MODELING, RESEARCH AND DEVELOPMENT OF JET ELEMENTS
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МОДЕЛИРОВАНИЕ, ИССЛЕДОВАНИЕ И РАЗРАБОТКА СТРУЙНЫХ ЭЛЕМЕНТОВ

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ABSTRACT

Current experimental and theoretical methods of research of jet elements used in agricultural means of mechanization are considered in the article. The work processes and aerodynamic flows in power jet elements have been researched on the basis of simulation modeling in ANSYS Fluent software environment. Elements for application in seeding systems of sowing machines were developed as a result of modeling. Dimensional, power characteristics and operation modes were optimized in the developed elements. Application of new jet elements produced as a result of modeling provides improvement of technical and economic characteristics of seeding systems and sowing machines.

АННОТАЦИЯ

В работе рассмотрены существующие экспериментальные и теоретические методы исследования струйных элементов, применяемых в аграрных средствах механизации. На основе имитационного моделирования в программной среде ANSYS Fluent исследованы рабочие процессы и аэродинамические потоки в силовых струйных элементах. В результате моделирования разработаны элементы для применения в высевающих системах посевных машин. В разработанных элементах оптимизированы размерные, энергетические характеристики и режимы работы. Применение новых струйных элементов, полученных в результате моделирования, позволяет улучшить технико-экономические характеристики высевающих систем и посевных машин.

INTRODUCTION

Seeding quality and productivity are major determinants of crop production technology. At the moment, however, cereal crops are sown with seeding devices whose operating principle is outdated and does not meet numerous modern requirements. These devices are the roller feeds and centralized seeding systems. They show overconsumption of seeds and their damage during sowing. It has been established that the imperfection of sowing machines leads to a yield reduction by 15...30% (*Pastuhov V.I. et. al., 2017; Devlikamov R.R., Laryushin N.P., 2013; Kulikivs'kij V.L., Hotins'kij E.V., 2015*). In addition, it is necessary to develop modern machinery with consideration for the requirements of ecology and environmental protection (*Voronov O.V. et. al., 2020*).

The effective use of current seeding devices has significantly exhausted its potential. Therefore, the implementation of new designs and principles of seeding devices with minimal production and operating costs, as well as automation and computerization of their work is relevant. A promising approach of increasing the efficiency of sowing is the use of the discrete operating principle of seeding devices connected by flexible discrete synchronization with the movement of the sowing machine. The discrete operating principle allows for more efficient automation of the work, in contrast to the analogue operating principle of traditional systems.

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At present, seeding devices with pneumatic elements (*Aulin V.V. et. al., 2017; Burkov Y. et. al., 2009; Pankov A.A. et. al., 2016; Pankov A. et. al., 2014; Aulin V.V., Pankov A.A., 2017*), and their control systems (*Le Pori W.A. et. al., 1974; Aulin V.V., Chernovol M.I., 2017; Aulin V.V., Pankov A.A., 2016; Aulin V.V. et. al., 2019*) have been developed. Samples of some devices are presented in fig. 1, a. New sowing machines have been created on the basis of such devices (fig. 1, b, c).

It has been established that the combination in a sowing machine of a split-aggregate layout pattern of group seeding with low material consumption and seeding system with reduced power consumption of work is possible only on the basis of pneumatic seeding devices of discrete operation with pneumatic elements. This makes it possible to reduce the power consumption of sowing machines and reduce their traction resistance by up to 12%, and to save operating costs by up to 16% compared with machines based on other layout patterns and seeding devices.

a)

b)

Fig. 1 – Seeding devices based on jet elements

a – seeding devices; b – cultivator drill for cereal crops;
1 – seeding unit; 2 – control unit; 3 – hopper; 4 – pressure source; 5 – seed pipes; 6 – ploughshares

However, further development of seeding devices with pneumatic elements is hampered by difficulties in developing more efficient designs of jet elements. Especially these are elements of increased linear dimensions (or power elements).

The following methods are used in research and development of jet elements (*Gradeckij V.G. et. al., 1966; Lebedev I.V. et. al., 1973*):

– empirical trial-and-error methods. The researcher chooses geometrical dimensions on the basis of analogy, intuition and notions about the mechanism of phenomena. This method is used in the works (*Chernovol M.I., et. al., 2015; Aulin V.V. et. al., 2018*);

– experimental methods based on visualization of flows (physical modeling). They consist of making streams visible in a certain way, for example through smoke or staining (*Lighthill M.J., 1972; Shimizu S., 1986; Gradeckij V.G. et. al., 1966; Balabanov A.V. et. al., 2015; Chaplic A.D., Astapov A.I., 2007*), fig. 2. By varying the geometric dimensions, the desired direction and configuration of flows are achieved. This method is a variation of the trial-and-error method and is characterized by illustrative nature.

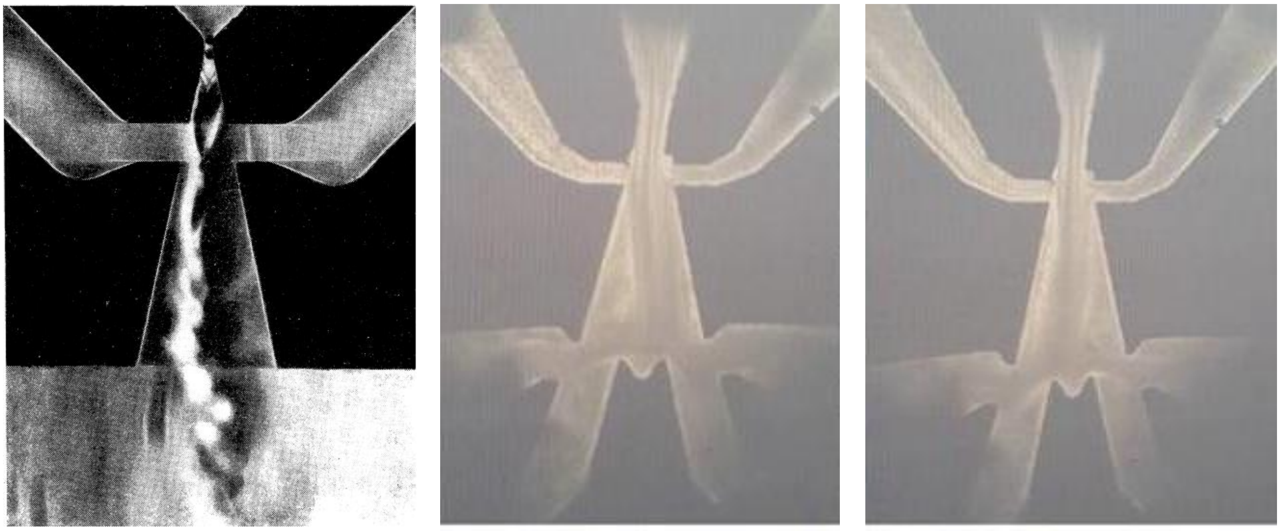
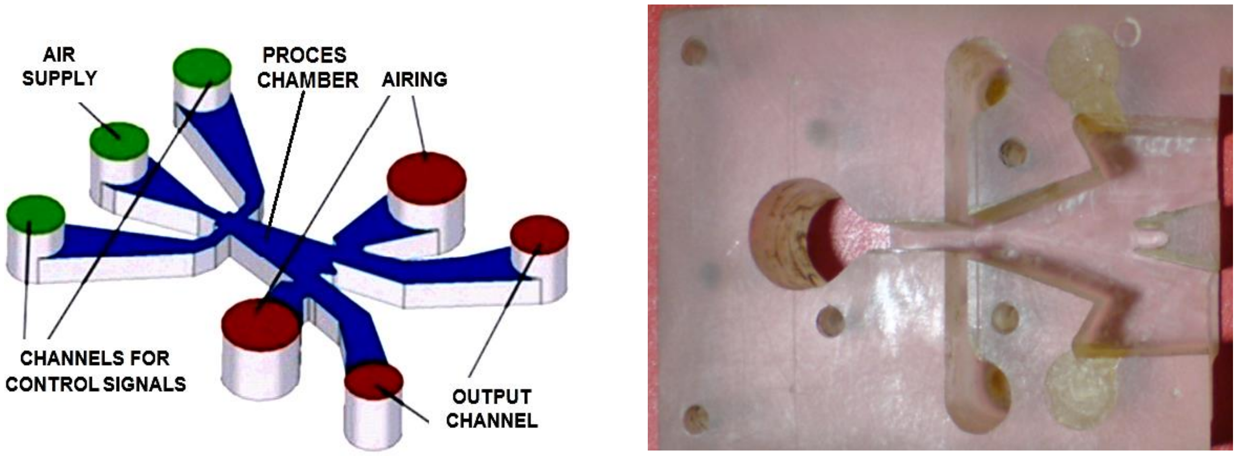


Fig. 2 – Physical modeling of flows in jet elements

– analytical and statistical methods. These are identification of peculiarities and analytical regularities in power transfer by jets in elements, determination and optimization of their dimensional and power characteristics. They were used in work (*Chorin A.J., 1973; Aulin V.V. et. al., 2018*).

Usually a jet element (scheme in fig. 3, a) is created for certain tasks. The preference is given to empirical and experimental methods. This makes it possible to create an element with satisfactory performance in a short time. For example, based on the empirical trial-and-error method, the element is created in fig. 3, b.



a) ***b)***

Fig. 3 – Jet elements

a - element scheme; b - power element developed by empirical method

Flow interaction processes in jet elements are complex and insufficiently studied. This constitutes the problem of selecting the optimum element geometry to obtain their improved performance. This requires replacing empirical methods with their elements of randomness with methods that have a more substantial justification. At present, an effective solution to this problem is possible on the basis of simulation modeling of aerodynamic flows using special software tools (*Gorobets V.G. et. al., 2018*).

MATERIALS AND METHODS

ANSYS Fluent 15.0 software environment was used for analysis of jet element operation. Using it, transition processes in the process chamber (fig.3,a) of the element were modeled (fig. 6-11). The simulation modeling was carried out in a two-dimensional formulation.

At the inlet to the feed channel of the element overpressure of 7...9 kPa and temperature of 300 K were modeled. Overpressure in the control channels was supposed to be constant. In this way the control signal was simulated. The conditions of tightness, adhesion and thermal isolation were set on the element walls in the process of software modeling.

For a given configuration of the jet element, the switching process was researched when the control signal was applied. During modeling, the geometry of the jet element was first set by software and the switching process of the power jet was modeled based on this geometry. The flow characteristics were used to determine whether the requirements for the element were met. If necessary, the geometry was corrected and the modeling of the switching process was repeated.

The next step was to establish the performance of the modeled element. For this purpose, the element was manufactured with the optimum geometric data obtained in the modeling (fig. 12). Tests of the element were carried out on the bench equipment (fig.4, fig.5). Feed pressure and air volume values were measured and then the air flow rate of the jet element was calculated. The power consumed by the element was also calculated from the pressure and flow rate values. This is the basic operating characteristic of the element which determines the power consumption of the seeding device.

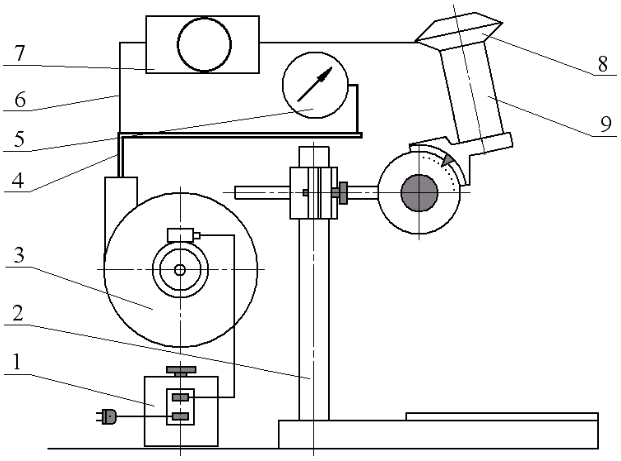
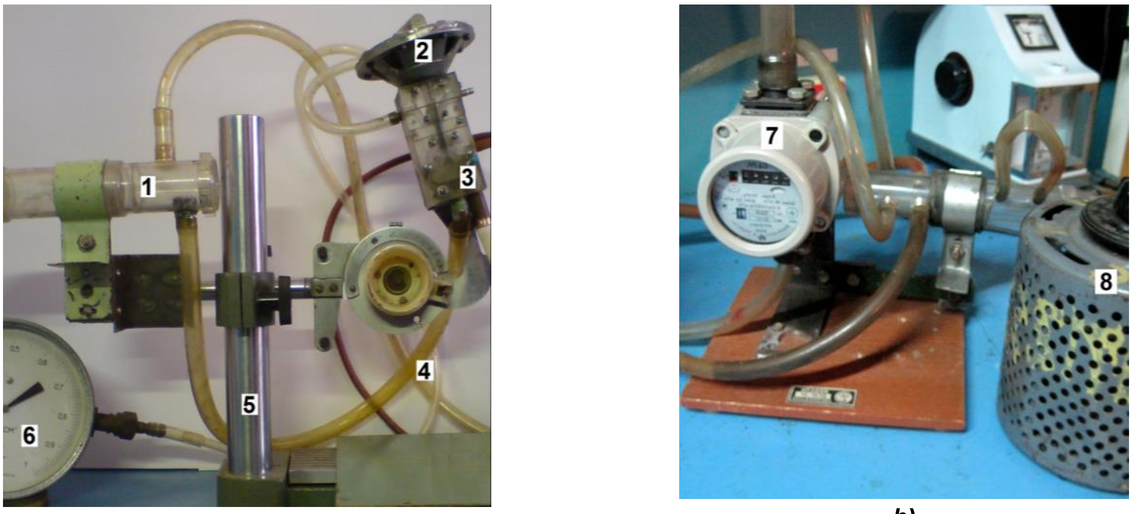


Fig. 4 – Scheme of the test bench for jet elements

1 – autotransformer, 2 – tripod with mounting brackets, 3 – compressed air source, 4 – air collector, 5 – pressure gauge, 6 – air ducts, 7 – air volume meter, 8 – throttle, 9 – jet element



a) ***b)***

Fig. 5 – Pneumatic jet element test equipment

a – measurement of the feed pressure of the jet element; b – measurement of air volume;
1 – air collector, 2 – throttle, 3 – jet element, 4 – air ducts, 5 – tripod with mounting brackets,
6 – pressure gauge, 7 – air volume meter, 8 – autotransformer

RESULTS AND DISCUSSION

In the modeled picture of gas dynamic processes at a given geometry, the main stages of air jet switching and pressure wave distribution are highlighted. Fig. 6 shows the process of establishment of the jet in the process chamber of the element after the feed pressure has been supplied. On both sides of the jet there is a process of formation of vortices. They are formed randomly. The working medium is partially drawn in from the control channels. The primary flow of the feed jet is discharged into the atmospheric windows and partially enters the outlet channels. The air jet is randomly positioned along the left wall of the process chamber. Fig. 6 shows the core of the jet and its basic direction. Fig. 7 shows how the pressure rises in the left outlet channel.

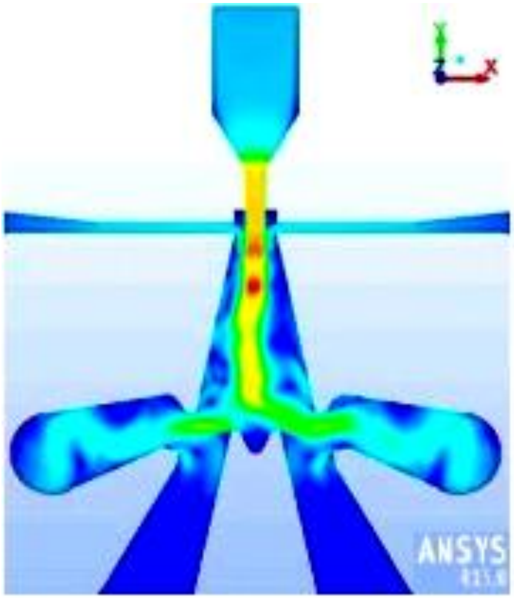


Fig. 6 – Modeling fragment of jet setting process in the process chamber after feed pressure is supplied

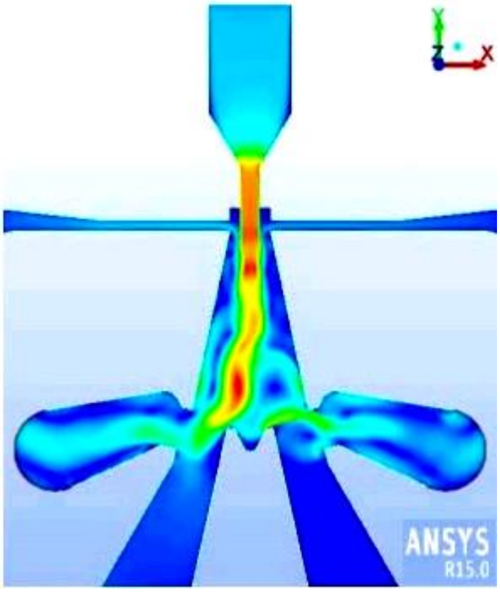


Fig. 7 – A fragment of increasing pressure in the left outlet channel

Control pressure is then supplied to the left control channel. The jet starts deflecting to the right. The process model (fig. 8) reveals that the jet, almost deflected to the right, is discharged into the left atmospheric window. It is not yet able to overcome the deflected flow vortex forming to its right. Pressure pulsations, which are formed by the pulsating working medium of the reflected flow, begin to be emitted into the right outlet channel. The pulsations can be a source of false element actuation. This can be seen in fig. 9 (“loops” in the outlet channels).

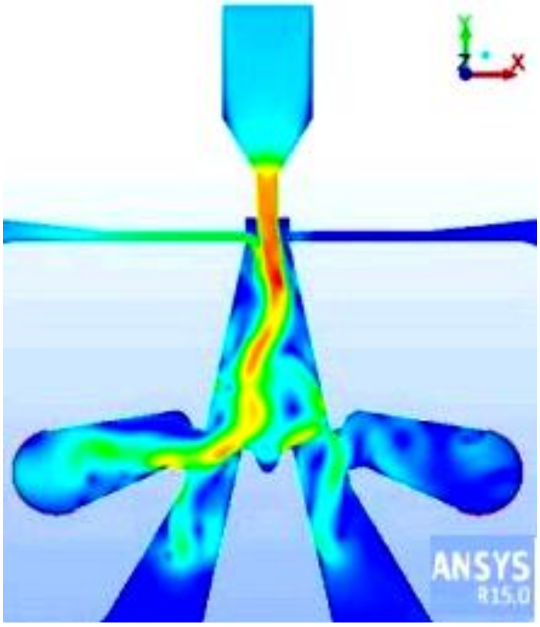


Fig. 8 – Moment of jet discharge into the left atmospheric window

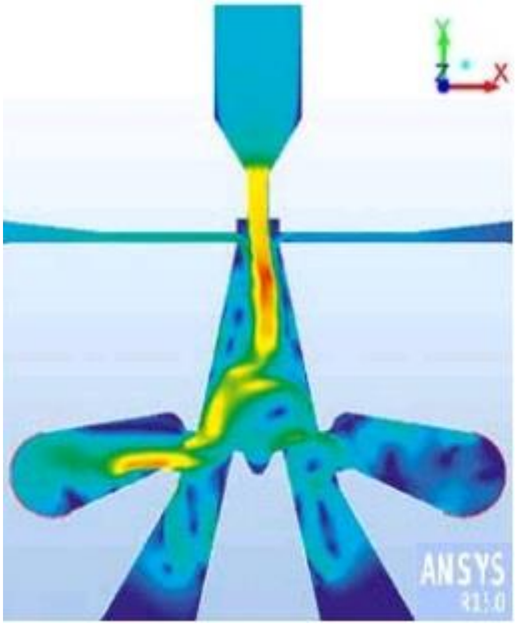


Fig. 9 – Fixation of moments of pulse tail pressure pulsation emissions into the outlet channels

The fragment of the process model (fig. 10) shows how the jet is set back to the “middle” position by deflecting away from the left wall.

The main flow is discharged into the left atmospheric channel. Reflected flows are formed on both sides of the jet. Pressure pulsations are formed in both outlet channels. At the moment in question, they prevail in the left outlet channel. The control pressure and flow rate enter the left control channel. The jet moves towards the right wall.

The jet then regains its integrity. Pressure pulsations in the left outlet channel lead to pressure pulsations in the left control channel. This causes instability in the position of the power jet and causes initial pressure pulsations in the right outlet channel. The pressure in the left control channel causes the jet to finally move to the right wall of the jet element, i.e. a switching operation takes place (fig. 11).

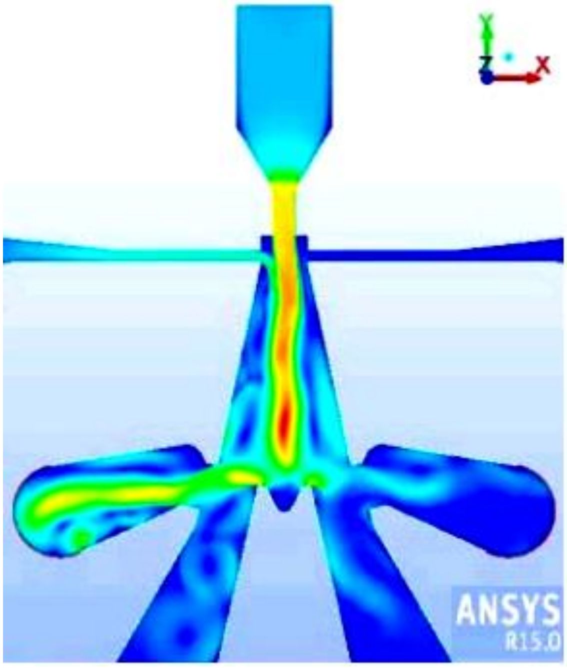


Fig. 10 – Fragment of jet setting in middle position

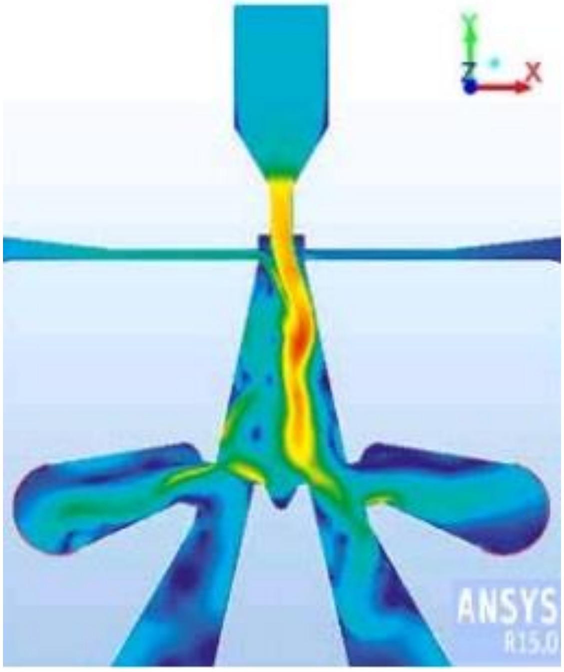


Fig. 11 – Fragment of jet switching to the right wall

Analyzing the jet switching cycle, it can be noted that:

- the switching pattern obtained differs from the empirical one (based on trial-and-error method). Previously, a switching model was applied, which did not have a complete picture of pressure pulsations during the switching process. This is essential in order to avoid false triggering of elements;
- at higher frequencies, jet switching is also influenced by discharge and pressure pulsations that occur in the element’s outlet channels during operation;
- jet switching in the process chamber of the element may also be of acoustic nature. It is a consequence of the fact that movement of the jet along the element edges, atmospheric and outlet channels with high speed causes appearance of acoustic waves. As the switching frequency increases, the frequency of this acoustic noise also increases;
- it has been determined that a shaped splitter (recess between the outlet channels, fig. 3, b) in the power elements is not compulsory. This simplifies the manufacturing of the elements.

The jet elements developed on the basis of modeling are shown in fig. 12.

Test results of the developed bistable element are presented in table 1.

Table 1

Dependence of air consumption Q on supply pressure P_S
(feed element nozzle cross-sectional area is $S = 34\ mm^2$)

P_S, kPa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$Q \cdot 10^{-4}$, m^3/s	7.35	10.2	13.2	15.8	18.1	20.0	21.8	23.5	25.1	26.7	28.2	29.6	31.1	32.4	33.7

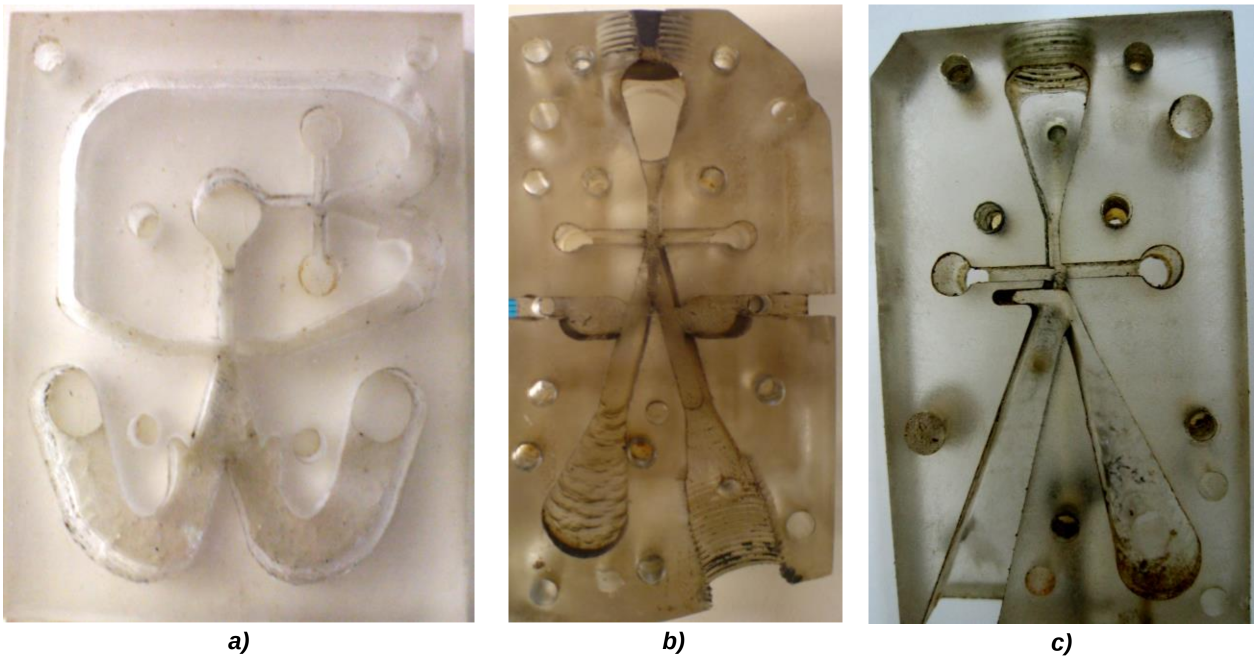

a) b) c)

Fig. 12 – Jet elements developed by modeling in Ansys Fluent 15.0

a – logic control element; b – power bistable element; c – power monostable ejector element

Consumed power (N_{cp}) of the jet element:

$$N_{cp} = P_S \cdot Q \text{ [Watt]} \tag{1}$$

where:

P_S is the air feed pressure (kPa), Q is air flow rate (m^3/s).

The received data for various values of pressure of a jet element feed are presented in table 2.

Table 2

Power consumption of N_{cp} element, depending on feed pressure P_S

P_S, kPa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N_{cp}, Watt	0.7	2.5	4.0	6.3	9.0	12.0	15.2	18.8	22.6	26.7	31.1	35.6	40.4	45.4	50.6

Graphic dependences of air flow rate Q and power consumed by N_{cp} jet element, depending on feed pressure P_S, are presented in fig. 13.

Fig. 13 – Dependence of air flow rate Q and consumed power N_{cp} on feed pressure P_S when feed element nozzle cross-sectional area is $S = 34\ mm^2$

Together with the control element (fig. 12, a) the power bistable element is assembled into a single unit (fig. 14) and then connected to the seeding unit.

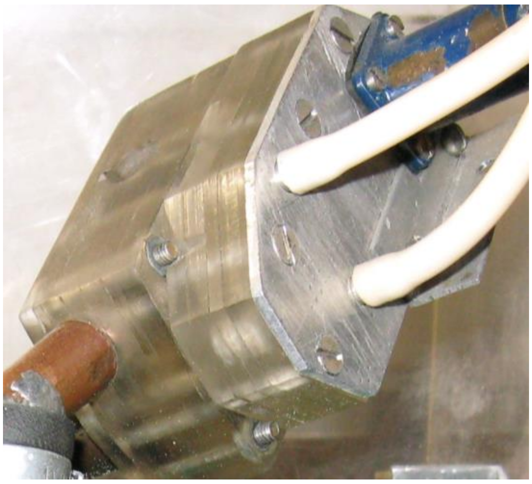


Fig. 14 – Jet element block of the seeding unit

Future research will focus on further improving the power output of the jet elements. Power efficiency can be improved by using more advanced power transmission methods in the jet devices. These are vortex blowers. In their working process power is transferred not only by turbulent exchange, but also by centrifugal force (*Syomin D.A., A. Rogovoy A.S., 2016*).

CONCLUSIONS

The aerodynamic flow pattern obtained from the simulation modeling shows that the geometric parameters of the jet elements used need to be optimized. An important parameter that needs to be optimized is the length of the process chamber of the element. The presented models show that the power jet has time to expand along the process chamber. This is an unfavorable effect in the operation of the jet element. It is found that in order to improve switching it is necessary to switch only the core of the jet and not the developed expanded jet which has ejective turbulent components.

The simulation modeling results revealed the occurrence of pressure pulsations in the outlet channels. As a consequence, the switching process can be repeated. A rupture of the main jet and the occurrence of harmful pressure pulsations has been detected. This is another source of false triggering of the jet element.

The elimination of the negative effects in the operation of the jet elements has improved their performance as well as the performance and economy of the seeding systems.

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