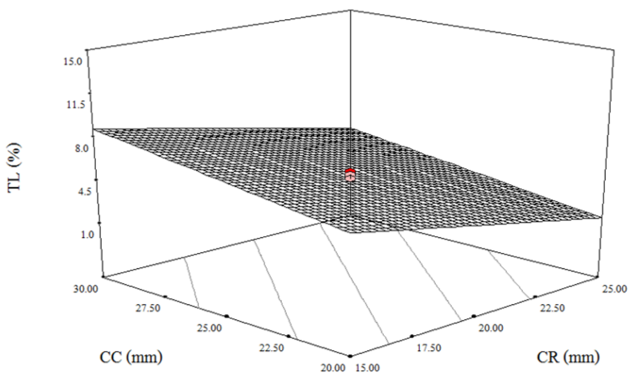

Figure 5. Response surface plot of shelling unit loss (TL) showing the effect of concave clearance (CC) and concave rod clearance (CR), when peg tooth clearance (PC) was 76.20 mm.

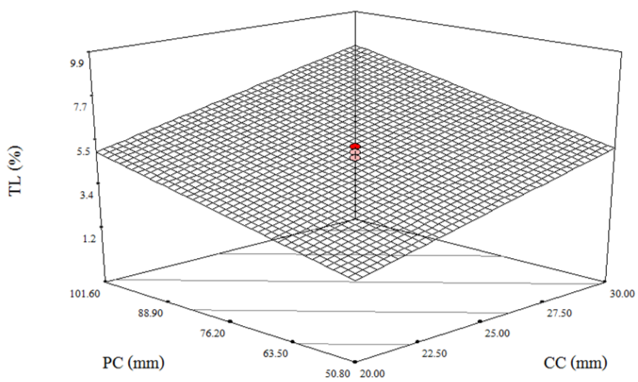

Figure 6. Response surface plot of shelling unit loss (TL) showing the effect of peg tooth clearance (PC), concave clearance (CC), when concave rod clearance (CR) was 20 mm.

Table 6. Analysis of optimal model of design factors affecting grain breakage by using CCD.

Source	Sum of Squares	df	Mean Square	F -Value	p-value Prob >F	
Sequential Model Sum of Squares						
Mean vs Total	2.50	1	2.50			Suggested
Linear vs Mean	4.649E-004	3	1.550E-004	0.11	0.9498	
2FI vs Linear	4.377E-003	3	1.459E-003	1.11	0.3906	
Quadratic vs 2FI	4.035E-003	3	1.345E-003	1.03	0.4349	
Cubic vs Quadratic	5.740E-003	4	1.435E-003	1.27	0.4386	Aliased
Residual	3.380E-003	3	1.127E-003			
Total	2.52	17	0.15			
Source	**Std. Dev.**	**R^2**	**Adjusted R^2**	**Predicted**	**PRESS**	
Model Summary Statistics						
Linear	0.037	0.0258	-0.1990	-0.5654	0.028	
2FI	0.036	0.2691	-0.1695	-1.5701	0.046	
QuadraticCubic	0.360.034	0.49330.8122	-0.1583-0.0017	-2.7482-26.2407	0.0670.49	Aliased

Table 7. Analysis of optimal model of design factors affecting power consumption by using CCD.

Source	Sum of Squares	df	Mean Square	F -Value	p-value Prob >F	
Sequential Model Sum of Squares						
Mean vs Total	2.234E+007	1	2.234E+007			
Linear vs Mean	3.140E+005	3	1.047E+005	10.23	0.0010	Suggested
2FI vs Linear	11807.81	3	3935.94	0.32	0.8075	
Quadratic vs 2FI	31912.60	3	10637.53	0.83	0.5163	
Cubic vs Quadratic	84517.41	4	21129.35	13.36	0.0297	Aliased
Residual	4743.99	3	1581.33			
Total	2.279E+007	17	1.340E+006			
Source	**Std. Dev.**	**R^2**	**Adjusted R^2**	**Predicted**	**PRESS**	
Model Summary Statistics						
Linear	101.14	0.7025	0.6339	0.4713	2.364E+005	Suggested
2FI	110.08	0.7289	0.5663	-0.0020	4.479E+005	
QuadraticCubic	112.9239.77	0.80030.9894	0.54360.9434	-0.63000.8038	7.287E+00587690.81	Aliased

Table 8. Analysis of variance design factors affecting power consumption.

Source	Sum of Squares	df	Mean Square	F -Value	p-value Prob >F	
Model	3.140E+005	3	1.047E+005	11.35	0.0010	significant
ST	1.776E+005	1	1.776E+005	21.73	0.0011	
CR	26551.79	1	26551.79	0.29	0.1312	
CC	1.099E+005	1	1.099E+005	12.03	0.0060	
Residual	1.330E+005	13	10229.37			
Lack of Fit	1.286E+005	11	11691.26	5.34	0.1682	Not significant
Pure Error	4377.94	2	2188.97			
Correlation Total	4.470E+005	16				

$$P = 2039.72 - 4.15ST - 8.15CR - 16.58CC \quad (5)$$

From Equation 5, response surface plot of power consumption (P) shows the effect of PC, CR and CC (Figure 7, 8, and 9).

From Figure 7 and 8 it can be seen that a decrease in concave rod clearance (CR) tended to increase power consumption (P) since the decrease in concave rod clearance (CR) meant the curtailment of the space for more shelled grains to pass the concave; the broken residual corns would be remain on the concave, so experiencing increased beating. The increase in peg tooth clearance (PC) meant fewer numbers of spike teeth resulting in a tendency for power consumption (P) to decrease because reduced beating as shown in Figure 7 and 9. From Figure 8 and 9, although CC did not statistically affect the shelling unit losses, an increase in concave clearance (CC) tended to reduce power consumption (P) since the increase in concave clearance (CC) meant the enlargement of the clearance between spike teeth and concave, leading to less capacity of the sheller in removing the grains from the cobs, thus decreased the impact of beating.

4. Conclusions

From the results of this study following conclusion can be drawn. Peg tooth clearance (PC), concave rod clearance (CR), and concave clearance (CC) significantly affected shelling unit loss and power consumption, but not grain breakage. Increase in peg tooth clearance (PC) and concave clearance (CC) or decrease in concave rod clearance (CR) resulted in an increase of total loss from the shelling unit. But increase in peg tooth clearance (PC), concave rod clearance (CR), and concave clearance (CC) resulted in reducing power consumption for shelling. The linear model was the optimal model of the design factors affecting shelling unit loss (TL), with 2.76 + 0.03PC - 0.20CR + 0.10CC with R^2 of 0.92. The linear model was the optimal model of design factors affecting power consumption (P), with 1987.99 - 4.76PC - 2.81CR - 17.98CC with R^2 of 0.72.

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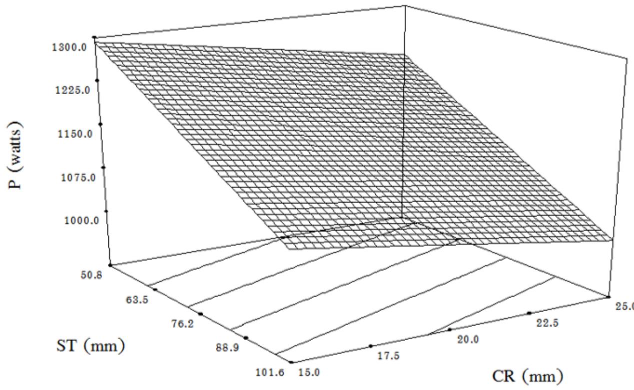

Figure 7. Response surface plot of power consumption (P) showing the effect of peg tooth clearance (PC) and concave rod clearance (CR), when concave clearance (CC) was 25 mm.

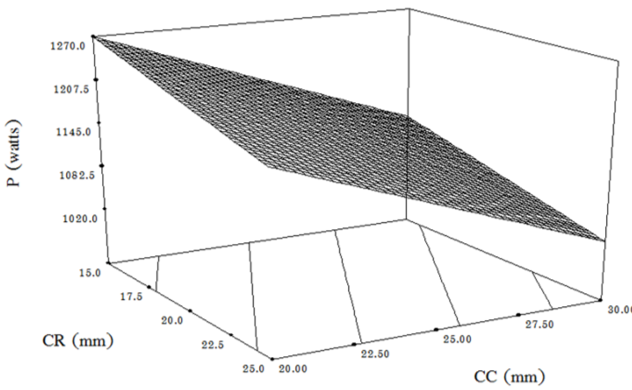

Figure 8. Response surface plot of power consumption (P) showing the effect of concave clearance (CC) and concave rod clearance (CR), when peg tooth clearance (PC) was 76.20 mm.

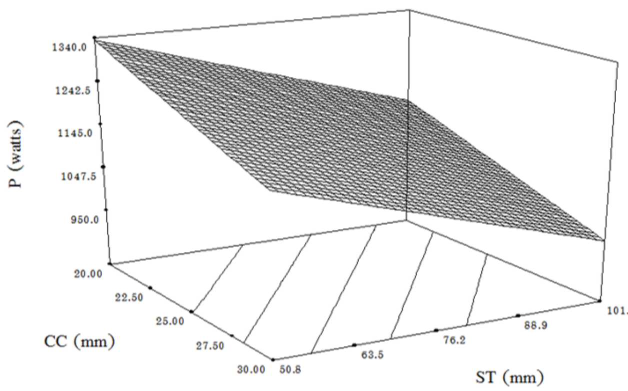

Figure 9. Response surface plot of power consumption (P) showing the effect of peg tooth clearance (PC) and concave clearance (CC), when concave rod clearance (CR) was 20 mm.

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