CHAPTER 3 EXPERIMENTAL SETUP AND METHODOLOGY

3.1   The experimental setup

The experimental set up for design improvement of a Thai sail windmill for water pumping are shown in Figure 3.1.

1. Field survey by local wisdom of a Thai sail windmill for improvement in laboratory scale testing and large scale testing.

2. Laboratory scale testing, which there was tested Thai sail rotor model (TSRM) through wind tunnel and the model test of Archimedean's pipe-screw model (APSM). In order to used the best model to modify the prototype of large scale testing.

3. Large scale testing, there were construction of the new prototype of Thai sail windmill and field performance of the new Thai sail windmill for water pumping of the best model coupled to water ladder pump and Archimedean's pipe-screw pump.

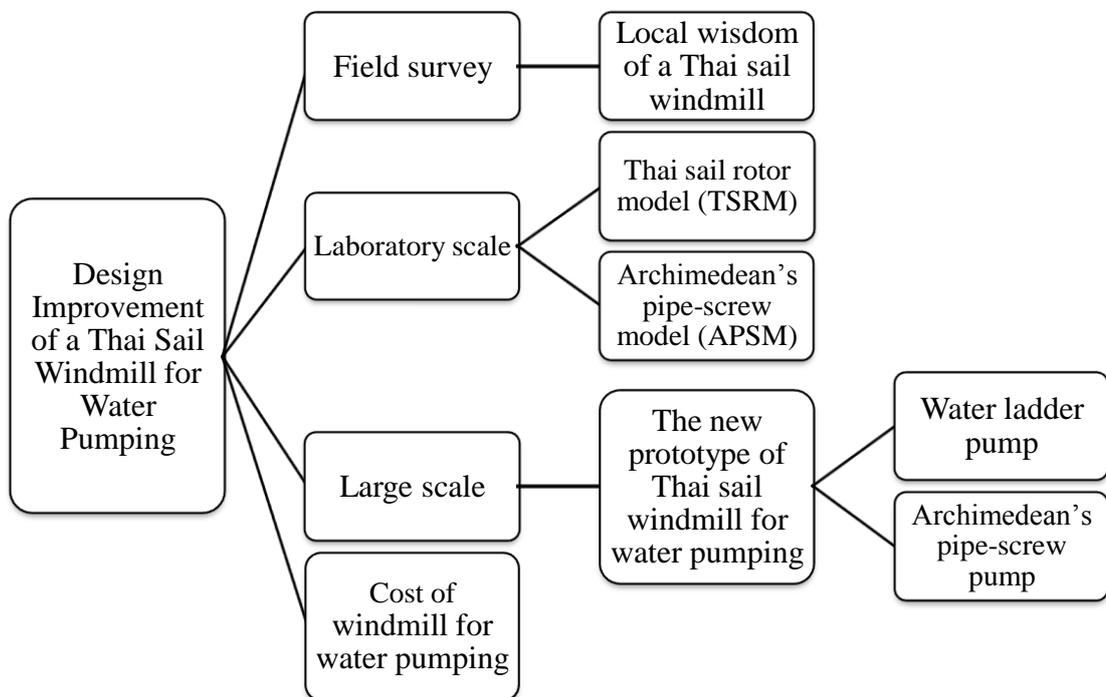4. Cost of windmill for water pumping to evaluate economy of the system.

Figure 3.1 The experimental set up for design improvement of a Thai sail windmill for water pumping

3.2   Field survey of the local wisdom of Thai sail windmill

The Thai sail windmill in Thailand has been used for salt farming along the highway near Samut Sakorn and Samut Songkram. In this step, to study the technological conditions of these original windmill and to talk about the characteristics of these windmill with a discussion of the results found. Study about Thai sail windmill in Thailand which is a type of low wind speed turbine by field survey at locally constructed windmill. These windmills have been used for salt farming along the highway near Samut Sakorn and Samut Songkram. Along with this we do the measurement of the component of windmill and interview the carpentry man. The main components of windmill are sail rotor diameter, constructed materials, number and shape of sails, direction of windmill, power is transmitted by a chain coupled to a water ladder pump. Here, we study the technological conditions of these original windmill and performance of Thai sail windmill for water pumping, using guide lines of UNESSCO, Consolidation of Information from Windpump Handbook (pilot edition), General Information Program and UNISIST United Nations Educational, Scientific and Cultural Organization, 1983 [4].

3.3   Laboratory scale of Thai sail rotor model testing

The Thai sail windmill rotor model have been carried out at the exit of a 1.20 m diameter of wind tunnel. The horizontal axis windmill rotor was away from the exit of the tunnel in all of the tests. The wind power input is determined by measuring the air velocity at the exit of the wind tunnel and using the relation.

Wind tunnel tests were conducted to assess the aerodynamic performance of Thai sail rotor systems. By considering a 1.0 meter in diameter, a family of rotor systems was manufactured with four, six, eight and twelve arms. In this study, tests on Thai sail rotors are conducted in an open jet wind tunnel with a wind tunnel outlet opening of 1.2 meters in diameter. Experiments were carried out to optimize the different parameters like degree of solidity by varying the number of sails and the size of the sails, power coefficient. The main outputs derived from these experiments are recommendations for development of the new generation of Thai sail windmill.

There is a need to test the model in an open jet wind tunnel conducted to assess the aerodynamic performance of Thai sail rotor model (TSRM) systems. By considering a 1.0 meter in diameter, a family of rotor systems was manufactured with six, eight and twelve arms. In this study, tests on Thai sail rotors have been conducted in an open jet wind tunnel with a wind tunnel outlet opening of 1.2 meters in diameter are shown in Figure 3.2.

Experiments were carried out to optimize the different parameters of the sail rotor model like degree of solidity by varying the number of sails and the size of the sails, power coefficient. Experimental set-up for housing and conducting experiments on rotating rotor are shown in Figure 3.3-3.4. The set-up is placed at a distance of 1.0 m downstream of the wind tunnel exit such that the centre of the rotating rotor is in line with the centre of the wind tunnel exit.

Wind velocity is measured with digital anemometer type K, J model : DIGICON DA-41A is shown in Figure 3.5. Rotational speed of the rotor is recorded by a non-contact type digital tachometer model: UN-360P is shown in Figure 3.6. Each bearing is lubricant for the reduction of friction before each testing. The rotor is loaded gradually to record spring balance reading, weights is shown in Figure 3.7 and rotational speed of the rotor n (rpm).

The experiments were carried out to optimize the different parameters of the sail rotor model like degree of solidity by varying the number of sails and the size of the sails, power coefficient (C_p), torque coefficient (C_q) of the rotor by using the brake drum measuring system.

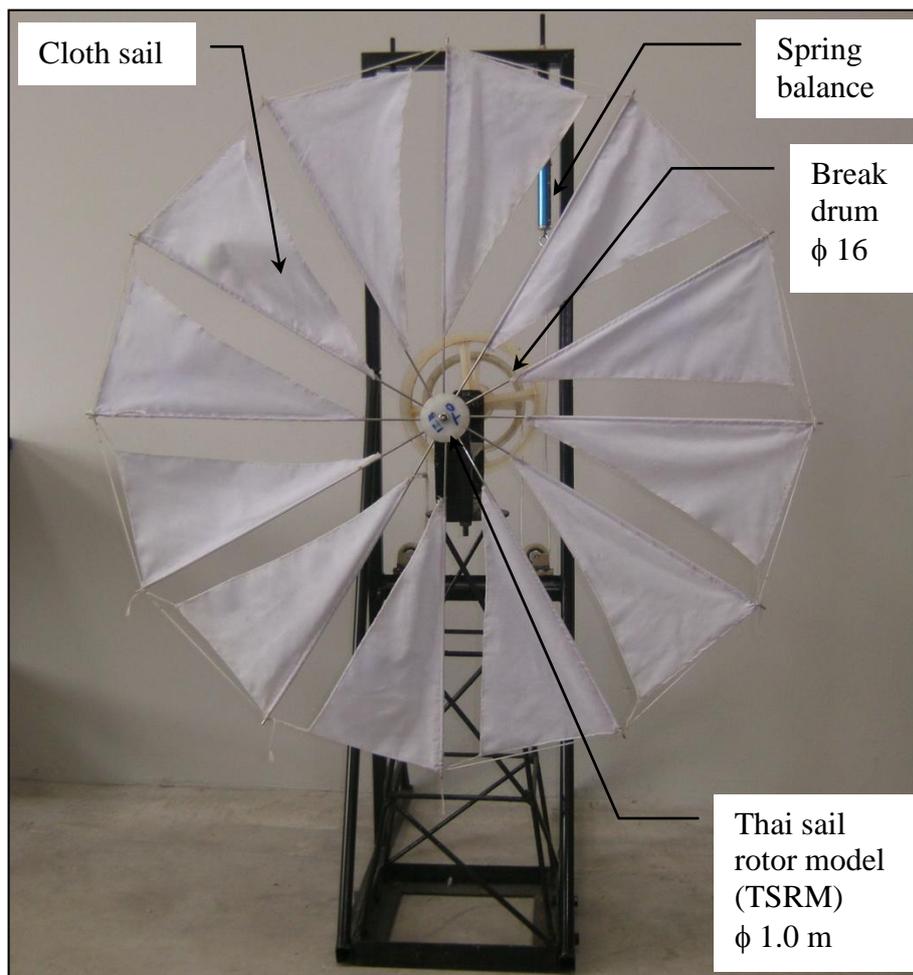**Figure 3.2** Open jet wind tunnel of 1.2 meters in diameter

Figure 3.3 Experimental Thai sail rotor model (TSRM) 1.0 meter in diameter by using
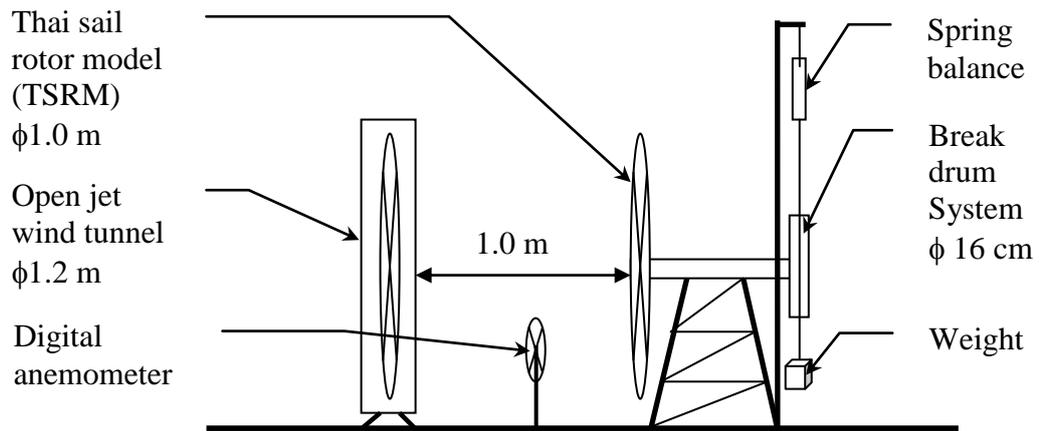the brake drum measuring system

Thai sail
rotor model
(TSRM)
ϕ1.0 m

Open jet
wind tunnel
ϕ1.2 m

Digital
anemometer

1.0 m

Spring
balance

Break
drum
System
ϕ 16 cm

Weight

Figure 3.4 Laboratory scale rotor system testing of the Thai sail rotor model (TSRM)

Figure 3.5 Digital anemometer type K, J model DIGICON DA-41A

Figure 3.6 Digital tachometer model UN-360P

Figure 3.7 Weight

An experimental rotor, 1.0 m diameter of a family of rotor systems were manufactured with four, six, eight and twelve arms were available. The family of Thai sail rotor model (TSRM) system in this experimental is 4B-T1, 4B-T2, 4B-T3, 4B-T4, 4B-T5, 6B-T0, 6B-T1, 6B-T2, 6B-T3, 6B-T4, 6B-T5, 8B-T1, 8B-T2, 8B-T3, 12B-T0 12B-T1 and 12B-T2 as shown in Table 3.1 and Figure 3.8 to Figure 3.24.

Table 3.1 Characteristics of Thai sail rotor model (TSRM)

Model	Number of sail blade (B)	Type of model (T)	A (cm)	B (cm)	C (cm)	Solidity (see Equation 6)
4B-T1		T1	22.5	26.5	37.5	0.15
4B-T2		T2	29.0	26.5	37.5	0.19
4B-T3	4	T3	35.0	27.5	37.5	0.23
4B-T4		T4	41.0	30.0	37.5	0.28
4B-T5		T5	47.5	33.6	37.5	0.32
6B-T0		T0	24.5	28.5	37.5	0.27
6B-T1		T1	18.5	32.5	37.5	0.23
6B-T2		T2	24.5	32.5	37.5	0.30
6B-T3	6	T3	31.5	34.0	37.5	0.38
6B-T4		T4	37.5	37.5	37.5	0.46
6B-T5		T5	39.5	41.5	37.5	0.51
8B-T1		T1	18.5	32.0	37.5	0.30
8B-T2	8	T2	24.5	32.5	37.5	0.40
8B-T3		T3	31.5	34.0	37.5	0.51
12B-T0		T0	18.5	37.0	37.5	0.51
12B-T1	12	T1	18.5	32.0	37.5	0.45
12B-T2		T2	24.5	32.5	37.5	0.60
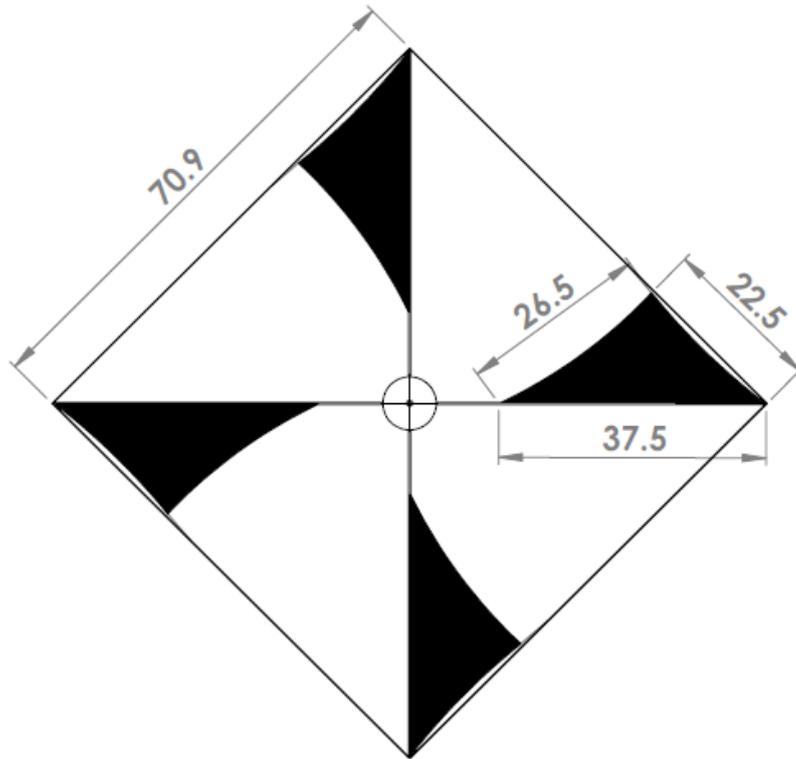
Figure 3.8 Thai sail rotor model (TSRM) 4B-T1
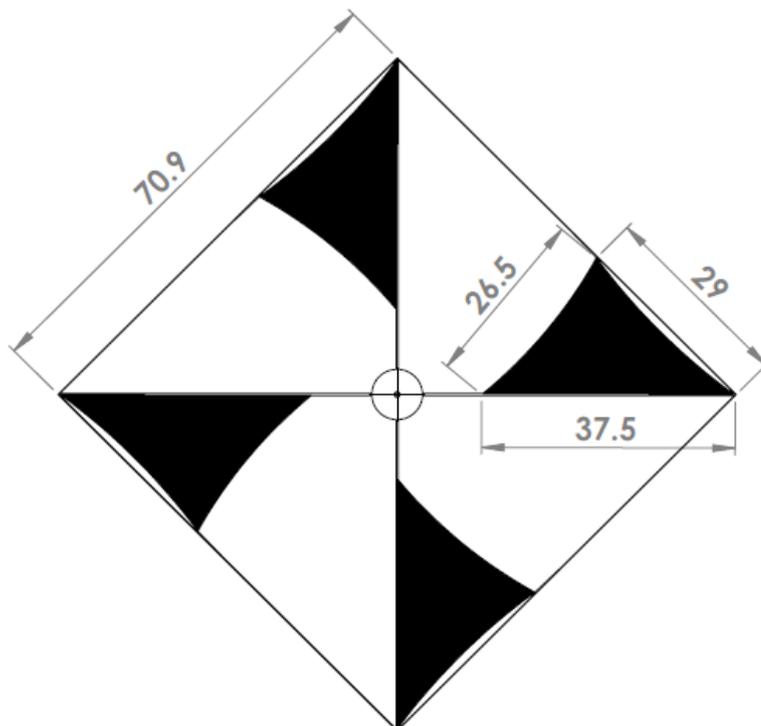
Figure 3.9 Thai sail rotor model (TSRM) 4B-T2
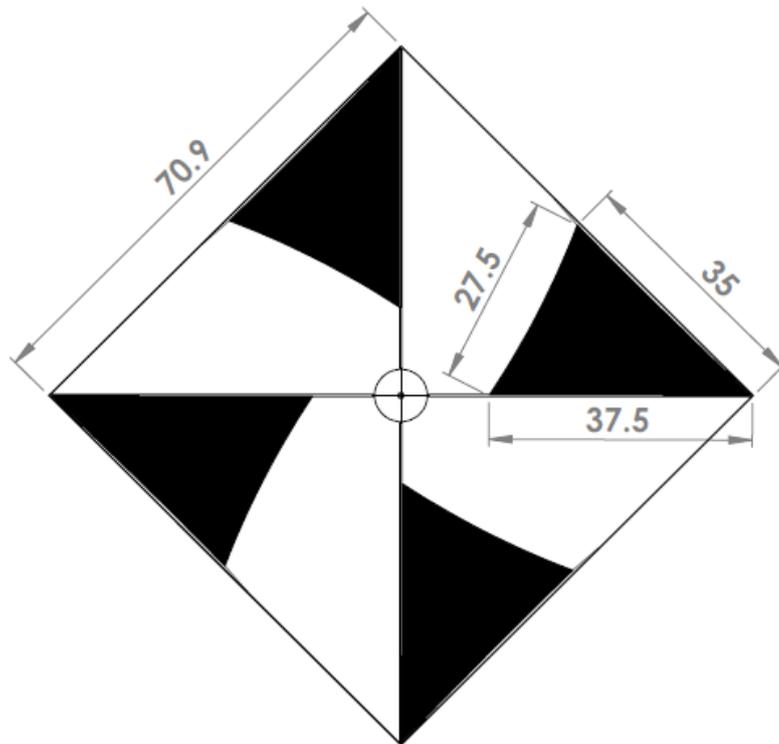
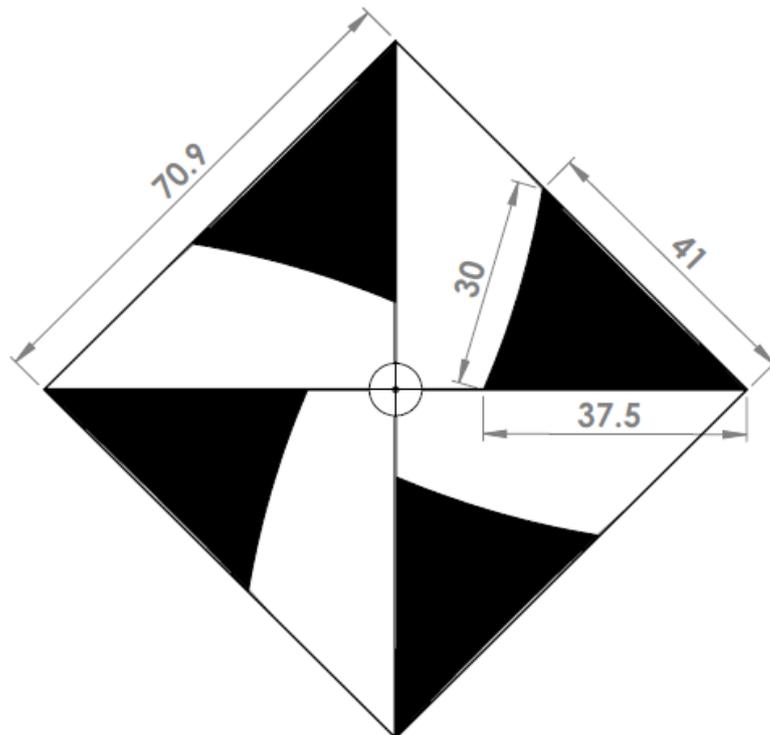**Figure 3.10** Thai sail rotor model (TSRM) 4B-T3

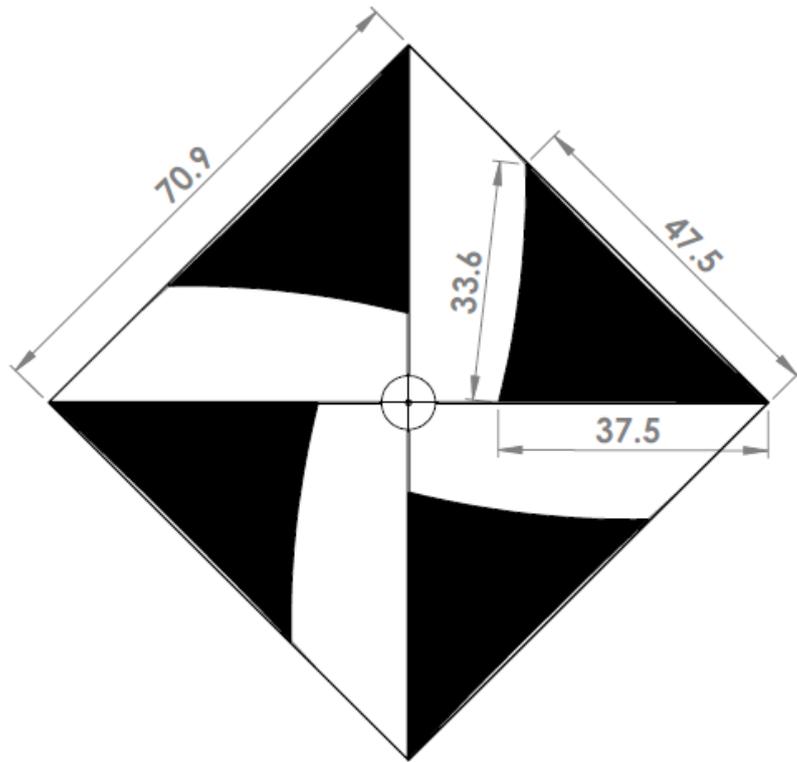**Figure 3.11** Thai sail rotor model (TSRM) 4B-T4
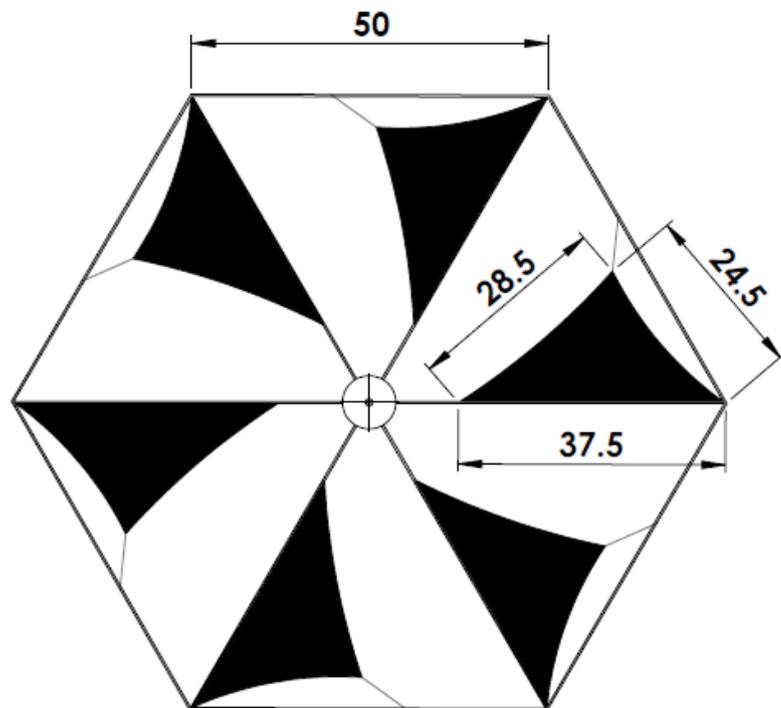
Figure 3.12 Thai sail rotor model (TSRM) 4B-T5

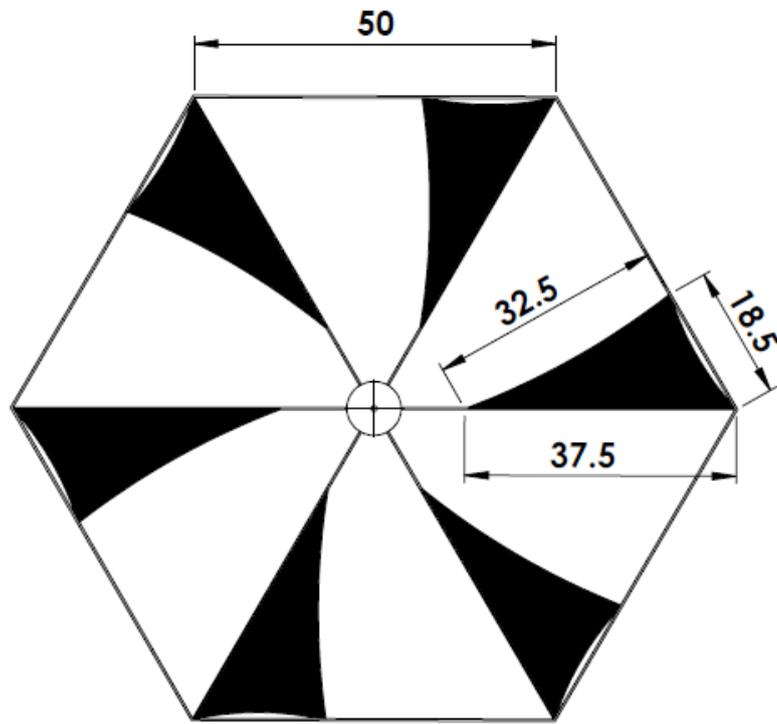**Figure 3.13** Thai sail rotor model (TSRM) 6B-T0

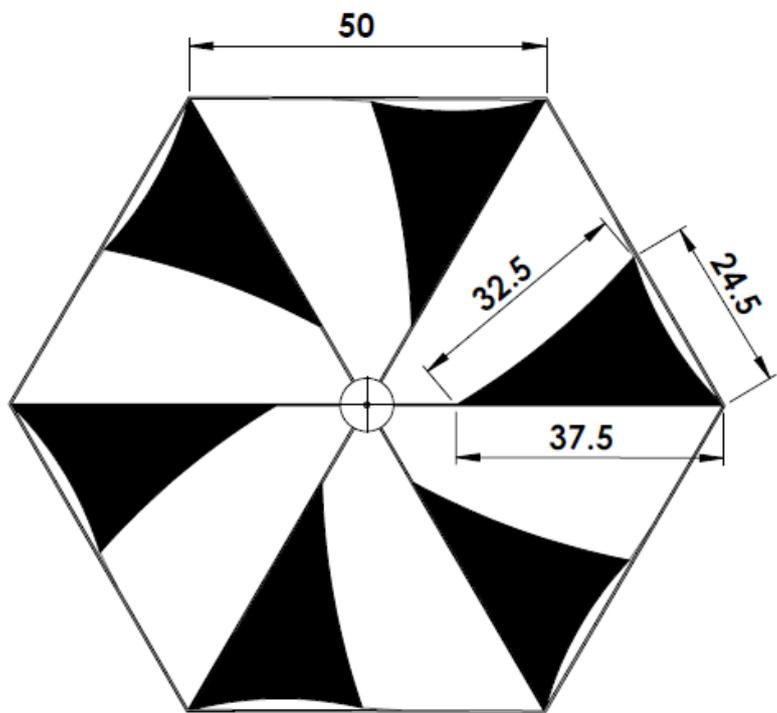**Figure 3.14** Thai sail rotor model (TSRM) 6B-T1

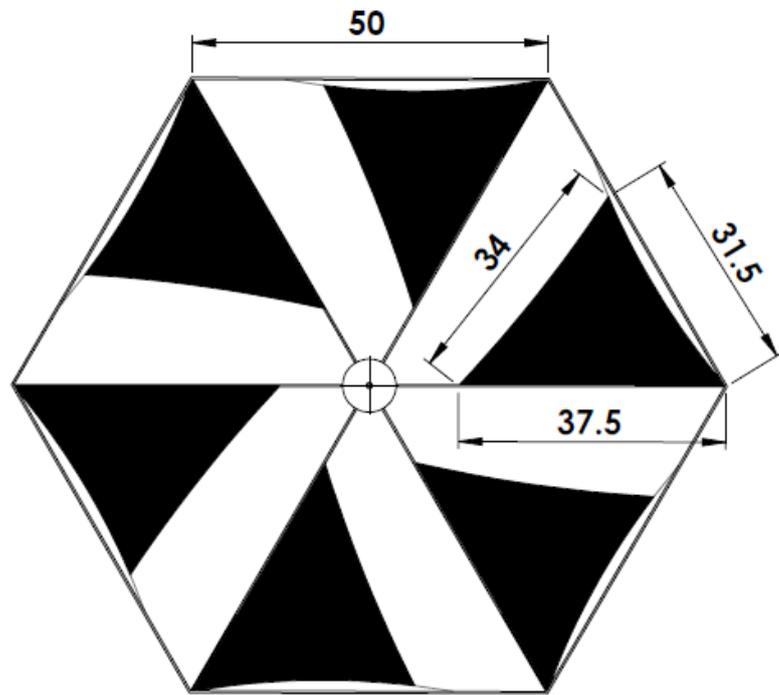**Figure 3.15** Thai sail rotor model (TSRM) 6B-T2

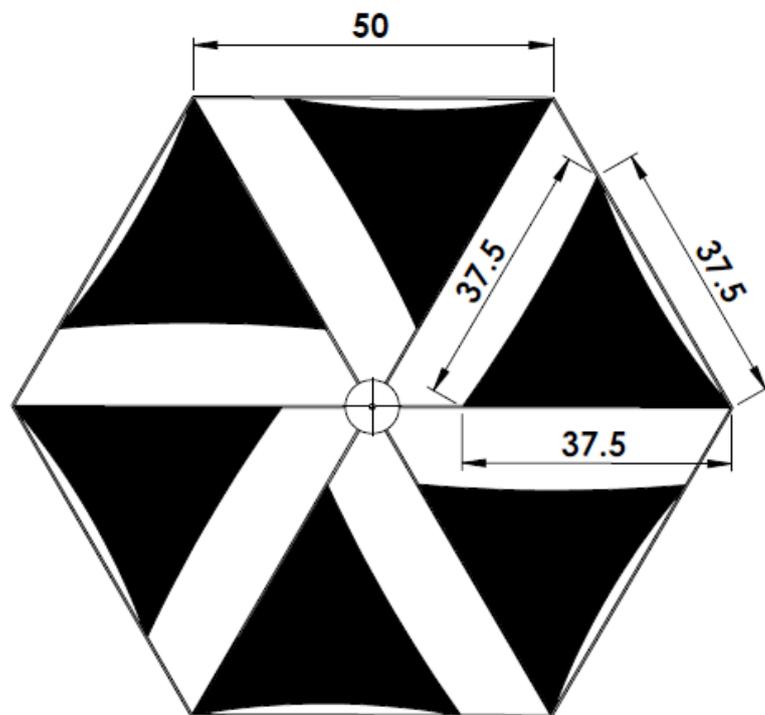**Figure 3.16** Thai sail rotor model (TSRM) 6B-T3

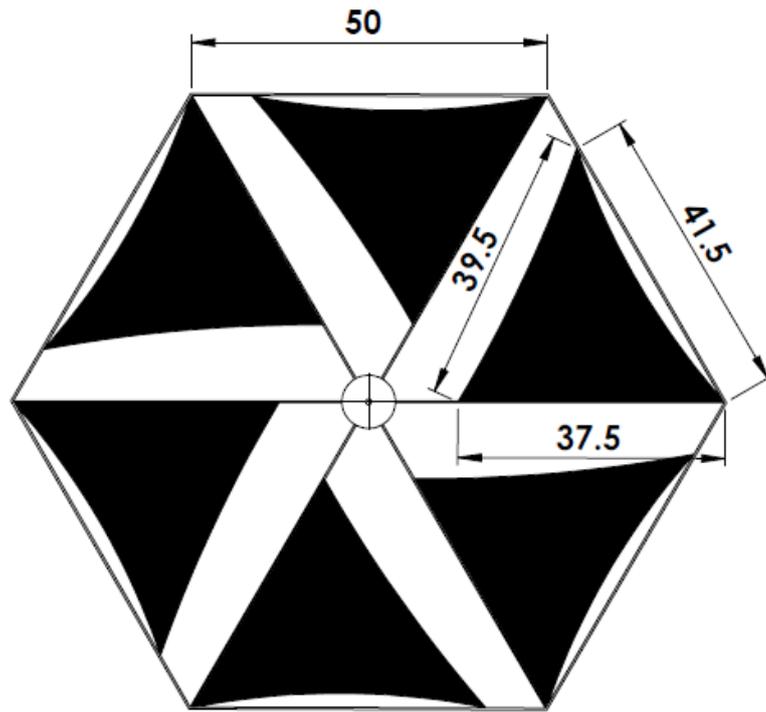**Figure 3.17** Thai sail rotor model (TSRM) 6B-T4

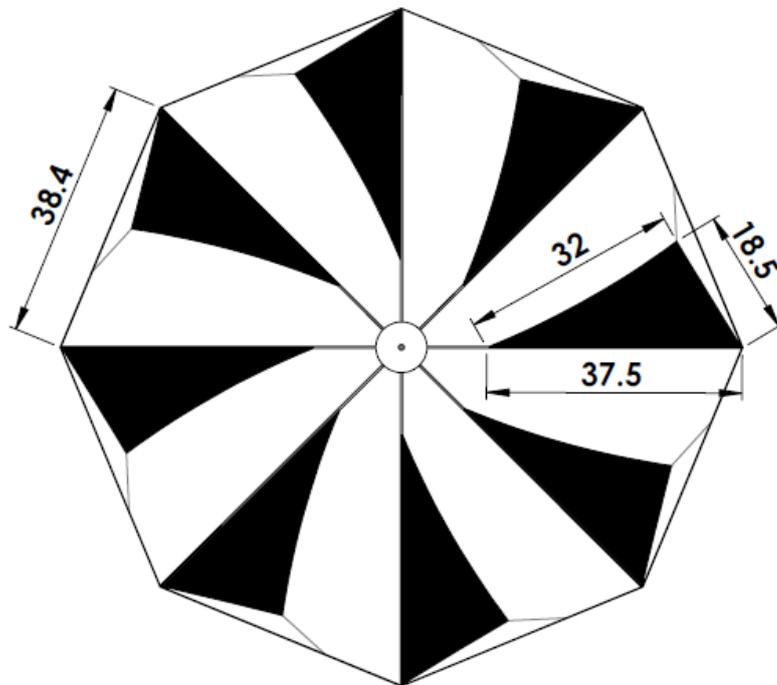**Figure 3.18** Thai sail rotor model (TSRM) 6B-T5

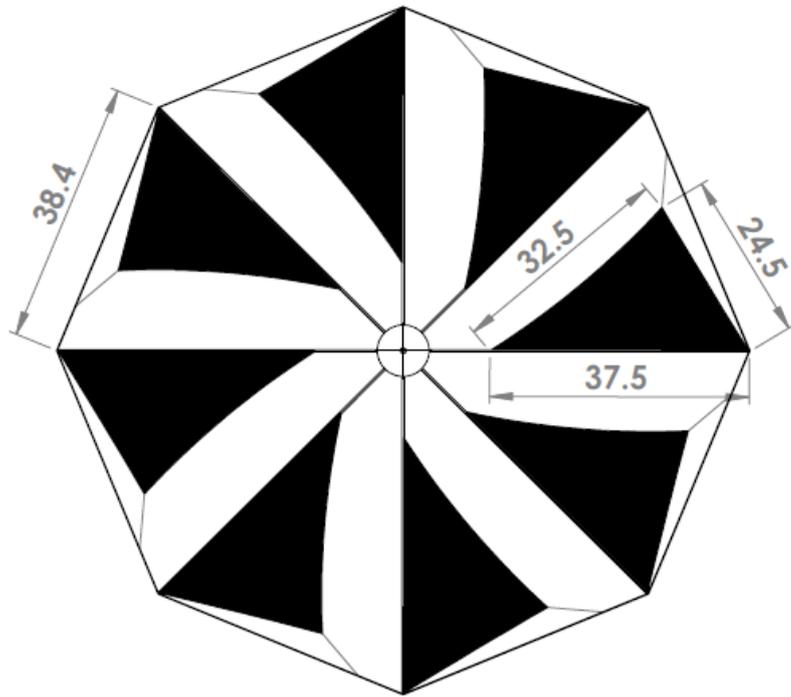**Figure 3.19** Thai sail rotor model (TSRM) 8B-T1
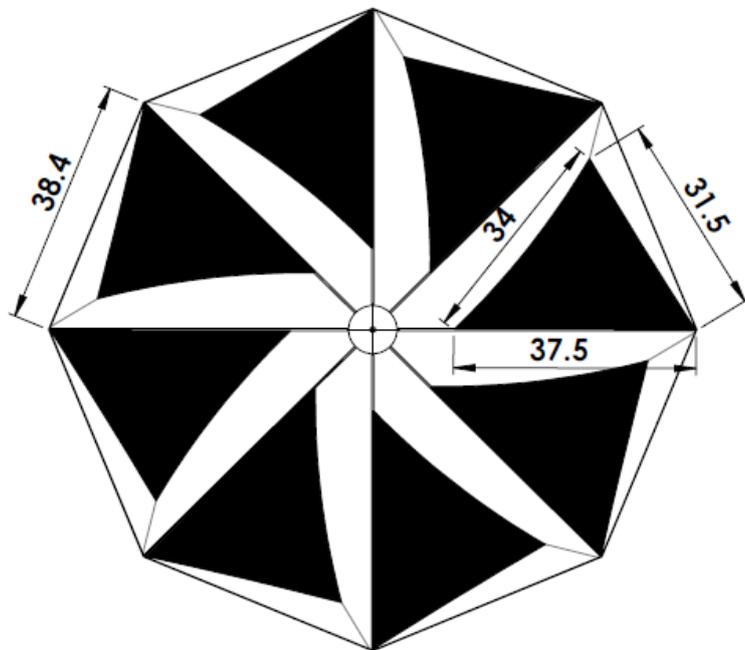
Figure 3.20 Thai sail rotor model (TSRM) 8B-T2

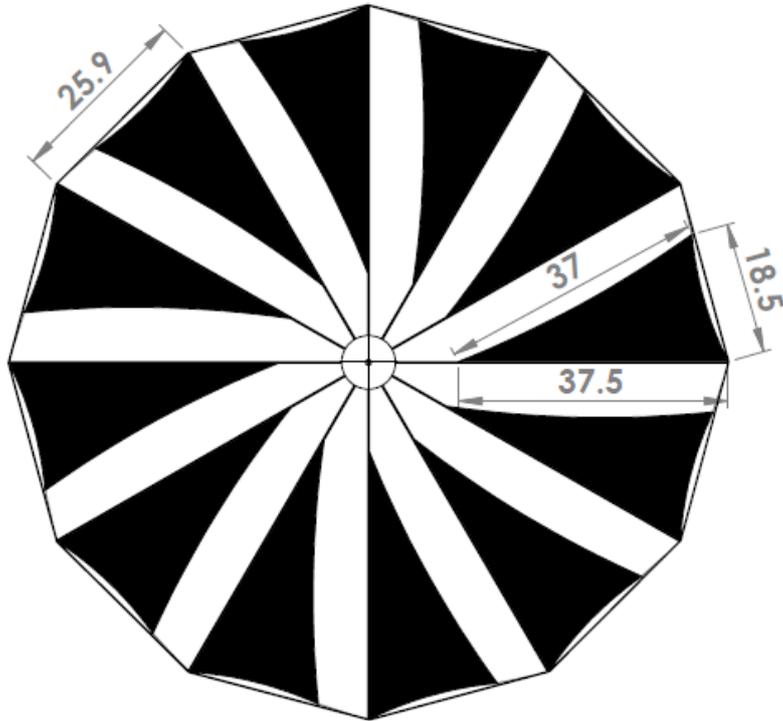**Figure 3.21** Thai sail rotor model (TSRM) 8B-T3

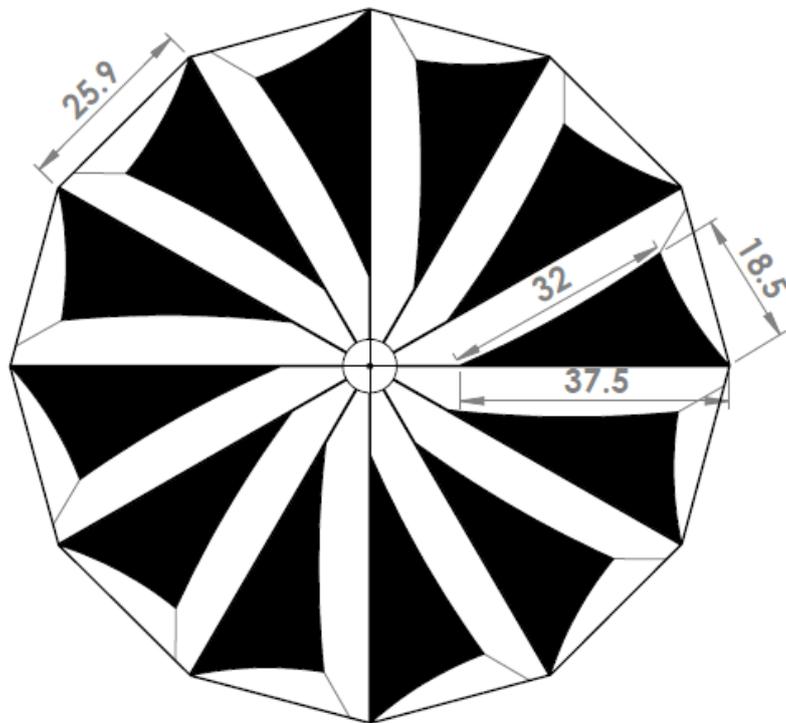**Figure 3.22** Thai sail rotor model (TSRM) 12B-T0

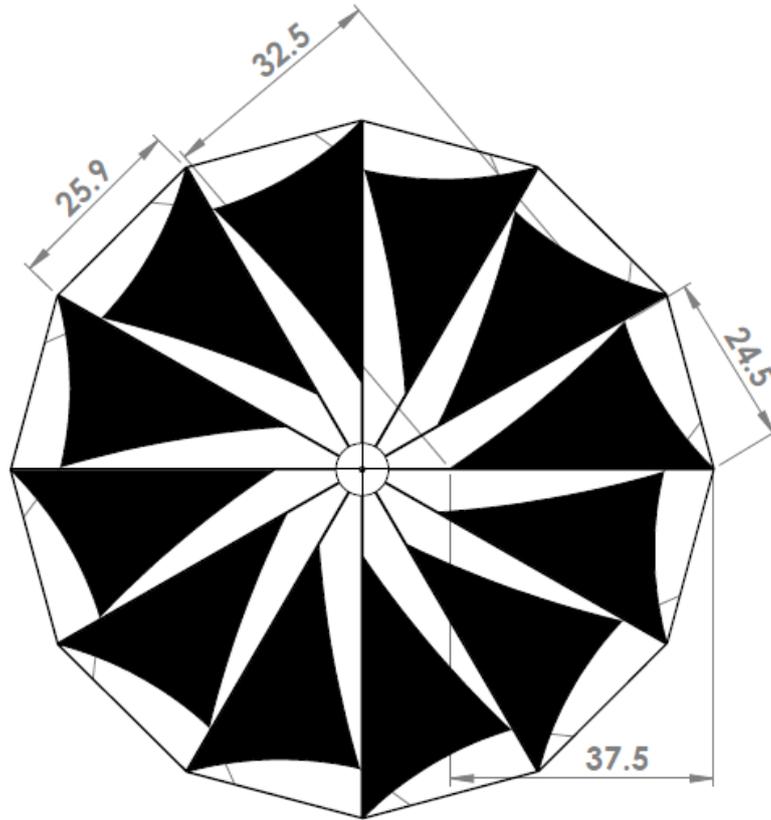**Figure 3.23** Thai sail rotor model (TSRM) 12B-T1

Figure 3.24 Thai sail rotor model (TSRM) 12B-T2

3.4   Laboratory scale of Archimedean's pipe-screw model testing

Water pumping tests were conducted to assess the performance of characteristics of Archimedean's pipe-screw model (APSM) testing apparatus as shown in Figure 3.25 and Archimedean's pipe-screw (APS) as shown in Figure 3.26. A model of pump has been manufactured, 1.0 meter long with the blade small rubber tube was constructed. Experiments were carried out to optimize the different parameters by very the number of blades, pitch, rotation speed of the pump shaft, lift head, intake submergence, angle slope and the size of the blade. The output of the experiments recommenced for development the prototype of Archimedean's pipe-screw pump for the Thai sail windmill.

Experiments were carried out the capacity of the screw to optimize the different parameters by very the parameter as follow : the number of blades, the size of the pipe is diameter of Archimedean's pipe-screw (φAPS) is φ5/8", φ1/2"and φ3/8", the diameter of the Archimedean's pipe-screw (D) is the outer diameter of the APSM (diameter of shaft add diameter of Archimedean's pipe-screw) case and test for pipe-screw φ5/8"or

use D is diameter of shaft of the APSM $\phi 1/2"$ and $\phi 3/8"$ case, the pitch Archimedean's pipe-screw (P) is 0.6D, 0.8D, 0.6D, 1.0D, 1.2D, 1.4D, 1.6D, 1.8D and 2.0D are shown in Figure 3.27 to Figure 3.30, rotation speed of the pump shaft (n) , lift head , intake submergence % is 50% and 25%, angle slope of the screw with the horizontal (α) is 20°, 25° and 30°.

Figure 3.25 Archimedean's pipe-screw model (APSM) testing apparatus

To setup the testing of ϕAPS 5/8" APSM-1, APSM-2 APSM-3, APSM-4, APSM-5, APSM-6, APSM-7 and APSM-8 are shown in Table 3.2. The testing of ϕAPS 1/2" APSM-9, APSM-10 APSM-11, APSM-12, APSM-13, APSM-14, APSM-15 and APSM-16 are shown in Table 3.3 and APSM-17 for ϕAPS 3/8" diameter of Archimedean's pipe-screw model (APSM) are shown in Table 3.4. The rotation speed of the pump shaft APSM (n) is 6, 15, 33, 55, 73 and 80 rpm as shown in Table 3.5.

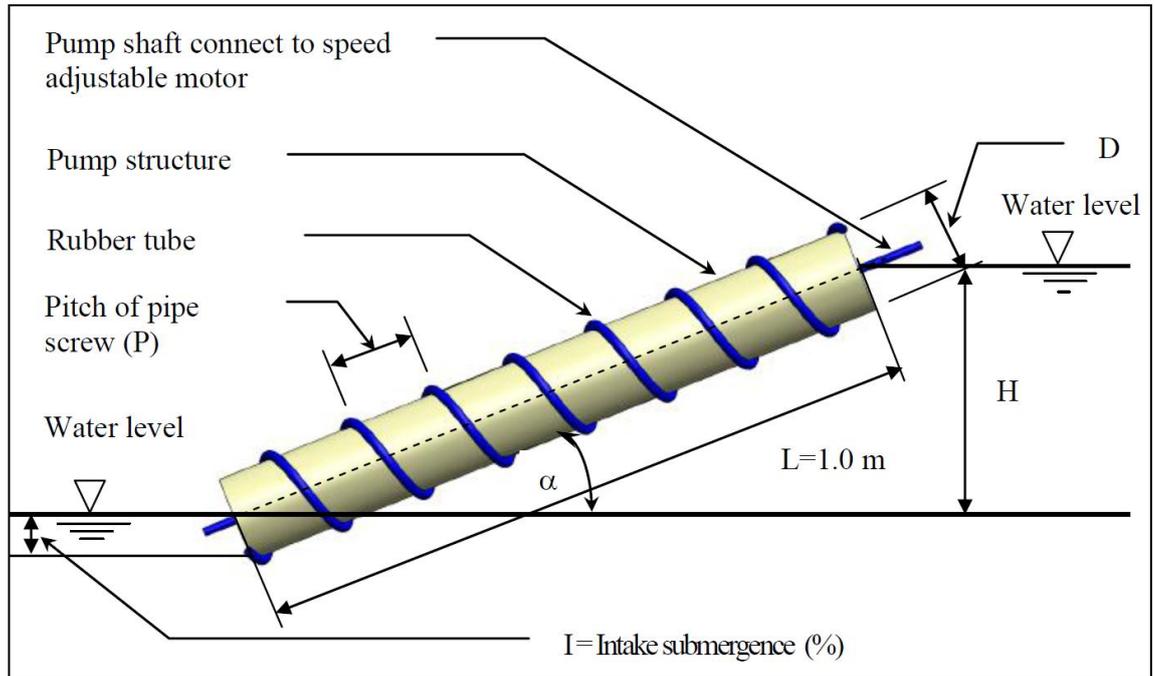Figure 3.26 Laboratory scale Archimedean's pipe-screw model (APSM) testing for rubber tube $\phi5/8"$, $\phi1/2"$ and $\phi3/8"$
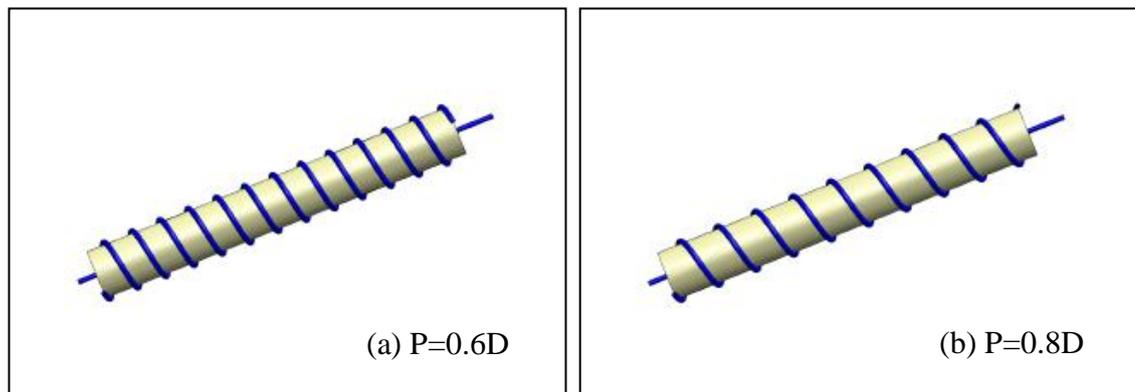

(a) P=0.6D

(b) P=0.8D

Figure 3.27 Archimedean's pipe-screw model (APSM), pitch of pipe screw
(a) P = 0.6D, (b) P = 0.8D
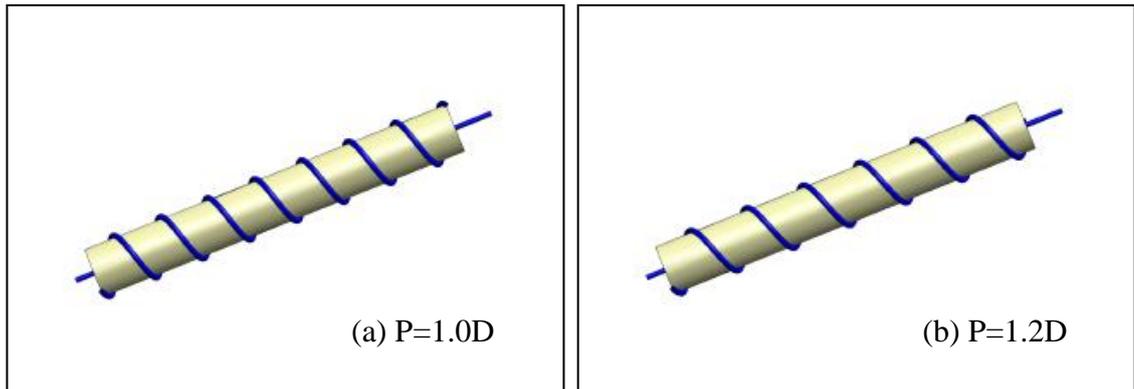
(a) P=1.0D

(b) P=1.2D

Figure 3.28 Archimedean's pipe-screw model (APSM), pitch of pipe screw

(a) P = 1.0D, (b) P = 1.2D

(b) P=1.4D
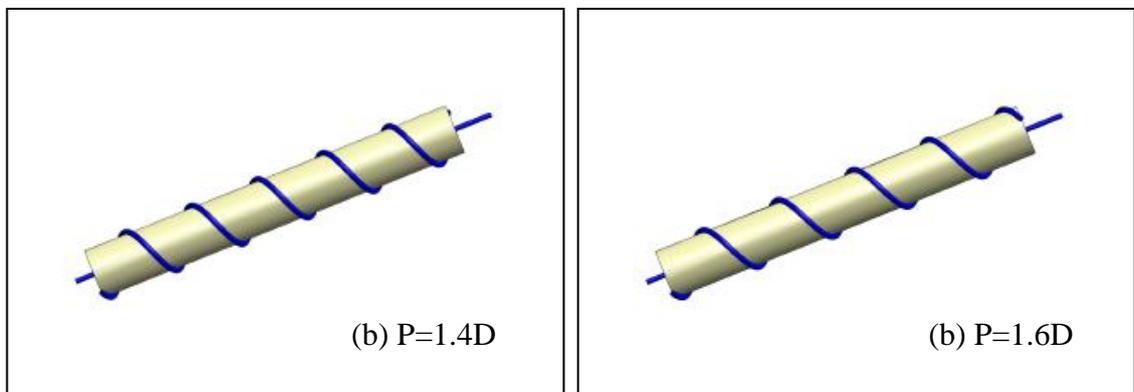
(b) P=1.6D

Figure 3.29 Archimedean's pipe-screw model (APSM), pitch of pipe screw
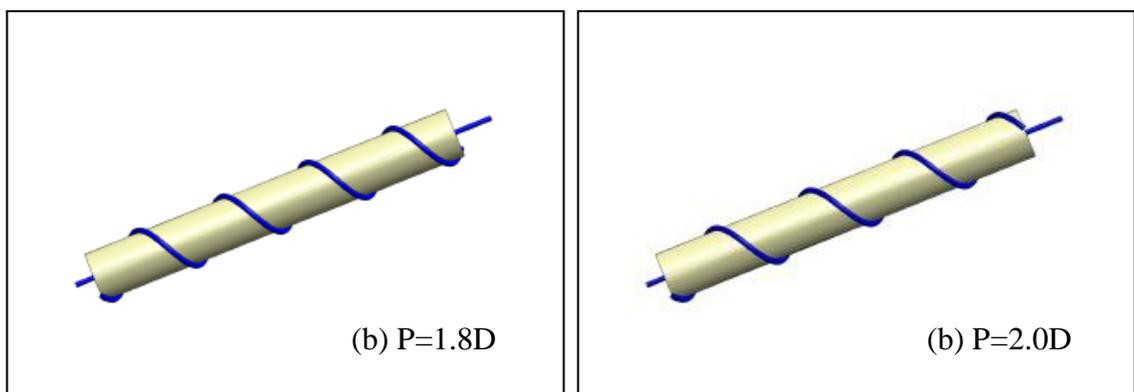
(a) P = 1.4D, (b) P = 1.6D

(b) P=1.8D

(b) P=2.0D

Figure 3.30 Archimedean's pipe-screw model (APSM), pitch of pipe screw

(a) P = 1.8D, (b) P = 2.0D

Table 3.2 Testing of ϕAPS 5/8" diameter Archimedean's pipe-screw

Model	Pitch of the APS P (cm)		Angle slope (α)	Intake submergence (%)
APSM-1	0.6D	11.1	20, 25, 30	50
APSM-2	0.8D	14.8	20, 25, 30	50
APSM-3	1.0D	18.5	20, 25, 30	50
APSM-4	1.2D	22.2	20, 25, 30	50
APSM-5	1.4D	25.9	20, 25, 30	50
APSM-6	1.6D	29.6	20, 25, 30	50
APSM-7	1.8D	33.3	20, 25, 30	50
APSM-8	2.0D	37.0	20, 25, 30	50
Remark D is outer diameter of the APSM (diameter of shaft and pipe screw)				

Table 3.3 Testing of ϕAPS 1/2" diameter Archimedean's pipe-screw

Model	Pitch of the APS P (cm)		Angle slope (α)	Intake submergence (%)
APSM-9	0.6D	9.0	20, 25, 30	50
APSM-10	0.8D	12.0	20, 25, 30	50
APSM-11	1.0D	15.0	20, 25, 30	50
APSM-12	1.2D	18.0	20, 25, 30	50
APSM-13	1.4D	21.0	20, 25, 30	25, 50
APSM-14	1.6D	24.0	20, 25, 30	50
APSM-15	1.8D	27.0	20, 25, 30	50
APSM-16	2.0D	30.0	20, 25, 30	50
Remark D is diameter of shaft of the APSM				

Table 3.4 Testing of φAPS 3/8" diameter Archimedean's pipe-screw

Model	Pitch of the APS P (cm)		Angle slope (α)	Intake submergence (%)
APSM-17	1.4D	21.0	20, 25, 30	50
Remark D is diameter of shaft of the APSM				

Table 3.5 Rotation speed of APSM

Speed	Rotating speed n (rpm)
1	6
2	15
3	33
4	55
5	73
6	80

3.5 Large scale the new prototype of Thai sail windmill

The characteristics of the prototype the Thai sail windmill model 12B-T0 as shown in Table 3.6. The prototype of 12 blade Thai sail windmill for water pumping consists of six major components: rotor assembly, the transmission, tail assembly, turntable, tower structure and pump. The prototype of 12 blade Thai sail windmill was tested at Rajamangala University of Technology Rattanakosin, 96 moo 3 Puthamonthon Sai 5, Salaya, Puthamonthon, Nakhon Pathom, 73170 Thailand as shown in Figure 3.31.

Table 3.6 Characteristics of the prototype the Thai sail windmill

Model	Number of sail blade (B)	Type of model (T)	A (cm)	B (cm)	C (cm)	Solidity (see Equation 6)
12B-T0	12	8.0	1.48	2.96	3.0	0.51

Rotor assembly: The rotor assembly has been designed to face the wind ahead of the tower. It consists of a circular plate hub plate on which 12 tubular steel spars of 42.7 mm outer diameter are mounted, the rotor which is 8.0 m in diameter as shown in Figure 3.32 and Figure 3.33. The rotor hub is keyed to the shaft which is about 800 mm away from the centre of the output shaft in order to have sufficient clearance between the rotor spars and the tower. The end of the spars are connected by means of a 12 mm diameter nylon rope which is stretched around the rotor circumference between the tips of each spar. The 12 support pipe of 34 mm outer diameter, link at the one meters of the spars from center of rotor assembly are connected through steel pipe of 42.7 mm outer diameter to a forward axial projection from the hub plate. This support pipe adds stiffness in the bending to spars when sails are opened to face the wind as shown in Figure 3.36, allows the blades to feather in high winds or when overloaded.

Sails: The sails, triangular in shape, are 12 in number and made of cloth as shown in Figure 3.32 and Figure 3.33. The base of sail dimension is 1.48 x 2.96 x 3.0 m^2. On the longest side of the sail, round holes are reinforced into the rotor spars. The loose end of the sails is connected on to the rotor circumference between the tips of each spar by means of a nylon rope of 4 mm in diameter.

Power transmission: The windmill is design uses a rigid rear axle and differential from a small car made for the upper gear box as shown in Figure 3.34 and Figure 3.35. The rotor center plate is bolted to the rear axle of a small car. The rotational speed of the drive shaft will then be approximately four times higher than that of the rotor mounted on the wheel drum. The other wheel is permanently locked, resulting in a transmission ratio of about 1:4 from the horizontal to the vertical, about 2:1 for the second an automobile lower gear box as shown in Figure 3.39 could be used to decrease the rotational speed and drive to a water ladder pump. The rear axle is free to swivel about the vertical on a turntable. The whole assembly is mounted on a small platform on a turntable, a single pipe on head of tower structure. The drive shaft and the two universal joints are used to transmit the rotor power to the driven machinery. The drive shaft can be lengthened by using pipe of approximately 48.6 mm outer diameter and the drive shaft is passed through the centre of the tower structure.
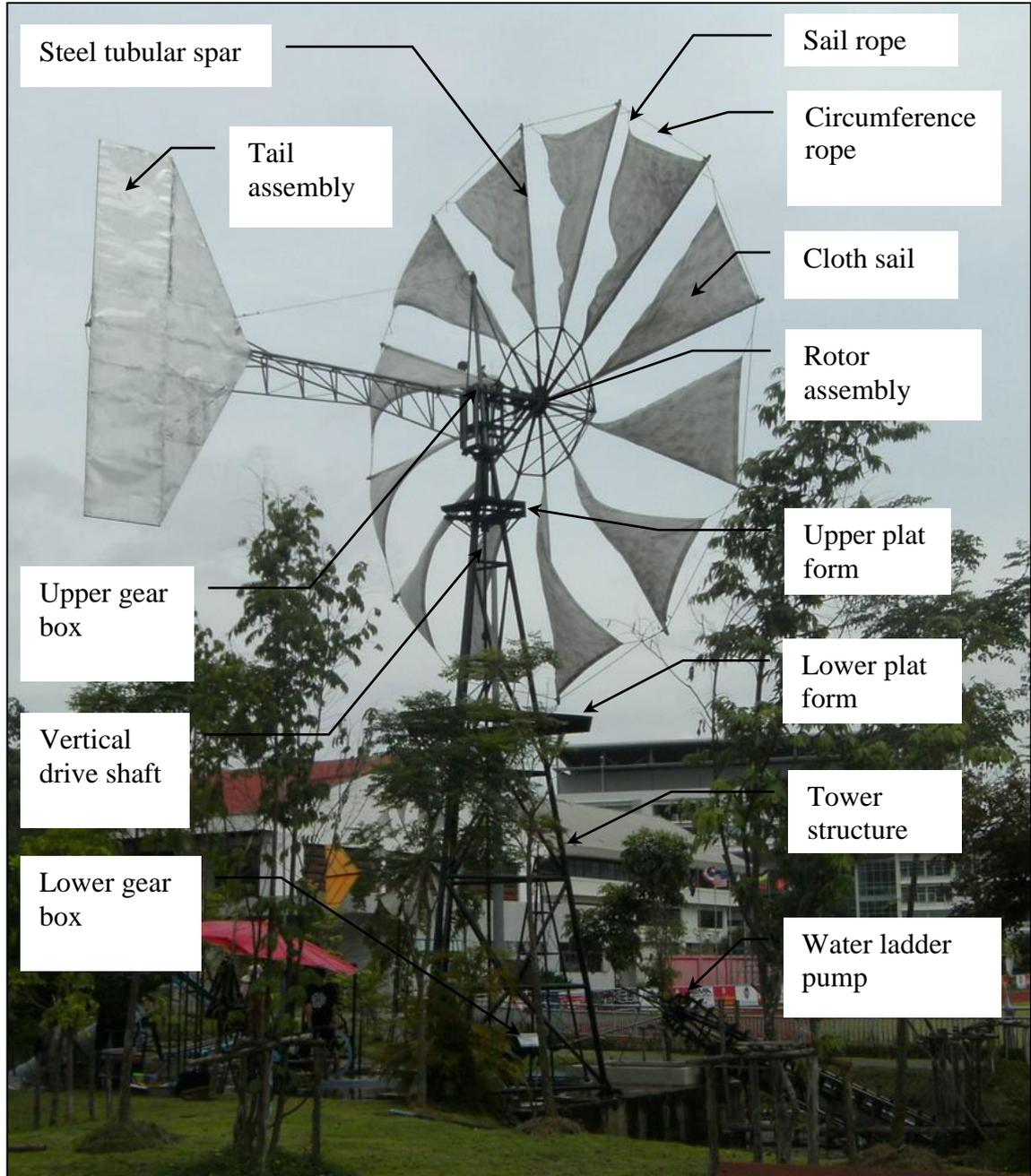
Figure 3.31 The prototype of 12 blade Thai sail windmill for water pumping

Tail assembly: The tail of the windmill is 5.2 m long and made of Galvanized sheet metal approximately 0.5 mm thick mounted on a framework of conduit pipes. The area of tail vane has a 6 m^2 as shown in Figure 3.34.

Turntable: The turntable provides a rigid frame for the rotor head of windmill mechanism, rotor assembly, tail assembly, the transmission, turns over the tower pipe to orient itself towards the wind as shown in Figure 3.34 and Figure 3.37. Basic materials for these are angle iron, some flat iron, bolts, nuts.
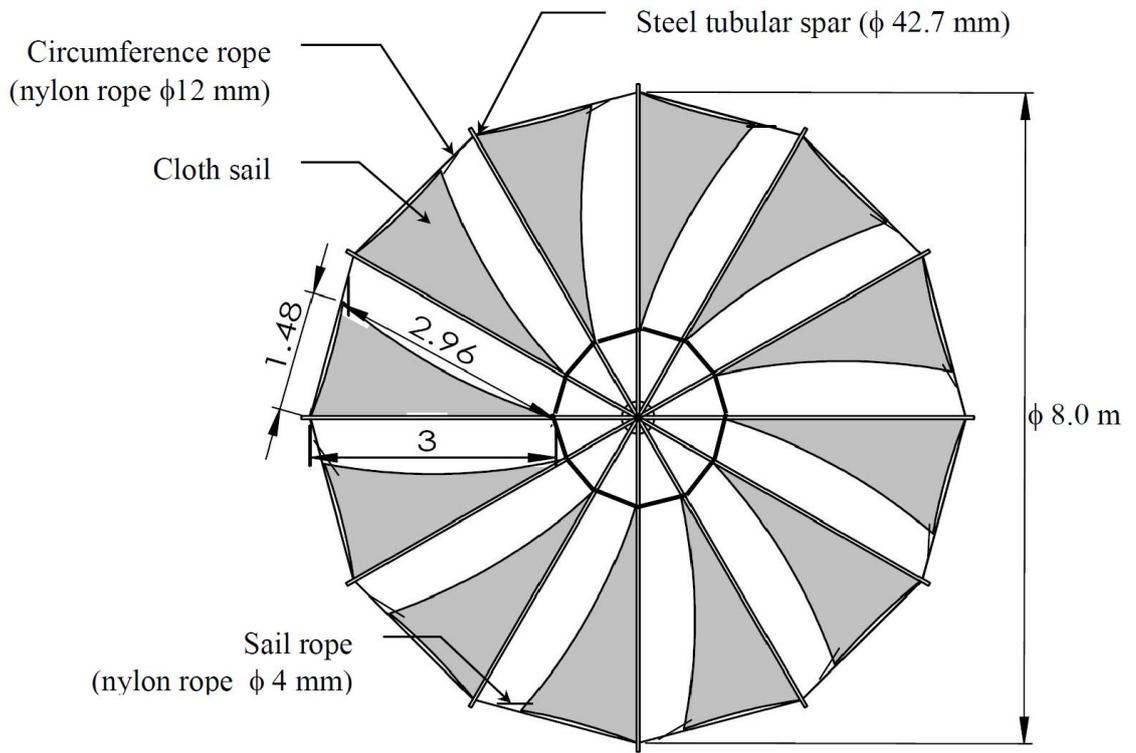
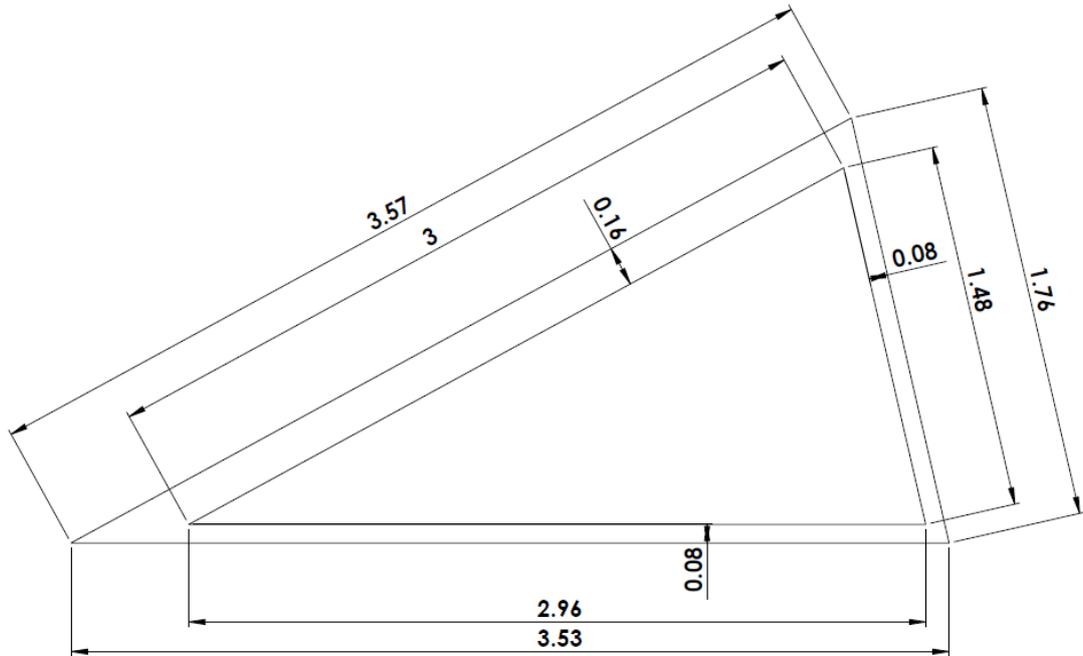**Figure 3.32** Rotor assembly showing detail of 12 blade Thai sail windmill 12B-T0

Figure 3.33 Dimension of cloth sail to cut for Thai sail windmill blade 12B-T0 model

Tower structure: The tower is 9.0 m high and is fabricated out of 48.6 mm, 60.5 mm, and 76.3 mm outer of diameter tower structure pipe. The base of tower dimension is 2.5 x 2.5 x 2.5 m^2 as shown in Figure 3.34, 3.38, 3.40 and Figure 3.41.

Pump: The open trough square-wooden pallet chain pump or water ladder pump used with the windmill as shown in Figure 3.34 and see "3.6 Large scale of water ladder pump coupled by the prototype of Thai sail windmill". For large scale Archimedean's pipe-screw testing for rubber tube ϕ2"used with the windmill as shown in Figure 3.47, see "3.7 Large scale of Archimedean's pipe-screw coupled by the prototype of Thai sail windmill".
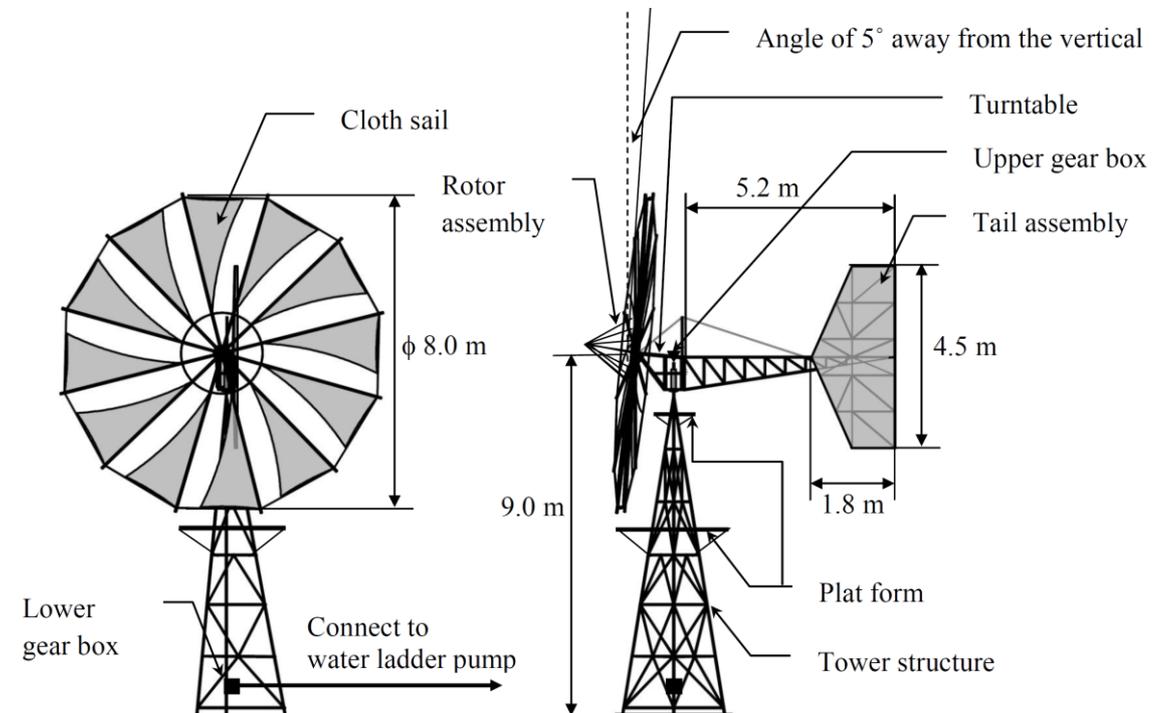

Figure 3.34 Diagram of the prototype of 12 blade Thai sail windmill for water pumping, 8 m in diameter of Thai sail windmill having twelve triangular cloth sail, upper gear box, lower gear box, tower, rotor assembly, plat form and tail assembly
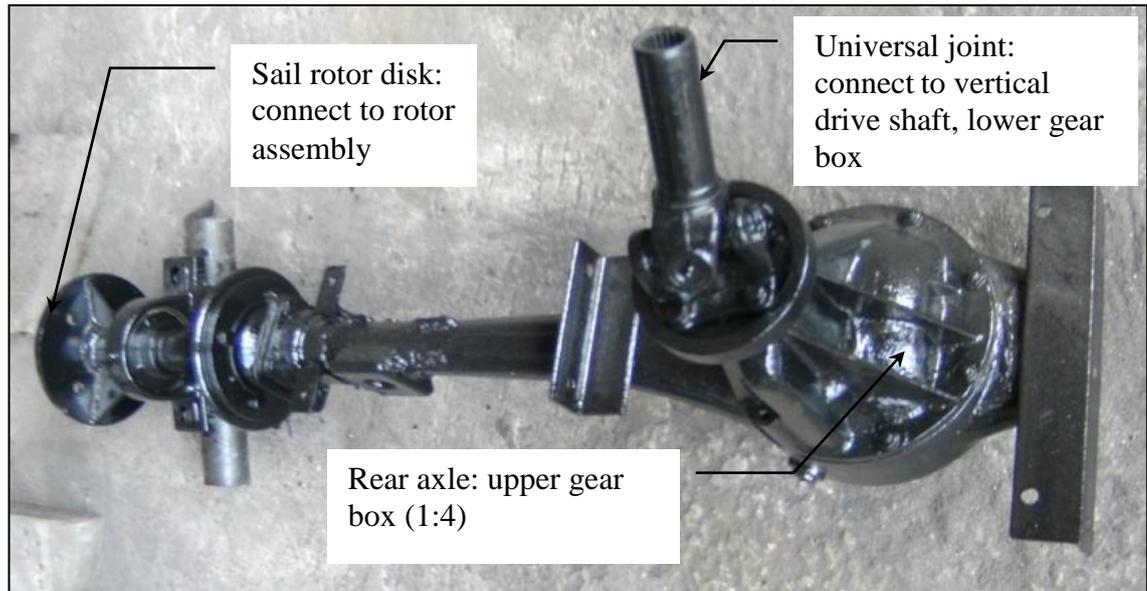
Sail rotor disk: connect to rotor assembly

Universal joint: connect to vertical drive shaft, lower gear box

Rear axle: upper gear box (1:4)

Figure 3.35 Power transmission : the rear axle made for upper gear box

Figure 3.36 Hub of rotor assembly

Figure 3.37 Head of turntable

Figure 3.38 Head of tower structure

Figure 3.39 Lower gear box (2:1)

Figure 3.40 Tower structure

Lower plat form

Tower structure

Vertical drive shaft

Lower gear box (2:1)

Horizontal drive shaft: connect to water ladder pump, Archimedean's pipe-screw pump

Figure 3.41 Lower gear box, drive shaft and tower structure

3.6 Large scale of Water ladder pump coupled by the prototype of Thai sail windmill Testing

The open trough square-wooden pallet chain pump or water ladder pump used with the windmill as shown in Figure 3.38, Figure 3.46 to Figure 3.49 head of water pumping 1.0 m. There are number of 54 wooden pallets and wooden chain. The size of water ladder pumps is 15 cm width, 4.0 m long and 0.50 m high. The water ladder pump coupled by horizontal drive shaft, universal joint, connect to lower gear box of the prototype 12 blade Thai sail windmill.

Figure 3.42 Tail side view of water ladder pump
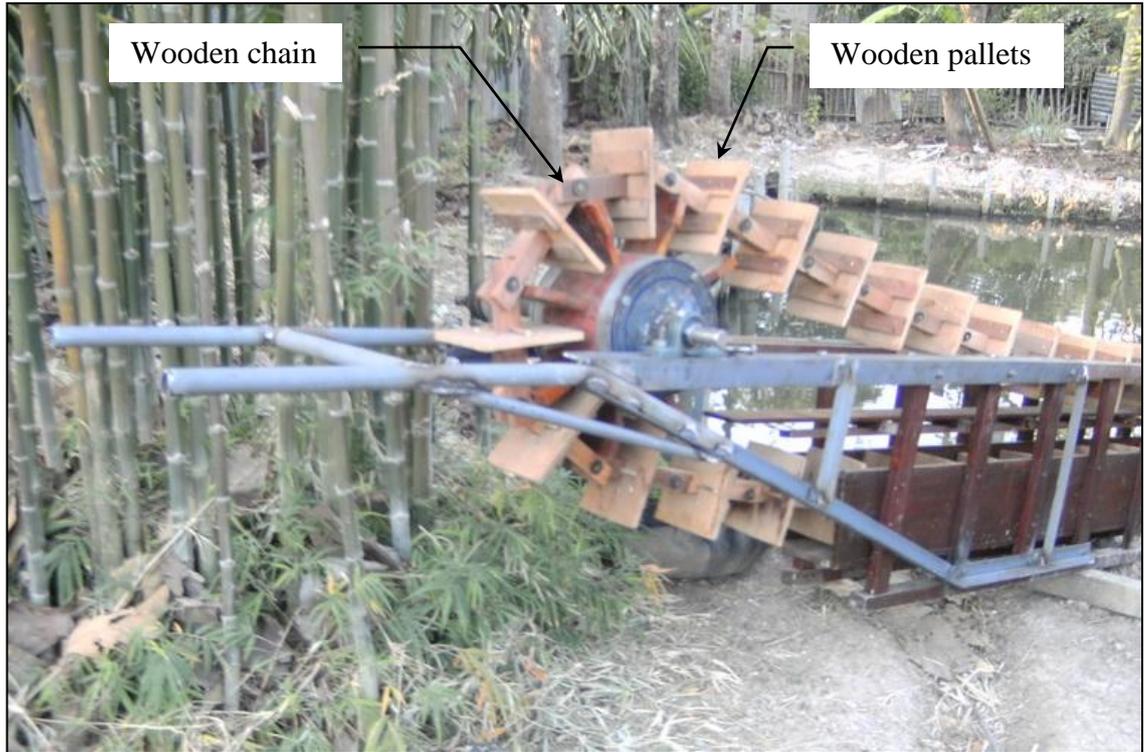
Figure 3.43 Head side view of water ladder pump

Figure 3.44 Water ladder pump coupled by the prototype of Thai sail windmill
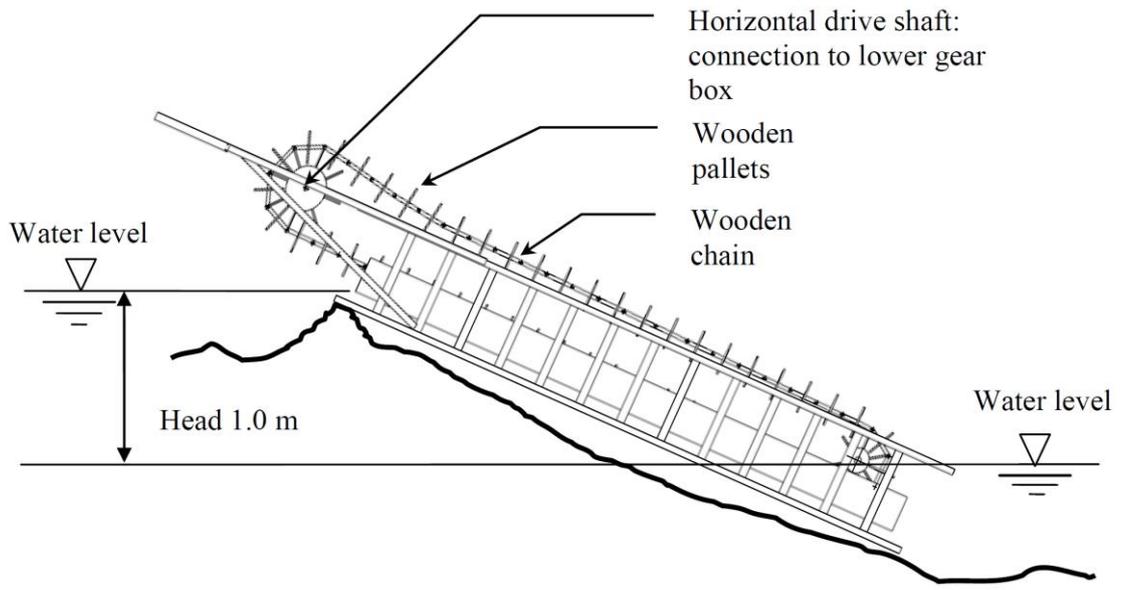
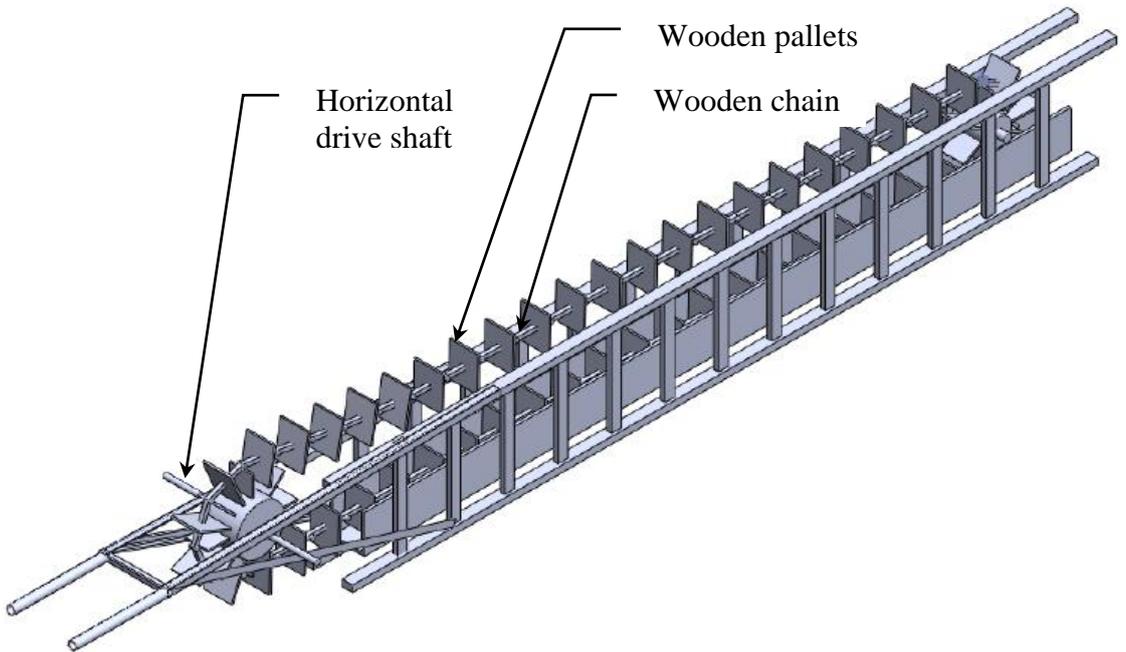**Figure 3.45** Diagram of water ladder pump testing

Figure 3.46 Isometric diagram of water ladder pump

3.7 Large scale of Archimedean's pipe-screw coupled by the prototype of Thai sail windmill testing

Large scale Archimedean's pipe-screw testing for rubber tube $\phi 2"$ used with the windmill as shown in Figure 3.47 to Figure 3.58, head of water pumping 1.5 m. Archimedean's pipe-screw pump has been manufactured, there are number of rubber tube $\phi 2"$ is 1 to 12. The size of Archimedean's pipe-screw pump is 4.0 m long and 0.50 m in diameter. The Archimedean's pipe-screw pump coupled by horizontal drive shaft, universal joint, connect to lower gear box of the prototype 12 blade Thai sail windmill.

Experiments were carried out the capacity of the screw by very the number of rubber tube $\phi 2"$ is 1 to 12 pipes, rotation speed of the pump shaft (n) , lift head 1.5 m, intake submergence % is 50% , angle slope of the screw with the horizontal (α) is 20.5°.
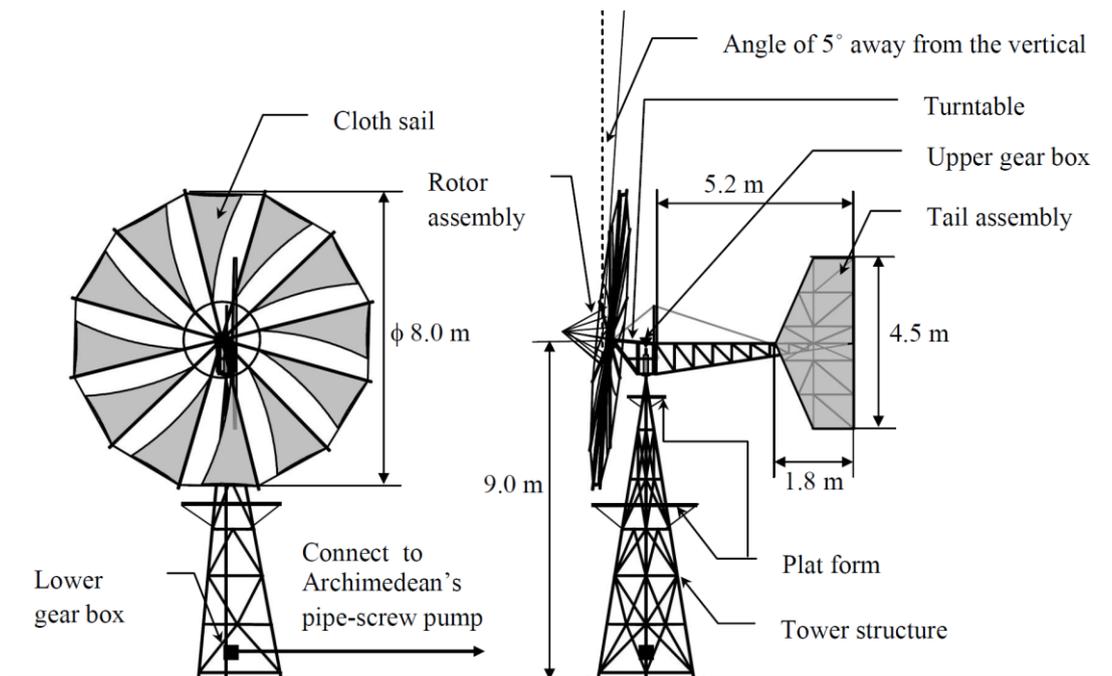

Figure 3.47 Diagram of the prototype of 12 blade Thai sail windmill coupled to Archimedean's pipe-screws pump for water pumping
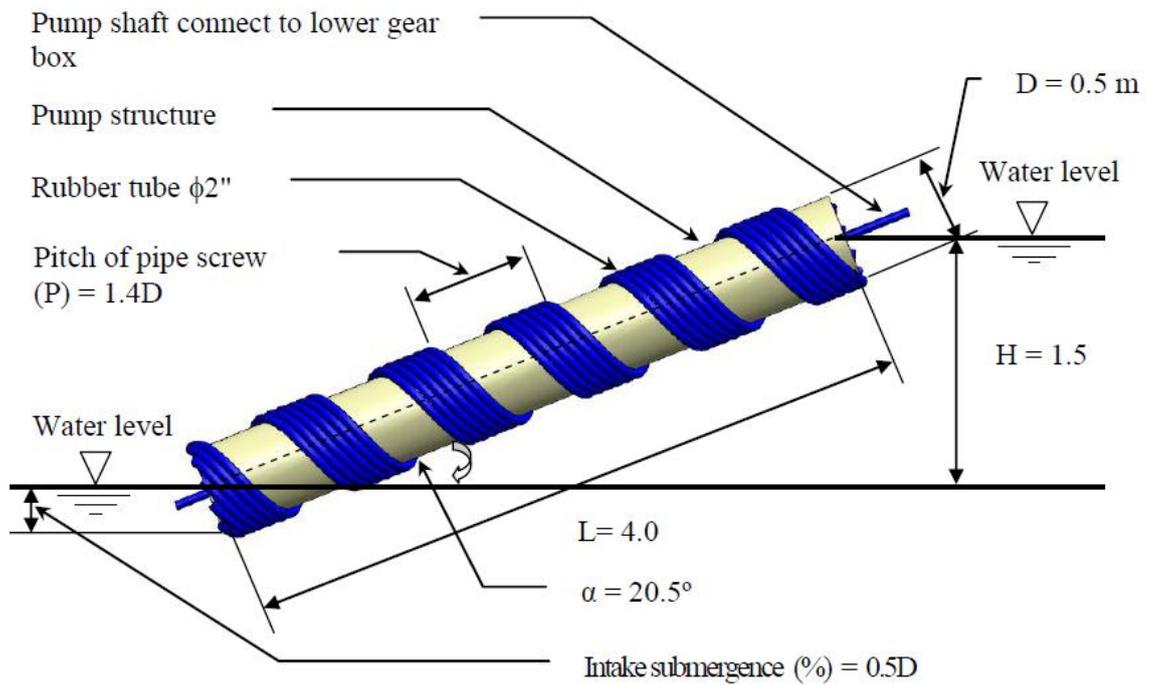
Pump shaft connect to lower gear box

Pump structure

Rubber tube $\phi 2"$

Pitch of pipe screw (P) = 1.4D

Water level

D = 0.5 m

Water level

H = 1.5

L= 4.0

$\alpha = 20.5°$

Intake submergence (%) = 0.5D

Figure 3.48 Large scale Archimedean's screw-pipe pump testing for rubber tube $\phi 2"$

Rubber tube $\phi 2''$

Pump shaft of Archimedean's pipe-screw connect to lower gear box

Pump structure of Archimedean's pipe-screw
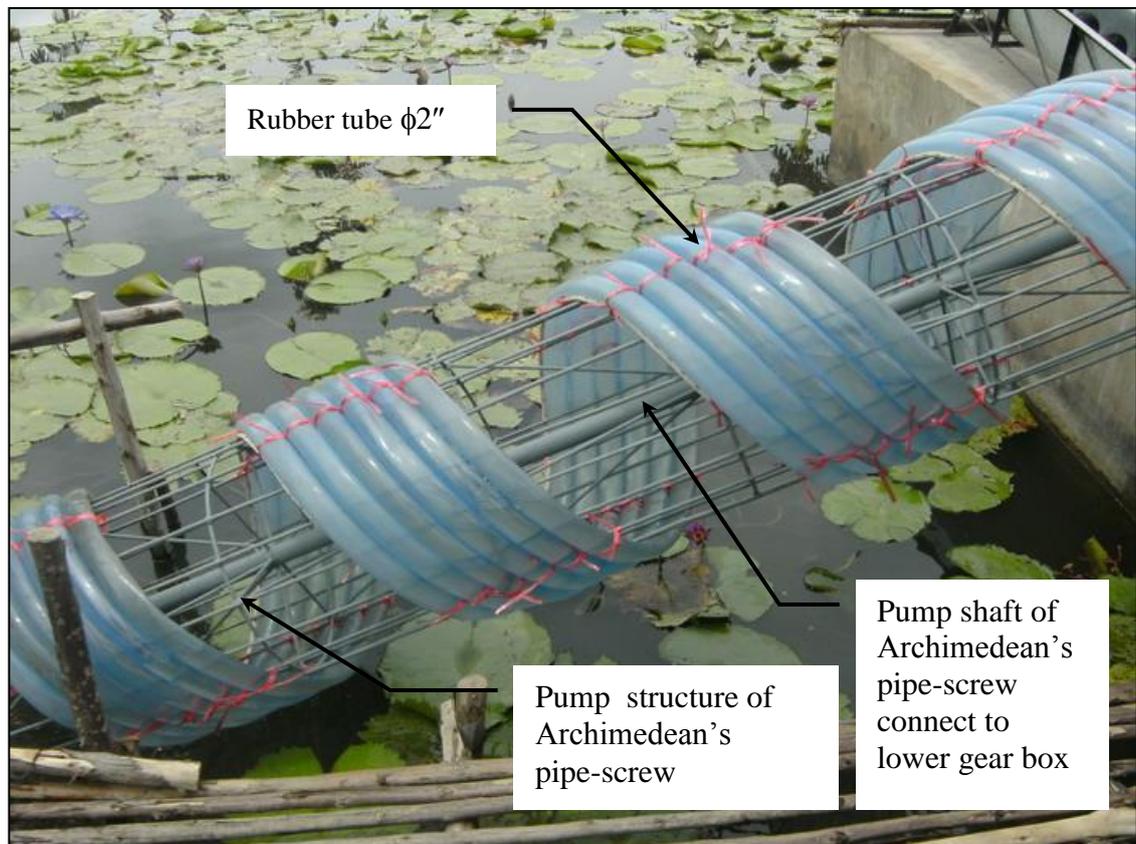
Figure 3.49 The prototype of six Archimedean's pipe-screws (6-APS) of rubber tube $\phi 2"$ at pitch of pipe screw 1.4D
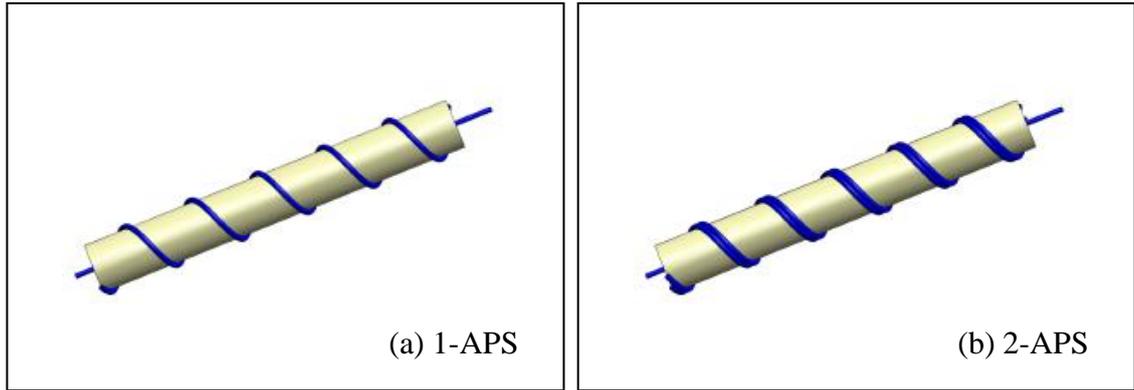
(a) 1-APS

(b) 2-APS

Figure 3.50 Diagram of Archimedean's pipe-screw (a) 1-APS, (b) 2-APS

(a) 3-APS

(b) 4-APS

Figure 3.51 Diagram of Archimedean's pipe-screw (a) 3-APS, (b) 4-APS
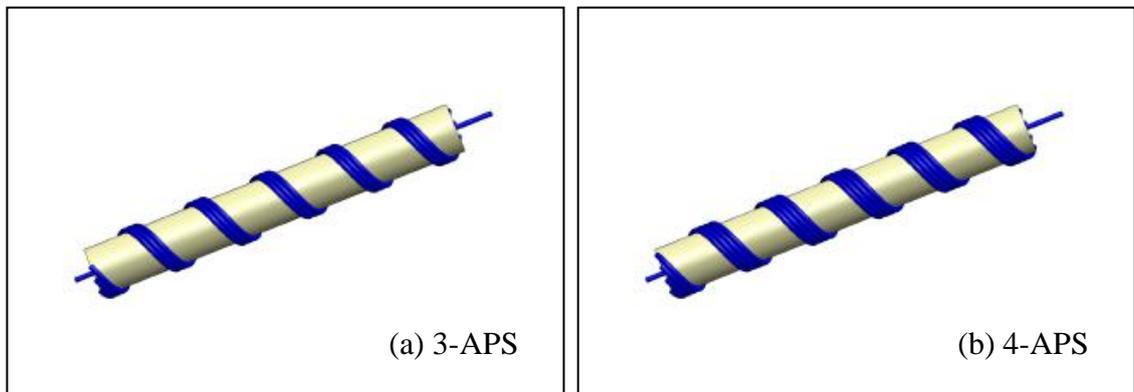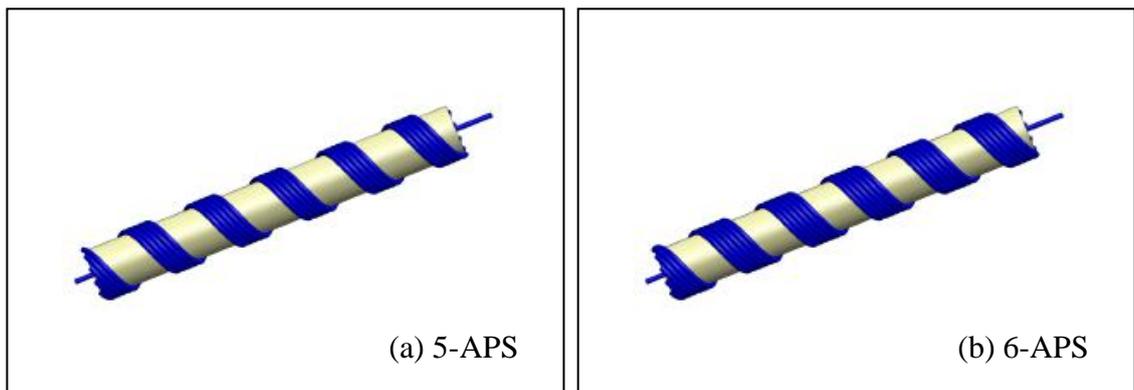

(a) 5-APS

(b) 6-APS

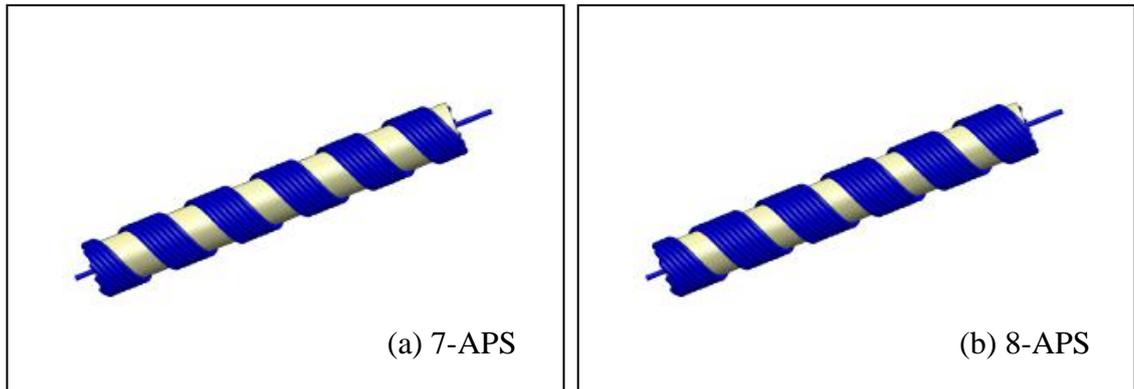**Figure 3.52** Diagram of Archimedean's pipe-screw (a) 5-APS, (b) 6-APS

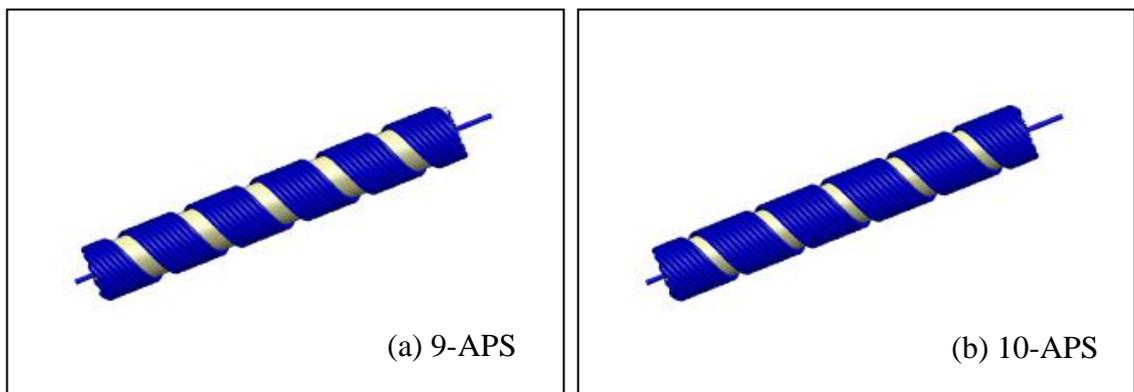**Figure 3.53** Diagram of Archimedean's pipe-screw (a) 7-APS, (b) 8-APS

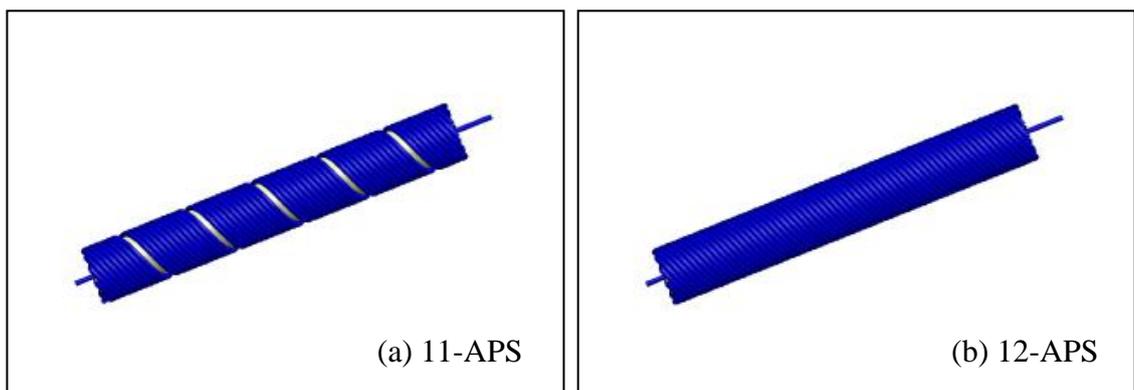**Figure 3.54** Diagram of Archimedean's pipe-screw (a) 9-APS, (b) 10-APS

Figure 3.55 Diagram of Archimedean's pipe-screw (a) 11-APS, (b) 12-APS

63

Figure 3.56 Structure of the prototype of Archimedean's pipe-screw pump

Figure 3.57 Archimedean's pipe-screw pump coupled by the prototype of 12 blade
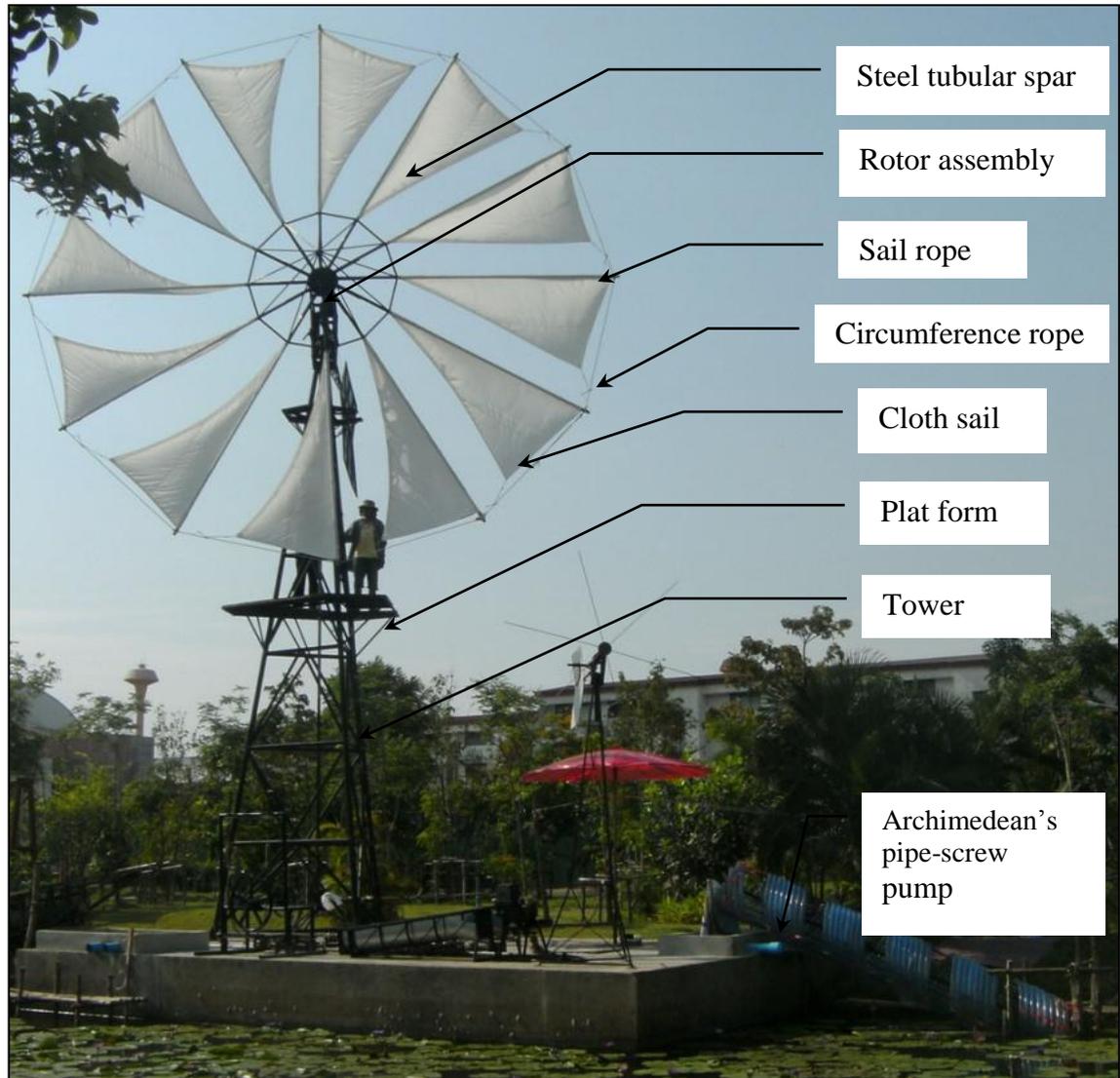
Thai sail windmill

Figure 3.58 The prototype of 12 blade Thai sail windmill coupled to Archimedean's pipe-screws pump for water pumping