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A Method to Compute Dimension of an Air Distribution Channel of a Pneumatic Cylinder

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Abstract–Dimension of an air distribution channel of a pneumatic cylinder is an important factor in a manufacturing process for developing a basic standard for industrial production. The main challenge is how to formulate a computation of the dimension in the form of a simple equation that can serve as a useful guide for local industries. The aim of this research is to determine the dimension of the air distribution channel of a pneumatic cylinder. Load cells and fitting dimension variant can be attached at the end of piston road and in inlet/outlet port of pneumatic cylinder. Furthermore moving time of piston road and loads derived from control valve and sensor operated. A number of factors related to various operating and loading conditions need to be considered to obtain optimum performance of the pneumatic cylinder. The results show that the working pressure and intake diameter are directly proportional to the cylinder performance. Increasing load of the cylinder causes a reduction in the pressure. For any changes in the dimension of the air distribution channel, the operation pressure and the external load influence the air flow speed entering the cylinder and at the same time also affect piston speed. Thus, an effective mathematical expression for computing the dimension of the channel in the pneumatic cylinder has been developed for that can be used in a manufacturing process, thereby yielding a useful product for both consumers and industries.

***Keywords**: Dimension, Channel, Cylinder, standard, performance*

I. INTRODUCTION

Packaging industries involving medicinal, food and drinking products typically use pneumatic system in the manufacturing process due to the very fact that air is a clean medium. This involves the use of pneumatic cylinders which come in various form depending on the manufacturer designed specifications and standards. Design and fabrication of a single and double acting cylinder has presented using sequencing circuit [1]. A model for a servo pneumatic cylinder were derived by [2]. In industrial application, the pneumatic cylinder is typically used as an actuator or a prime mover and is always associated with the main object to be moved, transported and controlled in a manufacturing system.

The design of the pneumatic system largely depends on the consumer needs and applications involving the use of an adequate number of pneumatic cylinders with varied dimensions.

It is deemed that one the most important aspects of a pneumatic cylinder is related to acquiring suitable dimension of air distribution channel in order to obtain the optimum effort performance.

For this purpose, a number of parameters need to be scrutinised and studied. Most of the cylinders fabricated or manufactured in Asia, particularly in Indonesia, are based on the limited numbers and dimensions recommended through appropriate licensing. The design and manufacturing of the cylinders in the meantime, follows what has been clearly defined.

Based on previous research result on pneumatic cylinder, it was found that a non-dimensional parameter with a constant value of k_s = 0.0679962 with a deviation of 37% was attributed to the manufacturing/fabrication standard of Festo company [3]. It was also revealed that this constant value of k_s is still a long way to reach the real or actual condition if the consumer needs and previous research results are to be taken into account. Therefore, there is an urgent need to create and develop an effective formula for reducing the size of the air connecting intake section to the cylinder so that the percentage deviation could be ultimately reduced. It involves the redesign of the dimension of the specific parameters of the air distribution channel to achieve optimum working condition.

To facilitate the cylinder production related to domestic industries, three important techniques should first be considered:

a) obtain a referenced formula for the manufacturing process so that it may assist the local industries to provide the pneumatic cylinder products for consumers.

b) determine a suitable value of k_s such that it could produce a deviation of less than 37%.

c) design a precise fitting dimension to obtain the optimum performance of the pneumatic cylinder.

The above will eventually assist in developing a suitable empirical formula as a guide for the manufacturing process of the pneumatic cylinder by the local industries. This research is also beneficial to future industrial communities so that the knowledge and technology gained are in line with that of the developed countries. The outcomes of the research are expected to obtain the value of a non dimensional parameter (constant value), k_s is somewhat better than the one computed in[3] considering Festo fabrication standard using cylinder type, DNU-63-50-PPV-

A. The percentage deviation should be less than 37%. The energy balance in the cylinder chamber shall be designed with reference to appropriate dimension of the air channel intake, to take into account the intake diameter (d_i) and piston cylinder diameter (D). Thus, the locally fabricated cylinders can be established, thereby providing solution according to the consumer needs [4].

II. CYLINDER TYPES AND PARAMETERS

It is a fact that the working direction of the pneumatic cylinder such as linear, rotary cylinder and coupling method can be created as well, i.e., for sliding linear operation (SPZ- type), for rotary movement (DSM-type) and for yoke or coupling transmission system (DPZ-twin type), respectively. As an example, for the opening and closing a door for a vehicle, the actuator deemed suitable is a DSM-type cylinder with a rotary adjustment angle from 0^o to 270^o.

A cylinder with type "MLO-POT-.-TLF" for positioning of the component accurately have been launched[5]. This is described as "Servo Pneumatic Positioning". The other cylinder type such as DGPL-Rodless can be used for roll plate operation.

In determining the dimension of the channel, apart from k_s, a number of parameters has to be considered as follows:

a) forward force, F_m (N)
b) return force, F_k (N)
c) loaded external mass, m (kg)
d) air flow rate, V_i (m/s) flows through the input channel of the fitting cylinder
e) linear velocity of the piston and connecting rod, V_k (m/s) lifting loads up and down
f) air pressure capacity flowing into cylinder, Q (m^3/s)
g) ratio between diameter of the air fitting channel, d_i (mm) and piston diameter, D (mm)

It is revealed in [3] that the foward force or return force on the piston connecting rod are governed by the amount of the air pressure that flows into the cylinder. Analysis of cylinder and piston of two stage reciprocating air compressors have been taken specification for both low and high pressure condition [6].

This is deemed to be not in optimum condition initially due to the inaccurate design of the air distribution channel (dimension). It creates an energy unbalance between the air pressure that flows into the cylinder and the available chamber capacity of the cylinder.

The conditions have to be investigated to develop suitable design technology in pneumatic cylinder manufacturing.

III. RESEARCH METHODOLOGY

Fig.1 shows the implementation of the research in the form of a flow diagram describing various phases and activities.

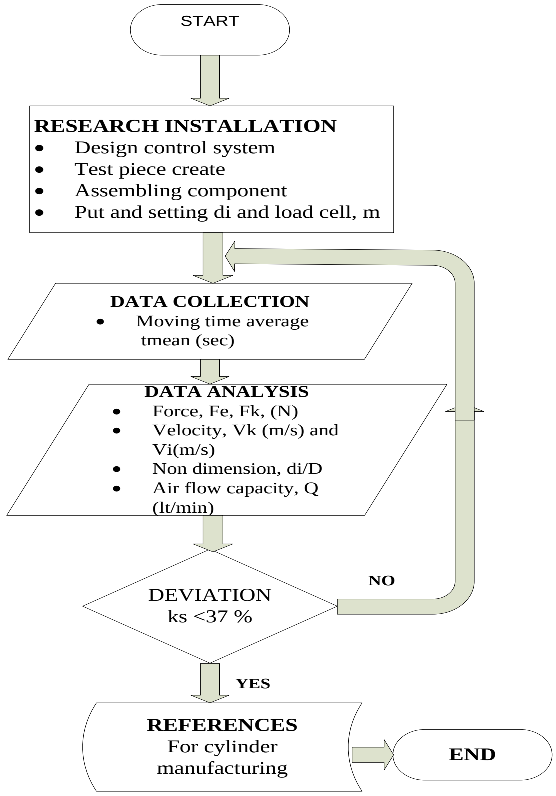

Figure 1. Research flow diagram

This system is developed with reference to the structural design of the pneumatic control system as shown in Fig. 2(a) considering a test piece fitting with varying channel diameters, d_i 8 from 3.5 mm to 8.0 mm.

Actuating the pneumatic piston cylinder 1 (with moving time average) will in turn moves the load cell 6 with the readings acquired through a recorder 5 which are connected to limit switch 7 and a U sensor . 2 .

The test piece fitting is located at the intake port of the cylinder with the load cells (6), *m* (kg) varied from 5 to 40 kg at the end of the piston connecting rod. The research installation system is executed by operating the valve actuator ON/OFF switch.

A. Experimental Set-up

The complete experimental installation is shown in Figs. 2(a),(b),(c) and Figs. 3(a) and (b). In Figs. 3(a) and 3(b), by pressing the pushbutton switch S1, it energizes solenoid Y1 via the pneumatic 3/2-way valve which in turn actuates the direction 5/2-way valve [7]. Furthermore, the load cell 6 in Fig. 2(a) can be moved up and down by operating the pneumatic cylinder after deriving control from the memory 5/2-way valve 3.

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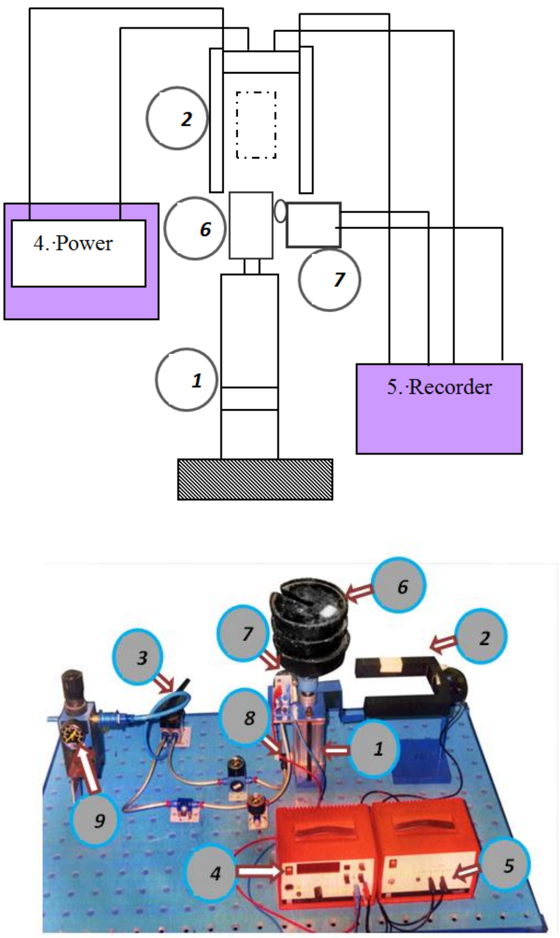
B. Data collection

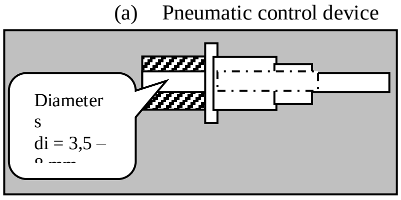
Each load cell located at the end of piston rod has different moving time average depending on its weight. The air distribution channel which is positioned at the inlet cylinder port can be arranged with d_i = 3.5 to 8.0 mm (increment of 0.5 mm), whereas the load cell masses can also be varied from m = 5 to 40 kg (increment of 5 kg).

The changes of the parameters directly affect the performance of the moving pneumatic cylinder. The loading conditions are related to channel diameter, d_i of the air connection 8, working pressure P (bar) and mass of load cell (kg).

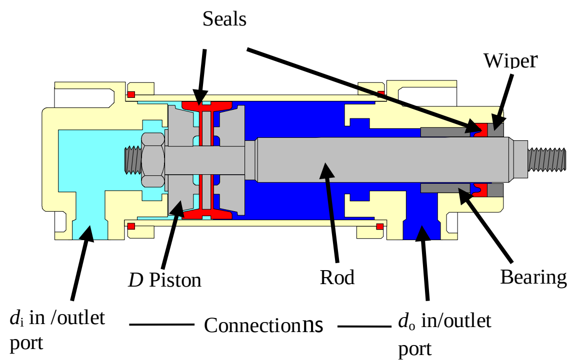
The preliminary data of the pneumatic cylinder test type:DNU-63-50-PPV-A refered to Festo Company references with dimension: Piston diameter, D = 30 mm, stroke l = 50 mm, cylinder wall material is GDALSi 12, Cr13 for piston rod coating and polyurethan for sealing material.



(a) Pneumatic control device

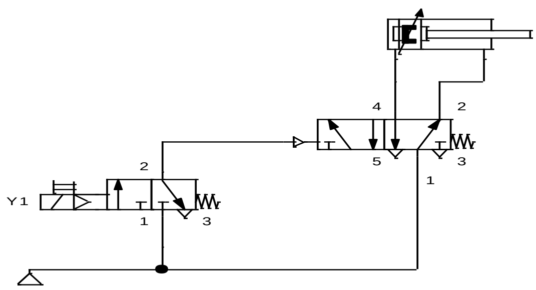


(b) Inlet cylinder port device

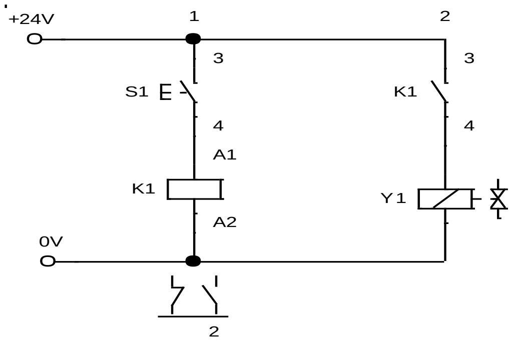


(c) Pneumatic cylinder construction

Figure 2. Schematics of the experimental set-up



(a), Pneumatic control diagram



(b) Electrical control diagram

Figure 3. Electro pneumatic circuits

C. Data Analysis

The number of data is analyzed using several formula which can be found in [3] which are actually related to the force for moving forward or up, F_k (N), Cylinder motion up velocity, V_k (m/s), air flow rate, V_i (m/s), non dimension parameter, Pressure P (bar) and air flow capacity, Q (lt/hour).

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IV. RESULTS AND DISCUSSION

The average time motion of the piston rod cylinder that was obtained from the measurement result is used to calculate the linear velocity of the pneumatic cylinder for moving up the load cells. The dependent variables, particularly in the electro pneumatic control system such as air pressure, P and the dimension of air distribution channel will be taken into account in the analysis. The effective force of piston to move up the load cell is determined through the following expression [8, 9]:

$$F_e = (1 - 0.1)\, F_t \qquad (1)$$

Where, F_t is the theoretical force which is related to the friction force in the cylinder wall. If the pressure (P) and the mass (m) are considered, then (1) becomes:

$$F_k = 280\ P - 8.83\ m - 17.31 \qquad (2)$$

If the work pressure P = 1 bar and mass of load cell m = 5 kg are substituted into (2), the derived effective force is computed as F_k = 218.54 N. The characteristics due to the changes in the pressure from 1 to 6 bar and the corresponding variation of the external loads from 5 to 40 kg can be seen in Fig. 4. The linear velocity of the piston rod cylinder to move the load cells up and down can be determined through the following equation:

$$V_k = \frac{15.57\ .\ C_k\ .\ P}{F_k\ .\ t} \qquad (3)$$

If P = 1 bar, the correction factor, C_k = 1.987, effective force F_k = 218.54 N with average time, t = 0.99 s, then the linear velocity of piston rod cylinder based on (3) is computed as:

$$V_k = 0{,}140149236 \text{ m/s.}$$

The relationship between V_k and load m can be seen in Fig. 5.

A. Air flow rate, V_i

The air flow rate in the cylinder chamber can be determined using the following expression [3]:

$$V_i = \frac{0.0168\ .C_k\ .P}{F_k\ .d_i^2\ .\ t} \qquad (4)$$

If the air channel diameter, d_i = 3.5 mm, F_k =218.54 N, t = 0.99 s and the pressure correction factor C_k =1.987 at P =1 bar, the air flow rate is determined as:

$$V_i = 46.332328 \text{ m/s}$$

The characteristic relation between V_k and d_i is shown in Fig. 6, while the curve V_i and d_i can be seen in Fig.7. Fig.8 illustrates the result for the relationship between V_i and V_k .

B. The Ratio, V_k/V_i

The ratio, V_k/V_i considering P = 6 bar, d_i = 3.5 mm and m = 5 kg can be obtained as:

$$V_k/V_i = 0.28/\ 63.85 = 0.004318$$

C. Non Dimension Parameter

The non dimension parameter related to the diameter ratio can be determined from the following equation [3]:

$$d_i/D = (V_k/V_i)^{1/2} \qquad (5)$$

Equation (5) is calculated to obtain the dimension of the air distribution channel. Thus the ratio is calculated as:

$$d_i/D = (0.004318)^{1/2} = 0.065713, \text{ or}$$

$$d_i = 0.065713\ D \qquad (6)$$

From the above equation, if the piston diameter of the cylinder tested previously is D = 63 mm, then d_i for the dimension of the air distribution channel is found to be:

$$d_i = 0.00414 \text{ m} = 4.14 \text{ mm.}$$

This result can be compared with the fabrication standard of Festo Didactic company, where d_i = 3.9 mm. It is obvious that the air tubing is based on PU-4 with d_i = 3.9 to 4.2 mm [10].

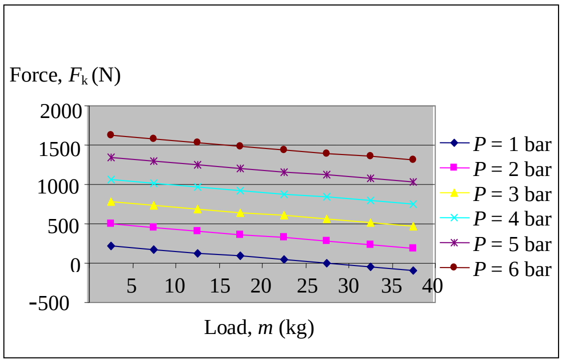

Figure 4. Relationship between F_k and m for various pressure setting

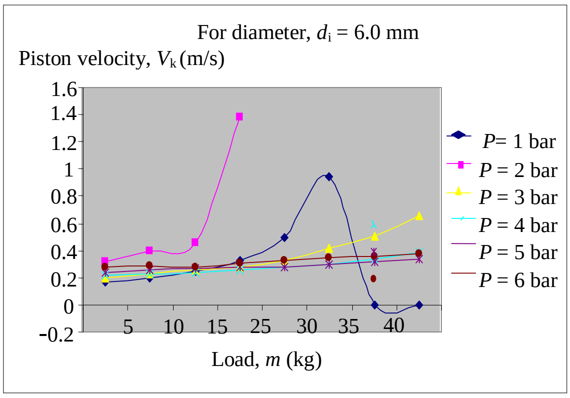

Figure 5. Effect of load variation with piston velocity and change in pressure for d_i = 6 mm

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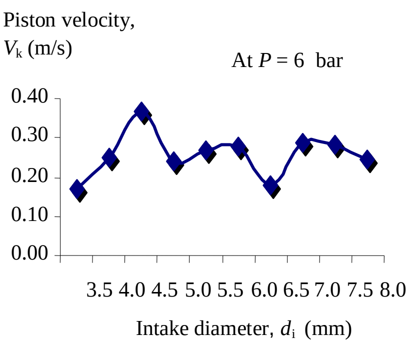

Figure 6. Result of V_k versus d_i at 6 bar

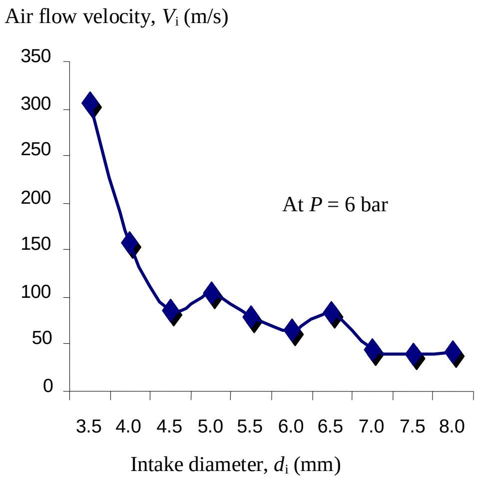

Figure 7. Characteristic of V_i versus d_i at 6 bar

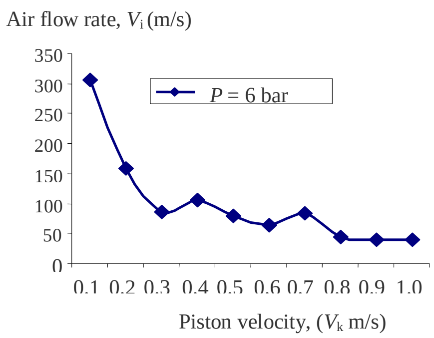

Figure 8. Relationship between V_i and V_k

From Fig. 4, it is clear that the pneumatic piston cylinder was not able to move the load cells from m = 30 to 40 kg at the operating pressure, P = 1 bar. However as the pressure gradually increases, it results in the increase of the effective force. It is also noted that the force is inversely proportional to the increase in the loads. The maximum effective force, F_k = 1618 N at P = 6 bar and m = 5 kg. This result is reasonably comparable to the one produced by Festo Didactic company [10] in which the force is obtained as F_k = 1680 N .

It was also found that the velocity of the piston rod motion is very much influenced by the dimension of the air distribution channel d_i, m and P as shown in Fig. 5. It is seen that the piston velocity V_k gradually shows an upward trend with the addition of the load cells and increase in the operating pressure apart from P = 1 bar. It seems that at P = 1 bar, the piston is not able to move the load m = 36 kg. However, a maximum velocity, V_k = 1.40 m/s can be reached at P = 2 bar with the channel diameter d_i = 6.0 mm. It was revealed that the average velocity of the pneumatic cylinder piston is in the range of 0.1 m/s to 1.5 m/s [8].

The effect of varying the air distribution channel dimension from 3.5 mm to 8.0 mm on the piston velocity V_k can be seen Fig. 6 in which it shows a sinusoidal fluctuation with a peak velocity at approximately 0.38 m/s with d_i = 4.5 mm.

Based on the study, the range of appropriate piston velocity was obtained as V_k = 0.13 m/s to 1.99 m/s which is comparable to the result quoted [10]. At the operating pressure of P = 6 bar, the velocity ratio is V_k/V_i = 0.004342 at d_i = 4.5 mm and V_k/V_i = 0.004318 at d_i = 6.0 mm. The non dimension parameter (diameter ratio) can be considered as a constant number, k_s = d_i/D, and assumed to be important reference to the product related to a pneumatic cylinder.

The 'optimized' effective force, F_k = 1618 N moves the load cell at P = 6 bar. As expected, the air flow rate decreases in an exponential manner with the increase in the intake diameter (d_i) as shown in Fig. 7. Similarly, it also decreases in almost the same fashion with the increase of the piston velocity (see Fig. 8). The obtained or computed dimension of the air distribution channel, d_i according to the result is 4.1 mm (compare this with d_i = 3.9 mm for Festo standard fabrication product). Thus, if the piston diameter for the test is D = 63 mm, then the constant parameter is found to be:

$$k_s = d_i/D = 4.1/63 = 0.065029$$

It implies that this value constitutes a deviation of approximately 35 % which is less than 37 % threshold with reference to the Festo counterpart. Thus, the optimum performance of the pneumatic cylinder type DNU-63-50-PPV-A should be designed considering the air distribution channel dimension with d_i = 4.1 mm (4.0 mm) according to the PU-4 specification.

V. CONCLUSION

A method for computing the 'optimum' dimension of the air distribution channel has been demonstrated. The deviation has been reduced marginally below 37 % threshold value. If the deviation value of k_s is smaller, the air distribution channel d_i approaches the standard value (recommended by Festo). Based on the experiments and through studyng the effects of force F_k, velocity V_k and air flow rate V_i, and a non dimension d_i/D, equation can be computed. This effectively reduces the pneumatic cylinder manufacturing problem without resorting to the overseas recommendation for the product design.

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