Design of conveyor type machine with numerical control for manufacturing of extrusion thermoplastic thread

T N Gorbunova\(^1\), I I Koltunov\(^1\), M B Tumanova\(^1\)

\(^1\)Department of Information systems and technologies, Moscow Polytechnic University, 38, Bolshaya Semenovskaya St., Moscow, 107023, Russia
\(^2\)Department of Applied mathematics, National Research Moscow State University of Civil Engineering (MGSU), 26, Yaroslavskoye Shosse, Moscow, 129337, Russia

E-mail: tngorbunova@yandex.ru

Abstract. The article is devoted to the development of a model and control program for a 3D printer working based on extrusion technology. The article contains descriptions of all components of the machine and blocks of the interface of the control program.

1. Introduction

Nowadays 3D printers which per se are machines with numerical control are widely spread. They process different polymers to create multilayer objects used in different branches to solve the most important tasks: creation of advanced designs of machines and devices, quality improvement and widening of a range of technical and consumer goods, significant improvement of architectural engineering, enhancement of agricultural manufacture and a number of other manufactures [1-3].

The production method of articles and half-finished goods of the desirable shape, namely polymer material melt punching though the shaping tool (head), is called extrusion.

2. Materials and methods

An extrusion line is the complex of equipment for extrusion, intended for issue of a finished product of polymers which includes the following: an extruder, a sizing device, a stretching device, a guiding device and a winding device.

An extruder is the main element of the extrusion line of polymer materials processing. Production of different extrusion articles is conducted by means of preparing a melting extruder and shaping of an extruder by means of pushing it though shaping heads of corresponding constriction with subsequent cooling and sizing, etc.

The simplest equipment for extrusion is a single-screw extruder without a degassing zone. Such extruders are widely used for production off films, plates, pipes, shapes, as a composite part of the granulator line, etc. [4,5]

The main elements of a single-screw extruder are a heated cylinder, a screw (with or without cooling), nets placed upon the grating and shaping head (Figure.1). Depending on the kind of polymer and technology processing mode, different screw shapes are used, particularly with different patterns of threading depth change \(h\) along the screw length [6,7].
The following main components of the machine can be marked out.

**Stepper motor.** An electric drive is essential for the rotation of the screw which was modelled and then produced in accordance with the model. One of the most powerful stepper motors Nema 42 was chosen to serve as an electric motor.

**Planetary reduction gear.** The reduction gear is essential for decreasing the load on the electric motor and for decreasing the rotating part frequency. The gear structure with many satellites provides a bigger number of tooth actions and decreases load on each tooth. This helps to achieve smaller sizes and weight if compared with an ordinary gear at the same transmission capacity. Coaxiality of the drive and driven shaft facilitates machine arrangement and cascade mechanisms. Equilibrium of forces in the gear decreases the noise level. The gear structure allows one to achieve a greater reduction ratio at a less number of wheels.

A screw (or worm) is used in extrusive installation which also can be called an expeller or tubing machine. The screw is the main component in extruders which together with the heating cylinder consolidates, melts and homogenizes polymeric mass and then pushes it through the outlet hole of the shaping head.

Numerical data about the diameter (D) and length-diameter relation (L/D) are values according to which extruder productivity can be assessed. The screw torque moment and its diameter are also parameters that characterize the extruder structure. Thus, extruders are clearly classified into its productivity and are produced only with certain types of screws.

An extruder head (draw die). The draw die is essential for equalizing pressures appearing in the extruder outlet and for shaping the desired material. It is easier to produce the draw die from aluminum plates with specific shape of the cut with laser. The structure has 4 through holes for fastening the extruder, one blind hole for screw bearing and channels for melted material output and its transformation into a thread with a diameter of 1.75 mm.

Motor and extruder fastening. Motor and extruder fastening is produced by means of laser cutting of 8 mm thick steel.

Assembly of all components into one model (Figure 2).
The control program is written in C# with the development of user interface in Microsoft Visual Studio.

The program user interface is represented by a shell which allows one to control all means and settings from the PC. For the user convenience, the buttons for power on, emergency shutdown, speed adjustment, switch on/off for different components, and graphical elements for visual aids were made. (Figure 3).

Explanation of main units

1. **Main motor control unit** Motor#1 (Figure 3.1) allows one to control electric motor operation mode settings and parameters such as rotation limits (Max and Min), motor rotation direction (Direction) and motor driver operation mode setting (Microstepping) [8]. The latter setting controls the change in the number of steps made by the motor during one full rotation. Possible options: 200, 400, 800, 1000, 1600, 2000, 3200, 4000, 5000, 6400, 8000, 10000, 12800, 20000, 25600, 40000 (steps per rotation). Prescaler – PWM operation mode setting (pulse-width modulation) of the timer on the machine controller. This setting allows one to change the mode of timer synchronization relative to microprocessor clock frequency. Possible options: 1, 8, 64, 1024. Speed control buttons (-20, -10, -5, -1, +1, +5, +10, +20) are necessary for quick speed change of the stepper motor. When pressing the button, the speed changes by the value displayed on the button in rpm. Set speed is displayed in the left part of the unit in rpm. When moving the slider above the speed control buttons, speed of the stepper motor also changes within limits from Min to Max.

2. **Broach motor control unit** Motor#2 (Figure 3.2) has the same settings and interface as the main motor control unit.
3. **Board communication control unit** (settings of com-port) (Figure 3.3). Change of com-port settings is necessary for establishing of stable communication with the machine controller. The unit allows one to choose PC connection Port, Baudrate – data transfer rate in bps.

4. **Activation and emergency stop unit.** For the control convenience, the following buttons were created: emergency stop (Figure 3.4), soft start (Figure 3.5) and machine motors acceleration (Figure 3.6).

5. **Heater control unit** (Figure 3.7). In this machine, 4 ceramic heaters with total power of 2 kW are used. Each of the heaters maintains a certain temperature set by the machine operator in the control program in its zone. Defining the temperature in the zone is conducted by reading indications of thermocouples.

Kp, Ki, Kd are coefficients of PID control which helps to adjust heaters power for maintaining the temperature set in the field Temperature (C).

Percentage scale in the bottom (0-100%) is a graphical image of output power of the heater. When the value grows it turns green and the numerical value is shown in percent.

6. **Automatic speed synchronization control unit.** An algorithm of PID control of stretching device motor speed was used for twig diameter sizing [9]. The faster the twig stretches, the thinner it will be and vice versa. For 3D printer operation, the necessary constant twig diameter equals 1.75 or 3.0 mm with tolerance of 0.1 mm. in speed synchronization unit when pushing the button ON/OFF Motor#2 speed correction is switched on considering the previous accumulated faults. Thus, the permanent quality control and the diameter of the produced plastic thread is conducted. The unit is shown in (Figure 3.8)

7. **Layer** (Figure 3.9) and **spool** (Figure 3.10) **units.** The services are necessary for twigs pooling and for laying of twig without overlapping so during the following work with the spool the twig will not tangle. After activation of spool unit, the program automatically calculates the speed for spool rotation with set sizes (diameter and width), so the plastic thread lies evenly without sagging and tension. After activation of the layer, the unit starts the motor of the laying device. The program automatically calculates the distance for shifting the gib, so the twig spools spirally and each loop lies next to the other without gaps.

3. **Results and Discussion**

Main technology steps taken during the design of the machine:

1. Program complex SolidWorks was used for modelling of numerous details, nods and mechanisms, the complex allows the following:
   - modelling of all machine components step-by-step,
   - assembly of all details into single unit,
   - output of drawings necessary for the machine production.

2. After that the developed drawings were passed to the production where the following numerically controlled machines were used: milling machine, turning machine, drilling and laser cutter for cutting details, nods and mechanisms of the designed machine. Before the final assembly work, all details were checked for defects, quality and compliance with the drawings.

3. Design of the machine controller, all its electronic components (sensors, converters, and drivers) was conducted simultaneously with the modelling

4. Development of the software for the machine controller and control program for operator communication with the machine was conducted with the help of Microsoft Visual Studio.

5. Then the assembly of the real machine was conducted as well as its setting, operability check of all units (motors, heaters, sensors) and sizing.

6. Launching.

The model of the machine for producing of thermoplastic thread which is used for work of 3D printers with FDM (Fused deposition modeling) [10] technology (modelling by method of layerwise building-up) was designed with the help of program complex Solid Works. Modelling of the machine in this program complex allows to consider all component sizes, included into the machine and make all necessary drawings for their production. Also, with the help of program complex Microsoft Visual
Studio in C# language, the control program for this machine was written, the program allows the operator to control all components of the conveyor line from the PC.

**Conclusion**

The developed model allows one to consider necessary parameters used in the production of technological equipment. The 3D printer designed on the base of this model demonstrates the effective raw materials use.

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