A Study of Gas Economizing Pneumatic Cylinder

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Abstract. The pneumatic cylinder is the most typical actuator in the pneumatic equipment, and its mechanism is so simple that it is often used to operate point to point driving without the feedback loop in various automatic machines. But, the energy efficiency of pneumatic system is very poor compared with electrical systems and hydraulic systems. So, it is very important to discuss the energy saving for the pneumatic cylinder systems. In this thesis, we proposed three methods to apply the reduction in the air consumed for pneumatic cylinder systems. An air charge accumulator is used to absorb the exhausted compressed air and a boost valve boosted the air to the higher pressure for used again. From the experiments, the direct used cylinder exhaust air may save about 40% of compressed air.

1. Introduction

In the “Kyoto conference (1997, 12)” which is known as the anti-global warming conference, they come up to a main target to decrease the outcome of CO$_2$ for 6% in 2010. From now on, the producing system and the saving energy of product will become a major lesson for the future business.

The pneumatic system has the benefit of low cost, lightweight, unpolluted, highly safe, easy to fix or repair and soft output. Based on these benefits, pneumatic system is one major technique to be highly used in semiconductor business and auto-producing system in the industry [1]. But the compressed air is totally different from the first energy or second energy. It is transferred from the air compressor in order to save the energy cost. In general, the electricity cost of compressed air is about 20% of all the electricity. So, it is very important to control the energy consumption of compressed air. The well-known company SMC and NORGREN has come up some ways of changing and modifying the total consumption of the air compressor system. Here are the four points of views. Stop: stop using air pressure. Eliminate: eliminate the leakage. Reduce: reduce the pressure, quantity and flow. Inspect: inspect and evaluate the flow and pressure management. In the consideration of reducing the energy cost, there is another way to reach this goal, which is recovering. In this article, we will try to discuss the exhaust energy and try to recover and reuse.

Pneumatic cylinder is always used in the linear transfer and compression of work pieces. As the diameter of cylinder is getting bigger and the stroke is getting longer, the air consumption is getting more and more obvious. Especially pneumatic system designers use the same air sources for cylinder intake and exhaust. So, when the cylinder reaches to the top, the inner pressure will rise to the same pressure as the air source. But when it comes to reverse action, we need to release the pressure inside and put in the air pressure from the other side to make the pistol to do the reverse action. By this way,
it really wastes lot of energy. Based on this kind of waste, there are so many research is about this and try to discuss lower this waste [2−4]. They apply the reducing pressure for the backward stoke for the cylinder or use accumulator to recover the exhaust air. In this article a new method is proposed. It’s using the air accumulator and boost valve to recover the compressed air.

2. Experimental system description
This article is using the air accumulator and the boost valve to recover the compressed air when the cylinder is exhausting the air. We will discuss three solutions about the recover effect. Figure 1 is known as the most general way, which uses the solenoid valves to control the cylinder to move forward or backward. The pressure reducing valve is setting up the pressure that controls the movement. Figure 2 is the way that we came up with and discussed most. The recover air is send back to the original pressure source. The air charge accumulator is used to hold up the compressed air when releasing. The 2/2-solenoid valve12 is used to decide whether give in the air from air source or release the stored pressure out. Because of the compressed air pressure that released is much lower than the air source, through the boost valve to increase the pressure and then send it back to the main accumulator in order to do the recover and save as much as energy we can. In Figure 3 we send the recover pressed air back to a air charge accumulator to do the recover avoiding to boost pressure to higher pressure in order to lower the lose. In Figure 4 we directly put an air-release hole into the recover way. The program logical controller used is FBs-40MC. All the experimental details can be gotten from computer by the communication. Besides we can evaluate the way and check also revaluate the system by its own design. The diameter of the experiment cylinder is Φ40mm and the stroke is 600mm. The 4/2 solenoid valve is MVSD-300-4E1 which has the efficient area 30mm². The boost valve is VBA1110-02. Also the ratio of pressure gain is 1:4. The diameter of the air charge accumulator is Φ100mm constructed by a cylinder, which is design to contain the air from 0 ሮ to 1.2 ሮ in order to compare the influence of the air charge accumulator volume. The pressure sensor is ISE-40-01-22, and the sensor pressure range is from 0.1 to 1.0 Mpa. Also has the output voltage from 1V to 5V.

3. Recover to the air source
Besides moving forward and backward of the cylinder, here are the few stages cooperated with the 2/2 solenoid valve.

1st → in-air forward: at this moment, the 4/2 solenoid valve and the 2/2 solenoid valve is magnified.
2nd → out-air forward: releasing the compressed air to the boost valve. At this moment, the 4/2 solenoid valves is magnified and the 2/2 solenoid valves 2 is magnified.
Figure 3. Recover to the air charge accumulator.

3rd in-air backward: the 4/2 solenoid valves is non-magnified and the 2/2 solenoid valve 1 is magnified.

4th out-air backward: releasing the compressed air to the boost valve. At this moment, the 4/2 solenoid valve is non-magnified and the 2/2 solenoid valve 2 is magnified.

By this kind of operation, we filled up the pressure to 8.1 kg/cm², and the pressure reducing valve is set to 5 kg/cm². Also set up the capacity of the air charge accumulator and then control the movement of the cylinder back and forth for 5 times. From the reference [4], we can imitate from the formula to reach the balance in just one second. Based on this, we can prepare more time to stabilize the pressure. So, we pause for 3 seconds between back and forth and record every single pressure and the time of one cycle. Repeat these steps for 10 times and calculate the average data. Furthermore compare the air consumption is based on the standard air condition and assumes the operating temperature is the same. The formation is shown as below [5]:

\[ Q_c = Q[(P_1 - P_2)/0.1013[(293.15/T)] (\text{cf ANR})] \]  

where:
- \( Q_c \) is the total air consumption (\text{cf ANR}),
- \( Q \) is the volume of the charge accumulator (\text{cf}),
- \( P_1 \) and \( P_2 \) are the initial and the final pressure (MPa),
- \( T \) is temperature (K).

Besides, in order to know the effect of recover compressed air to the velocity of the cylinder, so we record every single back and forth time to calculate the average speed.

\[ V_{avg} = \frac{S}{\Delta t} \]

where:
- \( V_{avg} \) is the average speed of back and forth (cm/sec),
- \( S \) is the move distance (cm) and here is 60 cm,
- \( \Delta t \) is the time cost of back and forth (sec).

Figure 5 is the compare figure of the air consumption. The used traditional circuit air consumption from figure 1 is about 54.13 (\text{cf ANR}). The used recover circuit (figure 2) air consumption is about 3 to 4% lower. From the result we have, we know that when the capacity is 0 has the best result. Its air cost is about 51.63 (\text{cf ANR}) that lower the air cost up to 4.6%. The main reason is because the gain pressure ratio of the boost valve is 1:4, and the initial pressure of the air source is 8.1 kg/cm². In order to reach this pressure, the air must be compressed. Also, the enter pressure must be much higher than. But the operating pressure of the cylinder is only 5 kg/cm² when the recover process is in action; the pressure has already gone low. The compressed air that can be recovered is not well, so the recover efficient is going down at the same time.

Figure 6 is the velocity change diagram of the cylinder goes back and forth. We can discover that if we use the circuit in pic2, the forward velocity and the backward velocity will increase. Before no recover the air, the velocity of the forward speed is 40.99 cm/sec. When the volume of the charge accumulator is 1.13, the forward velocity changes into 43.71 cm/sec which increases about 6.63%. The reason why we use this kind of recover system is because of the higher pressure is released on the
higher-pressure side and also it is easy to reach the goal of recycle. In other words, the traditional circuit doesn’t release the pressure from the higher end, but use the way valve to switch the tunnel. The original higher-pressure end goes to the release hole, and the lower pressure end goes to the pressure source. However it takes time to for the higher-pressure end to release the compressed air, this is the main reason that causes the increasing of the circuit velocity.

The recover to the air source is limited by the boost valve’s capability, so it lowers the efficient of recover. In order to prove this failure, we change the recover circuit as shown in figure 3. The operating way is still the same as in figure 2, which is to recycle air back to the air source, but the recover compressed air doesn’t goes back to the main air source. We use a recover accumulator to recover, and the recovered compressed air can be used to motivate some action that only needs lower pressure. Such as the backward motion of the cylinder…. The recycle air accumulator still uses formula 1 to compare the air consumption with conventional circuit. In figure 7 shows the air consumption difference between this method and the circuit that doesn’t cooperate with the recycle circuit. The total air consumption is the main air consumption of main accumulator minus of the recovered air.

\[ Qt = Qm - Qr \]  

(3)

\( Qt \) is the total air consumption (l [ANR]), and \( Qm \) is the air consumption in the main air accumulator (l[ANR]). \( Qr \) is the recovered air (l [ANR]). We can tell that the best recover efficient occurs when the capacity of the charge accumulator is 0 l. At this moment, the air recycle amount of

![Figure 5. Air consumption comparison chart for the recycling air to air source.](image1)

![Figure 6. Speed variation comparison chart for the recycling air to air source.](image2)

![Figure 7. Air consumption comparison chart for the recycling air to recover accumulator.](image3)

![Figure 8. Speed variation comparison chart for the recycling air to recover accumulator way.](image4)
the main store air tank is about 14.97 (l[ANR]). The total air cost is 41.85 (l[ANR]), and it is about 22.7% lower compares to the circuit that doesn’t cooperate with the recycle circuit. As the capacity of the air tank increases, the recycling amount of air decreases. The main reason is because of the boost valve still needs enough inner pressure, so the bigger air tank occurs a lower back pressure which directly reacts on the forward and the backward velocity. In figure 8, as the air tank capacity increases, the velocity of the pressure also increases. Before recycling, the forward velocity of the pressure tank is 40.99cm/sec. When the store air tank has the capacity as 1.13, the forward velocity is 58.25cm/sec. The velocity increases about 42.1%, and the reason is the same as before.

5. Direct recycling exhaust air to the recover accumulator

The recycle ways as mentioned before use the air first in the high-pressure side of cylinder, and then the left over compressed air is going to be exhausted by switching its own position. So we directly add the recycle circuit onto the exhaust circuit as shown in figure 4. When the cylinder move direction is switch by the solenoid valve, the compressed air in the high-pressure side is active by the air charge accumulator and the boost valve to send the air back to the recover accumulator. However by using this way will increase the backpressure. So we can decrease the backpressure by using the charge accumulator to save more time for the recycling. In figure 9 is the compare between this way and the circuit that doesn’t cooperate with recycles circuit. The best recycle efficient occurs when the capacity of the store tank is 0. At this moment the main air cost of the main store tank is 55.56 (l[ANR]), and the recycle air of the recycle store tank is 32.16 (l[ANR]). It is about 40.59% less than the circuit that doesn’t cooperate with the recycle circuit, which is the best recycle way of all. But as the capacity of the charge accumulator increases, the amount of recycle will decrease. However when the charge accumulator capacity is 1.131 still has the recycle amount about 34.13%, which is higher than the recycle way 3 and 4 we mentioned before. There is a big difference when observing the velocity of the cylinder goes back and forth. Figure 10 is the compare chart of the cylinder velocity when the capacity is different. We can easily find out that the reason of velocity decrease is totally different from the 2 ways of recycle we discussed. The main reason is because the compressed air can’t be released into the air when the direction valve has been active, it cause the hole system to create a back pressure and also effect the velocity of moving forward and backward. But as the capacity increases, it reduces the level of the velocity. When the charge accumulator capacity is 0, the forward velocity reaches 33.86cm/sec. It is about 17.4% slower compares to the forward velocity without cooperate with the recycle circuit. When the store tank capacity is 1.13, the forward velocity reaches 35.56cm/sec. The velocity is about 13.2% slower which has a 4.2% difference when the capacity is 0. However the air consumption has the difference around 6.46%, and the whole system reaches a good effect when the capacity is 0. Based on this result, if we hope to minimize the velocity effect, we could choose a bigger charge accumulator. Furthermore, if we hope to reach a better recycle efficient, then we have to reduce the capacity of the charge accumulator.

6. Conclusion

The air cylinder is the most typical actuator in the pneumatic systems. In order to change the direction before active, we need to release the air, which was in the higher pressure side of cylinder first, and then give the air in from the other side. This kind of operation caused waste. In the article, we have mentioned three ways to recover the released compressed air. First one is by using the boost valve to send the recovered air back to the air source. Second way is by using the boost valve to send the recovered air back to the recover accumulator for the other circuit. Third way is directly recover the air form the exhausted hole, and then use boost valve to send it back to the recover accumulator. The first and the second way are to release the air in the charge accumulator first, and this is why the recover efficient is much worse than the third way. Because of the limit of boost valve in the first way, it causes the low recovered efficient. However these two ways has the pre-released compressed air in the cylinder before change moving direction, the velocity of forward and backward has increased so much. The speed compares to the convention circuit fast to more than 40%, but the best recovered efficient
only reaches to 20%. If we use the way of directly recover the air from the exhaust, then we can
reaches the recovered efficient way more than 40%. However the forward and the backward velocity
is about 17% lower because of the backpressure. Basically we can use the increased charge
accumulator volume to correct this problem, but it lower the recovered efficient. In this article, we
only discuss the air consumption and the speed variation. However there is more research we can do
about the out-put force. Moreover if we can combine the simulation program with the best point of
view, then it is much more easily for us to decide the coefficients when operating.

![Figure 9. Air consumption comparison chart for the direct recycling exhaust air to recover accumulator.](image1)

![Figure 10. Speed variation comparison chart for the direct recycling exhaust air to recover accumulator way.](image2)

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