An Experimental Study of a Reciprocating Expansion Air Machine for Low Power Output of Wind Energy Application in THAILAND

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Abstract. The objective of this paper is to present an experimental study of a reciprocating expansion air machine (REAM) for low power output of wind energy application in THAILAND. REAM transforms the power from compressed air to the mechanical power, which is created from machine. REAM is not like the conventional machine, which use the fuel fossil for internal combustion, therefore, it don’t generate air pollution that is the main problem in environment. REAM prototype is designed with the local contents in THAILAND, which consists of two cylinders that apply from cylinder of general compressor operating alternatively with air pressurize. REAM operation is controlled by an electronics controller unit, which produces the on-off control signal for solenoid valves as the charging-discharging valves, in order to supply the air pressurize to machine. The experimental study will show the system design, investigate characteristic, and efficiency of REAM prototype. This application, REAM will design to use as prime mover coupling with electrical generator for renewable energy application.

Keywords: Reciprocating expansion air machine, REAM, Compressed air energy, Wind energy.

1. Introduction

The renewable energy sources are considered to be one of alternative choices for the power generation systems. THAILAND has potential for 14,300 MW. It composes of 1600 MW wind power, 700 MW micro-hydro, 7,000 MW of biomass power, and over 5,000 MW of solar electricity (reported by the Ministry of Energy, 2005). However, they are unreliable energy source because the power, when is needed, cannot produce all time. Thus, the appropriate technology is needed. In this work, wind energy potential of THAILAND is interested because it can provide electricity in area that not served by the conventional power grid but wind energy, especially in THAILAND, will changes both magnitude and direction all time resulting to the produced power by the conventional generator with a wind turbine fluctuates. Therefore, the energy storage as energy actuator is an alternative choice for solving this problem. There are many types of energy storage, including batteries, flywheels, ultracapacitors, superconducting magnetic energy storage, flow batteries, pumped hydroelectric energy storage (PHES), and compressed air energy storage (CAES). CAES, which are long service period, low cost of energy, low cost of maintenance and operation and high power efficiency [2], have been demonstrated as economically solutions for utility-scale energy storage on the hours timescale. This system have successfully implemented in Hantorf in Germany, McIntosh in Alabama, Norton in Ohio , a municipality in Iowa, in Japan and under construction in Israel [3]. The CAES produces power by storing energy in the form of compressed air in an underground cavern. An air is compressed during off-peak periods, and is used on demand during the peak periods to generate power with
a turbo-generator/gas turbine system. However, this system seems to be disadvantage as it is quite large power facility and is needed large underground carven, while having a limitation in terms of site installation.

In this paper, the low power output of wind energy applications based on CAES is proposed and shown in Fig.2. This system is a hybrid technology of energy storage and electrical power generation. The energy will transfer to the CAES system by using the air compressor, which produces high-pressure compressed air at ambient temperature, which stores in above ground pressure storage tank as a temporary storage. When we need its, It will be supplied to drive REAM that the shaft coupling with generator in order to generated the electric power. Then, electrical power is conversed by grid connected inverter, which is synchronized at distribution line. In this paper will focus in dash line box for doing experiment of REAM to obtain the characteristic and performance, which can helpful in system designing. The paper is organized as following : 1.Introduction, 2.REAM Development, 3.Experiment and result, 4.Conclusion, 5. Acknowledgement and 6.Reference.

Fig. 1: The proposed system of low power output of wind energy applications base on CAES

2. REAM Development

2.1. REAM theory

REAM is mechanical prime mover of electrical generator powered by the compressed air in storage tank. Then, the potential energy from vessel will be transformed to mechanical energy on the shaft of REAM by opening the solenoid valve that control two cylinder operating alternately. Therefore, it has two

Fig. 2: P-V diagram of air expansion engine operation

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thermodynamic cycles that the same. The full cycle is completed within one revolution for a two-stoke cycle. The engine composes of three steps: charging, discharging or expansion and exhaust, which displays the P-V diagram in Fig.2.

- **Charging:** The charging process is state (1) to (2) that is considered as isothermal process. When the charging valve is opened and discharging valve is closed, the compressed air from vessel is discharged into the cylinder resulting to the piston is slowly retreated within the cylinder from (1) to (2). The volume within the cylinder of which is filled with the compressed air is increased from \( V_1 \) to \( V_2 \) and the pressure within cylinder is expanded from \( P_1 \) to \( P_2 \). As the piston advances at (2) to (3), the charging is continued at a constant pressure (the vessel volume is much larger than the cylinder volume) and the volume is changed from \( V_2 \) to \( V_3 \). This is expansion stroke, (1)-(2)-(3), which produces the work of the cycle.

- **Discharging:** The discharging process is state (3) to (4) that is considered as adiabatic process. When the charging valve is closed and discharging valve is opened, the compressed air from cylinder is discharged into the ambient according to the law \( PV^\gamma = \text{constant} \). The piston stroke is returned resulting to the volume within the cylinder is reduced from \( V_3 \) to \( V_4 \) and the pressure within cylinder is decreased from \( P_2 \) to \( P_1 \).

- **Exhaust:** The return stroke of the piston exhausts the air from the cylinder to ambient, at constant pressure, according to the process (4) to (1). The piston stroke is readily returned resulting to the volume within the cylinder is reduced from \( V_4 \) to starting state at \( V_1 \). However, the work of the air expansion engine cycle can be continuously varied by adapting the timing of the charging and discharging valve closure.

The enclosed area (1)-(2)-(3)-(4)-(1) measures the net work done upon the piston, during the air expansion engine cycle, by the compressed air. The total work done by the compressed air during the processes of the cycle, this net work amounts to

\[
\text{Total work} (W_{\text{net}}) = W_{\text{charging}} - W_{\text{discharging}} - W_{\text{exhaust}}
\]

or

\[
W_{\text{net}} = \text{Isothermal work} - \text{Adiabatic work} - \text{Exhaust work}
\]

\[
W_{\text{net}} = \left( \int_{V_1}^{V_2} PdV + \int_{V_2}^{V_3} PdV \right) - \left( \int_{V_1}^{V_4} PdV \right)
\]

\[
W_{\text{net}} = \left[ PV_1 \ln \frac{P_2}{P_1} \right] + \left[ PV_3 - P_2 V_2 \right] + \frac{(\gamma - 2)}{\gamma - 1} \left( P_3 V_3 - P_4 V_4 \right)
\]

(1)

where \( P_1 \) and \( P_2 \) is pressure in initial and final state, respectively. \( V \) is cylinder volume and \( \gamma \) is specific heat. Equation (1), this is work for 1 stroke, therefore, the total work of the air expansion engine for 1 cycle is 2 times.

### 2.2. REAM implementation

![REAM configuration](image-url)
REAM is designed with the local contents. It consists of two cylinders with bore 8 cm and stroke 10 cm thus, the cross section area is 50.27 cm$^2$ and cylinder volume is 502.65 cm$^3$. They install like a boxer engine that operates alternatively. Show REAM configuration in Fig.3. REAM power depends on expansion pressure operation corresponding to solenoid valve controlling. The REAM operation is controlled compressed air supply by on-off solenoid valves, which are controlled by an electronics controller unit that like an ECU box of the general car engine. For power investigation, REAM ability to produce mechanical power is

$$P_E = \frac{T \cdot 2\pi N}{60 \cdot 1,000} \text{ kW.}$$

(2)

The REAM efficiency is

$$\eta = \frac{P_E}{W_{net} \cdot N} \cdot 100\%$$

(3)

where $P_E$ is REAM power, $T$ is REAM torque, $N$ is mechanical speed of REAM, $P$ is operation pressure, $D$ is cylinder diameter and $\eta$ is REAM efficiency. The command in control is produced from checking cylinder number and position of piston by induction proximity sensors. Then, ECU will evaluate and produce pulse on-off signal to control solenoid valve. The pulses signal of position checking are 240 pulses for half cycle resulting to engine turn 180$^\circ$ that the piston move 10 cm. Thus, full cycle is 480 pulses, engine turn 360$^\circ$. The relation of amount of pulse and turn angle is

$$\text{Turn angle} = \text{amount of pulses} \times \frac{180^\circ}{240}$$

(4)

Distance of piston move is

$$\text{Position Distance} = \text{amount of pulses} \times \frac{10}{240}$$

(5)

Therefore, 1 pulse is 0.75$^\circ$ and piston moves 1/24 cm. These data will use to compute the period time to control solenoid valve. The system block diagram is shown in Fig.5.

![Fig. 5: Control system configuration](image)

3. Experiment and Result

The experiment is set up in Fig. 3. The input signal, which use for executing command to control is shown in Fig.6(a). The signal for driving solenoid valve is presented in Fig.6(b) that the solenoid valve 1 and 3 will operate together in first half cycle then valve 2 and 4 will operate in second half cycle.
Fig. 7(a),(b) and (c) present the characteristic of REAM that the speed, mechanical power, air power and air consumption increase following the operating pressure increase, while torque starting increases at period 5 to 6.5 bar then decreases at duration 7 to 8 bar. The REAM efficiency in Fig.7(d) will decrease following the operating pressure increase because of thermodynamic loss in expansion that the temperature between input and output in operation is much difference. Moreover, mechanical loss adds, when the REAM speed boosts.

4. Conclusion

This experimental study is currently in progress of REAM for low power output of wind energy application in THAILAND in order to determine the REAM characteristic. The experiment results are satisfied with performance and efficiency that can be used for prototype to study. It is feasibility for real implementation as prime mover of electrical generator. However, REAM is absolutely no fuel required and
no combustion resulting in no generate heat and air pollution. Therefore, it is friendly environment and solves the energy crisis in present. This study can be helpful in system designing for the renewable energy applications, which can use the local available contents resulting to low initial cost. The proposed system can apply to uninterruptible power supply, peak shaving for the energy building management, pneumatic application and air power vehicle (APV).

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6. References