Development of Miniature Compressed Air Storage System Using Solenoid Valves for Dynamic Pneumatic Actuator

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***Abstract*—Currently, there are many research that involved pneumatic device on vehicles. There are some applications using compressed air storage system to produce vehicle power. However, there are several constraints in producing compressed air for outdoor purpose, since most of the compressors are in large size which will cause limited working space. Also, most of the compressors are not portable and hand-carrying size. This paper objective is to investigate the parameters of a miniature air compressor during the reciprocation process and to analyze the compressed air pressure of piston type double-acting cylinder for the miniature air compressor. The piston rod is connected to connecting rod for mechanical movement, which the movement of the rod will convert kinetic energy to the piston and generate compressed air inside the storage tank. The system design allows the air into the tank to increase via reciprocating cylinder. Number of strokes produced is investigated. Subsequently, pressurized air inside the tank can be used to generate kinetic power to the pneumatic actuator. The force generated from the mechanism is then measured. Synchronization of 5/3 Ways Directional Control Valves (DCV) is the key of the system to ensure the flow of compressed air well-kept in the storage tank. The pressurized air inside the tank transfers the power into kinetic movement via reciprocating piston and able to generate 200kPa of compressed air.**

***Index Terms*—Air Storage; Compressed Air; Pneumatic System.**

I. INTRODUCTION

To date, there are various types of compressors used in the pneumatic system. These compressors generated high compressed air pressure as energy storage. Recent years, it is found that the compressed air energy is a better choice for power output as it is clean, has high energy density and can drive lightweight air cylinders and air motors [1]. Lei Tian et al. [1] designed, constructed and evaluated a miniature free-piston engine and combined with a compressor with homogeneous charge compression ignition (HCCI), to produce a small internal combustion air compressor.

The compressors usually apply in the pneumatic system on a large scale and build with medium cost especially in industries and power plants. Shouhei Kumakura and Ikuo Mizuuchi stated that the large scale of the air compressors has limited the working space [2] for the worker to move around, large and heavy. Currently, there is less study on the portable and hand-carrying size of miniature compressed air storage system. Hence, the application of the miniature compressed air storage system is investigating and analyzing during the reciprocating process by using a piston type of double-acting cylinder as a compressor.

II. LITERATURE REVIEW

From previous studies, reciprocating compressors are widely used in stationary or portable service [3] compared to another type of compressors. The main advantages of reciprocating compressors are having a very high-pressure ratio with comparatively low mass flow rates compared to rotary and dynamic compressors. Reciprocating compressors can be divided by single-acting or double-acting compressors. This means the reciprocating compressors can develop pressure on one side or both sides of the piston [4,5]. While, double-acting compressor is selected as it can produce a compressed air in two-ways, extending and retracting process. Reciprocating compressors are always applied for portable systems on construction sites, smaller production lines with demands of high-pressure levels [6,7]. The previous development of miniature air compressor faced difficulties in handling the robots due to an insufficient pressure of output for producing dynamic motions like jumping [2].

Instead of using traditional fuels, there is an alternative for vehicle by using natural gas and diesel as energy power source. For example, Elgin et al. [8] proposed and developed a self-refueling compressed natural gas vehicle due to its fewer emissions of carbon dioxide. Similarly, compressed air engines are proposed by few of the researchers which used piston type engines to compressed air as a power source to replace IC engines [9,10]. The study shows that the motorcycle with compressed air engine that uses compressed air as a power source in piston type engines can operate at maximum speed around 38.2km/hr and distance up to 5 km [9].

The pneumatic compressed air inside vehicles can greatly reduce the effect on energy saving, free from the environmental issue and the compressed air energy can be recycled. Therefore, compressed air system can be an option for power generated in order to reduce the load weight and cost of development which then could be expanded into focused-sector.

The experiment involved kinetic energy to reciprocate the pneumatic cylinder and deliver air through the tube to the tank. This repetition process capable of producing compressed air up to 200kPa.

III. EXPERIMENTAL DESIGN

The design of a miniature compressed air storage system involved extending and retracting process of the double-acting cylinder. The experimental apparatus involves a pneumatic circuit of the compressed air storage system is illustrated in Figure 1. Each process has a different flow of air supply and air exhaust. Figure 2 shows an extending process of the piston during the compressed air to storage tank whereas Figure 3 shows a retracting process of the piston.

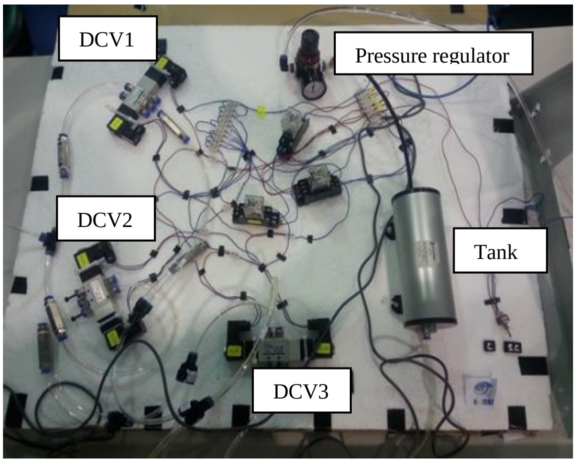

Figure 1: Pneumatic circuit of the compressed air storage system

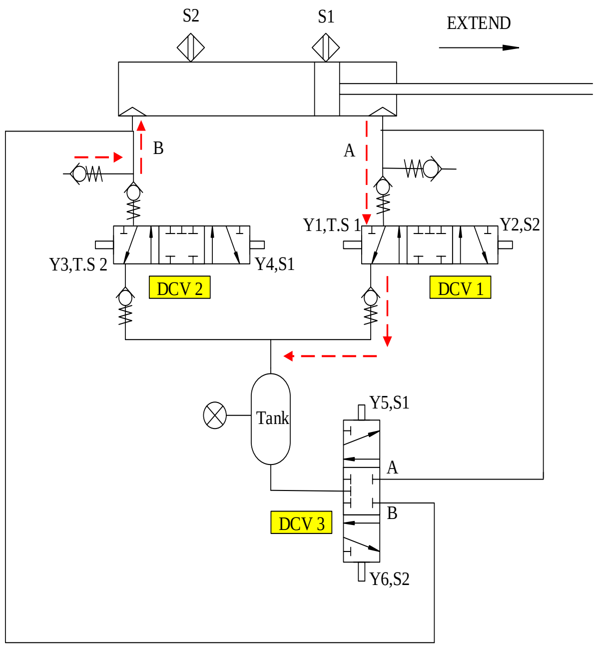

Figure 2: Extending piston of the miniature compressed air storage system

The piston rod is connected to connecting rod and will convert kinetic energy to the piston and generate compressed air inside the storage tank. Synchronization of 5/3 Ways DCV is the key of the system to ensure the flow of compressed air well-kept in the storage tank.

Both circuits operate under a solenoid circuit which is designed to allow electric current flows into the system and activate the 5/3 Ways DCV. The solenoid circuit is shown in Figure 4. The compressed air flows into the 5/3 Ways DCV which labeled as DCV1 and store inside the storage tank and DCV2 allow air from atmosphere flow through a check valve and into the upstream chamber of the piston. This is to prevent any vacuum chamber take places inside the piston.

In the process of retracting of the piston, the flows of compressed air are opposite to the extending of the piston, but both processes store the compressed air inside the storage tank. However, both processes need to operate under the solenoid circuit. The electric current flows into both ends of the DCV1 and DCV2 in order to activate the solenoids and switch position.

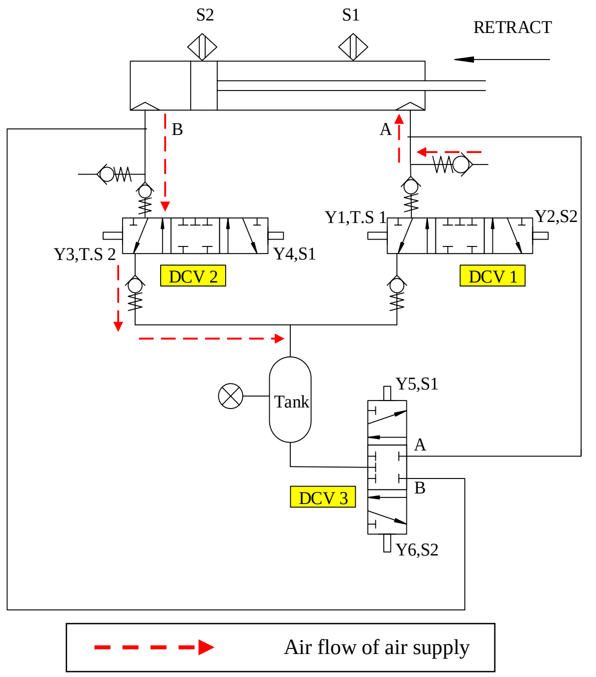

Figure 3: Retracting piston of the miniature compressed air storage system

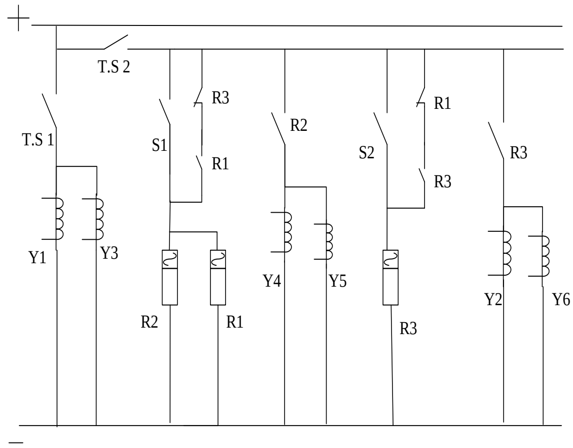

Figure 4: Solenoid circuit of miniature compressed air storage system

The solenoid circuit in Figure 4 is used to control the pneumatic miniature compressed air storage system. The solenoid circuit is operating with a toggle switch (TS), which the toggle switch has 2 modes, cycling mode (TS1) and stop cycling mode (TS2). TS1 is turning ON when the compressed air stored inside the storage tank and consequently the solenoids at the end of the 5/3 Ways DCV is activated. From solenoid circuit, relays that labeled as R1 and R2 are in normally-opened; however, the R3 is in normally-closed condition. The relays, R1 and R2 are used to control the function of the DCV 1, DCV 2 and DCV 3. Relays play an important role in determining the 5/3 ways DCV in activating or deactivating stage according to the solenoid design circuit.

Once the piston rod detects a switch sensor S2, it will trigger the solenoids at the end of the 5/3 ways DCV. R3 relay is in normally-opened whereas R1 and R2 are in normally-closed. This cycle will repeatedly keep on detecting sensor, S1 then S2 until the kinetic mode is stopped.

IV. Results and Discussion

Table 1 shows the number of strokes is increasing with the increased of generating the compressed air inside the storage tank. The compressed air has generated up to 100 kPa, 150 kPa, and 200 kPa. Also, the piston required to travel at least 35 strokes in able to generate 100 kPa. Continuously, to generate a 150 kPa compressed air, the extending and retracting of the piston should travel about 48 strokes. Compressed air at 200 kPa required 128 strokes of extending and retracting of the piston.

Table 1
Compressed air and the number of strokes (cycle) traveled by the piston

Compressed Air (kPa)	Number of strokes (cycle)
100	35
150	48
200	128

In this case, the intention is to generate force via pressurized air from kinetic energy via the reciprocating process of the pneumatic cylinder. As the compressed air kept increasing inside the storage tank, it is difficult to compress the piston in fully retract due to high pressure inside the system. Reciprocating process of pneumatic cylinder and the repeatable process able to generate up to 200 kPa however, a large force is needed to compress the high air pressure inside the upstream chamber of the piston.

Based on the experimental results obtained, the initial force exerted by the piston rod is affected by a range of pressurized air exhaust and the extending stroke length of the piston rod. Firstly, at the extending stroke length by the piston rod from the starting point to 10mm, the initial forces are found to be 42.2N, 56.0N, 71.6N, 84.0N, 95.2N, 108.3N, 119.2N, 132.1N according to the difference level of pressurized air exhaust from the storage tank respectively.

The pressure of more than 200 kPa is prepared via installing from high pressure compressed air. It shows that the higher the pressurized air, the larger the initial force exerted by the piston rod at the extending stroke length of 10mm. Thus, the shorter the extending stroke length of the piston rod, the lower the chance of energy lost to the surrounding. Figure 5 depicts the 10mm of the extending stroke length which indicated an increasing initial force exertion due to a high pressurized air is exhaust through the downstream chamber of the piston.

The plotted graph at various pressurized illustrates a curve shape, and the pattern is quite similar from every data collected. It shows an increment of the curve line and reaches its maximum point and decrease to the minimum peak. This curve shape mainly influenced by the friction force which takes place inside the miniature compressed air storage system. The friction fluctuates due to many circumstances like the temperature in the upstream and downstream chambers of the piston, humidity of the air, type of seal used in the system and others. From the beginning, the cylinder is in stable condition, which the friction force is higher in order to overcome the static friction force and cause the movement of the piston.

Consequently, when the intake pressure is large enough to overcome the static friction force and make the piston moving, the friction force will decrease as the value of sliding friction [14,15]. It indicates that for 300 kPa the experiment conducted in efficient condition with less ineffective uncontrollable factors which result in an increase in the performance of the design mechanism.

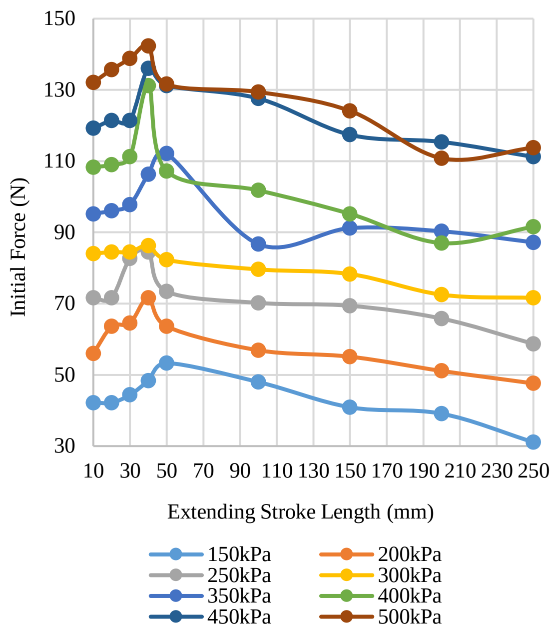

Figure 5: Extending piston stroke length (mm) versus Initial Force (N)

V. Conclusion

This paper presented the design and development of miniature compressed air storage system using a double acting cylinder to generate mechanical power from kinetic energy. The results obtained indicate the number of strokes traveled by the piston at first stage is increased as the volume of compressed air inside the storage tank is increased. Other result demonstrated that the extending of stroke length increased due to initial force exertion of a high pressurized air in the tank.

On the other hand, this miniature compressed air storage system can be used for outdoor and indoor activities and apply in a numerous area from small to medium scale size of the storage system. Its application can be an alternative to energy storage system in providing clean energy in future.

Acknowledgment

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