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Design Aspects of a 2 HP Stirling Engine for Powering Brown Rice Husking Machine

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Abstract

This paper presents design aspects of a 2 HP Stirling engine for powering brown rice husking machine. The stirling engine is a beta - type with rhombic drive mechanism. The engine has swept volume of 113 cc with bore and stroke of 60 mm and 40 mm, respectively. Heat exchanging parts comprise of heater, regenerator and cooler. The heater is a fired tube heater. The regenerator contains stainless wire mesh. The cooler is a shell-and-tube heat exchanger which working gas flows through many small tubes circulated externally by chilled water. The experimental tests were conducted over wide range of operating pressure. LPG is used to fuel the prototype in the proof of concept device. Rice husks are planned to use as a fuel for the future. The engine performance has been evaluated by the preliminary test. The engine is operated at pressure range of 2–7 bar. The initial testing result shows that the maximum torque was 1.32 Nm at 328 rpm while the maximum power was 67 W at 651 rpm with the fuel rate of 0.5 kg/hr. The engine performance is continuing measured and improved to achieve a few horse powers.

Keywords*:* Stirling engine, beta-type, rhombic-drive, Rice husking machine.

1. Introduction

Nowadays people are concerned of having healthy nutrition. Brown rice is one of the world's healthiest foods [1]. Brown rice, although, have similar amounts of calories and carbohydrate as same as white rice but the process producing brown rice peels only the husk or outermost layer. The hull of the brown rice kernel is the least damaging to its nutritional value. Therefore, the development of brown rice husking machines with variation scale production is increasing. Recently, small brown rice hullers are widely manufactured by many Thai companies. A midget rice husking machine is potable and suitable for household. It can produce fresh rice and remaining all of nutrients. The advantage of a small-scale rice husking machine requires low driving power. Thus, the power generation of brown rice can be obtained from various prime mover technologies. Stirling engine is an optional and interesting machine because of its simple construction, quiet operation, no internal combustion and emission. Stirling engine, hence, is a good potential driving machine for a rice huller because rice shells can be fueled the engine resulting in economization. There are many Stirling engines built in various sizes, configurations and driving mechanisms.

Rhombic-drive was invented in 1953 by Meijer [2] in Philips company, Holland. Rhombic-drive mechanism is one of the most balancing assemblies providing minimum side force on cylinder wall and compact in-line cylinder which is perfect for beta-type engine configuration. Many researchers, thus, employed rhombic drive and investigated its performance by simulation and experiment.

Timoumi et al [3] showed the numerical simulation model taking into account thermal losses to optimize the engine performance. This model has been tested using the experimental data obtained from the General Motor GPU-3 Stirling engine prototype.

Chin-Hsiang et al [4] presented the numerical model for predicting thermodynamic cycle and thermal efficiency of a beta-type Stirling engine with rhombic-drive mechanism by taking into account the non-isothermal.

Karabulut et al [5] studied of bata-type Stirling engine by means of analysis with the instantaneous temperature distribution of working fluid.

Eid [6] showed the performance of a beta-configuration heat engine having a regenerative displacer with theoretical analysis of engine is based mainly on Schmidt theory to investigate the optimum dimensions. In the comparison between his proposed engine which has a regenerator has more power and more efficiency than that of the GPU-3 engine.

In Thailand, Kwankaomeng et al [7] also presented the design, manufacture and test of the rhombic drive Stirling engine. With unpressurized engine, the maximum torque was 0.625 N.m at 202 rpm while the maximum power was 21.7 W at 425 rpm.

Although many papers presented Stirling engine performance that meet demand of power for rice husking machine but there are seldom presenting a Stirling engine application on a rice milling machine. Therefore, this paper aims to present a design concept of using a beta-type Stirling engine driving a brown rice huller.

2. Theory and Design Methodology

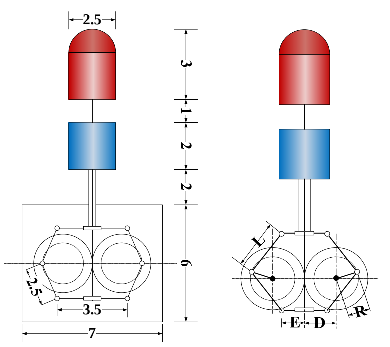
Stirling engine, first patented by Robert Stirling in 1816, is one of mechanical devices that convert heat from multi-fuels to be useful work. Stirling engine components are less than that of internal combustion engine therefore its simplicity makes this engine friendly usage and maintenance. The design aspect of a brown rice husking machine consists of Stirling engine as a prime mover coupling a rice milling machine. The Stirling engine prototype has rhombic drive machinery. The brown rice husking machine is considered using a commercial one.

2.1 Design of Stirling Engine Prototype

The prototype must be very compact and gives sufficient power to the huller. Rhombic machinery is suitable because it can be fit in a beta-type engine configuration, the displacer and power piston reciprocating in the same cylinder or in-line cylinders resulting in compact assembly.

The analysis and design considerations of rhombic-drive mechanism can be obtained major parameters from a compact engine design as given by General Motors for determining relative engine dimensions as illustrated in Fig.1 (a) [2].

The geometric parameters of a rhombic mechanism as depicted in Fig.1.(b) are determined in Eqs. (1) - (2) by the piston and displacer motions in which σ =2.5 and ρ =0.96 yield an exceptionally good cycle [2].



(a) (b)

Compact engine Geometric parameters

Fig.1 Compact engine dimensions.

where L is con rod length, 2E is yoke length, R is crank radius and D is gear pitch crank radius.

$$\sigma = \frac{L}{R} \tag{1}$$

$$\rho = \frac{D-E}{R} \tag{2}$$

2.2 A brown rice husking machine

Nowadays the rice husking machine technology has developed vastly in Thailand. Many small-scale rice huskers are produced commercially as home appliances. Especially, the rice husker can be driven by a low power motor and has various sizes for selection. Some of commercial products from Min Sen Machinery CO., LTD.[2] are shown in Table 1.

Table. 1 show a rice husk machine

Detail feature	Model			
	MS 33 BM	MS 50 BM	MS 100 BM	MS 150 RM
Producing characteristic	Brown rice	Brown rice	Brown rice	Brown &white rice
Motor power (Hp)	1/3	1/2	1	1.5
Motor speed(RPM)	1,440	1,440	1,440	1,440
Electric voltage	220	220	220	220
Transmission system	Belt	Belt	Belt	Belt
Husking rollers	Rubber	Rubber	Rubber	Rubber
Roller diameters (mm)	101.6 x 44.45	101.6 x 40.64	101.6 x 40.64	101.6 x 40.64
Machine Dimension (WxLxH)	26 x 72 x 72	75 x 46 x 110	75 x 46 x 110	75 x 46 x 110
weight (kg)	30	70	96	96
Performance (kg/hr)	20	50 - 60	50 - 60	50 - 60

Because of low power consumed by a paddy husker such as 1/3 Hp or 250 W and 1/2 Hp or 375 W. Stirling engine can be employed as a driver in either form of mechanical or electrical power to the huller. Moreover, an interesting point is that rice husk could be supplied as a fuel to the engine yielding free expense or payless machine.

2.3 A Stirling engine- rice husker concept

A midget brown rice husking machine is an attractive device to produce optimum amount of rice for daily meals providing fresh and maintaining full of nutritious value in brown rice that is conveniently processed just a short in time before cooking. The design concept of using a Stirling engine as a driving machine of a rice huller is depicted in Fig.2. The maximum power is focused on 2 Hp according to power requirement of commercial huller. When the Stirling engine is heated by rice husk combustion in the burner, the engine power is transmitted to the huller while rice shells as residues were handling to the burner simultaneously.

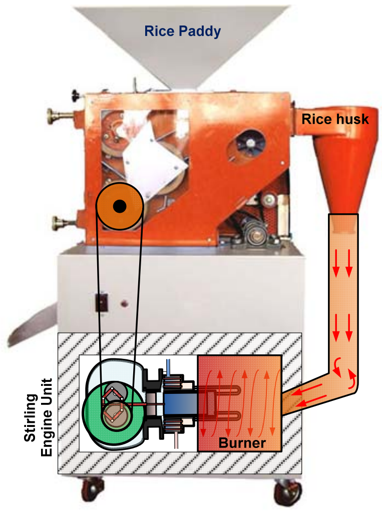


Fig.2 A Stirling-rice husker

3. Prototype

3.1 Engine Components

Stirling engine assembly is illustrated in Fig.3. The prototype components are disassembled as presented in Fig. 4.

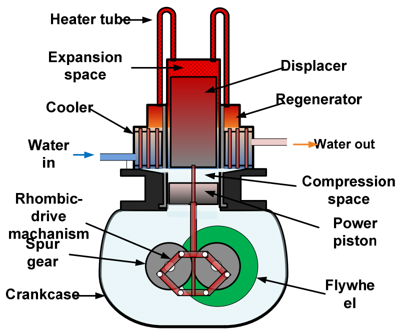


Fig.3 The schematic of prototype

Engine parts consist of drive machinery containing a pair of gear and rhombic assembly, reciprocating parts comprising of the displacer and the power piston and their cylinders, the heat exchanging parts including a fired tube heater, regenerator, and cooler. Power is transmitted by engine shaft coupling flywheel and pulley.

Fig. 4 Prototype assemblies

3.2 Engine Specifications

The specifications of engine prototype are listed in Table 2.

Table. 2 Design specifications of rhombic-drive Stirling engine prototype

Engine type	Beta
Swept volume	113 cc
Stroke	40 mm
Working piston cylinder diameter	60 mm
Displacer cylinder diameter	60 mm
Working piston diameter	59 mm
Displacer diameter	59 mm
Piston rod diameter/Length	12/77 mm
Displacer rod/Length	6/184 mm
Gear diameter	75 mm
Phase angle	60º
Hot / Cold space temperature	940K/ 305K
Cooling fluid	Water
Fuel	LPG
Torque at 328 rpm	1.32 Nm
Power at 651 rpm	67 W

4. Experimental Set Up

Before coupling the Stirling engine prototype with a rice husking machine, the engine characteristics must be evaluated and proved of concept device. The prototype must be initiated by run in. Since Stirling cycle engine is a reversible engine. Accordingly the prototype is first operated as heat pump for preliminary test on its ability by motor driving and then operated as a heat engine by heat from burner.

In the proof of concept device, the laboratory tests of the engine performance were conducted by using LPG as fuel for precisely and steady heat supply. Engine and equipment used in the experiment are exhibited in Fig.5. Gas burner is equipped with a LPG tank. Pressure regulator and an adjustment valve are used to control fuel delivering to power the engine. Gas consumption is measured by gas flow meter model ST75V. The inlet and outlet temperature of cooling water are detected by J-type thermocouples. The insulation block is installed for heat loss prevention of burner the engine's head surface temperature is measured by K-type thermocouples. Engine speed is detected by a photo tachometer DIGICON DT-250TP for rotational revolution observation.

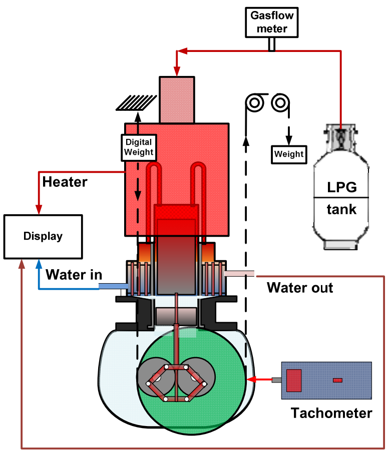


Fig.5 Schematic diagram of engine test set up

A rope-brake dynamometer is used to measure the engine torque. The 11cm diameter pulley is used as a brake drum. Loading weight is applied on the opposite rotational direction of flywheel. The braking load is measured by the loading weight as pictured in Fig.6.

The engine torque is calculated from Eq.(3),

$$T = (w_1 - w_2)R \qquad (3)$$

where w_1 and w_2 are the spring balance readings, and R is brake drum radius.

The actual engine power can be calculated from Eq.(4),

$$P = 2\pi TN / 60 \qquad (4)$$

where N is engine speed (rpm).

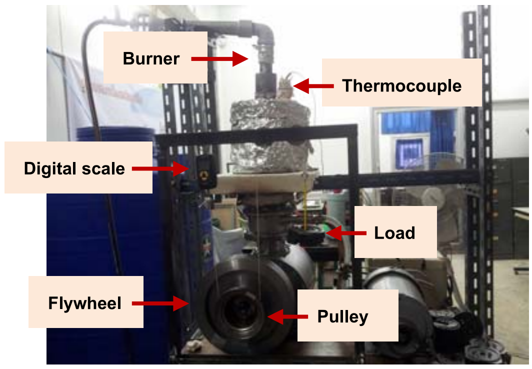


Fig.6 Engine test set up

5 Preliminary Tests and Results

The fuel consumption or LPG flow rate was set up at 0.5 kg/hr all preliminary testing. Air is used as a working gas was initially charged at pressure range of 2 - 7 bar. The water at room temperature was cooled the engine.

5.1 Starting Condition

The prototype was observed the operating condition. After of heat was supplied to the engine, it can be operated for few minutes in transient period and approached steady speed and heater temperature about 650 rpm and 400 °C, respectively, as presented in Fig 7. Because of heat gaining during pre-heat, the starting revolution was drastically increased.

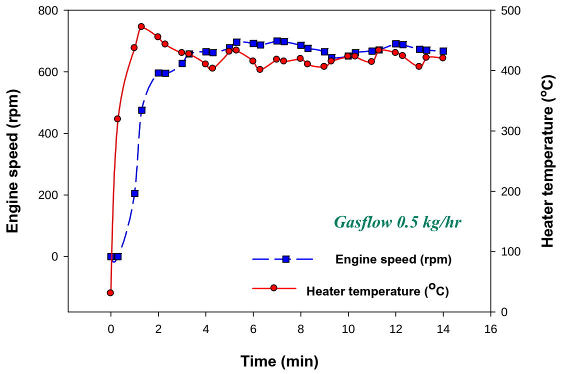


Fig. 7 The relationship between engine speed and heater temperature with time during starting

5.2 Engine torque

The relationship between engine torque and speed at different air charging pressure are illustrated in Fig. 8 and 9.

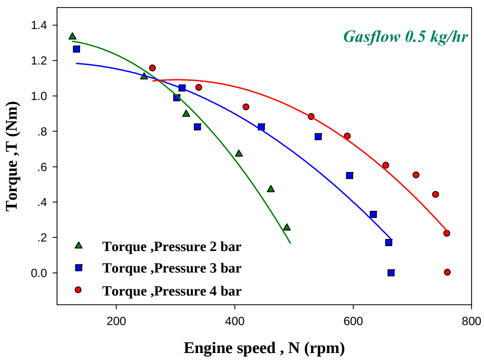


Fig. 8 The variation of engine torque and speed at different initial air pressure charge of 2-4 bar

As the air pressure increases, torque-speed curves in Fig. 8 and 9 shifts towards the higher speed range. When engine was pressurized at higher pressure, the maximum engine speed was greater. Torque was enhanced when the engine speed was reduced. At any specified pressure, torque increases with speed, reaches the maximum, and then decreases with the increasing speed. Figure 9 shows that the maximum torque was produced approximately 1.3 Nm with engine speed of 350 rpm when the engine was pressurized by air at 7 bar.

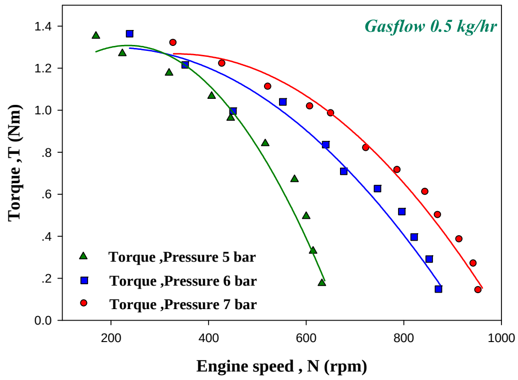


Fig. 9 The variation of engine torque and speed at different initial air pressure charge of 5-7 bar

The variations of engine power with speed at different air filling pressure are plotted in Fig.10 and 11. Figure 10 shows the power-speed curves at air pressure of 2, 3, and 4 bar while Fig.10 shows that at air pressure of 5, 6, and 7 bar.

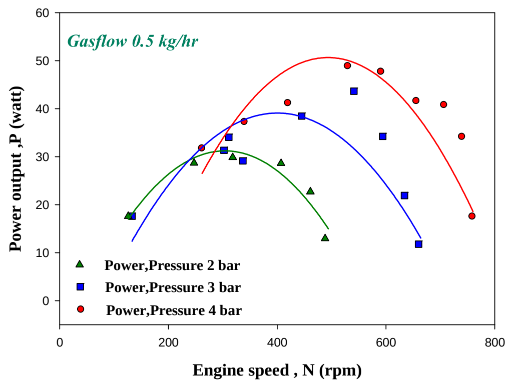


Fig. 10 Variation of brake power with speed at different initial air pressure charge of 2-3 bar

As the pressure increases, the peak of curve in Fig. 10 and 11 shifts towards the higher speed. Consequently, a larger power is produced at the wider speed ranges at higher pressure of pressurized air. The greater power produced the higher pressure charge requires. At any speed, the engine power increases with increasing pressure. At any specified pressure, power increases with speed, reaches the maximum, and then decreases with the increasing speed. The maximum power was 67 W at 650 rpm engine speed when the engine was charged at 7 bar.

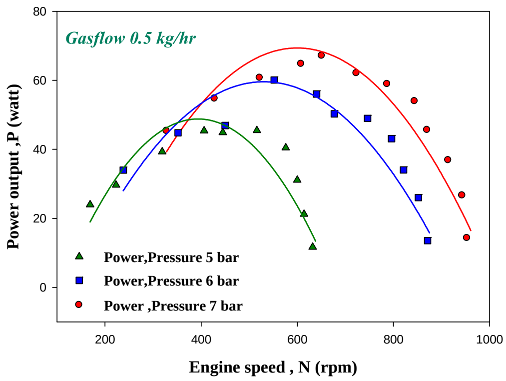


Fig. 11 Variation of brake power with speed at different initial air pressure charge of 5-7 bar

6. Conclusion and Discussion

The design concept of a Stirling engine-brown rice husker is focused on a small scale power of a rice husker as home appliance. However, the power requirement for some midget and commercial hullers is as low as 250 W. Therefore the prototype was designed providing the maximum power of 2 Hp, is sufficient and satisfactory.

The prototype has swept volume of 113 cc. A beta-type and rhombic drive is considered because of compact and robust. The prototype was preliminary investigation on engine performance at low pressure and using air as the working gas. For the proof of concept device, engine was heated by LPG burner as laboratory test. All preliminary tests were conducted with LPG consumption of 0.5 kg/hr and pressure range of 2-7 bar of air charge. The preliminary results revealed that the prototype started operation in a minute with starting revolution of 205 rpm at 437 °C heater surface temperature. Engine with 7 bar air pressurization, the maximum power and torque produced were 67 W at 651 rpm and 1.32 Nm at 328 rpm, respectively. The engine power is lower than that of the proposing because the prototype was preliminary tested at lower pressure than that of the designed pressure. However, the promising power obtained is satisfactory at low pressure. The engine performance investigation, hence, was continuing performed. The optimum power can be achieved by pressurization at high pressure level and using helium or nitrogen as the working gas for future development. After prototype was proved that can be transmitted sufficient power, the engine is then coupled with a brown rice husker.

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