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Applications

On Fluid Systems for Tracking Planar Trajectories

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Abstract: *The paper discusses the possibility for creating a pneumatic jet device for trajectory tracking, implemented as a sharp edge channel. The device is based on a full bridge circuit principle, with two constant and two variable throttles. The efficient cross-section of each of the variable throttles blocks partially the channel. Analytical expressions are derived for the dependence of the pressure drop on the device displacement against the channel walls. The static curve is built and the flow parameters are determined for a specific case.*

Keywords: *trajectory tracking, pneumatic jet device, arc welding.*

1. Introduction

The necessity of tracking a given trajectory appears in real processing of large details, such as electric arc welding of long seams, details covering, etc. The program is entered in a processing machine and it directs the operating instrument along an apriori set trajectory, but the real details have different geometric deviations and deformations, which cause processing errors. The application of a correcting system on the basis of mechanics, optics or electronics is necessary in this case. Under heavy industrial conditions like those of electric arc welding, the application of optics is restricted due to the presence of gases and high temperatures, and the use of inductive sensors is difficult, due to the considerable electromagnetic disturbances, occurring in the electric arc. The mechanical guiding is possible, but it implies the presence of large tensions on the leading element, that is inconvenient.

A tracking system on the basis of fluid elements is an appropriate solution of the problem. The fluid sensors use air or another gas for their work and their operation principle is not influenced by most of the industrial disturbances.

Two variants for this problem solution are possible – a direct and an indirect one. In the direct variant the trajectory tracking is realized after the direct perception of the edges and walls by fluid sensors. In the indirect method a flexible mechanic guide is used to follow a channel or an edge, for example the slot of the future welding. In both cases the displacement caused by the difference of a given trajectory with respect to the real one, is sensed by appropriate fluid sensors, it is amplified and input to an additional actuating mechanism attached to the robot arm or the automata. This directs the instrument according to the deviation obtained independently on the apriori set trajectory.

The deviations are reflected by a bridge scheme giving independence to the system with regard to the alterations in the supply fluid pressure within feasible limits. The signal obtained from the error is amplified by proportional pneumatic amplifiers, which move the operating instrument until matching with the desired trajectory.

The direct method is restrained as an application, since it requires guiding along specific angular surfaces or channel edges, nevertheless it is simple, reliable and exact. In the indirect method the mechanic guide can be moved along a near or remote parallel edge, channel or surface. The disadvantage in this is the necessity of a geometric removal of the guide in front of the instrument path in cases of electric welding, which leaves the last centimeters of the seam uncontrollable due to the guide leaving the channel. Figs. 1 and 2 show an indirect and direct fluid tracking systems.

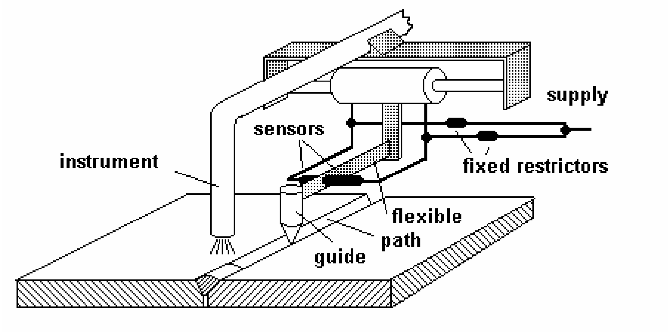

Fig.1

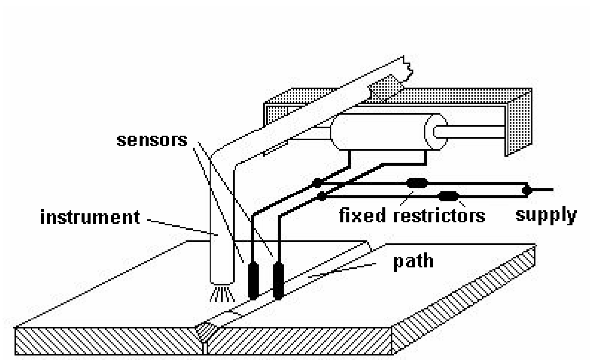

Fig . 2

2. Purpose of the study

The aim is to investigate a direct racking system (Figs. 3 and 4), and define the static characteristic in an analytical way, i.e., the relation between the pressure drop Δp and the displacement Δx with respect to the edges, forming the channel. The analysis of this relation can determine whether the practical use of a similar device in some practical cases is possible, for example electric arc welding with the help of an industrial robot.

2.1. Theoretic formulation

The design of the equpment used is shown in Figs. 3 and 4.

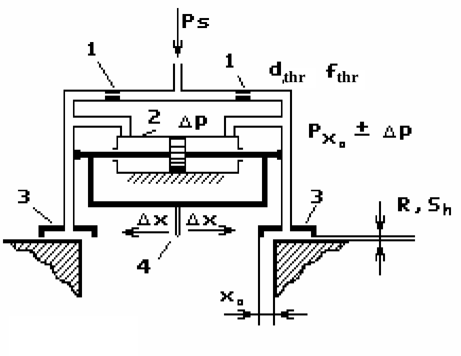

Fig. 3

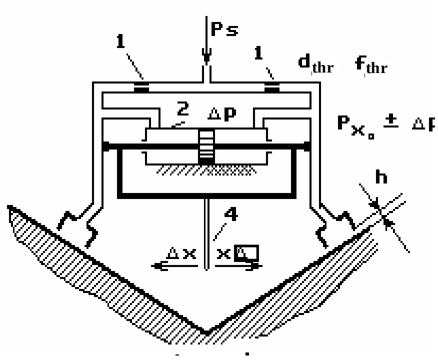

Fig. 4

The initial position is this, at which the resistances of the variable throttles are equal, i.e. $\Delta p = 0$. The tracking device is on the axis line of the channel. In this case, the following expression is obtained from the continuality equation for one of bridge arms:

(1) $$\mu_{\text{thr}} f_{\text{thr}} \sqrt{\frac{2}{p}} \sqrt{p_s - p_{s_0}} = \mu_{x_0} f_{x_0} \sqrt{\frac{2}{p}} \sqrt{p_{x_0}} + \mu_h S_{h_0} \sqrt{\frac{2}{p}} \sqrt{p_{x_0}}$$

where μ_{thr} is the coefficient of the flow through the constant throttle; μ_{x_0} – the coefficient of the flow through the opened part of the variable throttle, μ_h – the coefficient of the flow through the closed part of the variable throttle, $f_{\text{thr}} = \frac{\pi}{4} d^2_{\text{thr}}$ – the transition section of the constant throttle, $f_{x_0} = b_{x_0}$ – the transition section of the opened part of the variable throttle, $S_{h_0} = [2(a - x_0) + b]h$ – the throttling area of the closed part of the variable throttle; p_{thr} – supply pressure, p_{x_0} – over-pressure in the circuit chamber at $x = x_0$.

It can be accepted as first approximation that $\mu S = \mu O = \mu h$, then from equation (1) it will be obtained:

(2) $$f_{\text{thr}} \sqrt{p_s - p_{x_0}} = \left(f_0 + S_{h_0} \right) \sqrt{p_{x_0}}.$$

At $p_{x_0} = 0.5\, p_{thr}$ it follows that

$$f_{thr} = f_0 + S_{h_0} \quad .$$

Hence, it can be written:

(3) $$d_{thr} = \sqrt{\frac{4}{\pi}\left\{bx_0 + \left[2\left(a - x_0\right) + b\right]h\right\}} \,.$$

Equation (3) serves to determine the geometric parameters of the two throttles at given x_0. When the initial distance x_0 from the edge is decreased by Ax, the transition section of the variable throttle in one arm of the bridge is decreased, while in the other – decreased. At that the pressure in one chamber is increased by $\Delta p'$, and in the other circuit chamber it is decreased by $\Delta\, p''$.

2.2. Closing of the variable throttle

When the variable throttle is closed, equation (2) gets the form:

$$f_{thr}\sqrt{p_s - p_{x_0} - \Delta p'} = \left(f'_{x_0} + S'_{h_0}\right)\sqrt{p_{x_0} + \Delta p'} \,.$$

Hence for the pressure drop in the circuit chamber, it is obtained:

(4) $$\Delta\, p' = \frac{f_{thr}^2\, p_s - \left(f_{thr}^2 + \Sigma\, f'^2\right)p_{x_0}}{\Sigma\, f''^2 + f_{thr}^2} \,.$$

2.3. Opening of the variable throttle

In this case equation (2) is of the following type:

$$f_{thr}\sqrt{p_s - p_{x_0} - \Delta\, p''} = \left(f''_{x_0} + S''_{h_0}\right)\sqrt{p_{x_0} + \Delta\, p''} \,,$$

and the pressure drop in the circuit chamber is:

(5) $$\Delta p'' = \frac{\left(\Sigma f''^2 + f_{thr}^2\right)p_{x_0} - f_{thr}^2\, p_s}{\Sigma f''^2 + f_{thr}^2} \quad .$$

The pressure drop along the bridge diagonal is as follows:

(6) $$\Delta p = \Delta p' + \Delta p'' = \frac{f_{thr}^2\, p_s - \left(f_{thr}^2 + \Sigma f'^2\right)p_{x_0}}{\Sigma f'^2 + f_{thr}^2} + \frac{\left(\Sigma f''^2 + f_s'^2\right)p_{x_0} - f_{thr}^2\, p_s}{\Sigma f''^2 + f_s^2} .$$

At $p_{x_0} = 0.5\, p_s$, it is obtained:

(7) $$\Delta\, p = 0.5\left[\frac{f_{thr}^2 - \Sigma\, f'^2}{\Sigma\, f'^2 + f_{thr}^2} + \frac{\Sigma\, f''^2 - f_{thr}^2}{\Sigma\, f''^2 + f_{thr}^2}\right].$$

Having in mind that

$$\Sigma f' = f'_{x_0} + S'_{h_0} = bx_0 - b\Delta x + S_{h_0} + 2h\Delta x = \left(x_0 b + S_{h_0} \right) + (2h-b)\Delta x = k_1 + k_2 \Delta x,$$

$$\Sigma f'' = f'''_{x_0} + S''_{h_0} = bx_0 + b\Delta x + S_{h_0} - 2h\Delta x = \left(bx_0 + S_{h_0} \right) - (2h-b)\Delta x = k_1 - k_2 \Delta x,$$

equation (7) becomes:

(8)
$$\Delta p = \left[\frac{-A\Delta x^2 - B\Delta x - C}{2A\Delta x^2 + 2Bx + D} + \frac{A\Delta x^2 - B\Delta x + C}{2A\Delta x^2 + 2B\Delta x + \mathrm{D}} \right] p_0,$$

where

$$A = 0.5k_2^2 = 0.5(2h-b)^2,$$

$$B = k_1 k_2 = \{bx_0 + [2(a-x_0)+b]h\}(2h-b),$$

$$C = 0.5k_1^2 - 0.5 f_{\mathrm{thr}}^2 = 0.5\left\{ b_{x_0} + \left[2\left(a - x_0\right) + b \right] h \right\}^2 - 0.5\frac{\pi^2 d_{\mathrm{thr}}^4}{16},$$

$$D = k_1^2 + f_{\mathrm{thr}}^2 = \left\{ bx_0 + \left[2\left(a - x_0\right) + b \right] h \right\} + \frac{\pi^2 d_{\mathrm{thr}}^4}{16}.$$

2.4. Building of the static characteristic

The static characteristic built in an analytical way, is for a device with x_0=0.4 cm, b = 0.05 cm, a = 0.8 cm, h = 0.05 cm, A = 1.3×10^{-2} cm^2, C = 0, B = 3.1×10^{-3} cm^3, D = 7.7×10^{-3} cm^3.

The constant throttle is computed from equation (3), its diameter being d_{thr} = 0.28 cm. Replacing these values in equation (8), it is obtained:

(9)
$$\Delta p = \left[\frac{-1.3\Delta x^2 - 3.1\Delta x}{2.6\Delta x^2 + 6.2\Delta x + 7.7} + \frac{1.3\Delta x^2 - 3.1\Delta x}{2.6\Delta x^2 - 6.2\Delta x + 7.7} \right] p_S.$$

The relation expressed by equation (9), is shown in Fig. 5a, and the same relation at supply pressure of 140 kPa – in Fig. 5b. In case the load along the diagonal bridge

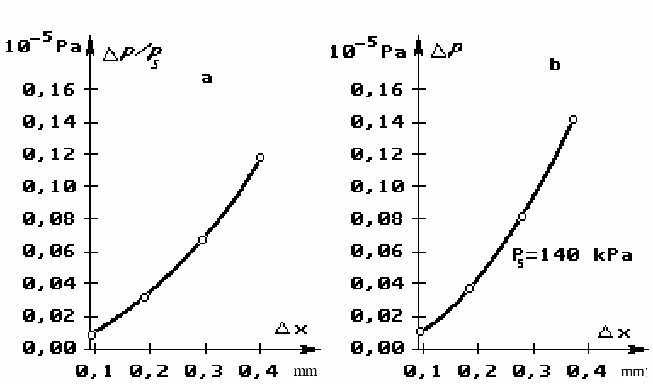

Fig.5

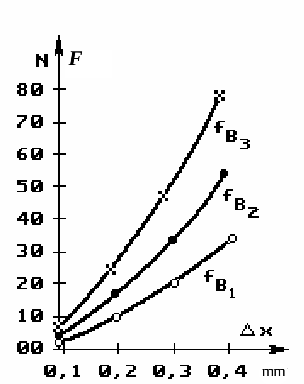

Fig. 6

is a bilateral plunger cylinder, the alteration of the force obtained on the plunger rod in relation to the displacement, is shown in Fig. 6 at supply pressure of 140 kPa and different efficient areas of the plunger (f_{b1}= 18.8 cm^2, f_{b2} = 27.5cm^2, f_{b3} = 48.5 cm^2)

2.5. Parameters of the flow

For the examples discussed at p_{x_0} = 0.5p_s and p_{thr} = 140 kPa, the theoretical value through the constant throttle, is:

$$c_{t_1} = \sqrt{\frac{2\nu}{\nu-1}\frac{p_s}{\rho_s}\left[1-\left(\frac{p_{x_0}}{p_s}\right)^{\frac{\nu-1}{\nu}}\right]} = 234 \text{ m/s}$$

and through the variable throttle is:

$$c_{t2} = \sqrt{\frac{2\nu}{\nu-1}\frac{p_{x_0}}{\rho_{x_0}}\left[1-\left(\frac{p_a}{p_{x_0}}\right)^{\frac{\nu-1}{\nu}}\right]} = 256 \text{ m/s} \quad .$$

The actual speed through the constant throttle at a coefficient of the speed φ = 0.8, is $c_1 = \varphi\, c_{t_1}$ = 187 m/s, and Reynolds number will be Re = $c_1 d_{thr}/\nu$ = 84.5×10^3. It can be obtained for the speed and Re through the variable throttle respectively that $c_2 = \varphi\, c_{t_2}$ = 205 m/s, Re = $c_2 b/\nu$ = 21.4×10^3. As it is obvious, the flow is turbulent. The maximal value of the flow consumed at absence of a flapper and with a flow coefficient μ = 0.7, will be respectively $Q = 2\mu\, abc_2$ = 5 m^3/h.

3. Conclusion

The results above considered indicate that the direct scheme discussed can be applied in creating jet devices for plane trajectories tracking.

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Флуидни системи за следене на траектории

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(Р е з ю м е)

Представен е анализ на възможността за използване на флуидни сензори за изграждане на система за следене на траектория при електродъгово заваряване на големи детайли. Използвана е диференциална схема на сензорите с два постоянни и два променливи дросела. Изведени са аналитични зависимости на пада на налягането от изместването на инструмента спрямо зададената траектория. Представени са статичните характеристики за директна следяща система.