Analysis of Warren's Fluidic Counter

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(Received May 9, 1970)

Synopsis

Though the Warren's fluidic counter has a very simple construction, the matching problems of the main jet supply pressure with the input pulse may take place and so there may be some working conditions under which this counter cannot work. Up to now, these matching problem have been hardly investigated.

In this study the following things were systematically investigated: the static and dynamic characteristics of the memory and the control flip-flops with different geometric parameters, the behavior of the counter which are constructed by two of them, and finally the flow in the counter.

The obtained results are as follows:

(1) Under some clear and accurate conditions, the Warren's counter works satisfactory without any auxiliary circuit.

(2) In the control part, the input pulse flow don't reattach on any side wall, but branches into both output ports.

(3) The necessary condition under which the Warren's counter behaves successfully is as follows:

$$(1-2\alpha)\,Q_i > Q_{ms},$$

where α is the distribution factor of the control part, Q_i is the input pulse flow rate and Q_{ms} is the switching control flow rate of the memory part.

§ 1. Introduction

In the construction of a digital control system, the counter is a very important element. The first fluidic binary counter was reported by S. W. Warren[1]. This is constructed of two usual wall reattachment flip-flop devices, and has a very simple construction (**Fig. 1**). In his report Warren outlined the basic principle of his counter, but did not investigate more precisely about it.

T. A. Shook et al.[2] pointed out that the matching of the supply pressure into the memory part with the input pulse pressure became the essential condition for the acceptable

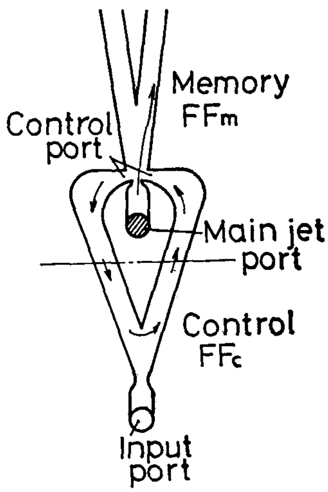

Fig. 1 Warren's fluidic counter

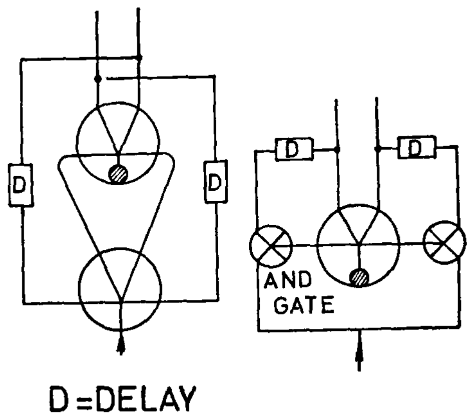

Fig. 2 Fluidic counter with auxiliary circuit

counting action of the Warren's counter. They, however, did not go too far into the matching problems, and attempted to stabilize the counting action by means of the addition of some auxiliary circuits into the primal Warren's one (**Fig. 2**).

After that, any investigation about the Warren's counter have not been reported. However, this counter has some advantages, i. e. it can be very simply constructed by a few elements, and so the air consumption is considerablly small.

In this study some experiments were carried out and the mathematical model of the counter was proposed in order to obtain some important matters of the Warren's counter design.

§ 2. Experiment

The experimental apparatus is shown schematically in **Fig. 3.** The Warren's counter is

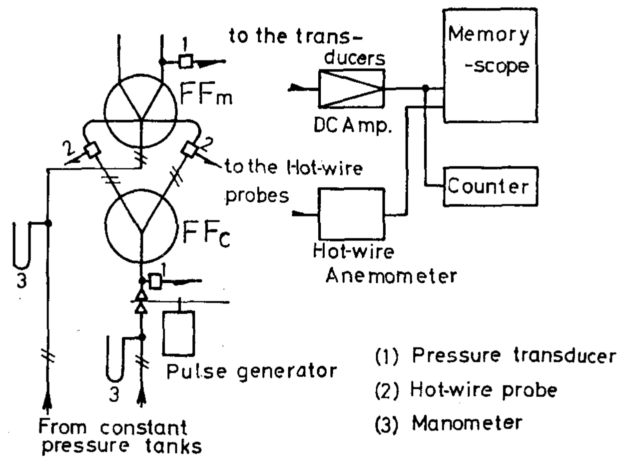

Fig. 3 Schematic diagram of experimental apparatus

consisted of two wall reattachment flip-flop devices and the control ports of one flip-flop (FF_m) are respectively connected with the output ducts of another flip-flop (FF_c) by means of vinyl tubes of 10 mm outer diameter, 8 mm inner diameter, and 180 mm length. In **Fig.3**, the pneumatic pulse generator is constructed by a rotating disk driven by a motor and a set of air jet supplying and receiving ducts. The rotating disk of 200 mm diameter is notched at four equal interval positions with 22.5 deg. central angle. The jet flow is blocked periodically by the rotating disk, and so the pneumatic pulses are obtained.

In experiments, the pulse pressure applied

Table 1 Geometoric parameters of flip-flops

Main jet nozzle width	1 mm
Control nozzle width	1 mm
Aspect ratio	4
Offset	0, 0.5, 1.0, 1.5 mm
Inclined wall angle	10, 15, 20 deg.
Splitter distance	6, 9, 12 mm

Tabce 2 Experimental conditions

Supply pressure of memory flip-flop P_s	0~0.3 kg/cm^2
Input pulse pressure P_i	0.025~0.085 kg/cm^2
Frequency of pulse	5 c/s
Rise time of pulse	3 ms

into FF_c is kept at some constant levels, the main jet supply pressure of FF_m are gradually changed, and the input and the outpt pressures are recorded by an oscilloscope.

If the output pressure of a counter changed at each of twenty input pulses, the action of the counter was judegd to be satisfactory. The main sizes of the flip-flop devices, and the experimental conditions are shown in **Table 1** and **2.**

§ 3. Results and Discussion

3.1 Construction of Fluidic Counter and Counting Action

The effect of the gains of the control flip-flop G_c and of the memory flip-flop G_m on counting action is shown in **Fig. 4.** It is deduced from these results that the larger the gains G_c and G_m are, the counting action is the better, i. e. the matching of the control part and the memory part is the better, and when the gain G_c is less than a critical value (in this case $G_{ccrit}=2$), the counter don't work satisfactorily, even if the memory flip-flop of any gain is combinated with this control flip-flop. The typical input and output wave forms of counter are shown in **Photo. 1.**

In **Fig. 5,** the same effects of the gains G_c and G_m are reexplained on the geometric para-

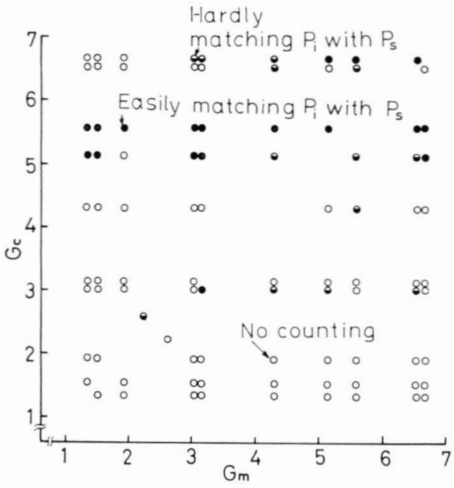

Fig. 4 Effect of gains on counting behavior

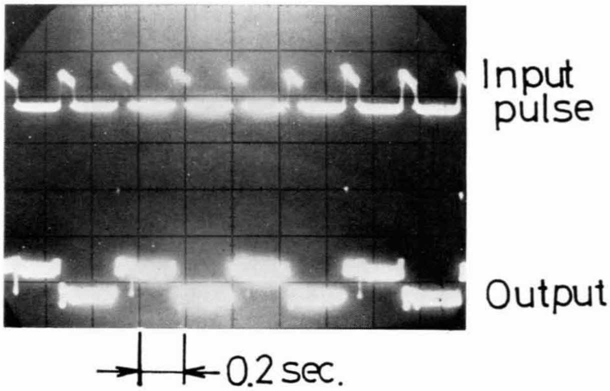

Photo. 1 Counting behavior

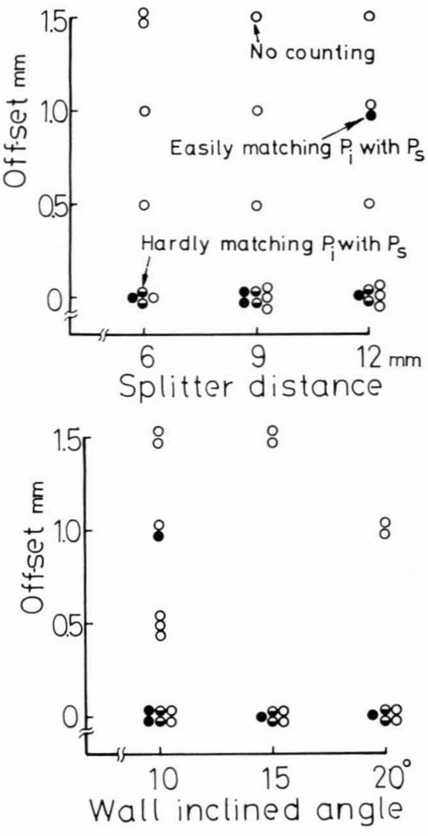

Fig. 5 Effect of geometric parameters on counting behavior

meters of the control flip-flop connected with the memory flip-flop of the gain G_m more than 6. From these it is unquestionable that the desirable flip flop, used in the control part of counter, must have no offset or a very small offset in the geometry, and the splitter distance and the wall angle are negligible factor in this experiment.

From **Fig. 4,** it will be noticed that the gain G_m affects on the countable range of the main jet total pressure P_s. And so, the relation between this P_s and the input pulse pressure P_i was investigated under the counter circuit consisted of a certain control flip-flop and one of the memory flip-flops of a large and a small gain G_m. These results are shown in **Fig. 6.** For a certain P_i, the larger the gain G_m is, the countable range of P_s is the wider. That is, the main jet total pressure P_s and the input pulse pressure P_i can be easily matched.

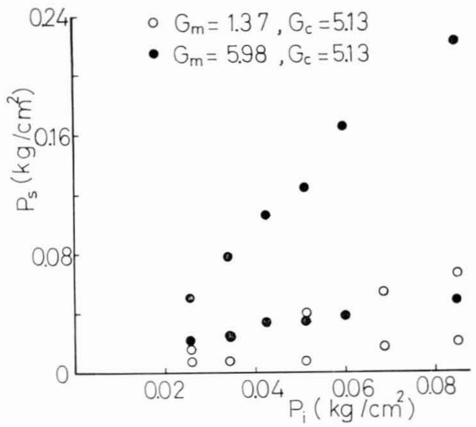

Fig. 6 Example of maching condition ··· upper and lower limits of matching are plotted.

The above mentioned results have effective suggestions for the design of the Warren's counter. In order to establish the design techniques, however, it will be necessary that the flow field in the counter is investigated in detail. Especially the circulation flow in the connecting tubes will be most important. By this circulation flow, after Warren, the input pulses are alternatively guided into the respective attaching side control port of the memory part and the counter works satisfactorily.

3.2. Effects of Some Factors on Circulation Fow

The effects of some factors on circulation flow are investigated by means of a hot-wire anemometer, as shown in **Fig. 3.** As known, the output ot the anemometer indicates an absolute value of velocity. So, in order to see flow direction, the small aluminium foil was hanged in the tubes. From the inclination of the foil the directions of velocities u_r and u_l were recognized. In **Fig. 7,** are shown the relations between the gain G_c or G_m and the circulation flow velocity u_{co} defined by following equation :

$$u_{co}=\frac{1}{2}(u_{ro}-u_{lo}), \tag{1}$$

where u_{ro} and u_{lo} are velocities in the respective connecting tubes without input pulse, and both velocities have the direction to the control ports of the memory part. In this experiment, the applied range of the main jet total pressure and volume flow rate are $P_s=0.01\sim1.0\text{kg/cm}^2$ and $Q_s=12\sim82\ l/min$ respectively. This results suggest the distinct mode that the velocity u_{co} is in inverse proportion to the gain G_m and indpendent of the gain G_c. As the flow gain of the flip-flop is defined here by the ratio of a supply flow rate Q_s to a switching flow rate Q_{ms}, the above mentioned matter, in other words, may be equivalent to the following : u_{co} is in proportion to Q_{ms}.

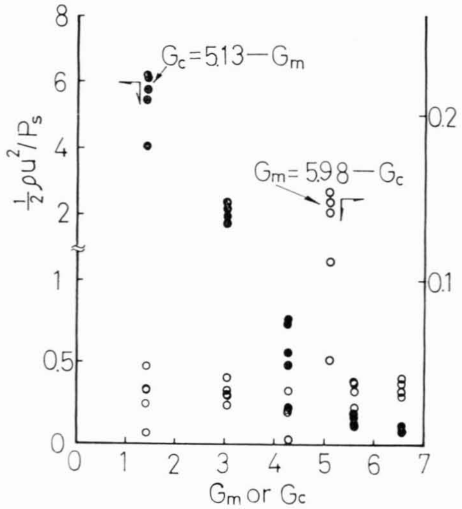

Fig. 7 Relations between gains and circulation flow velocites in connecting tubes

The modes of the velocities u_r and u_l in connecting tubes of working counter are shown in **Photo. 2.** By the above foil, it can be recognized that the pulse fluid flows into both control ports of the memory flip-flop. Thus, were introduced the distribution factor α defined as follows :

$$\alpha=\frac{u_r}{u_r+u_l}. \tag{2}$$

The factor α may be affected by the geometries and supply pressure P_s of the memory flip-flop. One example is shown in **Fig. 8.**

As shown in photograph and figure, it is interesting that the factor α is a function of P_s and asymptotic to 0.5, as P_s increases, and the input pulse does not completely reattach on the side wall of the control flip-flop (with the duration of 100 milliseconds and less, at least), but the pulse flow may be branched into the both output ducts of the control flip-flop. Thus, in the case of excessive P_s, the input pulse flow will be equally branched into both control ports of the memory part and so the switching function may be missed, and the counter can not work satisfactorily.

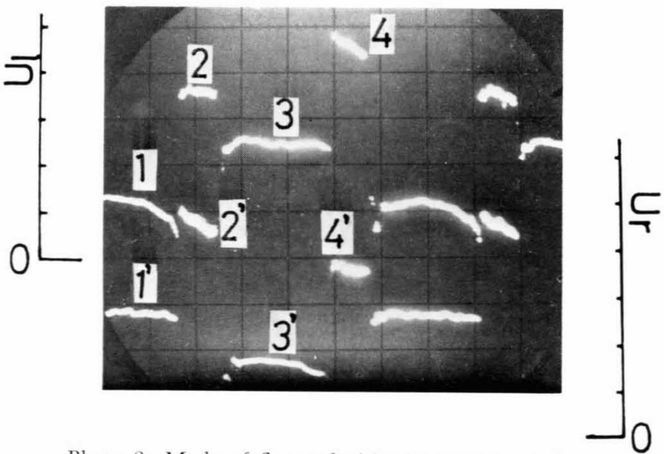

Photo. 2 Mode of flow velocities in counting tubes

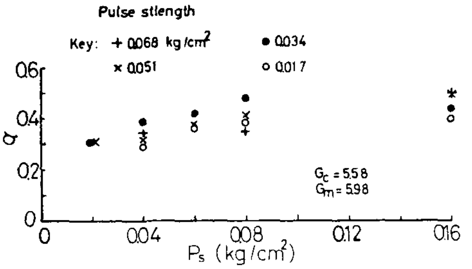

Fig. 8 Effect of supply pressure on distribution factor

3.3 Mathematical Model of Warren's Counter

On the basis of the above mentioned experimental results, the mathematical model of the Warren's counter will now be investigated. In this counter, Q_{ir} Q_{il} and Q_i, express the volume flow rate of branched input pulse flow into the connecting tubes and input pulse flow, respectively. Assuming the incompressible fluid, the equation of continuity is

$$Q_i = Q_{ir} + Q_{il}, \qquad (3)$$

Introducing the factor α, this equation can be rewritten as follows :

$$Q_{il} = \alpha Q_i, \quad Q_{ir} = (1-\alpha)\ Q_i, \qquad (4)$$

where α is not only a function of the geometric parameters, but also that of the supply pressure P_s.

Now, the switching criterion may be written as follows :

$$Q_{ir} - Q_{il} > Q_{ms}, \qquad (5)$$

where Q_{ms} describes the switching flow rate of a memory flip-flop. That is, when the difference of the volume flow rates into the control ports of the memory flip-flop is more than the switching volume flow rate of this flip-flop, the switching occurs. Substituting Eq. (4) into Eq. (5), the criterion can be represented by

$$(1-2\alpha)Q_i > Q_{ms} \qquad (6)$$

In **Table 3,** the results from Eq. (6) are compared with the experiments. By this model, the counting action can be well explained.

Table 3 Criterion compared with experimental results

Gain	P_s	α	$(1-2\alpha)Q^i$	Q_{ms}	Countable
G_m = 5.98	0.02	0.27	722	45	Yes
	0.04	0.33	543	69	Yes
C_c = 5.58	0.06	0.41	283	84	Yes
	0.08	0.48	63	95	No
G_m = 5.98	0.02	0.30	628	47	Yes
	0.04	0.38	377	68	Yes
G_c = 5.13	0.06	0.41	261	83	Yes
	0.08	0.48	47	92	No

§ 4. Conclusions

As the leading factors in the Warren's counter, were picked up the gains of the control part G_c and the memory part G_m, the geometric parameters of these parts, the input pulse pressure, the supply pressure to the memory part, and the circulation velocities in the connecting tubes. And the effects of these factors on counting action were systematically investigated.

From these investigations, the following things were made clear :

(1) Under some clear and accurate conditions, the Warren's counter works satisfactorily without any auxiliary circuit.

(2) In the control part, the input pulse flow does not reattach on a side wall, but branches into both output ducts.

(3) If the folowing condition is satisfied, the counting action is good :

$$(1-2\alpha)Q_i > Q_{ms}.$$

Refferences

1) S. W. Warren : *Fluid Amplification-3,* Diamond Ordnance Fuze Laboratory (1962)

2) T. A. Shook, T. F. Chen, and T. D. Redder : *Fluid Amplification-12,* Harry Diamond Laboratory (1964)