DOI 10.1007/s11015-016-0329-0
Metallurgist, Vol. 60, Nos. 5–6, September, 2016 (Russian Original Nos. 5–6, June–July, 2016)

FILTERING ELEMENTS OF A NEW DESIGN AND EQUIPMENT FOR THEIR MANUFACTURE

N. N. Zubkov[1] **and V. A. Vasil'ev**[2] UDC 621.791.03:621.9.04

Existing designs and manufacturing techniques for filters with a slot-hole structure are analyzed. It is proposed that slotted filter tubes be made by the method of deformational cutting. The method has been realized by through wall slotting of longitudinally corrugated welded metal pipe. Options are discussed for the basic structure of complexes designed to make slot-hole filtering pipes.
Keywords: *filtration, slot-hole filter, screen pipe, deformational cutting, corrugated metal band, TIG welding, pipes with a longitudinal seam, through wall slotting.*

The problem of filtering liquids and gases is important in almost every sector of industry – machinery manufacturing and the chemical, petrochemical, food, and mining-concentration industries, oil and gas extraction, water treatment and water purification systems for population centers and industrial facilities, etc.

At present, the mechanical separation of solid particles is most often done by using metallic mesh filters and cermet filters, as well as paper and cloth. Use of the filter must be discontinued when the filtering element becomes contaminated. The high cost of replacing fouled filtering elements makes the use of filters that can be regenerated a promising alternative. Such filters are cleaned by a countercurrent flow of the medium that is being filtered. The use of a slot-hole structure in the filtration process ensures low hydraulic resistance and a high level of efficiency in cleaning filters by a counter flow. Regeneration with a counter-flowing working medium makes it possible to clean filters without disassembling them and to lengthen the life of the filter element by a factor of 20 or more [1]. However, the technology available for making slotted filtering baffles has several serious limitations related to the minimum width of the slots, low productivity, and consequent high fabrication costs.

Figure 1 presents a classification of the methods used to make slotted filtering structures.

Regarding the mechanical methods used to make slotted filters, the most popular are forming and cutting. A wide range of slotted grids is made both by the method of channel forging and by simultaneous slitting and drawing [2]. A significant shortcoming of these methods is the limitation on the widths of the slots that can be obtained – no greater than 500 μm. As a rule, such grids are used as permeable protective housings that serve to protect filtering elements.

The *cutting* of slots is done with disk cutters. Through slots can be formed on a tubular semifinished product with lengthwise internal grooves by turning on a lathe [3]. Among the problems with methods based on cutting and the removal of chips are their low suitability for industrial use, low productivity, and the fact that it is not possible to obtain slots narrower than 120 μm [4]. The production of slotted filtering tubes by the method of the deformational cutting (Fig. 1) will be examined below.

One promising trend in the fabrication of slotted filtering baffles is *the use of laser treatment* [5]. Sheets or tubes of different profiles can be used as the semifinished product. Laser piercing makes it possible to obtain slots from 5 μm and up, which accounts for the use of this method to make filters for moderate-level and fine cleaning. Among the drawbacks are the high equipment cost and the amount of energy consumed in the production process.

[1] Bauman Moscow State Technical University, Moscow, Russia; e-mail: zoubkovn@bmstu.ru.
[2] Institute Tsvetmetobrabotka, Moscow, Russia; e-mail: cmet@mail.ru.

Translated from Metallurg, No. 5, pp. 77–82, May, 2016. Original article submitted November 17, 2015.

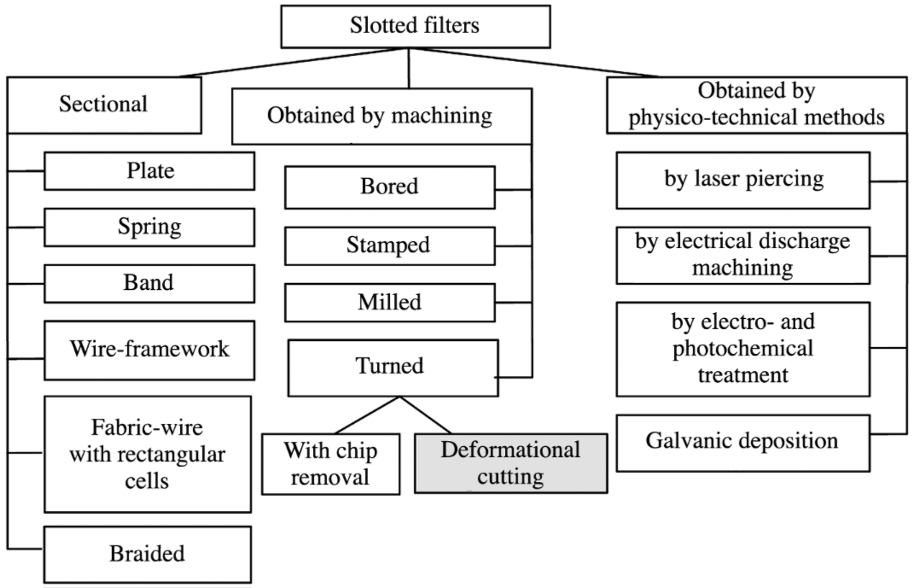


Fig. 1. Methods of obtaining slotted filters.

Electrical discharge machining is also used to obtain slotted filtering structures [6]. However, this technology is characterized by low productivity, and the process for making the electrode-tool is complicated.

Slotted filtering structures can be obtained from sheet materials by methods based on electrochemical treatment with the use of masks for protection from etching [7]. Various types of photo-polymers are used as the masks. Electrochemical treatment makes it possible to obtain slots of 60 μm or larger. The method is best suited for obtaining slotted sheets of small thickness, since the width of the slots cannot be less than the thickness of the sheet; the walls of the opening under the mask will be etched if the sheet is of substantial thickness.

Buckbee-Meers Co. Inc. (U.S.) is obtaining *galvanoplastic grids* on a glass substrate with slots ranging from 6 μm. The materials are copper, nickel, and silver. However, this method is environmentally hazardous and is characterized by low productivity.

Sectional designs of slotted filtering structures based on wire grids are currently the most popular. Fabric grids with rectangular cells, grids comprised of wire-enveloped tubes, and welded grids formed from wire all have a slotted structure. The width of the slots of such grids is limited to the minimum diameter of the wire comprising the warp and the weft. warp and the weft range up from 20 μm in size (from 40 μm in Russia). The tubular grid (braided) has thicker warp wires, which are woven with the thin wires of the weft that are immediately adjacent. The grids have low permeability, which is a serious shortcoming.

In welded wire-framework filters, the slotted filtration surface is formed by winding wire of circular or special cross-section about a permeable framework [8]. The framework could be a perforated shell with spiral grooves, to cite one example (Fig. 2*a*). The wire is wound in the grooves and welded to the framework by roller welding. In another variant, the framework could be stringers comprised of circular or specially shaped wire (Fig. 2*b*) [1]. The fineness of the filtration process and hydraulic resistance are determined by the pitch of the spiral groove and the thickness of the wire. A filter of the design just described is distinguished by its stiffness and strength.

The use of wire of triangular (Fig. 2*c*) or trapezoidal reduces the probability that particles of contaminants will become wedged in the filter because the slots expand in the same direction that the medium being filtered is traveling. This technology makes it possible to obtain slotted filters with a filtration fineness ranging from 75 μm. Among their undoubted advantages are their substantial stiffness and strength, although when the slots are narrower than 100 μm the cross-section coefficient (the ratio of the area of the slots to the area of the filtering surface) is just 2–10%. This creates high hydraulic resistance, which is a serious drawback. In addition, the productivity of these filters is low, which accounts for the high cost of the filtering element.

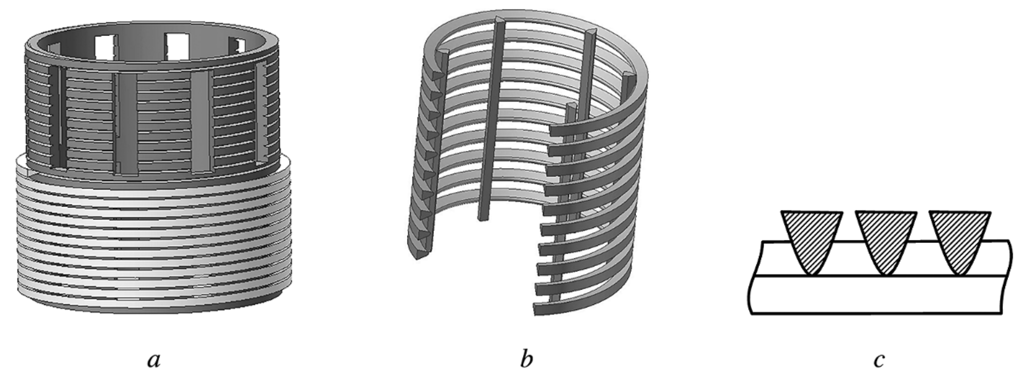


Fig. 2. Welded wire-framework filters: *a*) housing type; *b*) based on stringers; *c*) variant with wire of triangular cross section.

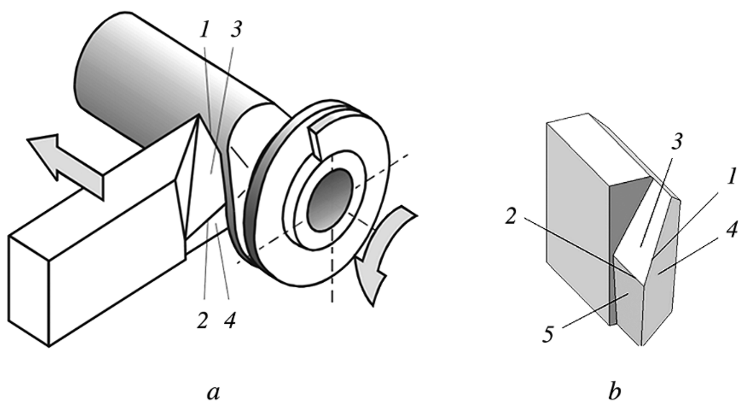
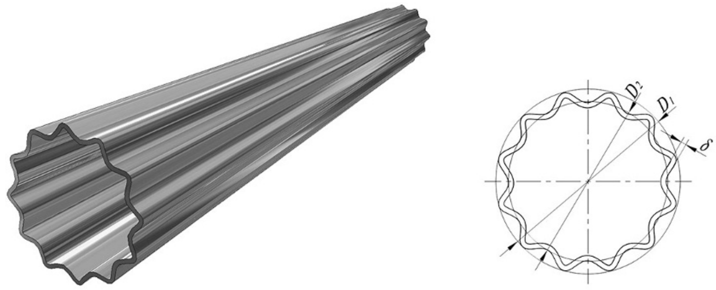


Fig. 3. Scheme for forming fins on tubes by the DC method (*a*) and tool for its implementation (*b*): *1*) cutting edge; *2*) deforming edge; *3*) front surface; *4*, *5*) main and auxiliary back surface.

The principle behind a slotted filtering surface is also employed in *band filters*, which use a *corrugated strip* [9]. For example, the filtering element of slotted filters used for drainage is formed by two spiral strips. One of these strips is corrugated and the other one is flat. The strips are wound inside one another and welded filtering slots are formed thanks to the rectangular corrugations on one of the strips. This design has become commonly used in the drainage-distribution equipment of filtering systems at water treatment facilities. It is employed in sand, coal, and ionite filters with a slot width of at least 100 μm. The largeness of the slots is their main shortcoming.

Plate-type filters have a slotted filtering surface formed by a set of plates. The plates are installed on an arbor with the use of spacers, the thickness of which determines the widths of the slot. Plate filters provide for filtration with a fineness of 20 μm or more. However, the widths of the filtering slots (filtration fineness) are unstable due to the low stiffness of plates (foils). Such filters are poorly suited for industrial fabrication and are complicated in design. One advantage of plate filters is that they can be mechanically cleaned with scrapers.

In *spring filters*, a wound spring is compressed to the end and its turns are pressed against one another. The filtering surface is formed by the use of notches made along the wire, with the projections of the wire forming the filtering gap [10]. Such filters can be opened for subsequent cleaning by a countercurrent flow of the medium being filtered, which is their distinguishing advantage. There is a variety of spring-adjustable filters [11], with the width of the slot being determined by the degree of compression of the spring. This makes it possible to adjust the width of the slot up from 10 μm and also increase its width during the countercurrent washing. The main shortcoming of these filters is the low cross-section coefficient.



a *b*

Fig. 4. Lengthwise-corrugated semifinished product for obtaining slotted filtering tubes by the DC method (*a*); cross-sectional profile of the semifinished product (*b*).

a *b*

Fig. 5. Slotted brass and copper filtering tubes (*a*) and view of the slotted filtering surface (*b*).

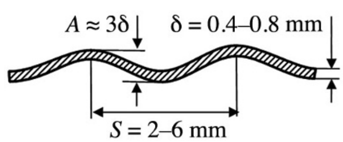
The method of deformational cutting (DC) for making slotted filtering tubes is based on the cutting of layers of material and plastic deformation of the cut layers, the result being the formation of a macrorelief in the form of fins (Fig. 3) [12, 13]. One feature of the waste-free DC method is the possibility of forming narrow gaps between the fins. The width can range up from 10 μm and the depth of the gaps can be several millimeters. With through cutting of a section of the wall of the semifinished product, it becomes possible to obtain a permeable baffle. This makes it possible to propose the use of the DC method to make fine-, medium-, and coarse-cleaning filters with a filtering surface having a slotted structure. As regards filtration applications, the DC method has been used to fabricate metallic micro grids and polymeric filtering tubes [14, 15]. This article examines the use of the DC method to obtain metallic filtering tubes with a slot-hole filtration structure.

We are proposing to obtain such tubes by using lengthwise-corrugated semifinished products (Fig. 4*a*) and using the DC method for through cutting of the crests of the corrugations. The material of the semifinished product that is inside the circle of the diameter D_2 (Fig. 4*b*) is not subjected to the action of the cutter, which imparts structural strength to the filtering tube.

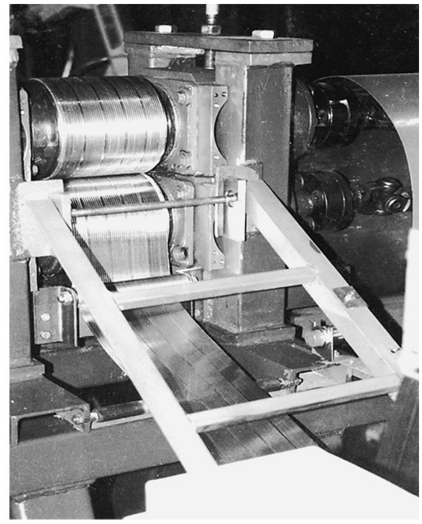
The circumferential spacing of the corrugations and the thickness δ of the wall of the tubular semifinished product are determined by the technological limitations of the DC method and depend on the ductility and strength of the material of the semifinished product. Preliminary experiments established that a wall thickness $d > 1.0$ mm and a circumferential spacing greater than 6 mm are inexpedient due to the instability of the DC process.

We obtained copper and brass specimens of filtering tubes with a slot width of 30 μm by through-cutting of the vertices of corrugations with the use of the DC method (Fig. 5). The tubular design of the filtering element allows it to be used with large pressure gradients.

Equipment for making semifinished products for slotted filtering tubes. Companies that make equipment for the petroleum industry are heavy users of these tubes, as are facilities that treat and purify water in industrial and residential



a



b

Fig. 6. Profile of corrugation (*a*) and production line for making the corrugated semifinished product (*b*).

water-supply systems. The large potential demand requires the development of highly productive equipment to make slotted filters. Shown below are the parameters of slotted filtering tubes that will be in demand in the market and that are being used to come up with specifications for that equipment:

Material	Corrosion-resistant austenitic steel 08Kh18N10T
Diameter of filtering tubes, mm	14–70
Length of filtering tubes, mm	100–4000
Width of slots (filtration fineness), μm	30–200
Thickness of tube wall, mm	0.4–0.8

The key elements in making slotted filtering tubes are obtaining a lengthwise-corrugated tubular semifinished product and through-cutting of the vertices of the corrugations by the DC method.

The most efficient method of obtaining the necessary semifinished product entails profiling a metal strip of corrosion-resistant steel and obtaining corrugations of the required profile. The tubular semifinished product is formed and is welded with a non-fusing tungsten electrode so as to form a lengthwise weld at the bottom of the corrugation [16].

The metal strip can be profiled in a line built to produce corrugated strip with a two-roller stand in which the body of the rollers is shaped so as to ensure that the corrugation geometry shown in Fig. 6*a* is obtained.

Figure 6*b* shows a prototype of a line for producing corrugated strip. This line was originally designed to use the two-roller scheme to obtain corrugated strip for making screens for lighting systems. However, it can also be used to fabricate corrugated strip for slotted filtering tubes. The line uses coils weighing up to 500 kg, the widths of the strip being 150 mm. Strip thickness can be varied within the range 0.1–0.8 mm. Depending on the thickness of the strip, the productivity of the line is within the range 3–15 m of profiled strip per minute. The strip is rolled into a coil.

The final stage in the production of the corrugated tubular semifinished product is forming the strip into a tubular semifinished product and welding the edges of the strip with a longitudinal weld. The Institute Tsvetmetobrabotka has had success in the design, introduction, and use – including abroad – of mills for the argon-arc welding of tubes (ATWM) (Fig. 7) [17, 18].

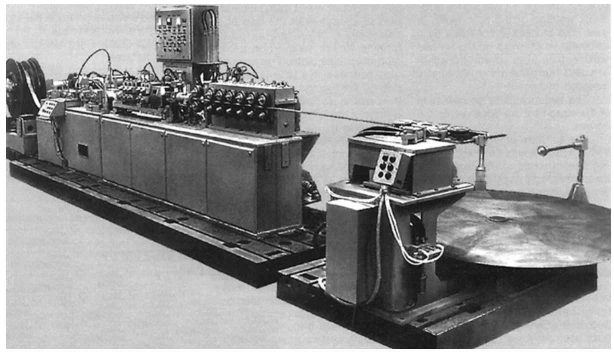
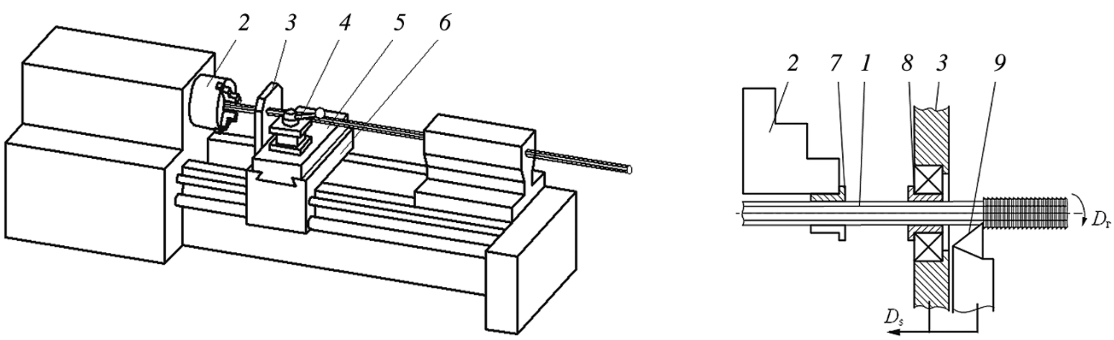


Fig. 7. Argon-arc tube-welding mill ADST5– 25-1M.



a *b*

Fig. 8. Making of through slits in the longitudinal corrugated tube on a lathe: *a*) general layout; *b*) diagram of processing.

The mill includes the following: a butt welder to join the ends of the strip at the beginning and end of the coil; disk shears to trim the edges of the strip on both sides; a forming unit; longitudinal-welding machine; cooling block; tensioning device; bundler which operates with cutoff of the tubular semifinished product [18]. The most important technical decision that is made in creating AWTMs is the use of an undriven forming unit. That has made it possible to develop simple designs for forming stands and to shape the strip-like semifinished product based on the principle of “into a gap” [19]. It has also made it possible to perform the forming operation with a prescribed amount of back tension and thus help stabilize it and the welding operation. The forming stands are equipped with devices for axial and radial adjustment of the rolls, it being possible to execute an axial adjustment while the mill is operating. With minimal additional processing, the use of such mills allows the production of lengthwise-corrugated tubular semifinished products in the diameter range 5–25 mm. This requires the use of a second cutoff device, which is needed to form not bundles but straight segments of tubing having a prescribed length on the tube discharge table (along with the previously cut roll of bundles). The production of lengthwise-corrugated semifinished products with a diameter greater than 25 mm will necessitate the design of new mills that operate by the same basic principles.

Equipment for obtaining lengthwise-corrugated slot-filtering semifinished products. The DC method is currently being used to form fins on heat-exchanger equipment with the use of screw-cutting lathes that have undergone minimal upgrading [20]. The principles behind this operation have been approved for the production of filtering tubes. Lathes can easily be adjusted to use the DC method for the through-cutting of different sizes of tubular semifinished products into semifinished products with a diameter of 6–60 mm (the diameter of the semifinished product is limited by the diameter of the opening in the spindle of the lathe).

Lengthwise-corrugated tubular semifinished product *1* (Fig. 8) is passed through the opening of the spindle and a movable guide *3*. It is then pressed through incised bushing *7* into the chuck *2* of the spindle. The tang of the cutter, with hard-alloy cutting plate *9*, is compressed in cutter-holder *4* and can be moved radially by lateral support *5* to establish the specified cutting depth. Movable guide *3* is secured to longitudinal support *6*, which can only be moved along the axis of the tube. A roller bearing with a press-fitted bushing *8* is used to reduce the friction between the rotating tube and the guide *3*. The maximum length of the tube section that can be machined is determined by the travel of longitudinal support *6* and depends on the lathe. Fins are formed on a long tube by successively machining different sections of it and re-securing it each time. In this case, the rotating tube must be supported to the left of the lathe and the right of the machining zone. The supports can be of any design that satisfies safety requirements. For example, they could be in the form of sectional pipes.

The productivity of the CR method depends on the axial spacing of the through cuts (the feed per rotation of the spindle), the allowable speed of rotation of the tube, then the time required for auxiliary operations. A cutting speed within the range 0.7–1.0 m/sec is recommended for processing corrosion-resistant steels by the CR method. The productivity of the finning operation on a lathe (without consideration of the preparatory-concluding time period) is $Q = NS_0$, m/min. Here, N is the number of spindle rotations, rpm, and S_0 is the spacing of the fins, meters. For example, with a spindle speed of 1200 rpm and through-type slots spaced 0.4 mm apart, productivity will be 0.48 lin. m of filtering tubes per minute.

Conclusion. The patented method of deformational cutting allows the production of stiff, strong metallic tubular filtering elements with a slotted filtration structure that allows them to be regenerated by a counter flow of the medium being filtered. Specific technical solutions were found for the high-productivity manufacturer of filtering tubes with the use of tubular lengthwise-corrugated semifinished products obtained on argon-arc welding machines.

REFERENCES

1. K. Sutherland, *Filters and Filtration Handbook*, Oxford, Elsevier Science Ltd (2008).
2. V. M. Gavrilenko and V. S. Alekseev, *Filters for Drilling Wells*, Nedra, Moscow (1976).
3. V. N. Konoplev, Yu. V. Konopleva, and A. A. Radchenko, Patent No. 2102110 RF, IPC B23D29/44, “Well filter and method of making it,” subm. 04.09.1996, publ. 01.20.1998, *Byull.*, No. 2 (1998).
4. D. Matanovic, M. Cikes, and B. Moslavac, *Sand Control in Well Construction and Operation*, Springer Verlag, Berlin, Heidelberg (2012), pp. 38–49.
5. E. D. Vaks, M. N. Milen’kii, and L. G. Saprykin, *Practical Experience with Precision Laser Treatment*, Tekhnosfera, Moscow (2013).
6. P. P. Serebrenitskii, *Modern Electrical-Discharge Machining Technologies and Equipment*, Lan’, St. Petersburg (2013).
7. V. P. Zhitnikov and A. N Zaitsev, *Impulsive Electrochemical Treatment*, Mashinostroenie, Moscow (2008).
8. D. Purchas D. and K. Sutherland, *Handbook of Filter Media*, Elsevier Advanced Technology, Oxford (2002), 2nd ed., pp. 245–250.
9. P. M. Maiorov and G. G. Pyatyshkin, *Water Purification. Methods and Equipment: Handbook*, Donetsk Nats. Tekh. Univ, Donetsk (2010).
10. K. Raghavachari, Patent No. 5207930 US, IPC B01D29/62, “Filtration system with helical filter cartridge,” Crane Co., App. No. 738152 (1993).
11. B. I. Kolesnikov, Patent No. 2035202 RF, IPC B01D29/62, “Filter,” subm. 09.10.1990, publ. 05.20.1995, *Byull.*, No. 14.
12. N. N. Zubkov and A. I. Ovchinnikov, Patent EP No. 0727269, IPC B23C 3/00, “Method of producing a surface with alternating ridges and depressions and a tool for carrying out the said method,” subm. 04.27.1994, publ. 08.21.1996.
13. N. N. Zubkov, “Features of using the method of deformational cutting,” *Tekhnol. Mashinostr.*, No. 1, 19–26 (2001).
14. N. N. Zubkov and A. D. Slepcov. “Production of slotted polymer tubes by deformational cutting,” *Russ. Eng. Res.* **30**, No. 12, 1231–1233 (2010).

15. N. N. Zubkov and A. D. Slepcov, "Production of micro-grids and permeable slotted tubes by machining," *Izv. Vuzov. Mashinostr.*, No. 3, 56–60 (2007).
16. S. V. Parshin, *Processes and Machines for Making Profiled Tubes*, UGTU-UPI, Ekaterinburg (2006).
17. V. A. Vasilyev, "Tube-welding equipment for making tubes of copper and its alloys," *Svarshchik v Rossii*, No. 4, 13–16 (2014).
18. I. I. Dobkin and V. A. Vasilyev, "Welding mills ADST 5…25-1: high efficiency of argon-arc welding of thin-walled tubes," *VO Machinoexport*, No. 32–92, 12–15 (1992).
19. E. M. Donskoi, V. A. Vasilyev, and N. V. Sidorova, Patent No. 2050996 RF, IPC6 B21C37/08, "Working stand of tube-forming mill," subm. 12.23.1992, publ. 12.27.1995, *Byull.*, No. 36.
20. N. N. Zubkov, "Finning of heat-exchanger tubes by undercutting and bending back the surface layers," *Nov. Teplosnab.*, No. 4. 51–53 (2005).