

## Evaluation of prospective directions of production of fluidics systems

A Davydov<sup>1</sup>, I Zyubin<sup>1</sup>, O Gavryushina<sup>2,3</sup> and A Sinitsyna<sup>2</sup>

<sup>1</sup>Moscow Power Engineering Institute

<sup>2</sup>Bauman Moscow State Technical University

<sup>3</sup>E-mail: gavros7@rambler.ru

**Abstract:** the modern possibilities of manufacturing technologies of pneumatic automation systems based on fluidic switching elements are considered. The perceptivity of using the fluidic systems as the alternative to using the relay automation systems is noted.

### Introduction

The fluidic systems have proven themselves in various industries where high reliability and explosion and fire safety are needed, for example, in process automation in the food and chemical industries [1–5]. However, a certain technological complexity of the design and manufacture of control units limited the general industrial use of the fluidic.

At the same time, sequencing automation systems based on electromagnetic relays have found quite wide application [6–7]. Relay automation has good qualities in terms of compact installation, maintainability, but have a relatively high cost and short service life. The use of fluidic automation makes it possible to reduce the cost of automation modules and increase their service life. Modern design and manufacturing technologies make it possible to almost completely replace relay units to units of fluidic switching elements with a significant increase in the reliability and service life of sequencing automation systems. Indeed, the service life of typical industrial coupling relays is about  $10^5$  switching cycles, while the resource of a fluidic control system is limited by the quality of the membrane amplifier and provides about  $10^6$  cycles. At the same time, the number of critical elements limiting the life of the system is much smaller, since membrane amplifiers are installed only at the output of the control system, and arithmetic logic units are formed on the basis of fluidic elements, with practically unlimited service life due to the absence of moving parts.

The changes in technology make it possible to obtain fluidic elements at a significantly lower cost than coupling relays, even within small batches. Also design techniques for connecting fluidic elements do not differ from the techniques used in the formation of schemes of electronic device in the widely known ECAD systems.

As the advantages of the relay can be specified the load capacity when up to 20 of the same type of relay are connected to one contact block and each such relay provides control of four independent contact blocks. At the same time, as fluidic elements have a relatively low (up to 5 similar connected elements) load capacity. However, a huge margin on the speed of fluidic elements makes it possible to align this disadvantage by using coupling fluidic power amplifiers of the data signal.

A separate question is the power provision of the fluidic automation system with low-pressure air. There are a number of ways to reduce the air consumption by the system as in general, as well as



reduce the cost of its manufacturing as part of a pneumatic actuator, the consideration of which is beyond the scope of this work.

The factors that provide the advantages of the fluidic system over relay automation are a long service life and operation speed. The experimentally proved that the maximum achievable cutoff frequency in the system on bistable fluidic elements with a blast nozzle width of 0,4 mm is currently from 0,5 to 9 kHz, depending on the supply pressure. At the same time, electromagnetic relays are limited by the actuation time and relay-releasing time of the lock of 25 ms, which corresponds to frequencies up to 20 Hz.

The factor of increasing actual frequencies and reducing air consumption are associated with the need to reduce the dimensions of the fluidic element, in particular, to reduce the width of the blast nozzle. Taking into account the need of the preparation compressed air (drainage and cleaning) for industrial use, elements with a size of 0,4 to 0,05 mm are especially interesting. In current systems of volumetric pneumatic automation, for example, made by Festo and Camozzi, splits of less than 0,1 mm are allowed, standard filters provide filtering of particles up to 40 microns. A further decrease in the nozzle width allows increasing the actual frequencies of automation systems, but is accompanied by a significant complication of the power fluid preparation system.

## Methods

The sizes of the flow part of the fluidic element allow classifying it as a micro product. The main types of technologies for the manufacturing of micro products are discussed in detail in [8]. Over the past period, new types of technological processes did not appear, but they developed qualitatively.

In general, the list of technologies providing the possibility of manufacturing microfluidic elements includes the following types: mechanical (cold stamping and hot plastic stamping), electrophysical methods (electroerosion and laser), chemical methods (chemical milling, including photochemistry, electromachining, galvanoplasty) [9–10].

Stamping, both cold and hot, of miniature products can be effective in mass production. However, the cost of machine-tool attachment and machine accessories manufacturing is very high, and there is no flexibility in production. The requirements for feedstock are also pretty high in terms of stability of stress-related properties. Due to these disadvantages, this method will not be considered in detail in this article.

The most accurate replication of a given contour is possessed by electrodischarge machine with continuous wire feed. Modern types of machines work with a diameter of 20 microns of wire and can ensure the accuracy of the sizes of the flow part (maintaining a certain technology)  $\pm 5$  microns. This method has good manufacturing flexibility, but the manufacturing speed of parts is relatively low. Although thin plates are processed in a single batch and one cycle makes it possible to obtain from 10 to 20, and with corresponding technological development a larger number of modules, refixturing the thread into new holes makes it difficult to combine elements into functional blocks. Respectively, such a technology is more suitable for model-experimental work and the production of small series of typical elements.

The laser cutting technology is a pretty interesting area nowadays. Cutting can be carried out both by the material itself and by the easily removed sacrificial layer applied to it. For the manufacture of flow parts according to a variant where the flow part is a through profiled hole, it is possible to use the methods used in the electronic industry in the manufacture of templates for applying solder paste to printed circuit boards. Moreover, solid-state lasers, including fiber ones, are the most effective for cutting metals. For plastics processing it is possible to use cheaper lasers based on gas filled laser tubes.

Most fiber-optical lasers come with lenses with a focal length of 2,85-4,0 inches, which allows to get a minimum spot diameter of 25 microns [11,12]. For a gas filled laser with a focal length of 2 inches, the minimum spot diameter will be much larger — 120  $\mu\text{m}$ , which is associated with a significantly longer radiation wavelength [13]. Respectively, laser cutting can theoretically provide nozzles with a minimum width of 25 to 75 microns in metal when using solid-state cutting heads and

from 0,12 to 0,4 mm on gas-filled lasers, depending on the quality of realization of the machine's position control system.

The main disadvantage of metal platescutting is the thermal reflow and contamination of the edges of the cutting, which leads to low-precision manufacturing of fluidic products. Moreover, with a decrease in the thickness of the blank and an increase in the width of the blast nozzle, the influence of this factor decreases. According to the results of studies of the processing of stainless steel by an fiber laser inMoscow Power Engineering Institute, the blast nozzle width of 0,2 mm was practically achievable with a ratio of this width to the blank thickness of 1: 1. Moreover, after cutting the dirt on the surface of the plate (along the edges of the cut), it is necessary to remove, for example, by electromachining. This ratio (1: 1) in comparison with the often used ratio 1: 2 reduces the operation speed and load capacity of the fluidic element, but also reduces air consumption and increases the compactability of the stack installation. It should be noted that the potential of the method has not been exhausted due to the limited time of the researches.

An interesting idea was not to carry out cut through by a gas laser, but to carry out the so-called laser engraving. A non-metal layer is applied to the metal surface, for example, epoxy resins or various types of coatings based on polyester or acrylic resins. There are various technological features in this process. Some of them are associated with the features of focusing and the effect of the beam on the polymer. When polymer is burned, combustion products are emitted, which, settling, change the processing space. Also, single holes are made in the form of a crater, tapering to the bottom. Both problems can be solved by carrying out the processing in two steps. As a result, the combustion products are burned out and, with subsequent washing, are carried away from the surface of the base plate, the bottom of the crater is burned up, while the boundaries of the crater are out of the energy flow and saved. It turns out a relatively clean surface with good verticality of walls.

Processing in several steps has a disadvantage - a component of the mechanical positioning of the focusing system is added to the beam focusing error, which additionally limits the possibility of reducing the width of the nozzle. The real result achieved in practice on typical industrial equipment corresponds to a nozzle width of 0,2 mm, which is relatively close to the technological capabilities of CO<sub>2</sub> lasers.

At the same time, laser technologies are more likely methods acceptable for the manufacture of prototypes and small series of devices, for them mass production it is economically feasible to produce the products by chemical methods.

It should be immediately noted that the ratio of the nozzle width to the element height 1: 2 excludes the possibility of effective use the chemical milling, as the speed of the process across the thickness of the material is comparable with the pickling of metals speed in plan. Experiments with aluminum have confirmed this phenomenon: the contours of the hole are greatly distorted.

Electrochemical processing (when pickling of metal is carried out along the contour of the template) has a greater accuracy of repeating the contour, however, the manufacture of templates is difficult, since their accuracy must be higher than the accuracy of the flow parts of the fluidic elements themselves. Also, maintaining the quality of the electrochemical process, due to the small size of the channels, is difficult. Modern machines provide reproduction accuracy up to 1 μm, however, this applies to the repeatability of the contour while limiting the cutting width to 20 μm. Thus, taking into account the wear of the template, the prospects of the method for both prototype and serial models can be estimated extremely low.

An interesting direction in the production of blocks of fluidic elements in the form of volumetric structures, uniting several elements in layers is photolithography using photosensitive glass-ceramics (glass-crystalline material obtained by crystallization of photosensitive glass). However, the authors do not have data on the practical use of this method in the field of production of fluidic elements. Nevertheless, it was mentioned in [14] that by such methods it is possible to obtain bulk sewers with nozzles width up to 60 μm. However, the depth of the processed material, in which several layers of the hydraulic scheme will be located, does not outnumber 1,5 mm.

A more studied direction in the production of fluidic elements, and not so single ones as blocks, is galvanoplasty. The main idea is that there are technological materials, the so-called photoresists, which have the ability to dissolve in a solvent under the influence of radiation (most often UV radiation). The production scheme consists of several stages: preparing a negative photographic mask, exposure a photoresist, clearing not light-exposed photoresist and obtaining a protruding profile of the elements system with sections of connecting lines, applying an electroconductive layer, galvanic metal deposition, filling the obtained profile with a compound, clearing the light-exposed photoresist and obtaining a final plate with elements and connecting lines.

There are different types of photoresists, providing different thicknesses of the photosensitive layer. In particular, the positive liquid photoresist FP-051Ku (TU F-11833392-0-2006) provides a resolution of 0,8...1,2  $\mu\text{m}$  per layer with a minimum thickness of 2  $\mu\text{m}$ . An increase in the layer thickness due to the application of several layers of a photoresist does not significantly reduce the resolution, so it is possible to obtain elements with a nozzle width of 20...30  $\mu\text{m}$ . The uniformity of the deposition of layers is highly dependent on production technology. Modern machines used in the manufacture of printed circuit boards provide discrepancy in thickness is 5...14% on significant dimension. The image exposure can be carried out both by the photographic mask and by the scanning exposure method directly from the electronic model of the hydraulic system profile.

The application of an electroconductive layer for the galvanoplasty process is possible according to the technologies described in [15–20]. Most often, micronized graphite is used as an electrically conductive material.

The next step is the galvanic deposition of the material (for example, copper) on the prepared surface. Then, the resulting cavities are poured to provide the compound strength. The existence of galvanically deposited material reduces the probability of distortion of the contours of the flowing parts captured in the process of gas bubbles filling. After the compound has cured, the light-exposed photoresist is washed out. The place freed from the photoresist is the flow part of the block of fluidic switching devices.

This method can be used for mass production of groups of fluidic elements combined into blocks in the form of automation plates opened on one side with a minimum nozzle width of 30  $\mu\text{m}$ . The production of three-dimensional blocks by this method is difficult due to the complexity of reliable removal of the photoresist. Unlike photosensitive glass-ceramics, the method does not require special materials and has well-proven technologies, which ultimately reduces its total cost in the production of plates with elements of a large surface area.

## Results

From the most modern methods, the use of 3D printers for the manufacture of parts of pneumatic automation systems can be noted. However, the method of forming layers of plastic or metal leads to a degeneration of surface quality, that's why this method is not suitable as a method for forming the flowing parts of the fluidic devices. Nevertheless, the combination of electric erosion machining for the manufacture of typical elements and a 3D printer for "printing" base plates with sewers for a specific particular task is commensurate in costs with the manufacture of similar small-lot relay automation units when electromagnetic relays are installed in a printed circuit board. And much cheaper if the volumetric installation is needed.

## Discussion

In general, it can be noted that complex and element-filled systems can be performed by chemical methods, however, the specifics of their application will be still limited to special areas where miniaturization and operation speed are more important than the cost of the module.

The possibilities have expanded for the manufacture of dies by the electrochemical method for mass casting of typical active elements layers, included in multilayer assemblies with switching layers, which are plates with holes and can be made on laser machines, or even on milling machines. Templates for electrochemistry can be made by the electroerosion method.

The formation of the block topology can be carried out on the base of existing ECAD software packages.

General changes in manufacture technologies make it possible to rely on the economic efficiency of implementation of fluidic control systems not only in special fields, but also in industry as a whole. At the same time, for small series it the use of electrical discharge machining and laser cutting with a nozzle width limitation of up to 0,4 mm can be recommended. At the same time, it is economically feasible to produce typical fluidic elements and prepare their unifying units using 3D printing for a specific customer.

### List of reference

- [1] Zverev, A.V., Ivanov, A.I., Pishimova, A.A., Andronik, M., Echeistov, V.V., Mikhailov, S.A., Ryzhikov, I.A., Rodionov, I.A. Optofluidic lab-on-chip platform for realtime sensing applications (2017) Progress in Electromagnetics Research Symposium, pp. 1267–1272.
- [2] Agustini, D., Fedalto, L., Agustini, D., de Matos dos Santos, L.G., Banks, C.E., Bergamini, M.F., Marcolino-Junior, L.H. A low cost, versatile and chromatographic device for microfluidic amperometric analyses (2020) Sensors and Actuators, B: Chemical, 304, article № 127117.
- [3] Zhang, X., Xia, K., Ji, A. A portable plug-and-play syringe pump using passive valves for microfluidic applications (2020) Sensors and Actuators, B: Chemical, 304, article № 127331.
- [4] Jia, Y., Su, C., He, M., Liu, K., Sun, H., Lin, Q. Isothermal titration calorimetry in a 3D-printed microdevice (2019) Biomedical Microdevices, 21 (4), article № 96.
- [5] Oleg, T. The experience of creating compact energy efficiency hydrostatic servo drive (2015) Proceedings of 2015 International Conference on Fluid Power and Mechatronics, FPM 2015, article № 7337187, pp. 603–609.
- [6] Miyanaga, K., Matsumoto, S., Takahashi, K., Shah, S.K., Takei, F., Nakamura, A., Kurata, Y. A Study on Growth of Dust of Needle-like Crystal from a Flame Retarder of Electromagnetic Relay Housing (2019) Electrical Contacts, Proceedings of the Annual Holm Conference on Electrical Contacts, 2018–October, article № 8611773, pp. 516–520.
- [7] Kirschbaum, L., Dinmohammadi, F., Flynn, D., Robu, V., Pecht, M. Failure Analysis Informing Embedded Health Monitoring of Electromagnetic Relays (2019) Proceedings — 2018 3rd International Conference on System Reliability and Safety, ICSRS 2018, article № 8688839, pp. 261–267.
- [8] Krasnikov, V.F. Technology of miniature products. - M.: Mechanical Engineering, 1976. — 327 p.
- [9] Adamopoulou, T., Nawada, S., Deridder, S., Wouters, B., Desmet, G., Schoenmakers, P.J. Experimental and numerical study of band-broadening effects associated with analyte transfer in microfluidic devices for spatial two-dimensional liquid chromatography created by additive manufacturing (2019) Journal of Chromatography A, 1598, pp. 77–84.
- [10] Zhou, Z., He, G., Zhang, K., Zhao, Y., Sun, D. 3D-printed membrane microvalves and microdecoder (2019) Microsystem Technologies, 25 (10), pp. 4019–4025.
- [11] Manufacture of stencils for applying solder paste [Electronic resource] / ELINFORM — 2007, August 2. — Access mode: [http://www.elinform.ru/articles\\_13.htm](http://www.elinform.ru/articles_13.htm).
- [12] Types of laser equipment [Electronic resource] / Company Reklab. — 2013 — Access mode: <http://reklab.ru/articles/laser-types>.
- [13] Spilka S. Digital flexography and types of laser exposure devices. — Flexo Plus magazine: Flexography and special types of printing. — 2004, No. 3. — Access mode: <http://www.vipsys.ru/upload/files/00/03/c1.pdf>.
- [14] Laser-induced structural phase modification of glassy materials / V.P. Veyko, E.I. Ageev, A.V. Kolobov [and others] // Journal of Instrument Engineering. — 2014, b. 57, № 6, pp. 7–31.
- [15] Handbook of Thin Film Technology [trans. from English]/ Leon I. Maissel, Reinhard Glang. — M.: Publishing House, 1977, b. 1 — 768 p.
- [16] V Cheremushkin and V Lomakin 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **492** 012039

- [17] T Valiev and APetrov 2019 *IOP Conf. Ser.: Mater. Sci. Eng.***492** 012038
- [18] V Lomakin and O Bibik 2019 *IOP Conf. Ser.: Mater. Sci. Eng.***492** 012037
- [19] A Petrov et al 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **492** 012036
- [20] A Shablovskiy and E Kutovoy 2019 *IOP Conf. Ser.: Mater. Sci. Eng.***492** 012035