

*Original Article*

## Study and design for creating a small-scale branch chipper utilizing a urethane rubber coupling in power transmission

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### Abstract

This research aimed to study and design a small-scale branch chipper that does not use belt-based power transmission, to provide a simple, efficient, energy-saving, cost-effective, and equipment-size-reducing system. The chipper power transmission has a urethane rubber coupling, replacing conventional belt systems. The approximate dimensions of the chipper were 42 cm x 68 cm x 69.5 cm, and it had a cutting set consisting of two blades. Various thickness blade sets were available at 6, 9, 12, and 15 mm, set at a blade angle of 40 degrees. The chipper was powered by a 2-horsepower motor run at 1,500 revolutions per minute. The upper part of the small-scale branch chipper had a chute for feeding the branches, angled at 45 degrees to the flat surface. Experimental results indicated that the chipper could effectively process branches ranging from 10 to 30 mm in diameter and approximately 50 to 70 cm long. The 15 mm thick blades provided the best chipping results in the shortest time. The chipper processed approximately 45 kilograms of branches in one hour.

**Keywords:** design, machine creation, small-scale branch chipper, urethane rubber coupling, power transmission equipment

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### 1. Introduction

Thailand has an annual air pollution issue; the primary problem is the high PM 2.5 level. One of the contributing factors is the burning of wood and leaves by the public, leading to the release of ashes and carbon dioxide into the atmosphere. However, the available branch chippers are large and have components unsuitable for rural community lifestyles. Research reports, such as the one conducted by Lueang-pipatsorn (2018) have developed a grass and animal feed chipper to enhance the chipping and compressing capabilities, thereby saving time and labor during operations. This improvement also helps reduce the farmer's animal feed production costs. A 3-horsepower motor powers the chipper,

and the study involves variables such as motor speeds at 1,300, 1,500, and 1,700 revolutions per minute and the use of a belt-based power transmission.

Additionally, that study investigated the blade angles for grass chipping at 15, 30, and 40 degrees. The test results revealed the best motor speed and blade angle for compressing and chipping animal feed grass were 1,500 revolutions per minute and 40 degrees, respectively, yielding an average working capacity of 229.4 kilograms per hour. The average electricity consumption was 1.53 kilowatts. Meanwhile, Yaemphurn, Poonnayom, Wattanjitsiri, Triwanapong, and Kimapong (2018) studied the influence of the cutting blade's shape and the number of blades on the performance of a vertical palm leaf chipper. They found that chipper blades made from carbon steel should not undergo heat treatment after quenching, as it reduces their hardness and resistance to wear. Semi-v-shaped palm leaf blades exhibited better hardness and strength than v-shaped blades,

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with a hardness value of 481 HV and a blade-tip weight loss of 6.24%. Semi-v-shaped blades resulted in higher chip production than v-shaped blades when operating at a maximum speed of 1,200 revolutions per minute and produced 3,878 grams of chips. An increased number of blades improved efficiency of palm leaf chipping.

Punluang, Nualma, and Tedsawat (2011) conducted a study on the design of a branch chipper capable of chipping fresh branches with a size range of 100-200 mm, yielding an average weight of 18.7 kilograms per hour, and dry branches of the same size yielding an average weight of 13.2 kilograms per hour. Additionally, the chipper was tested for chipping fresh branches with a diameter not exceeding 40 mm, resulting in an average weight of 60.1 kilograms per hour, and dry branches with a diameter not exceeding 40 mm, yielding an average weight of 42.1 kilograms per hour. Moreover, Kamma (2018) designed and built three different-sized vegetable waste chippers for household use: small, medium, and large. He set the blade rotation speeds at 417, 500, 700, 900, and 983 revolutions per minute. The test results revealed the best blade rotation speed for the chipper was 763 revolutions per minute, which could chip small-sized materials to produce 46.2 to 120.0 kilograms per hour, with an efficiency rate of 65.0%  $\pm$ 3.5

Furthermore, Manomai and Leakmuinwai (2020) designed a woodchipper and tested it at three different motor speeds: 1,150, 1,800, and 2,450 revolutions per minute, to determine the most suitable speed for chipping wood. They selected various local wood types, Acacia wood, Jam tree, Neem wood, and Narong Acacia wood, with a diameter of 4 inches and a length of 45 centimeters for the test. The chipper was powered by an 11-horsepower agricultural diesel engine and used belt-based power transmission to drive the chipping mechanism. The test results showed that at a motor speed of 1,800 revolutions per minute, the chipper could effectively chip all types of wood, and the chipped wood exhibited good texture and suitability for further use. However, it should be noted that woodchippers tend to be large and come with expensive components.

The research team studied previous branch chipper machines and then designed a small-scale branch chipper that utilized a urethane rubber coupling for power transmission instead of conventional belts. The purpose was to create a simple, affordable, easy to maintain, lightweight, safe to use, and suitable chipper for rural community lifestyles.

## 2. Materials and Methods

The research team conducted the design and assembly of the machine's essential components as follows.

### 2.1 Design of the shaft

The shaft is mainly subjected to cyclic stress due to its continuous rotation. Additionally, the applied forces may also vary. Therefore, the shaft is prone to fatigue damage. To calculate fatigue, the ASME method utilizes statistical principles, which require the consideration of a Fatigue Factor:

$$d^3 = \frac{16}{\pi\tau} \sqrt{(C_t T)^2 + (C_m M)^2} \quad (1)$$

Here

- $C_m$  = Bending fatigue factor
- $C_t$  = Torsion fatigue factor
- $d$  = Size of the shaft to be determined (m)
- $M$  = Maximum bending moment occurring in the shaft (N.m)
- $T$  = Torque applied to the shaft (N.m)

### 2.2 Motor power design and selection

The motor is the prime mover providing power to various components to enable the machine to function. Therefore, it was necessary to calculate the power required by different parts to obtain the combined total required power. Subsequently, the appropriate motor was selected to have the desired working power. The equation used to calculate power was:

$$P = \frac{2\pi nT}{60} \quad (2)$$

Here

- $P$  = Motor power (Watt)
- $T$  = Torque (N.m)
- $n$  = Rotational speed (rpm)

### 2.3 Bearing design

The following equations determined the power loss due to friction:

$$W_p = \frac{2\pi nT}{60} = \frac{\pi f F_r d n}{60} \quad (3)$$

or

$$W_p = \frac{\pi f F_a d n}{60} \quad (4)$$

where

- $W_p$  = Work power (Watt)
- $T$  = Torsional moment due to wear (N.m)
- $n$  = Rotational speed of the shaft (rpm)
- $d$  = Bore size of the bearing (m)
- $F_r$  = Radial force acting on the bearing (N)
- $F_a$  = Axial force acting on the bearing (N)
- $f$  = Coefficient of friction

### 2.4 Theory of wedge design

According to the theory of maximum shear stress, the allowable shear stress in a material will be approximately  $\frac{1}{2}$  the allowable compressive stress in the material. In other words, when values are substituted  $\tau = 0.5\sigma_c$ , it will yield that  $b = h$ .

If the wedge and the shaft are made from the same material, the length of the wedge can be determined by assuming that the wedge and the shaft have the same torsional moment. Therefore,

$$T = \frac{bl\tau d}{2} = \frac{\pi d^3}{16} \quad (5)$$

when

$$l = \frac{\pi d^2}{8b} \tag{6}$$

where

- T = Torsional moment on the shaft (N.m)
- F = Force acting on the wedge (N)
- d = Diameter of the shaft (m)
- b = Width of the wedge (m)
- l = Length of the wedge (m)
- $\tau$  = Shearing stress on the wedge (N/m<sup>2</sup>)

### 2.5 Theory of coupling design

The selection of coupling size in standard dimensions is based on the size of the pulley used. Manufacturers have designed and constructed couplings to transmit torsional moments up to the maximum pulley capacity. Therefore, the size of the pulley was used to determine the appropriate coupling size.

### 2.6 Illustration of small-scale branch chipper



Figure 1. Small-scale branch chipper

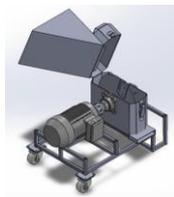


Figure 2. Small-scale branch chipper (with the protective cover open)

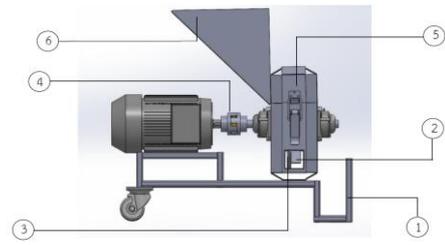


Figure 3. Experimental device setup

Table 2. List of materials and equipment corresponding to the numbers in Figure 3

No.	Equipment list
1	Chipper base
2	Blade mounting set
3	Branch chipper blade
4	Urethane rubber coupling
5	Blade cover box
6	Branch container

Notes: Item number 4, the Urethane rubber coupling, utilized the MT-70 model with a lathe. The shaft hole on the motor side of 24 millimeters, had groove dimensions of 8x3.3 millimeters, and a blade set box side of 25.4 millimeters, with grooves 8x3.3 millimeters.

### 2.7 Experimental procedure

The experiment was conducted following the steps below.

1. Install the 6-millimeter-thick blade.
2. Set the urethane rubber coupling center between the motor shaft and branch chipper.
3. Divide branches not exceeding 3-centimeter diameter into four sets of 100, 200, 300, and 400 grams, as shown in Figure 4.
4. Plug the motor into the power supply and switch on the power. After approximately 5 seconds, the motor stabilization period, measure the initial rotational speed using a tachometer. The value is measured by shooting light onto the shaft axis, as shown in Figure 5.

Table 1. Dimensions of flange couplings according to JIS B 1451 – 1975 standard

Size A	Size shaft D		L	C	B	F	H	K	Number of Bolts n	a	Spigot and socket			B (Approximate)	C (Approximate)
	Max	Min									E	S <sub>2</sub>	S <sub>1</sub>		
112	25	16	40	45	75	16	22.4	4	4	10	40	2	3	2	1
125	28	18	45	50	85	18	25	4	4	14	45	2	3	2	1
140	35	20	50	63	100	18	25	4	6	14	56	2	3	2	1
160	45	25	56	80	115	18	25	6	8	14	71	2	3	3	1
180	50	28	63	90	132	18	25	6	8	14	80	2	3	3	1
200	56	32	71	100	145	22.4	31.5	6	8	16	90	3	4	3	1
224	63	35	80	112	170	22.4	31.5	6	8	16	100	3	4	3	1
250	71	40	90	125	180	28	40	8	8	20	112	3	4	4	1
280	80	50	100	140	200	28	45	8	8	20	125	3	4	4	1
315	90	63	112	160	236	28	45	8	8	20	140	3	4	4	1
355	100	71	125	180	260	35.5	63	10	8	25	160	3	4	5	1

Unit in mm.

Source: Eungphakorn, W., & Thanadngan, C. (2013). Machine design, Volume 2, 13.



Figure 4. Example of a set of branches weighing 400 grams (before the experiment)



Figure 5. Method for measuring the motor's rotational speed

5. Place branches with weights of 100, 200, 300, and 400 grams into the chipper sequentially and record the time to chip each branch weight set in the data recording table.
6. Collect and weigh the chipped branches from step 5 (Figure 6), and record the results in the data recording table.
7. If the motor's rotational speed during branch chipping decreases by more than 10% compared to the initial measured value, conclude the experiment. Three iterations of the experiment are to be performed.
8. Change the blade set by opening the blade set box cover, and install the blades of the next size in the order 9, 12, and 15 millimeters thickness, as shown in Figure 7.
9. The experiment is then repeated from steps 3 to 8 until three iterations have been completed.



Figure 6. The weight of the chipped branches after the experiment was completed.



Figure 7. Branch chipper blades

### 3. Results and Discussion

The small-scale branch chipper experiment tested blade thicknesses of 6, 9, 12, and 15 millimeters and used branches with a diameter not exceeding 3 centimeters. The rotational speed of the motor during chipping, the time taken to chip the branches, the weight of the chips after the process and the chipping efficiency were recorded (as shown in Table 3. to Table 5).

Table 3. The relationship between the weight of the branches (in grams) and the rotational speed of the motor during branch chipping (%)

Time	Motor speed (1500 rpm.)			
	Blade thickness			
	6 mm	9 mm	12 mm	15 mm
<b>100 grams</b>				
1	1,493 (99.5%)	1,494 (99.6%)	1,494 (99.6%)	1,488 (99.2%)
2	1,492 (99.5%)	1,491 (99.4%)	1,493 (99.5%)	1,492 (99.5%)
3	1,485 (99.0%)	1,491 (99.4%)	1,496 (99.7%)	1,493 (99.5%)
Average	1,490 (99.3%)	1,492 (99.5%)	1,494 (99.6%)	1,491 (99.4%)
<b>200 grams</b>				
1	1,489 (99.3%)	1,491 (99.4%)	1,486 (99.1%)	1,482 (99.8%)
2	1,496 (99.7%)	1,487 (99.1%)	1,492 (99.5%)	1,494 (99.6%)
3	1,494 (99.6%)	1,488 (99.2%)	1,493 (99.5%)	1,487 (99.1%)
Average	1,490 (99.5%)	1,492 (99.3%)	1,494 (99.3%)	1,491 (99.2%)
<b>300 grams</b>				
1	1,491 (99.4%)	1,486 (99.1%)	1,491 (99.4%)	1,489 (99.3%)
2	1,489 (99.3%)	1,493 (99.5%)	1,487 (99.1%)	1,487 (99.1%)
3	1,489 (99.3%)	1,482 (98.8%)	1,484 (98.9%)	1,490 (99.3%)
Average	1,489 (99.3%)	1,487 (99.1%)	1,487 (99.1%)	1,489 (99.3%)
<b>400 grams</b>				
1	1,485 (99.0%)	1,490 (99.3%)	1,488 (99.2%)	1,492 (99.5%)
2	1,482 (98.8%)	1,489 (99.3%)	1,484 (98.9%)	1,489 (99.3%)
3	1,489 (99.3%)	1,486 (99.1%)	1,486 (99.1%)	1,492 (99.5%)
Average	1,485 (99.0%)	1,488 (99.2%)	1,486 (99.1%)	1,491 (99.4%)

The bar graph in Figure 8 illustrates the relationship between the weight of the branches (in grams) and the rotational speed of the motor during branch chipping (in percentage). It was found that for the blade thickness at 12 millimeters, the rotational speed percentage during branch chipping tended to decrease as the weight of the branches

Table 4. The relationship between the weight of the branches (in grams) and the time taken to chip the branches (in seconds)

Motor speed (1500 rpm.)				
Time	Blade thickness			
	6 mm	9 mm	12 mm	15 mm
100 grams				
1	15.08	11.87	13.64	12.34
2	12.84	14.62	14.72	9.89
3	13.59	12.47	10.36	10.34
Average	13.84	12.98	12.91	10.86
200 grams				
1	24.37	26.12	12.96	24.57
2	22.38	22.97	24.84	18.92
3	25.43	21.19	24.36	17.65
Average	24.06	23.43	20.72	20.38
300 grams				
1	34.42	30.89	22.35	26.15
2	35.95	34.62	32.88	25.74
3	30.04	32.78	29.62	24.63
Average	33.47	32.76	28.28	25.51
400 grams				
1	36.57	36.22	36.92	32.91
2	34.65	35.38	32.45	30.68
3	37.74	37.07	33.26	32.72
Average	36.32	36.22	34.21	32.10

increased. In the meantime, for the weight of the branches at 300 grams, it was found that the rotational speed percentages of the blade thickness at 9 and 12-millimeters during branch chipping were similar. However, according to the overall data in Table 3, the rotational speed percentages of the motor were relatively close to each other. The average efficiency fell within the range of 99.00% to 99.62%. In addition, it also revealed that the weights of the branches at 100, 200, 300, and 400 grams, along with the blade thickness at 6, 9, 12, and 15 millimeters, did not significantly affect the rotational speed of the motor. The factor that impacted the motor's rotational speed was the number of branches chipped simultaneously.

From the bar graph shown in Figure 9, which illustrates the relationship between the weight of the branches (in grams) and the time taken to chip the branches (in seconds), it was found that with a blade thickness of 6 millimeters, took the longest time to chip the branches. As the blade thickness was increased incrementally, the time to chip the branches decreased accordingly. According to the data in Table 4, the chipping time for all four sizes of the blades (6, 9, 12, and 15 millimeters) increased with the weights of the branches. The average chipping times for branches weighing 100, 200, 300, and 400 grams were 12.65, 22.15, 30.00, and 32.21 seconds, respectively.

From the bar graph shown in Figure 10, which illustrates the relationship between the weight of the branches before chipping (in grams) and the weight of the chipped branches after the process (in percentage), for the blade thickness at 6 millimeters, the weight of the chipped branches increased when the weight before chipping increased.

Table 5. The relationship between the weight of the branches before chipping (in grams) and the weight of the chipped branches after the process (%)

Motor speed (1500 rpm.)				
Time	Blade thickness			
	6 mm	9 mm	12 mm	15 mm
100 grams				
1	100 (100%)	90 (90.0%)	90 (90.0%)	100 (100%)
2	95 (95.0%)	100 (100%)	100 (100%)	95 (95.0%)
3	95 (95.0%)	100 (100%)	95 (95.0%)	100 (100%)
Average	96.7 (96.7%)	96.7 (96.7%)	95.0 (95.0%)	98.3 (98.3%)
200 grams				
1	195 (97.5%)	200 (100%)	195 (97.5%)	195 (97.5%)
2	190 (95.0%)	190 (95.0%)	200 (100%)	195 (97.5%)
3	195 (97.5%)	195 (97.5%)	195 (97.5%)	195 (97.5%)
Average	193.3 (96.7%)	195 (97.5%)	196.7 (98.3%)	195 (97.5%)
300 grams				
1	295 (98.3%)	295 (98.3%)	295 (98.3%)	300 (100%)
2	300 (100%)	300 (100%)	290 (96.7%)	300 (100%)
3	290 (96.7%)	285 (95.0%)	285 (95.0%)	295 (98.3%)
Average	295 (98.3%)	293.3 (97.8%)	290 (96.7%)	298.3 (99.4%)
400 grams				
1	400 (100%)	395 (98.8%)	400 (100%)	390 (97.5%)
2	395 (98.8%)	390 (97.5%)	395 (98.8%)	395 (98.8%)
3	395 (98.8%)	395 (98.8%)	400 (100%)	395 (98.8%)
Average	396.7 (99.2%)	393.3 (98.3%)	398.3 (99.6%)	393.3 (98.3%)

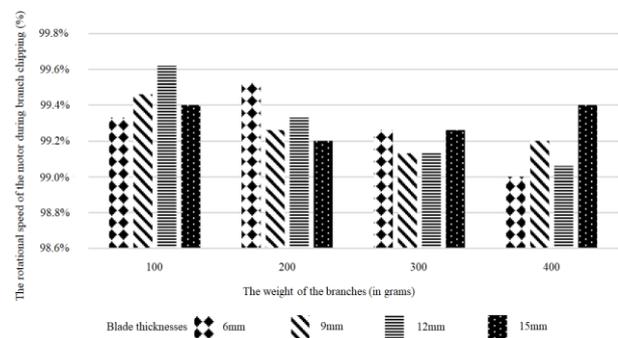


Figure 8. Bar graph showing the relationship between the weight of the branches (in grams) and the rotational speed of the motor during branch chipping (%)

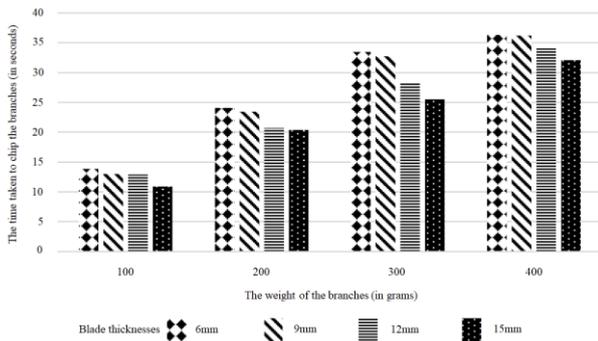


Figure 9. Bar graph showing the relationship between the weight of the branches (in grams) and the time taken to chip the branches (in seconds)

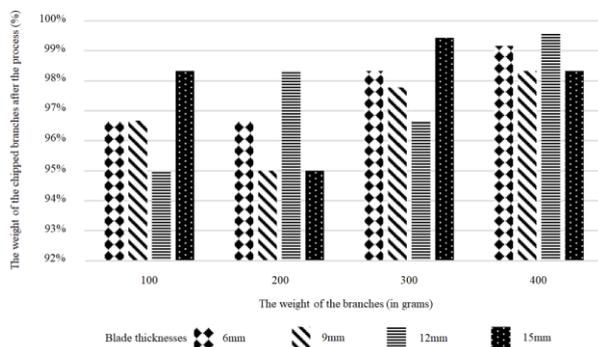


Figure 10. Bar graph showing the relationship between the weight of the branches before chipping (in grams) and the weight of the chipped branches after the process (%)

According to the data in Table 5, it was found that the weight percentages of the chipped branches after the process under the weights of the branches at 100, 200, 300, and 400 grams, along with the blade thickness at 6, 9, 12 and 15 millimeters were relatively similar; and the average weight fell within the range from 95.00% to 99.58%

According to the data in Tables 3, 4, and 5, it was found that the weights of the branches at 100, 200, 300, and 400 grams, along with the blade thickness at 6, 9, 12, and 15 millimeters, did not affect the rotational speeds. The chipping time of all four sizes of the blades increased with the weights of the branches. The weight percentages of the chipped branches were similar. The blade thickness of 15 millimeters had the best efficiency for chipping the branches into small pieces.

#### 4. Conclusions

Based on the experiments conducted on the small-scale branch chipper utilizing a urethane rubber coupling for power transmission and using blade thicknesses of 6, 9, 12, and 15 millimeters, it was observed that the motor speed was relatively similar for all blade thicknesses, with an average efficiency from 99.00% to 99.62%. The weight of the branches did not significantly affect the motor speed; however, the number of branches loaded simultaneously in each run impacted the motor speed. Regarding the blade thickness, the 6-millimeter blade took the longest time to chip

the branches because its cutting edge was small due to its proximity to the base. As the blade thickness increased, the chipping time decreased accordingly. Additionally, the weight of the chipped branches after the process was relatively consistent, with an average range from 95.00% to 99.58%. The experimental results showed that the 15-millimeter blade was the most efficient in chipping the branches into smaller pieces.

Therefore, the small-scale branch chipper design and build using a urethane rubber coupling for power transmission instead of a complex belt system proved to be an excellent model for branch chipping machinery. This design offers simplicity in usage, high efficiency, energy conservation, and cost-effectiveness due to reduced equipment costs and minimized device size. As a result, it is suitable for rural community lifestyles.

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#### Author Contributions

Keattipoom Pratumnrat and Niphon Chinchusak: Designed research. Phantongtae Kornkiew, Keattipoom Pratumnrat, Adchariya Chawpratum and Niphon Chinchusak: Performed research. Phantongtae Kornkiew, Chaowan Jamroen and Niphon Chinchusak: Contributed new reagents/analytic tools. Phantongtae Kornkiew, Keattipoom Pratumnrat, Adchariya Chawpratum and Niphon Chinchusak: Analyzed data. Chaowan Jamroen, Akekachai Pannawan: Coordinated research. Phantongtae Kornkiew and Niphon Chinchusak: Wrote the paper.

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