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An Air-Operated Multi-Input Logical “OR” Module*

Bogdan Stoyanov, Vlaiko Peichev, Jordan Beyazov

Institute of Information Technologies, 1113 Sofia

Abstract: *The paper presents an 18-input air-operated logical “OR” module on the basis of throttle-diaphragm elements. Some relations are derived defining the switching process of throttle-diaphragm elements. A decoding circuit of pneumatic signals is synthesized for encoding objects that have reached the working position in a conveyer line. An application example is discussed.*

Keywords: *logical module, throttle-diaphragm element, pneumatic signals decoder, acoustic sensors, conveyer line.*

1. Introduction

The pneumatic control and computing devices usually include switching elements, which serve to transform and further process the signals. The use of universal devices for this purpose is comparatively expensive.

The purpose of the present study in the area of diaphragm techniques is the development of a specialized air-operated multi-input logical “OR” module intended for use in a pneumatic system for images recognition, mainly when painting details in a conveyer with the help of a pneumatic painting robot.

The basic requirements towards the pneumatic diaphragm switching devices are [1, 2]: a large coefficient of amplification of the pneumatic information signal, good high speed of the device logical status switching, compatibility of the output signal in a pneumatic system, relatively low losses of energy, comparatively small dimensions, standard attaching to pneumatic systems, relatively low cost.

These requirements towards the quality of the main element in pneumatic switching devices are met to a great extent by the well-known single-diaphragm element,

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operating on the aerodynamic “flapper-and-nozzle” principle. With the help of uncomplicated means it ensures a large amplification coefficient and a relatively good switching speed. On the other hand, the single-diaphragm element enables the constructive building in multi-input integral logical diagrams, like the air-operated logical “OR” module designed by the team.

2. Structure of the multi-input logical “OR” module

Fig. 1a shows the cross section of the construction of an air-operated multi-input logical “OR” module, and Fig. 1b – its simplified scheme. The main elements of the structure are: supply (1) and output (5) pneumatic lines with constant chokes, a circuit chamber (7), input diaphragm-throttle elements, including a diaphragm (2), a cylindrical nozzle (3) and a pneumatic input with a chamber (4). The input elements are located symmetrically to the circuit chamber and their number corresponds to the sensors number and could be unlimited.

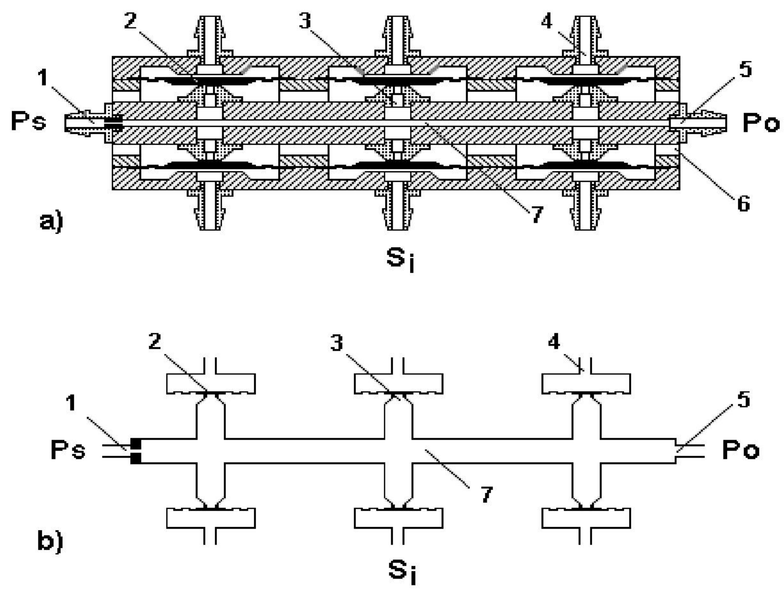

Fig. 1

In initial position, when there is no actuated sensor, air is supplied to all input chambers (4), its pressure acting on the diaphragms (2), as a result of which the nozzles (3) are closed and the pressure established at the output of the logical module corresponds to the pressure in the circuit chamber (7) and is equivalent to logical “1”. In case any of sensors (S_i) is actuated, the air supply towards the corresponding input of the module is terminated and as a result the pressure in the respective input chamber drops down. The diaphragm to this chamber is separated by the nozzle, through which the air from the circuit chamber flows out to the atmosphere. The pressure in the circuit chamber rapidly decreases, its value obtained corresponding to logical “0”.

The switching and frequency characteristics of the logical module, and its reliability also depend mainly on the characteristics of the diaphragm-throttle elements, which will be discussed below.

3. Characteristic features of the diaphragm-throttle elements

The diaphragm-throttle elements of the logical module contain a circuit chamber (7), a diaphragm (2), a nozzle (3) and a diaphragm chamber (4). They can be regarded as analogs to the pneumatic elements of "flapper-and-nozzle" type, in this case the role of the flapper being carried out by a mobile elastic diaphragm. Under the action of the input discrete signal the diaphragm can be located in two final positions – a "closed nozzle" and an "open nozzle" position, corresponding to logical states "0" and "1" respectively.

In a "closed nozzle" position, the pneumatic output signal P0, corresponding to logical "1", is defined by the pressure of the air in the circuit chamber. The pressure N on the diaphragm at closed nozzle is

(1)
$$N = \frac{\pi}{4}\left(P_k D^2 - P_0 d_2^2\right),$$

where P_k is the air pressure in the diaphragm chamber (4), D – diameter of the efficient area of the diaphragm (2), d_2 – diameter of nozzle (3).

The conditions below given are required for reliable closing of the nozzle:

(2)
$$P_k \geq P_0 \frac{d_2^2}{D^2},$$

(3)
$$l_{P_k} \geq L ,$$

where l_{P_k} is the diaphragm shifting under the action of pressure P_k of the air entering through the sensor. The characteristics of the relocation of the technical diaphragm with width 0.4 mm in relation to the pressure P_k in the diaphragm chamber is given in Fig. 2.

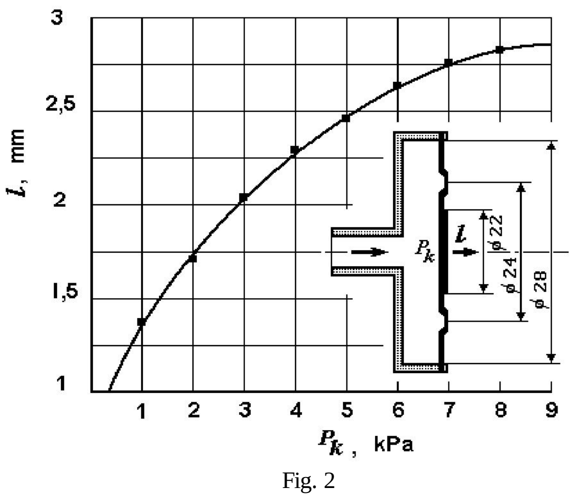

Fig. 2

When the diaphragm is separated from the nozzle, the air from the circuit chamber flows out to the atmosphere. The process of flowing out and the movement of the elastic diaphragm define the switching characteristic of the diaphragm-throttle element.

The analysis of the process of the air outflow from the circuit chamber through the nozzle to the atmosphere is based on the hydrodynamic theory of the pneumatic “flapper-and-nozzle” element [4, 7], using some empiric dependences for diaphragm relocation. The main parameters of the circuit chamber (Fig. 3) are: its volume – *V*, the area of the output section of the nozzle (inconstant choke) *F*, pressure in the chamber P_0, pressure after the nozzle P_a and temperature of the air in chamber *T*.

It is assumed that the condition for under-critical outflow of the air is satisfied:

$$\frac{P_a}{P_0} \le \overline{P^*}, \tag{4}$$

where $\overline{P^*}$ is a dimensionless value of the pressure in the chamber at outflow sound speed.

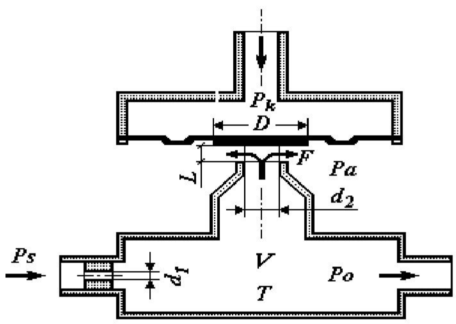

Fig. 3

In order to define the speed of the pneumatic throttle-diaphragm element (the time for the air outflow from the chamber to the atmosphere, through the nozzle), it is necessary to obtain the relations for the change of the pressure P_0 and of the flow rate *Q*. The following dimensionless parameters are introduced, which are relations of the momentum values of a backed up flow with respect to its initial values:

$$\overline{P_m} = \frac{P_m}{P_0};\ \overline{\rho_m} = \frac{\rho_m}{\rho_0};\ \overline{T_m} = \frac{T_m}{T_0};\ \overline{a_m} = \frac{a_m}{a_0} = \sqrt{\overline{T_m}}. \tag{5}$$

If assumed, with certain approximation that the outflow is isentropic due to the quick pressure drop P_0, the relation below given follows:

$$\frac{P_m}{P_0} = \left(\frac{\rho_m}{\rho_0}\right)^k = \left(\frac{T_m}{T_0}\right)^{\frac{k}{k-1}}, \tag{6}$$

$$\overline{\rho_m} = \overline{P_0}^{\frac{1}{k}};\ \overline{T_m} = \overline{P_0}^{\frac{k-1}{k}};\ \overline{a_m} = \overline{P_0}^{\frac{k-1}{2k}}. \tag{7}$$

where k is an adiabatic indicator, for air under normal conditions $k = 1.4$.

The mass flow that is variable during the outflow time is

(8) $$q = \rho\, aMF$$

and in a dimensionless form it is

(9) $$\bar{q} = \frac{\bar{\rho}(M)\bar{a}(M)}{\bar{\rho}^*\bar{a}^*} M \overline{\rho_m}\,\overline{a_m},$$

hence for the case of critical outflow

(10) $$\bar{q} = \overline{\rho_m}.\overline{a_m},$$

where ρ is the tightness of the air flowing out, a – sound speed, M – Mah number.

For an elementary period of time dt, an air mass qdt will flow out, and the air tightness in the chamber will be decreased by $d\rho_m$, and its mass – by $Vd\rho_m$, i.e.

(11) $$dt = -\frac{Vd\rho_m}{q}.$$

The equality (11) in a dimensionless form will be:

(12) $$\overline{dt} = \frac{1}{\overline{\rho^*}.\overline{a^*}} \frac{d\overline{\rho_m}}{\bar{q}} = \text{const}\frac{d\overline{\rho_m}}{\bar{q}}.$$

For the case of the under-sound outflow assumed with isentropic expansion of the air, equation (12) gets the form:

(13) $$\overline{dt} = -\left(\frac{P_a}{P_0}\right)^{-\frac{k-1}{2k}} \left(1 + \frac{k-1}{2}M^2\right)^{\frac{2-k}{k-1}} dM.$$

After solving equation (13) and replacing the values for Mah number, the dimensionless time of the air outflow from the circuit chamber to the atmosphere is obtained as:

(14) $$\bar{t} = 1.24\left(\frac{P_a}{P_0}\right)^{-\frac{k-1}{2k}}$$

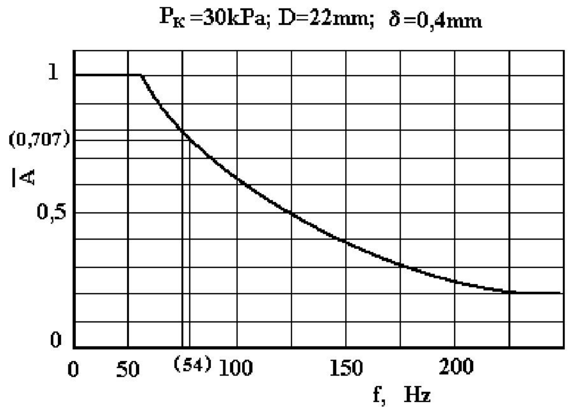

Fig. 4

from where it follows that the duration of the sub-sound outflow depends on the relation between the counter-pressure and the initial pressure in the circuit chamber:

Fig. 4 shows the experimentally determined amplitude-frequency characteristics of the throttle-diaphragm element. The bound working frequency is 54 Hz, which enables the wide practical use of these elements, respectively of the air-operated multi-input logical "OR" module designed.

4. An example of the application of the logical "OR" module

One application of the air-operated multi-input logical "OR" module can be in a decoding circuit of pneumatic signals controlling the process of recognition and painting of pneumatic cylinder cases of different size by robots. The cylinders are hanged on a slow moving conveyer line. Pneumatic acoustic sensors [3] are used to determine the presence and type of the cylinder to be painted when it reaches the working position.

The principal diagram of the decoder containing passive logical "OR" elements for signal coding and an active logical "OR" element for system starting, is shown in Fig. 5. Signals S0-S9 from the corresponding sensor devices AS0-AS9 (acoustic sensors in the case), are connected to the decoder outputs I-IV with the help of a pyramidal circuit of passive logical "OR" elements and also to a specially designed logical module M, which is a multi-input active logical "OR" element with an inverted output.

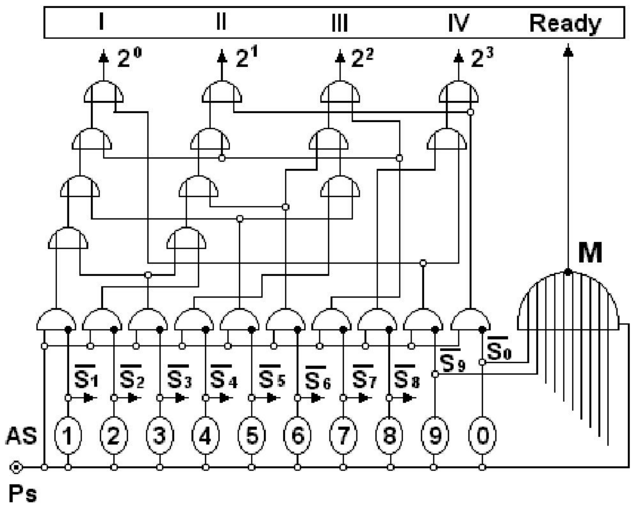

Fig. 5

When actuating any of the acoustic sensors AS, its pneumatic output signal enters the corresponding decoder output bus after logical processing and at the same time, with the help of logical module M, it is input to the system for starting its work. If we assume that sensor AS_6 is actuated, a pneumatic information signal will be obtained at output buses II and III. If assumed that each bus possesses as a number the respective degree of the number 2, added 1 (for example, bus III is assigned $2^{3-1} = 2^2$), then a combination of pneumatic signals will be obtained at the output buses, corresponding to the number of the actuated sensor. Thus for the example considered $6=2^{3-1}+2^{3-2} = 2^2+2^1$.

The structure and the characteristics of the acoustic sensors and of the air-operated logical elements are described in publications [1, 3]. The signals obtained from the sensors are logically processed by the "OR" module or by the decoding circuit. An output signal describing the type of the cylinder that is to be painted is encoded with the help of a decoder and the module outputs a signal, which starts the system controlling the painting process. The laboratory tests of the system with reference to the recognition and encoding of the type of the cylinders painted by a robot, have shown good accuracy, satisfactory high speed and reliability of work under heavy exploitation conditions.

5. Conclusions

On the basis of the results obtained from the theoretic-experimental investigations of the air-operated multi-input logical "OR" module designed, the following more important conclusions can be made:

– an approach is suggested for the engineering calculation of the throttle-diaphragm elements comprising an air-operated multi-input logical "OR" module;

– on the basis of the throttle-diaphragm elements, an 18-input air-operated logical OR element is designed;

– on the basis of flow elements of FALOMA fluid system, a decoding circuit of pneumatic signals is synthesized for encoding objects that have reached the working position in a transportation line,

– some significant results have been obtained during the laboratory tests of the process of recognition and encoding the type of cylinders painted by a robot, with the help of the system proposed, which includes acoustic sensors, a pneumatic decoding circuit and an OR module. These results are the basis for high evaluation of the device applicability in practice and especially its use for operation under hard working conditions – heavy dust loading and contamination of the working environment, rapid alterations of the temperature and electromagnetic fields, strong vibrations and oscillating movements of the objects controlled.

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Пневматичен многовходов логически модул “ИЛИ”

Богдан П. Стоянов, Влайко С. Пейчев, Йордан Й. Беязов

Институт по информационни технологии, 1113 София

(Р е з ю м е)

На базата на мембранно дроселни елементи е разработен 18-входов пневматичен логически модул “Или”. Изведени са зависимостите за определяне на процеса на превключване на мембранно дроселните елементи на модула. Синтезирана е логическа схема на дешифратор на пневматични сигнали за кодиране на обекти, достигнали работна позиция в конвейерна линия. Разгледан е конкретен пример на приложение.