NEW CONCEPTS FOR THE ACTIVE GROOVED-FEED SECTION EXTRUDER

M.Sc K. Głogowska.[1], Prof. J. W. Sikora[1], M.Sc Ł. Majewski[1]
Faculty of Mechanical Engineering –Lublin University of Technology, the Poland [1]
k.glogowska@mail.com

***Abstract**: The article discusses the current state of knowledge about the active grooved feed section of an extruder and presents its new constructional solutions. The grooved feed has been known for thirty-five years; there are not so many constructional solutions, and most of them come from the United States and Poland. Unlike the passive grooved feed section, the active grooved feed section has not, as yet, been used in industrial processing machines.*

Keywords: ACTIVE GROOVED FEED SECTION, EXTRUDER, CONSTRUCTIONAL SOLUTIONS

1. Introduction

Only a few original designs of the active grooved feed section are known, used in laboratory prototype extruders, which were used to test their characteristics. The active grooved feed section, as opposed to the passive one, is characterized by the possibility of changing the constructional features during the extrusion process, without the need to stop the process. These features are: the number of grooves, the angle of inclination of the grooves, the depth of the grooves, the direction of the grooves' rotation, the angle of rotation, the shape of the grooves' cross-section. The paper describes the latest design solution of the active grooved feed section of a single-screw extruder developed within the international research project NEWEX, implemented in the EU Framework Programmer Horizon 2020.

This paper reviews the state of the art in the design of the active grooved feed section of a single screw extruder, including patented embodiments as well as results of many hours of brainstorming and discussions on the desired structure of this extruder part. All the CAD models of the described in the paper are fully functional, kinematically tested, and tested for structural integrity.

2. Prerequisites and means for solving the problem

The active grooved feed section differs from the non-adjustable section in that its design parameters can be changed during extrusion without the need to interrupt the process. The parameters in question include the number of grooves, their inclination angle, handedness, depth, and cross-sectional shape. The adjustable grooved feed section was invented by Meyer, who first described his invention in 1983 in US Patent No. 4462692 (Fig. 1). Meyer's rubber extruder had a sleeve (cylindrical insert) mounted in its internal surface, extending from the feed opening section into part of the feed (compression) section of the plasticizing system, in which a spiral undercut had been made with a wrapping angle of about 480°. The width of the undercut at the feed opening was the same as the diameter of this opening. The width and depth of the spiral slot reduced continuously in the direction of the extruder head to end in a point. A worm gear mounted to the sleeve having the spiral undercut allowed the sleeve to be rotated in order to change the cross-sectional shape of the slot.

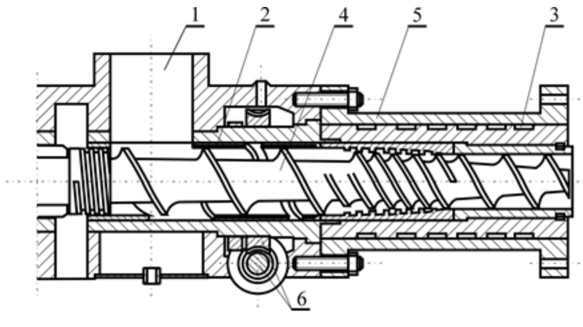


***Fig. 1** Longitudinal section diagram of an adjustable grooved feed section of an extruder: 1 – feed opening, 2 – sleeve with a spiral undercut, 3 – cooling channels, 4 – screw, 5 – barrel, 6 – worm gear [1]*

In another US Patent No. 4678339, two sleeves (feed bushes), an inner and an outer one, are seated in the barrel of the plasticizing system of an extruder. The sleeves extend along the feed opening and part of the feed sections of the machine. The inner sleeve is rotationally fixed and the outer sleeve is rotatable (Fig. 2). The inner sleeve comprises numerous countersunk holes with adapters disposed in them. The adapters are mounted to a roller-spring mechanism, which allows to lower or lift them. When the adapters are retracted, the wholes cut in the sleeve form longitudinal grooves. The adapters are lowered and lifted by rotating the outer sleeve by a piston drive system. The roller of the adapter's roller-spring mechanism, slides along a specially shaped surface of the outer sleeve (cam ring), retracting or advancing the adapter and providing the desired angle of inclination of the grooves and thus their desired depth.

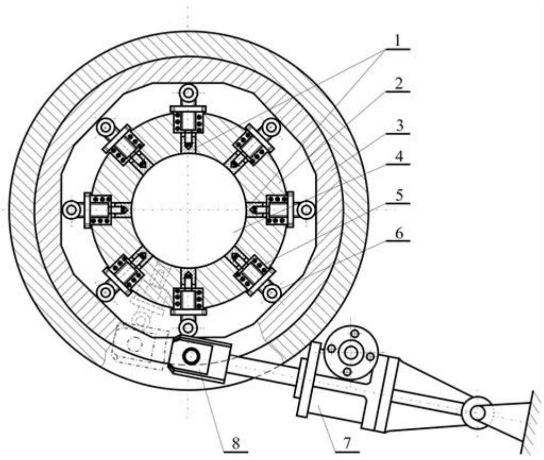


Fig. 2 *Schematic of the cross section of a plasticizing system with an active grooved feed section: 1 - adapters, 2 - rotationally fixed sleeve, 3 - rotatable sleeve, 4 - feed opening, 5 - spring, 6 - roller, 7 - lifting spindle gear, 8 – bolt [2]*

In yet another US patent, No. 5783225, the extruder barrel in the area under the feed opening and slightly beyond it has three pockets confined by the surfaces of the flight and the screw root and by the surfaces of the barrel and the slats (ribs) provided in the barrel (Fig. 3). The screws mounted at the ends of the slats allow for a change in their position and thus a change in their displacement (outward/inward) and angle of inclination, resulting in a change in the volume of the pockets.

To give another example, in US Pat. No. 5909958, the extruder has a grooved sleeve which allows one to change the number of grooves, their depth and inclination angle during extrusion by lowering or raising one end of the slats (keys) placed in sloping groove channels machined in the inner wall of the extruder barrel (Fig.4).

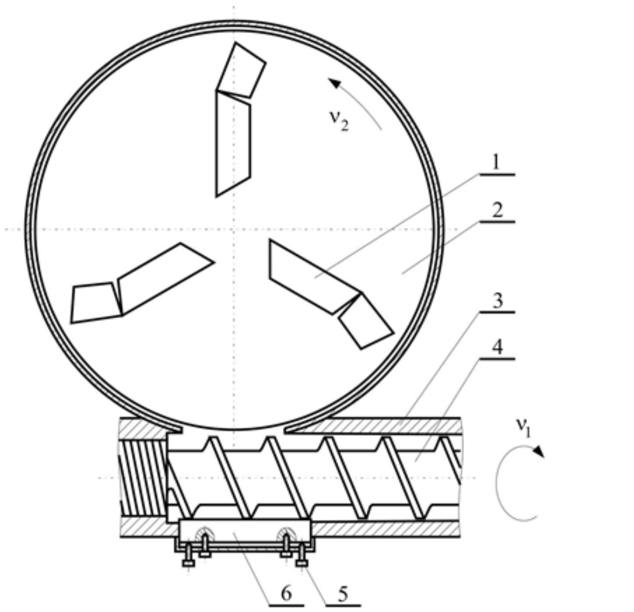


Fig. 3 *Schematic of the longitudinal section of the feed opening and feed sections of an extruder plasticizing system: 1 - sharp working edges, 2 - rotating tool, 3 - barrel, 4 - screw, 5 - adjusting screw bolts, 6 - slat (rib), v_1- rotational speed of the screw, v_2- rotational speed of the rotating tool [3]*

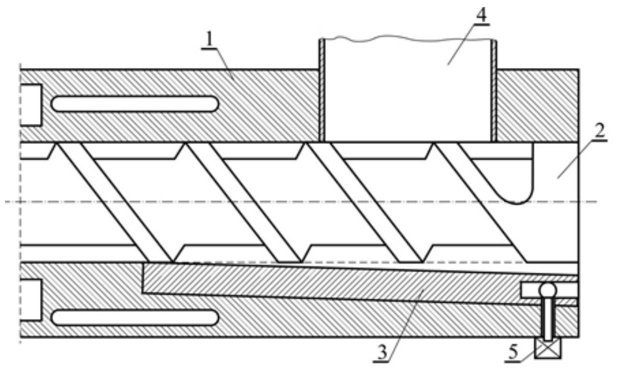


Fig. 4 *Longitudinal section diagram of the adjustable grooved feed section of an extruder: 1 – barrel, 2 – screw, 3 – slat (key), 4 – feed opening, 5 – actuator [4]*

Figure 5 shows a design in which the feed section can be adjusted by changing the number of grooves and by continuously and independently changing their depth and inclination angle. Adapters (2) are mounted in the barrel (1) of the plasticizing system. The bolt (3) can be screwed in to rotate the adapter (2) on the articulated joint (4) and thus to increase the inclination angle and the depth of the grooves thus formed (5).

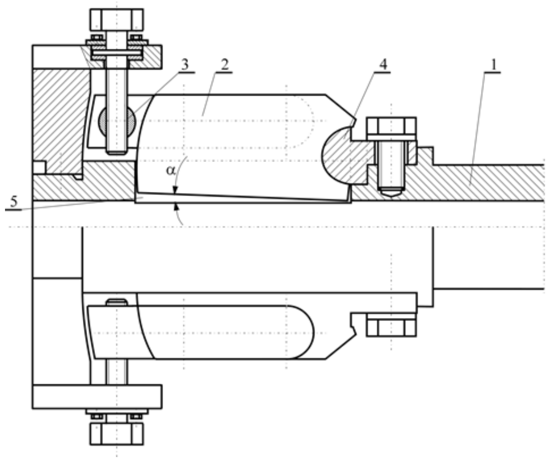


Fig. 5 *Longitudinal section diagram of the active grooved feed section with four longitudinal grooves, description in the text [4]*

In turn, Figure 6 shows a longitudinal section diagram of a grooved zone, in which the inclination angle, the handedness and the cross-sectional shape of the grooves can be changed continuously by a twisting mechanism comprising a worm gear. In this case, the grooved sleeve is fixed to the barrel permanently at the end closer to the extruder head. Depending on the direction of twisting, the longitudinal grooves become right or left-handed. The disadvantage of this solution is that the shape of the feed opening can be deformed when twisting the sleeve, which limits the obtainable range of twisting angles.

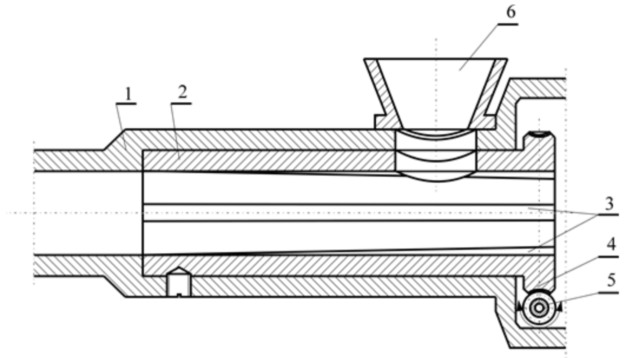


Fig. 6 *Longitudinal section diagram of the active grooved feed section with the twisting sleeve: 1 – barrel, 2 – grooved sleeve, 3 – grooves, 4 – worm wheel, 5 – worm, 6 – hopper [6]*

The design shown below (Fig. 7) eliminates the issue of deformation of the feed opening due to the twisting of the sleeve. In this solution, the part of the grooved sleeve comprising the feed opening is rotated, while the remaining part of the grooved sleeve is twisted. This is done by means of a twisting mechanism placed downstream of the feed opening.

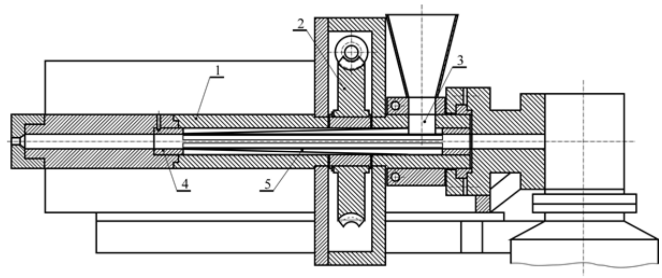


Fig. 7 Longitudinal section diagram of the active grooved feed section of the extruder which eliminates shifting and deformations of the feed opening: 1 – barrel segment, 2 – worm wheel, 3 – feed opening, 4 grooved sleeve, 5 – grooves [7]

It follows from the Polish Patent No. 212185 that this design can be modified by introducing a rotary ring that allows continuous change of the depth of all grooves at the same time. Rotation of the ring (5) sets into longitudinal motion a system of wedges (4), which in turn set into rotational movement the slats (3), thereby changing the inclination angle β and depth of all the grooves (Fig. 8).

In the embodiment disclosed in the Polish Patent No. 199018, the swivel grooved sleeve has at least two types of segments joined longitudinally at their sides (Fig. 9). Both types of segment have the shape of a longitudinal section of a sleeve with one type (4) having an outer cylindrical surface (5) parallel to the inner cylindrical surface (6) and the other type (7) having non-parallel outer (8) and inner (9) cylindrical surfaces. Together they form slender wedges. The segments comprising the swivel grooved sleeve which have the same shape, are arranged alternately with segments of a different geometry to form grooves (10) of varying depth. This design enables twisting of the split sleeve, left- or right-wise, with significantly less torque compared to single-piece sleeves, also allowing the formation of left or right-handed grooves in the sleeve.

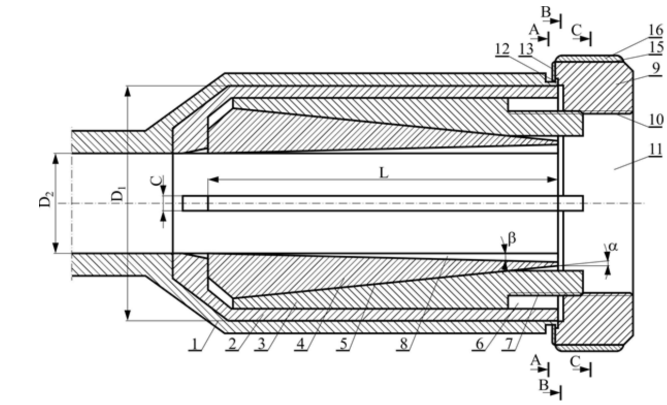
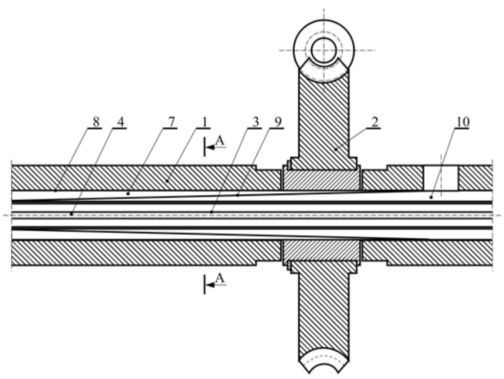


Fig. 8 *Longitudinal section diagram of the active grooved feed section of an extruder equipped with a set of slats and wedges set into motion by a rotary ring: 1 – grooved sleeve, 2 – barrel, 3 – slat, 4 – wedge, 5 – rotary ring, 6 – groove with adjustable depth [8]*

A)



B)

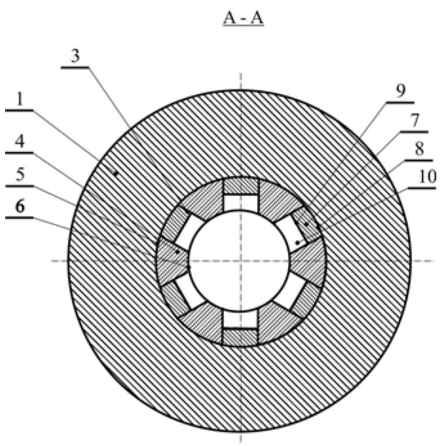


Fig. 9 *Schematic of a swivel sleeve; a) longitudinal section with twelve segments forming six grooves, b) cross-section: 1 - barrel, 2 - worm wheel, 3 - longitudinal side surfaces, 4 - first type of segment, 5 - outer cylindrical surface of segments of the first type, 6 - inner cylindrical surface of segments of the first type, 7 - second type of segments, 8 - outer cylindrical surface of segments of the second type, 9 - inner cylindrical surface of the second type of segments, 10 - grooves [9]*

Polish Patent No. 219984 describes a solution in which the grooved section is comprised of annular segments (Fig. 10). The segments have grooves with a trapezoidal cross-section cut in them. Each of the annular segments can be rotated independently by means of a worm wheel. Right handed grooves are formed by rotating the successive segments more and more to the right and left-handed grooves are formed by rotating the successive segments more and more to the left.

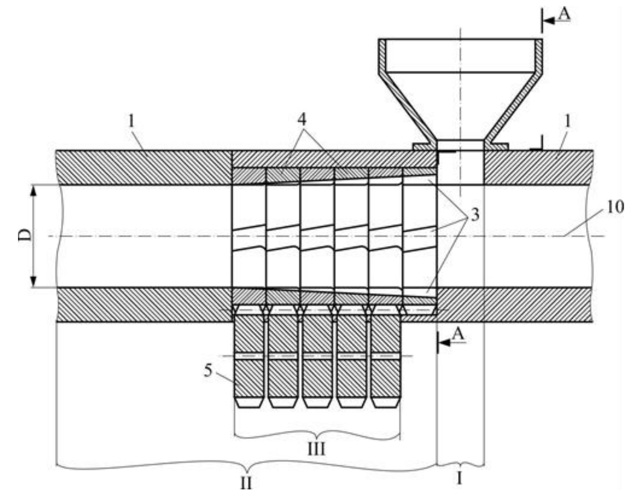


Fig. 10 Longitudinal section diagram of the active grooved feed section of an extruder with a twistable sleeve formed by rotary ring segments: a) before twisting, b) after twisting; 1 - barrel, 2 - right-handed grooves, 3 - longitudinal grooves, 4 - rotary ring segments, 5 - worm wheel, β - groove twisting angle [10]

3. Solution of the examined problem

The preliminary assumptions of the presented visualizations are the following: models are made in Catia v5 system as 3D models, they are fully functional. They were tested for their regularity and collision occurrence. Also, virtual prototypes were created to determine the risk of any irregularities during movement.

The constructional assumptions of an active grooved feed section are the following:

- the grooved section is 5D long, therefore it is 100 mm,
- the width of the grooves is 6 mm,
- the maximum height of the grooves is 6 mm,
- the inner diameter of the barrel is 25 mm.

Two different constructional solutions of an active grooved feed section were presented in the form of CAD models. They are the development of existing solutions but also totally new ones. Them have innovative advantages and they will be submitted for legal protection in the form of appropriate industrial property rights.

4. Results and discussion

The functioning rule of an active grooved feed section in this concept is the possibility of closing the grooves (section without grooves) and their partial opening (section with grooves) by means of rotating the segments. In Figure 11 an axonometric view of the concept model is presented. The particular elements are also visualised in the exploded view - Figure 12. In this concept, the taper angle of grooves can be changed and therefore also the grooves depth can be changed along the grooved section, either in an individual way, independently adjusting each groove, or in a collective way, adjusting all grooves simultaneously.

The closing (lack of screws) and the opening of the grooved section is achieved by rotating the moving segments 3 around the hinge axis 4. The rotation is forced by an adjusting bolt 10. In the moment of achieving an appropriate depth of the groove, the rotational movement of the segment is blocked by means of an adjusting screw 8.

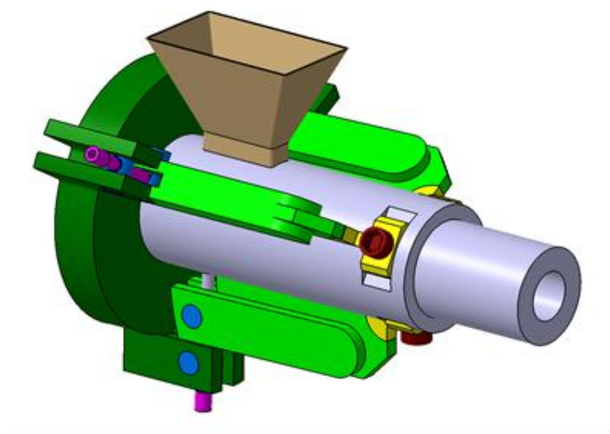


Fig. 11 *Concept model No 1. Assembly view*

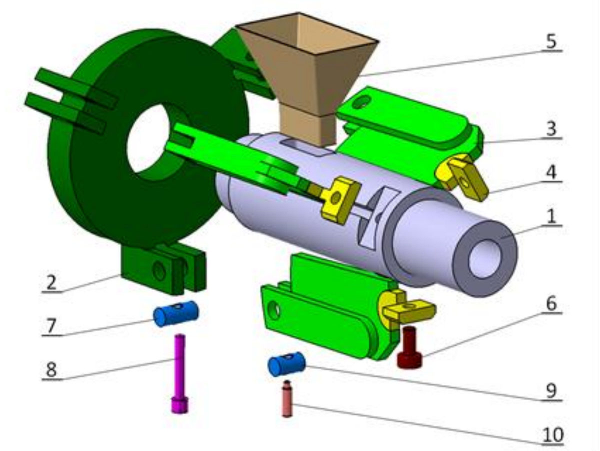


Fig. 12 *Concept model No 1. Exploded view: 1 – main sleeve, 2 – fixing plate, 3 – moving segment, 4 – hinge, 5 – hopper, 6 – fixing screw, 7 – front pivot, 8 – adjusting screw, 9 – back pivot, 10 – adjusting metal bolt*

Concept No 2 is a modification and significant improvement of concept No 1. The functioning rule of this active grooved feed section is the possibility of changing the depth of the grooves along the section without the necessity to stop the extrusion process and make a troublesome exchange of the grooved sleeve. In the assembly Figure 13 the axonometric view of concept model No 2 is presented, the particular elements are shown also in the exploded view (Fig. 14).

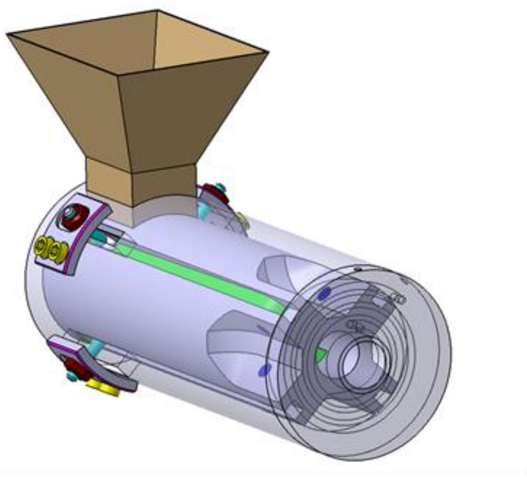


Fig. 13 *Concept model No 3. Assembly view*

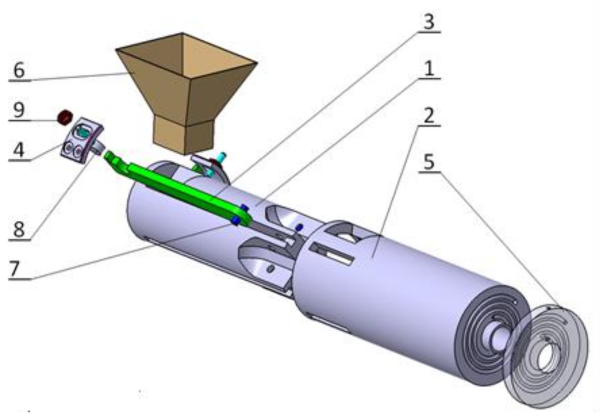


Fig. 14 *Concept model No 2. Exploded view: 1 – main sleeve, 2 – barrel, 3 – moving segment, 4 – fixing element, 5 – separating cooling disc, 6 – hopper, 7 – fixing pivot, 8 – adjusting screw, 9 – nut*

The closing (smooth inner surface) and opening (grooves) of the grooved section is achieved by rotating segments 3 around the axis of pivots 7. This rotation is forced by an adjusting screw 8.

5. Conclusion

The single screw extruder (SSE) is one of the most important pieces of equipment in the polymer processing industry. Therefore, it is not surprising that there is a lot of interest in improving this technology. The innovative extruder can provide ensure higher polymer flow rate, better quality of extrudate mainly due to higher homogenization of mechanical and thermal properties, as well as improved structure of the material, smaller unit consumption of energy, and higher energy efficiency compared to currently used extruders. This innovative solution is expected to outperform in all aspects the current ones by at least 10%.

6. Funding

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 734205 – H2020-MSCA-RISE-2017.

7. References

[1] Mayer, P. Screw extruders, Patent US 4462692 (1983).
[2] Peiffer, H., Eberhardt H. Screw extruder, Patent US 4678339 (1985).
[3] Helmut, B., Helmut, S., Georg, W. Apparatus for processing thermoplastic synthetic plastics material, Patent US 5783225 (1997).
[4] Rauwendaal, Ch. Screw extruder with independently adjustable groove depth, Patent US 5909958 (1997).
[5] Sikora, R., Sikora J. Extruder for high-molecular plastics, Polish patent 174623 (1994).
[6] Sikora, R., Sikora, J. Autothermal extruder, Polish patent 174068 (1994).
[7] Sikora, R., Sikora, J. Plasticizing device for extruders, Polish patent 330890 (1999)
[8] Sikora, R., Sikora, J., Sasimowski E. Extruder's plasticizing device, Polish patent 212185 (2007)
[9] Sikora, J.: Extrusion moulding machine for polymeric materials, Polish patent 199018 (2001).
[10] Sikora, R., Sikora, J. Placticising unit an extrusion machine, Polish patent 219984 (1999).