FLUIDICS IN CONTROL OF FLIGHT VEHICLES

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ABSTRACT

Evolution of variation characteristic of fluidic elements was analyzed. There was given technical information of reliability control fluidic devices based on long field experience:

- In control system of parameters aviation powerplant (gas turbine engine) in such environment as high and low temperatures, pressures and vibrations;
- In flight control system in such environment as perturbation action electromagnetic or nuclear radiation.

New organization method of combined flight control system created on automatic elements of different physical nature is proposed. In this control system the redundant one was realized wholly on fluidics.

Keywords: fluidics, sensor of angular velocity, backup control channel, flight vehicle, pressure of workspace, air, reliability, hostile environment.

INTRODUCTION

The control systems (CS) of flight vehicles (FV) have to maintain operability in the real conditions including electromagnetic fields and radiation, lightning discharges, and so on. Reliability of the FV CS is increased if the control hardware is based on diverse sets of elements. A special place among the automation facilities is occupied by the fluidics. Being a natural continuation of the traditional pneumatics, fluidics improved its speed by the order of two, reduced the outer dimensions of the control facilities, and expanded the area of their application mostly owing to higher reliability of operation in the extreme conditions. These qualities are due to the execution of the functional tasks of control on the flows of fluid media such as gases or liquids without using the moving mechanical parts and to the possibility of using the printed-circuit board technology to produce the components such as the primary functional elements, communication channels, resistances, capacitors, and so on. Virtually all electronic elements performing combinational (logic) or multistep (flip-flops, shift registers, and so on) operations have fluidic counterparts. Fluidics was very popular in the early 1960's. It was believed that one of its main tasks is the design of slow but reliable computers. This enthusiasm (or delusion from the today standpoint) was characteristic of many experts. A computer replicating the structure of a large electronic computer was constructed in the USA (Glaskin, Jacoby and Reader, 1965). Similar studies were also carried out in the USSR (Kasimov, Mamedli, and Melnikov, 2000; Kasimov and Popov, 2002).

Later on the designers and users for various reasons experience disappointment caused by a reduction

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of the application areas of fluidics. In our opinion, this was due to the regard for the general laws of operation of systems with many primary fluidic elements and developed interaction chains where faults occurred sometimes. Leaving aside the “romanticism” of the designers of these days who believed in the possibility of replacing electronics to a large extent, it is possible to specify the following points:

- fluidics can operate in severe environments characterized by high and low temperatures and pressures, vibration, shocks, electromagnetic noise, external radiation, and directed radiations of energy of diverse electrical nature;
- the functional fluidic elements can be manufactured by printing, the devices can be integrated;
- fluidics restores operability after possible overloads in supply and environmental pressures;
- the fluidic systems can be manufactured as a rule from uniform materials such as plastics, glass, metals, and so on, which makes them available for a long time owing to the lack of chemical corrosion, ageing, and deterioration of the physical properties of the components.

The practice of designing the fluidic systems is oriented to their realization in the form of programmable chains, which rules out the software errors. Therefore, the need arises, on the one hand, to explore ways to increase speeds of the fluidic devices up to some feasible limit and, on the other hand, to study the possibility of designing devices executing the tasks of control in the rigid real-time scale.

FLUIDIC ELEMENTS, MODULES, AND AGGREGATES

The functional characteristics of the primary fluidic elements are most important for high performance of the fluidic control devices. An intensive experimental study of various fluidic elements enables us to select the basic printed primary fluidic elements (profiles) for construction of more sophisticated fluidic devices. The following requirements were satisfied at that. For the active (powered) fluidic elements performing logical operations, the boundaries between the discrete states «0» and «1» were moved more apart by increasing the static stability of «0» and «1» with the use of additional internal (aerodynamic) and external (channel) negative feedbacks with the passage to the positive feedback at the instants of switching from «0» to «1» and vice versa (Kasimov, 1965). As for the passive fluidic elements (without pressure supply), only the internal aerodynamic feedbacks were used. At that, the aerodynamic noise to the other fluidic elements was reduced, and for the continuous-action fluidic elements the output noise components were reduced (Korotkov, Vanskiy, Zazulov, and Peisahovich, 1976). Modules executing the standard OR, NOR, AND, NAND, FLIP-FLOP and other operations were constructed of the primary fluidic elements (Mamedli, Samedov and Sobolev, 1998). On the standard board, the logic functions are realized, at that, with pressure-normalized and flow-normalized inputs and outputs. Combination of active and passive elements within a module improves their mutual modes of operation and in fact minimizes the aerodynamic input and output noise, which enables one to interconnect the modules into more complicated circuits without mutual updating of their adjustments. As applied to the FV control, such molded-plastic modules are intended for the standby aircraft CS’s.

AIF was developed for control of the aviation GTE’s (Popov, 1988). In it, the fluidic elements were cut out from the stainless metallic plates through profiles on the programmed electro-erosion machines and then assembled into aggregates which executed the desired algorithms of control of the engine individual parameters. The AIF was intended for designing high-reliability CS’s powered by the on-board air from the GTE compressor at the temperature of 600°C. Another distinction of the AIF is its modularity, that is, the possibility of using the same blocks to design other control devices.

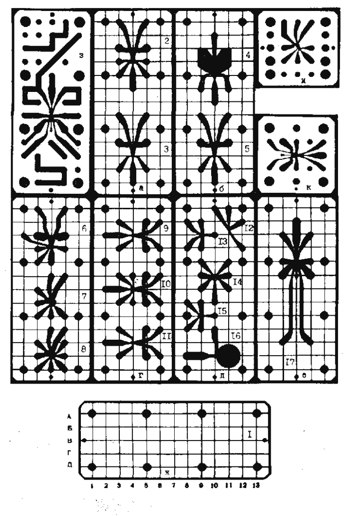

Fig. 1. Fluidic boards

Standard 96 x 40 or 40 x 40 mm plates (Fig. 1) of thickness 0.6, 0.8, or 1.0 were used to manufacture the fluidic and communication boards, whereas the spacers were made of 0.5 mm-thick plates. Breadboarding of the individual circuits makes use of the boards with the required set of different elements that are assembled into a packet with spacers clamped between them. The width of the supply channels of the active fluidic elements varied from 0.4 to 0.8 mm depending on their purpose. The modular coordinate grid with 3.5 x 3.5 mm cells simplifies the interlayer conjugations of the element boards and allows one to assemble promptly any circuit by means of the breadboarding connecting boards or plastic tubes and carry out the necessary testing. The designed and refined units are individual aggregates having their installation places on the engine. The fluidic aggregates operate under unstable supply pressure (of 0.5 kPa and higher) and variable environmental pressure. The AIF has a library of programs developed for automatic cutting of more than twenty primary discrete and analog fluidic elements, as well as various configurations of channels with branchings and turns. Devices for acquisition of information about the control parameters such as the angular velocity fluidic sensors (AVFS), sensors of pressure ratio, revolutions per minute, flows, temperature, and so on are essential for the fluidic CS's. The purpose of AVFS is to generate the feedback signal for control of the FV spatial position. The AVFS was designed for the backup flight control system (Stepanov, Kasimov, Belukov and Vologodskiy, 1999).

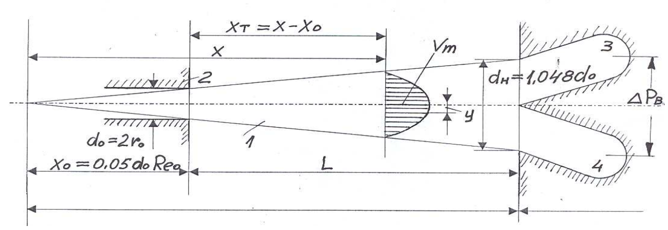

Fig. 2. Diagram of the sensitive elements

Figure 2 depicts the diagram of the sensitive elements. Upon leaving the supply nozzle 2, the laminar air jet 1 propagates in the inertial space and comes to two differential reception channels 3 and 4. In the case of no angular velocity, jet 1 is not shifted about the reception channels 3 and 4, and the difference of static pressures Δp in channels 3 and 4 is zero. In the presence of the angular velocity, the free jet is shifted about the axis of pressure receivers. The shift is proportional to the angular velocity and is measured by the difference of pressures Δp in channels 3 and 4.

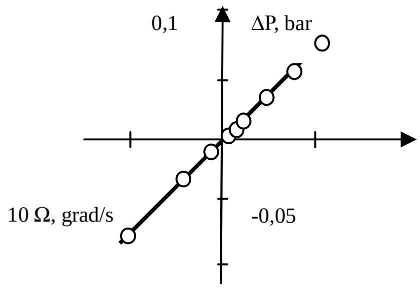

Fig. 3. Static characteristic of angular velocity

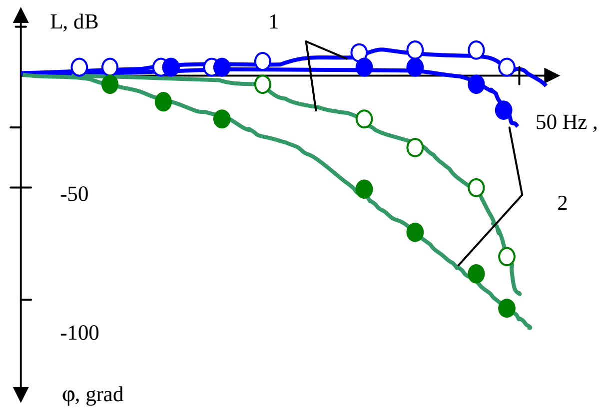

Fig. 4. Amplitude-phase-frequency characteristic

Figure 3 shows the static characteristic, and Fig. 4, the amplitude-phase-frequency characteristic (APFC) with jet flight length L = 12 mm and supply nozzle 2 width 0.8 mm. The angular velocity is measured within the range of 0…80°/sec. Linearity of the static characteristic of the AVFS with ten-stage fluidic amplifier with gain 105 on the whole is at least 1%, the phase shift is 10° at the frequency 4 Hz and load in the form of a flowless chamber. At connection of a load in the form of a long pipeline (d =2 mm, l=15 m), the phase characteristics worsen appreciably. The time constant in angular velocity of the entire fluidic channel at that exceeds 100 ms. Any control system needs a storage or generator of the reference parameter such as either the level of signal intensity (pressure, for instance) or the relative distribution of the levels in space (digital code) or time (frequency, period, phase, pulse shape). For the FV operating under different supply and environment pressures, it is difficult to have a constant reference pressure. In this case, the constant (reference) frequency proves to be the most useful parameter. The AIF system includes a reference frequency generator (RFG) with fluidic excitation system retaining its operability under variations of the supply pressure, temperature, and environment pressure and under dynamic overloads. Examination of different schemes and designs of the fluidic RFG's demonstrated that the fluidic mechanical oscillation generator with the pulse scheme of excitation of the balance resonator is the best choice (Stepanov and Shihman, 1992).

The pulse scheme of excitation enables one to limit the supply of excessive power to the mechanical generator and thereby reduce the impact of pressure variations on the balance oscillation swing and, consequently, on the frequency of its natural oscillations. The coordinating communications lineup the exciting pulse and the peak of the balance oscillatory velocity. The balance wheel has the form of a planar disk connected to the stationary axis by flexible spokes. At its periphery there are shutters with openings whose edges at oscillations of the balance modulate a flow coming to the input of the excitation circuit. The force pulses from its output are directed by the nozzles to the planar flexible spokes to push the balance at the passage of the neutral position. The RFG is excited by the supply pressure of 20 KPa. Figure 5 shows the frequency f vs. the supply pressure. The error in frequency is 0.12% within the dynamic range of supply pressure variation 1:10.

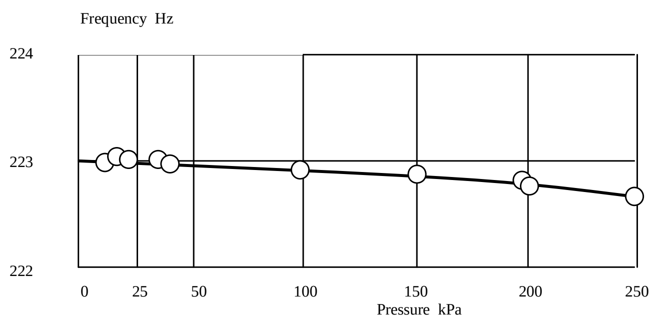

Fig. 5. Frequency vs. the supply pressure

The existing maneuverable aircraft use configurations with aerodynamic (static) instability at the subsonic flight modes, which increases the requirements on the reliability of the CS maintaining the given characteristics of aircraft stability and controllability. Reliability of the electrical remote control system (ERCS) is based on the multiple redundantization of the control channels, but even in this case it is not protected against transient failures of the on-board electrical power supply. It was required to estimate the possibility of designing a fluidic backup for the emergency control of the aircraft longitudinal motion as a solid body using the hydro-mechanical part of the electro-hydraulic control actuator (CA) of the ERCS (Vanskiy and Kasimov, 1976).

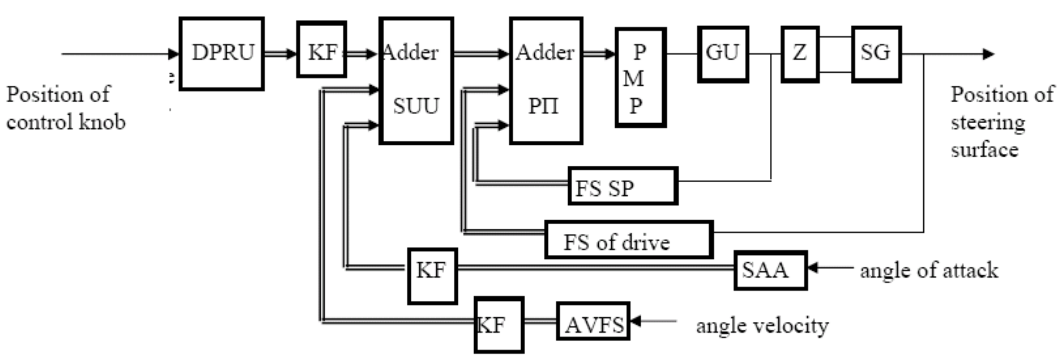

Fig. 6. Working model of fluidic backup control channel

Figure 6 depicts a block diagram of the working model of the fluidic backup control channel. The system has an input circuit from the control stick to the CA input summing amplifier and a feedback circuit from the attack angle sensors (AAS) and the angular velocity sensors (AVS) of the aircraft with correcting filters (CF), as well as the loop by the position of drive rod and the sliding valve (Vanskiy and

Kasimov, 1976).The pneumatic «nozzle–shutter» transducer having actually no dynamic errors within the control frequency band was selected as the sensor of the linear displacements for measuring the position of the pilot's control stick, CA rod, and hydraulic control valve. Air was chosen as the working medium despite its essential disadvantages such as the high compressibility and relatively low sound speed which limit the length of the pipeline connections owing to the requirements on the dynamic characteristics of the fluidic system paths. As compared with the liquid medium, the advantages of the gas medium lie in the availability of the working medium (air), possibility to work at low pressure, small size, mass, and power supply, fire-resistance, virtual insensitivity to overloads, and simplicity of operation.

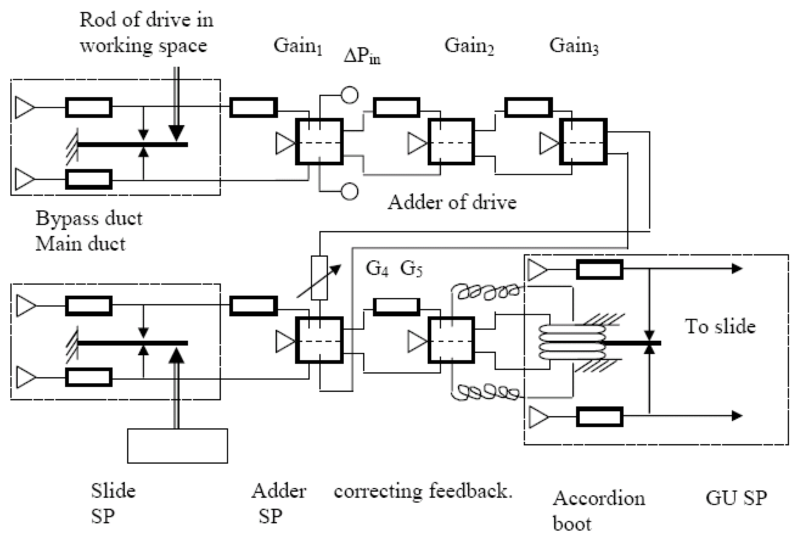

Fig. 7. Block diagram of the fluidic CACS

Figure 7 depicts the block diagram of the fluidic CACS. The issues of conjugation of the fluidic channel with the electric backup channels are not discussed here. The differential signal of the sum of signals from AAS and AVS arrives to the inputs 3 and 7 of the amplifier A1. The routes of the fluidic chain of the control signals from all feedbacks are diagrammed in Fig. 8. The pipelines of 3 and 12 m that are defined by the location of the pilot's control stick and the weathercock AAS are the weak points of the chain. The AVS is located closer to the CA drive because its characteristic is independent of the place of installation.

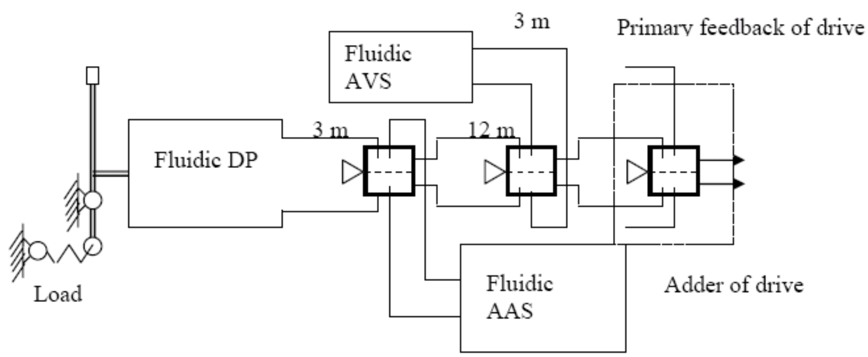

Fig. 8. Routes of fluidic chain of control signals

The CA with fluidic control based on the hydro-mechanical part of the redundant electro-hydraulic CA has a two-chamber power hydraulic cylinder (PHC), throttling hydraulic control valve, and the multichannel autopilot servo controlling the position of the hydraulic control valve slide. The fluidic actuator CS was constructed by substituting in one of the redundantization channels the fluidic elements for the electrical ones with retention of its structure. System operability was verified by including the aircraft mathematical model into the closed loop with the physical CS breadboard. The heaviest flight modes were modeled in both the statically stable and statically unstable variants of the aircraft configuration. The basic aim of modeling was to estimate the possibilities of providing stability of the closed-loop system. The aforementioned AIF system underlies the designs of more than twenty fluidic controllers of various GTE parameters using the air from the GTE compressor at temperature up to 600 º C.The pneumatic CS's enable one to provide the optimal characteristics of the power unit by using nontraditional control parameters characterizing the air flow through the engine such as the ratios of air pressure in different sections of the engine, changes in the relative local velocity, values of the local Mach number, changes in the position of compression shocks, striking angles of air flow on the compressor blades, and so on. The flight tests of the fluidic CS of the air inlet wedge bar panels were successfully carried out in previous work by the author (Viktorov, 1976Two schemes used the ratio of the static pressure P_{st} on the internal wall of the air inlet channel to the full pressure P_{st}/p^*. In one of these schemes, the pressure ratio signal was generated by means of two flow reduction gears and one static pressure taken off the channel wall with support of the mode $P_{st}/P_{red1} > \varepsilon > P_{st}/P_{red2}$. In the second scheme, the reduced full pressure was compared using the Laval nozzle with two static pressures supporting the mode $P_{st}/p^* < \varepsilon < P_{st2}$. The system was supplied either by the engine compressor or the approach ram air. In the third scheme, control was based on the local Mach velocity in the channel within the dead zone. To retain the anti-surge margins, correction by means of the pneumatic weathercock sensors of the attack angle (AAS) and sideslip, as well as by the signal of air pressure drop after the compressor was used in the system. In all schemes, as soon as the work signals leave the dead zone the logic unit generates a signal to pull the wedge panels in or out subject to the mismatch sign. The flight tests of the fluidic CS were carried out at the Mach velocities from 1.1 to 2.1 within the height range H=12…20 km in the course of horizontal rectilinear speedup and deceleration, at climb, turns, and sliding with the extreme deviation of pedals, as well as at engine throttling and pickup, in the modes of surge and autorotation. In the course of flight tests, the CS worked faultlessly in all of these modes. Good characteristics demonstrated by the air inlet CS made for further successful use of fluidics in the GTE automation. The passage of the psychological barrier of distrust to such control systems was of no less importance.

Controllers of the compressor bypass valve and the input directing apparatus (IDA) were designed for the GTE family to prevent the surge in the engine D-36 of the YAK-42 aircraft (Viktorov, 1976). The controller relies on the fluidic sensor of the pressure ratio, gas-dynamic divider, flow reduction gears, fluidic comparison element, fluidic amplifier, and an actuator generating commands to the mechanisms of air bypass from the compressor. The controller has a relay characteristic with hysteresis within 0.1…0.25. Its mass is equal to 2.5 Kg. Such modular fluidic controllers were designed and found wise use for the GTE's of passenger aircraft such as YAK-42, AN-24, AN-74, IL-96, Tu-204, and others. There was not a single claim for replacement during the entire time of their use. An experimental small two-mode athodyd was designed (Viktorov, 1976) for which an astatic fluidic control system of hydrogen flow in the CC and cooling system was selected. This engine was for the first time tested in flight by the hypersonic flying laboratory (Vaiser and Kasimov, 1975). The engine gas-dynamic parameters in the form of pressure ratios in the sections of engine channels were used for control of the hydrogen flow. On the whole, the implemented fluidic CS of fuel flow that worked for a short time at a temperature of more than 900 º C performed all the necessary functions at four flight starts in all modes along the flight trajectory, including limitation of the CC wall temperature and prevention of surge at thermal CC blocking with repeated engine startup.

PROMISING FLIGHT VEHICLE CONTROL SYSTEM

Tests and practice of using fluidics in FV control, suggest promising principles of designing the backup CS's not only for the FV's. In connection with the advent of sophisticated technological plants, complexity of their CS's grows dramatically, and higher requirements are presented on their survivability under the action of the destabilizing factors (DF). Indeed, any fault of the FV CS's, nuclear power stations, oceanic liners, passenger coaches and trains can lead to unpredictable consequences and catastrophes entailing huge human and economic losses. That is why survivability of the CS's of such plants is so topical. The redundant electronic high-performance FV CS's support acceptable operability in rigid real time upon occurrence of physical malfunctions (faults and failures) in their individual elements (Vaiser and Kasimov, 1976). Since the methods of detecting the design errors in the applied and system software also are well developed for these systems in previous work by the author (Zalmanzon, 1965), they find wide use as the main FV CS's. However, even the most sophisticated redundant electronic structures (Zalmanzon, 1966) cannot protect them against the external DF's that can entirely disable them for some time, which in rigid real time implies inadmissible interrupt of the control and loss of the FV.

Let us consider an FV CS protected against both its inherent and external DF's. It operates in two modes. In the working mode, the main, electronic CS operates in the control loop, whereas the backup, fluidic one idles, although calculates in parallel the same algorithms as the main system. Expectedly, the backup CS channel has lower accuracy. Therefore, after each basic cycle the main CS channel corrects its backup counterpart. Consequently, the CS backup channel over small intervals must approach accuracy of the main channel. Upon occurrence of an external DF, the system switches to the emergency mode and activates the backup channel. Upon cessation of the external DF, computations are resumed in the main channel using the information from the backup one. The above structure providing the virtually absolute survivability can be realized only upon attaining the desired speed of the fluidic elements and digital integrators of the indicated type. As was shown in (Zalmanzon, 1965), the speed of fluidic elements grows with reduction of their linear dimensions and increase in the velocity of gas flow in the supply channels. Therefore, the main methods for increasing the speed of the fluidic element-based backup CS are as follows:

- Miniaturization of the fluidic elements primarily by narrowing the supply channels of the fluidic elements to 0.1 mm and less;
- Use along with air of less dense gases such as helium, hydrogen, and helium-hydrogen mix;
- Use of the working gases having higher sound wave speeds (the same helium and hydrogen);
- Improvement of the manufacturing technology and transition to devices with the degree of integration of up to 15...20 and more elements in the cubic centimeter. Obviously, by using the aforementioned method, one can reach the maximum speed.

The planar technology is most popular in the manufacture of the fluidic devices. The fluidic elements and functional modules in the form of printed boards with communication channels are assembled into multilayer modules performing the desired control laws. In these constructions, it is the linear dimension that plays the speed-defining role because the passage of signal through the device circuit depends only on it. Therefore, in what follow we consider only its impact on the speed of fluidic elements. For the transient motions, the dynamic similarity criterion is expressed by the dimensionless Strouhal number

$$S_t = \frac{VT}{L} \tag{1}$$

where V is the gas flow speed; T is the characteristic time (period for the transient periodic processes); and L is the characteristic linear dimension. If the variables V, T, and L take different values denoted below by the subscripts 1, 2, ... n, then for these aerodynamic processes

$$\frac{V_1 T_1}{L_1} = \ldots = \frac{V_n T_n}{L_n} \tag{2}$$

If the mean flow speed does not vary (for the fluidic elements this will take place for constant supply pressure), then

$$\frac{T_1}{L_1} = \ldots = \frac{T_n}{L_n}, \ \frac{L_1}{L_2} = \ldots = \frac{L_{n-1}}{L_n} \tag{3}$$

Therefore, the process time is directly proportional to the element's linear size. Hence, reduction in the linear dimensions of the supply channel (flow area) of the fluidic element reduces the flow of working medium proportionally to the square of dimension. The power of the supply flow is reduced by the same factor. This characteristic is extremely important for the FV because it defines the CS size–mass characteristics (SMC). The physical characteristics and parameters of the working gas define the gas-dynamic processes in the fluidic elements: the gas supply pressure, pressure in the environment to which the gas is discharged upon passing the fluidic devices, the gas itself with its density and speed of sound wave propagation in it. Let us consider the impact of these parameters of the working medium on the speed of fluidic elements. We assume for simplicity that the coefficient of working medium flow from the nozzle retains constant value at variations of the supply pressure, working medium density, and absolute environmental pressure. For the subcritical flow speeds, the air mass obeys the formula:

$$G = \varepsilon f g \sqrt{2\rho_0 p_0 \frac{k}{k-1}\left[\left(\frac{p_1}{p_0}\right)^{\frac{2}{k}} - \left(\frac{p_1}{p_0}\right)^{\frac{k+1}{k}}\right]}, \tag{4}$$

where ε is the flow coefficient, f is the fluidic element nozzle cross-section area, g is the gravitational acceleration, p_0 and p_1 are the absolute gas pressures before and after the supply nozzle, k is the isentropic index, and ρ_0 is the density of gas before the supply nozzle. Since the gas density after the supply nozzle follows p_0/gRT, where R is the gas constant and T is the Kelvin absolute temperature, expression (4) is representable as

$$G = \varepsilon f g \sqrt{\frac{2g}{RT}\frac{k}{k-1}\left[\left(\frac{p_1}{p_0}\right)^{\frac{2}{k}} - \left(\frac{p_1}{p_0}\right)^{\frac{k+1}{k}}\right]}, \tag{5}$$

according to which the weight flow of gas through the supply nozzle is for a given absolute gas temperature a function of the absolute pressure at the nozzle input and the ratio of this pressure to the absolute gas pressure after the nozzle (environment). Formula (5) is calculated using the tables of gas-dynamic functions. However, comparative analysis can do without accurate determination of flow; it suffices to determine the qualitative nature of the dependence of speed on the aforementioned parameters within the range of observation of the self-similarity principle of gas-dynamic processes. Therefore, it is possible to use formula (3) which provides results that are close to those obtained through (2) for the entire range of the subcritical flow modes if the gas density is calculated from the pressure p_1

$$G = \varepsilon f g \sqrt{2\rho(p_0 - p_1)}, \quad \text{or} \quad G = \varepsilon f g \sqrt{2\rho\Delta p}, \tag{6}$$

where Δp is the difference of pressures before and after the nozzle. Correspondingly, for the volume flow,

$$Q = \varepsilon f g \sqrt{\frac{2\Delta p}{\rho}} \tag{7}$$

For the same nozzle cross-section and different flow conditions, the relations of the weight flows are representable as

$$\frac{G_1}{G_2} = \sqrt{\frac{\rho_1}{\rho_2}} \sqrt{\frac{\Delta p_1}{\Delta p_2}} \tag{8}$$

and those of the volume flows as

$$\frac{Q_1}{Q_2} = \sqrt{\frac{\rho_2}{\rho_1}} \sqrt{\frac{\Delta p_1}{\Delta p_2}} \tag{9}$$

For the FV CS's, the most important characteristics of the fluidic elements are speed, weight flow of the working medium, and power consumption. In fact, they define the FV CS SMC. Let us also consider the dependences of these characteristics on the supply pressure, choice of the working medium, and pressure of the environment into which it is discharged. For convenience of specifying the nature of these dependences in the fluidic elements, we introduce relative coefficients and compare them with certain coefficients used as the initial ones. The certain values for the active fluidic element having supply channel width 0.4 mm, operating on air with excessive supply pressure 1 kPa at absolute environmental pressure of 100 kPa are used as the initial values. Under these conditions, the volume flow Q = 40 nl/h. At that, the specific weight of air is 1.29 kg/m^3, and the weight flow is G = 0.05 kg/h. We introduce the following relative coefficients. The relative speed coefficient λ_V corresponding to the ratio of the gas flow through the supply nozzle at operation with the chosen working gas and supply pressures of the working medium and environment to the speed of flow though the nozzle under the aforementioned conditions. In the calculations of λ_V, the ratio of speeds can be replaced by that of the volume flows under the same conditions. The relative coefficients λ_G and λ_N define the corresponding ratios of the weight flows and powers to the same initial values, the aforementioned coefficients for these conditions being equal to unity. The coefficients for the fluidic elements operating with different working media such as air, helium, and hydrogen at different excessive environmental pressures (0.1; 1.0; 10, and 100 kPa) and absolute environmental pressures (100; 10, and 1 kPa) were calculated from formulas (3) - (6) and compiled into a table. In all cases, the flow of working medium was assumed to be subcritical. The calculations assumed that the flow is isothermic and the working media densities are proportional to the absolute environmental pressure.

Table 1. Coefficients of fluidic elements with different working media

Workspace	Overpressure of power supply	Absolute pressure of environment		
		100 kPa	**10 kPa**	**1 kPa**

	kPa	λ_V	λ_G	λ_N	λ_V	λ_G	λ_N	λ_V	λ_G	λ_N
Air	0,1	0,32	0,32	0,03	1,0	0,1	0,1	3,2	0,032	0,32
	1,0	**1**	**1**	**1**	**3,2**	**0,32**	**3,2**	**10**	**0,1**	**10**
	10,0	3,2	3,2	32	10	1	100	-	-	-
	100,0	10	10	1000	-	-	-	-	-	-
Helium	0,1	0,84	0,12	0,08	2,65	0,038	0,265	8,4	0,012	0,84
	1,0	**2,65**	**0,376**	**2,65**	**8,4**	**0,12**	**8,4**	**26,5**	**0,038**	**26,5**
	10	8,4	1,2	84	26,5	0,38	26,5	-	-	-
Hydrogen	0,1	1,2	0,084	0,12	3,8	0,026	0,38	12,0	0,008	1,2
	1,0	**3,76**	**0,265**	**3,76**	**12**	**0,084**	**12**	**37,6**	**0,026**	**37,6**
	10	12	0,84	120	38	0,265	380	-	-	-

Analysis of the tabulated data suggests the following conclusions:

- Independently of the gas used by the fluidic elements, the density of the working medium is the main factor defining the coefficients λ_V, λ_G , and λ_N for the given excessive supply pressure.

- The speed of the fluidic elements grows dramatically with reduction in the working gas density and absolute environmental pressure. At that, there is an appreciable power gain as compared with that reached only by the increase in the supply pressure.

For example, in order to increase by the factor of three the speed of elements working with air at supply pressure under normal condition, a ten-fold increase in the supply pressure (up to 10 kPa) is required. At that, power consumption is increased by the factor of 30. With helium and the same supply pressure, the speed increases by the factor of 8.4 and power increases by the factor of 30. With hydrogen, this gain is even more pronounced: the power increases by the factor of 30, the speed, by the factor of 12. Yet, if the absolute environmental pressure is reduced from 100 kPa to 10 kPa, then we get the same increase in speed without any increase in the supply pressure. At that, the power increases only three times, and the weight flow decreases three times. At simultaneous reduction in the absolute pressure with the use of light gases, the speed of fluidic elements may be more than 30 kHz. The above discussion concerns the fluidic elements with the supply channel width of 0.4 mm. The up-to-date technology allows one to make channels of width 0.1 mm, which increases speed by the factor of four and enables the speed of 100 kHz. Further increase in speed up to 200 kHz is possible by making the supply channels of widths smaller than 0.1 mm and increasing the flow speeds up to 800 and over 1.000 m/sec, respectively, for helium and hydrogen, the speeds of sound being, respectively, 965 and 1284 m/sec. Special studies are required to optimize transmission of the information signals under such conditions.

CONCLUSIONS

- The backup FV CS's may be implemented with the fluidic elements as special-purpose computers.

- High-speed fluidic-electrical and electrical-fluidic converters with switching frequency of at least 5 kHz are required for fast real-time information exchange between the main and backup CS's.

- Substantial increase in the speed of fluidic devices is concerned primarily with reduction in the linear dimensions of the primary functional fluidic elements and in the absolute environmental pressure (in the cavity of working medium discharge) and with the use of light gases.

- The present level of science and technology enables speed of fluidic element of the order of 200 kHz.

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