Design of alpha type stirling machine biomass-based innovation design with the capacity of 100 watt

D Satria, S Susilo, R Lusiani and Y Hermawan
Mechanical Engineering Department, Universitas Sultan Ageng Tirtayasa, Indonesia

Abstract. Stirling machine has the advantage that it can utilize all kind of fuel, so that it is suitable for biomass utilization. In this study the analysis of best design of stirling machine different from previous study was carried out, which is design innovation on alpha type stirling machine by making phase angle become 180°, with the aims of lowering the gravitational force when cool cylinder is compressed, because the existing phase angle used is (90°) has the disadvantage of cool cylinder which is perpendicular, so that the compression is against gravitational force. The designing method was conducted by using Quality Function Deployment. The result of this study was to obtain the best variance of shape and machine stirling design dimension, which is variance 5, biomass stove- pulley and belt- was directly used. Variance 5 is chosen because it was the most suitable with the designed specification. Biomass stove is chosen as heat source, because the fuel used is classified as alternative fuel. Pulley and belt were chosen as mechanism of work transmission, because it has less noise compare to sprocket and chain. Its output work was directly chosen because its construction is simpler and the energy used is more optimal.

1. Introduction

The energy source is depleting as the demand of energy increase. This phenomenon occur because energy source depends on fossil fuel in which this scarcity of fossil fuel is because the amount is limited and it is nonrenewable [1][2]. One of the attempts to fulfill the increasing demand is by using alternative energy source as fossil fuel replacement, which is easily found and renewable energy source. One of recommended application for utilizing alternative energy source is by using external combustion engine because it has advantage, it can utilize all kind of fuel. Stirling machine is a an external combustion engine machine which can be used energy or heat from various energy source. This study is about stirling machine design which has been previously conducted by several authors [3 – 10].

This study is a development of previous study, in which this study stirling machine use alternative energy of biomass to produce power or electricity, as one of the solutions for energy security because biomass is an abundant alternative energy source, easily obtained and weather independent. In addition, in this study design innovation of alpha type stirling machine by making phase angle into 180°, with the aim to reduce gravitational force when cool cylinder is compressed, because the existing phase angle used (90°) has disadvantage, the cool cylinder is perpendicular makes the compression against gravitational force.
2. Methodology
The method in designing the alpha type stirling machine which is biomass based design with capacity of 100 watt is by using Quality Function Deployment (QFD) method [11, 12], consist of Design Requirement and Objective (DRO) collecting steps, House of Quality formulation step, and analysis and implementation step. Based on House of Quality, designed stirling machine specification was obtained. The next step is the determination of level function, function morphology and the best variant.

3. Result and Discussion
The first step in designing innovation design stirling machine is implementing Quality Function Deployment (QFD), consist of three types, the first step is planning and preparation step, those three steps are: Design Requirement and Objective (DRO) step, House of Quality formulation step, and analysis and implementation step. DRO is used as guidance to design alpha type stirling machine of innovation design. Initial step of designing is started from information collecting. The next is designing limitation determination which is described in one list supporting the design. From those information it was determined the items shown in limitations or requirements as follow: the first is absolute requirement (Demand), which is a requirement has to be fulfilled in any condition. If the requirement is not fulfilled the design will be failed. The second is hoped requirement W (Wishes), which is the requirement which is optionally fulfilled. If this requirement is not fulfilled there will no problem and has insignificant effect toward the design.

| Table 1. Design requirement and objective | Demand = D | Wishes = W |
|------------------------------------------|------------|------------|
| **Functional**                           |            |            |
| Machine can generate big power           | D          |            |
| Machine is easily operated               | D          |            |
| Machine has low noise                   |            | W          |
| **Operation**                            |            |            |
| Machine can be used for 7 hours per day  | D          |            |
| Using alternative energy source          | D          |            |
| There is a cooling system in machine     | D          |            |
| Can bear the overall load                | D          |            |
| Machine size is not too big              |            | W          |
| Is not easily broken by accident         | D          |            |
| Machine is easily moved                  | W          |            |
| **Safety**                               |            |            |
| Machine is safe for operator             | D          |            |
| Machine is environmentally friendly      | W          |            |
| Machine is easily manufactured           | D          |            |
| **Production**                           |            |            |
| Machine price is considerably cheap      | W          |            |
| Machine component is easily found in market | D        |            |
| **Installation**                         |            |            |
| Machine is easily to be ensemble         | W          |            |
| **Maintenance**                          |            |            |
| Machine is easily maintained             | D          |            |

The next step is requirement list the items which become the whishes is prioritized accordingly. Making priority by the method of comparing all the wishes, and make the scale 1 if the wishes is more prioritized and 0 if it is not prioritized. The priority scale of the wishes is tabled as follow (Table 2).
### Table 2. Priority scale

| Requirement                          | Correlation matrix | Total | Rank |
|--------------------------------------|--------------------|-------|------|
| Machine is easily moved              | 1 0 0 0            | 1     | 4    |
| Machine is easily to be re ensemble  | 0 1 0 1            | 2     | 3    |
| Machine has low noise                | 1 0 0 0            | 1     | 4    |
| Machine is environmentally friendly  | 1 1 1 1            | 5     | 1    |
| Machine price is considerably cheap  | 1 1 0 0            | 1     | 4    |
| Machine size is not too big          | 1 0 0 0            | 2     | 3    |

Analysis and implementation of House of Quality, that designated stirling machine has advantage compare to the other stirling machines. Those advantages are: the first is that it can be use alternative energy as it energy source, in which this machine will use energy source from biomass, such as dry wood, rice husk, and so on. As fuel to heat the cylinder the heat is come from biomass stove. The second is there is a cooling system in machine, in which the machine will be equipped with cooling box which will be fulfilled with cooling water. The water is used as cooling the cool cylinder of stirling machine. It is hoped that the temperature difference between the hot cylinder and the cool cylinder will be high. In addition, the designated stirling machine will have innovations in its design. Stirling machine type is actually an alpha type stirling machine, but between a hot cylinder with a cool cylinder made into an angle of 180° or parallel to each other. In which, the design will serve to minimize the gravitational force on the piston during the compression stroke.

Therefore specifications can be made from the stirling machine to be designed, based on an analysis of Quality Function Deployment (QFD), as follows: capacity = 100 watts, rotational speed = 600 rpm, strength = 5 KN, dimensions = 1 m², mass = 100 kg, noise = maximum 70 dB, price = maximum is 5 million rupiah.

As for determining the level function, in the design of this stirling machine, there are two level functions. The first level function, the input is in the form of thermal energy. The thermal energy makes the gas in the hot cylinder of the expanded stirling machine (function 1.0). Then the gas in the cool cylinder of the stirling machine is also compressed (function 2.0). This repetitive condition makes the shaft rotate (function 3.0), so the output is kinetic energy.

![First level function](image)

**Figure 1.** First level function

The second level function of the expanded gas is the change in pressure in the cylinder (function 1.1). The pressure presses the piston (function 1.2) which then produces torque on the shaft.
Figure 2. Second level function of expansion

The second level function of compressed gas is the change in pressure in the cylinder (function 2.1). The pressure pulls the piston (function 2.2) which then produces torque on the shaft.

Figure 3. Third level function of compression

The second function level of the rotating shaft is the presence of torque on the shaft (function 3.1) which then produces a rotating speed on the shaft (2.2).

Figure 4. Second level function of rotating shaft

After determining the level function, the concepts are made based on the level functions that have been described above. The concept is described in the morphology table of the function. The determination of the best variant step is the step of describing the variants that might be applied to this stirling machine from the function variants, shape variants, to physical variants. The next step is to make a table so that the best variant can be chosen by considering the advantages and disadvantages of several variants. These variants are taken from existing stirling machine and from previous studies that about the design of the stirling machine. In the design of this stirling machine, there are several components having variants that have advantages and disadvantages, it will describe several component variants which is used as well as several formed variants.
Table 3. Function morphology

| Function     | Concept          | Concept          |
|--------------|------------------|------------------|
| 1.0          | Pressure change  | Temperature      |
| Expansion Gas| 1.1              | Up               |
|              | 1.2              | Down             |
|              | Pressing piston  | Axial direction  |
|              | 1.1              | Radial direction |
|              | Temperature      | Combination of   |
|              | Temperature      | axial and radial |
| 2.0          | Pressure change  | Down             |
| Compression  | 2.1              | Axial direction  |
| Gas          | Pulls the piston | Radial direction |
|              | 3.1              | Rotating shaft   |
| 3.0          | Torsi            | Clockwise        |
| Rotating shaft| 3.2              | Counter clock wise|
|              | Rotating speed   |                  |

Table 4. Function variant

| No | Function Variant | A               | B               |
|----|------------------|-----------------|-----------------|
| 1  | Beat source      | Kerosene stove  | Biomass stove   |
| 2  | Power transmission| Pulley and Belt| Sprocket and chain|
| 3  | Output Power     | Directly used   | Stored in battery|

From the function variant table, there are several variants. In the design of the stirling machine in one finished device. The variants obtained are (Table 5):

Table 5. Variant of alpha stirling machine design innovation

| No | Variant | Note                                      |
|----|---------|-------------------------------------------|
| 1  | (1A-2A-3A) | Kerosene stove – Pulley and Belt – Directly used |
| 2  | (1A-2A-3B) | Kerosene stove – Pulley and Belt – Stored in battery |
| 3  | (1A-2B-3A) | Kerosene stove – Sprocket and Chain – Directly used |
| 4  | (1A-2B-3B) | Kerosene stove – Sprocket and chain – Stored in battery |
| 5  | (1B-2A-3A) | Biomass stove – Pulley and Belt – Directly used |
| 6  | (1B-2B-3B) | Biomass stove – Sprocket and chain – Stored in battery |
| 7  | (1B-2B-3A) | Biomass stove – Sprocket and chain – Directly used |
| 8  | (1B-2A-3B) | Biomass stove – Pulley and Belt – Stored in battery |

After many variants are obtained, the variants are selected to be the best variant according to the design requirements specifications.

Variant 1 was not selected because it uses a kerosene stove heater. This makes fuel scarce. Variant 2 was not selected because it uses kerosene stove and the output power is stored in the battery. This makes
fuel scarce, its construction is less simple, and the energy stored in the battery is less than optimal when used. Variant 3 was not chosen because it uses kerosene stove heater and the power transfer uses a sprocket and chains. This makes fuel scarce, less safety, and noisier when the engine is operating. Variant 4 was not selected because it uses kerosene stove heater, the power transfer uses a sprocket and chains and the output power is stored in the battery. This makes fuel scarce, less than optimal energy when used, less safety, and noisier when the engine is operating. Variant 5 was chosen because it is most appropriate for the specifications designed. Biomass stove was chosen as a heating source, because the fuel used is included as an alternative fuel. Pulleys and belts were chosen as a power transmission mechanism, because they are smoother than the sprocket and chains. The output power directly used is chosen because the construction is simpler and the energy used is more optimal.

Variant 6 was not chosen because the power transfer uses a sprocket and chains, and the output power is stored in the battery. This makes the machine become more machine during operation, less safety, less simple construction, and less than optimal energy when used. Variant 7 was not chosen because the power transfer uses a sprocket and chains. This makes the engine noisier and less safety when operating. Variant 8 was not chosen because the output power is stored in the battery. This makes construction less simple and energy becomes less optimal when used.

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