Development of an Extruder Module for Additive Manufacturing with Granulated Polymeric Materials [1].

Victor Manoel Andrade dos Santos[2]; Gabrielli Laurindo[3]; Guilherme Bueno Silveira[4]; Leonardo Santana[5]; Rodrigo Acácio Paggi[6] Aurélio da Costa Sabino Netto[7]

Extended Abstract

[1] Work funded by Notice No. 16/PROPPI/2013, from the Office of Research, Graduate Studies and Innovation
[2] Fellow; Instituto Federal de Santa Catarina; Florianópolis, SC; vector4100@gmail.com; [3] Fellow; Instituto Federal de Santa Catarina; Florianópolis, SC; gabriellilaurindo@hotmail.com; [4] Fellow; Instituto Federal de Santa Catarina; Florianópolis, SC; guilherme094@hotmail.com; [5] Researcher; Universidade Federal de Santa Catarina; Florianópolis, SC; leonardosantana29@gmail.com; [6] Professor; Instituto Federal de Santa Catarina; Caçador, SC; rodrigo.paggi@ifsc.edu.br; [7] Professor; Instituto Federal de Santa Catarina; Florianópolis, SC; asabino@ifsc.edu.br.

ABSTRACT: We currently live in a period of strong expansion of 3D printers that use Fused Deposition Modeling (FDM) technology. The spread of this technology is mainly due, above all, to the use of open-source software, low cost of components for assembling the machine and ease of operation. However, the cost of polymeric raw material (PLA, ABS, etc.) that consists of pre-fabricated polymer spools has become a limiting factor in the expansion and cost reduction of the process. This project aims to develop an extruder module that allows the use of thermoplastic materials in granulated form. The PRODIP methodology was used for selection and choice of the most suitable components to constitute the mechanical and electro-electronic modules. The result obtained is a consistent and reliable design, produced based on research on conventional extruders and, despite the prototype being in the manufacturing phase, it is believed that the machine will meet all expectations.

Keywords: 3D Printer, extrusion, granulated polymer.

INTRODUCTION

The Fused Deposition Modeling (FDM) process was developed in 1989 by the American company Stratasys (STRATASYS INC., 1992). Currently, it is the most widespread additive manufacturing process in the world, using raw material in filament form (VOLPATO et al., 2007). This limits the use of the technology to building parts with commercially available materials. On the market, generally, spools produced with the ABS and PLA polymers are available.

The use of different concepts for the extruder module has been the subject of some research to enable the use of different polymeric materials. Kretschek (2012) noted that the most studied concepts are plunger extrusion and screw extrusion. Both concepts present positive and negative aspects. Plunger extrusion uses less material but does not allow continuous use of the machine, since the material in the plunger needs to be replaced. Screw extrusion allows continuous machine use, but presents a more complex constructive solution.

There is great interest in evaluating the use of FDM technology with other polymeric materials such as: biopolymers, engineering polymers, high-performance polymers and polymeric composites.

The objective of this work was to develop an extruder module that allows the use of thermoplastic materials in granulated form.

METHODOLOGY

For the development of the extrusion module, as well as the electrical systems of the equipment, the PRODIP methodology was used (BACK *et al.*, 2008). From the project requirements, it was possible to establish the functional synthesis shown in figure 1, and then the components and architecture were defined.

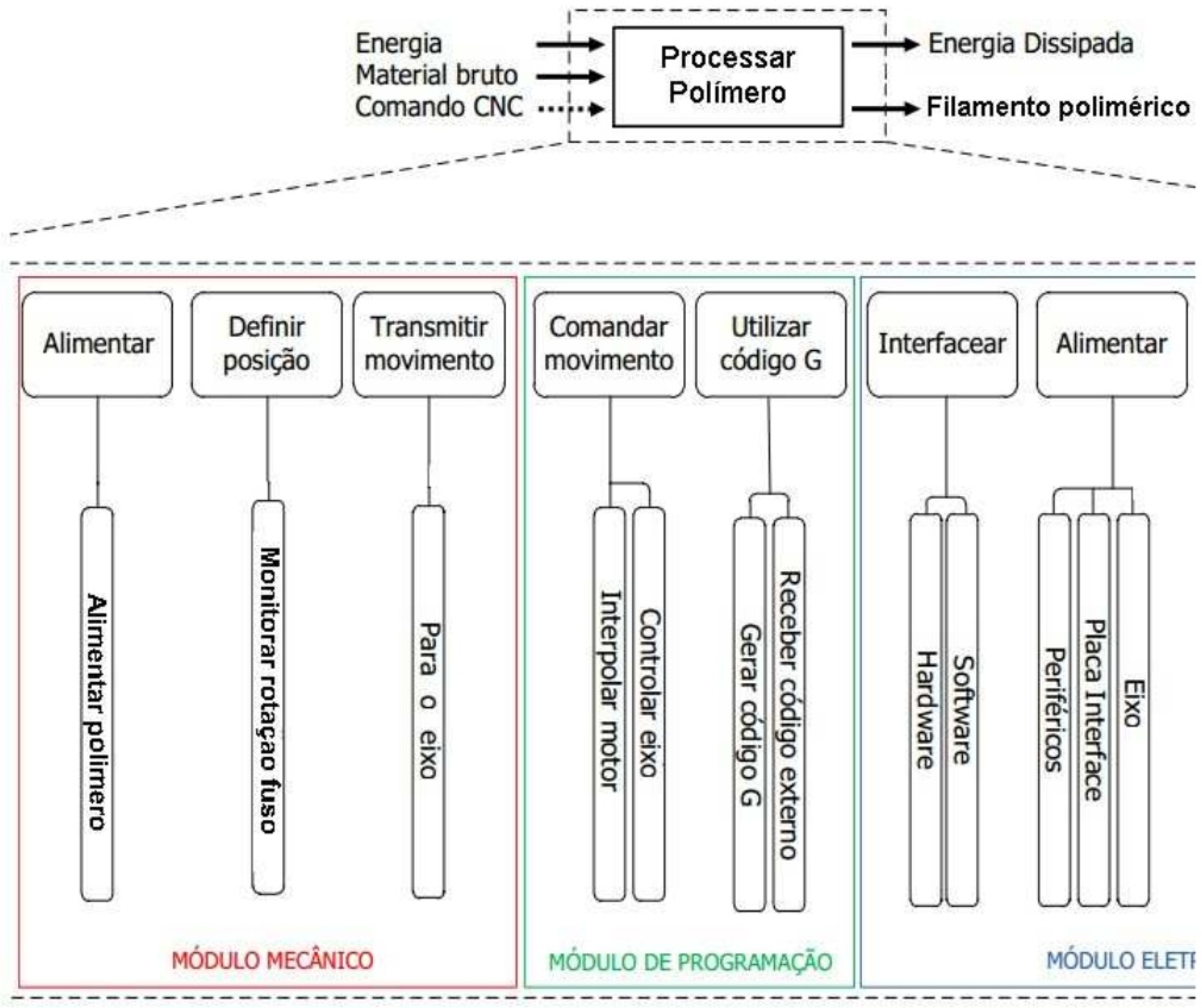

Figure 1: Functional synthesis for the extruder module.

Development of the Mechanical Module

The design of the mechanical module was based on algumas extrusoras de laboratório (Haake, Brabender and AXPlásticos). A schematic of the system proposed is shown in figure 2.

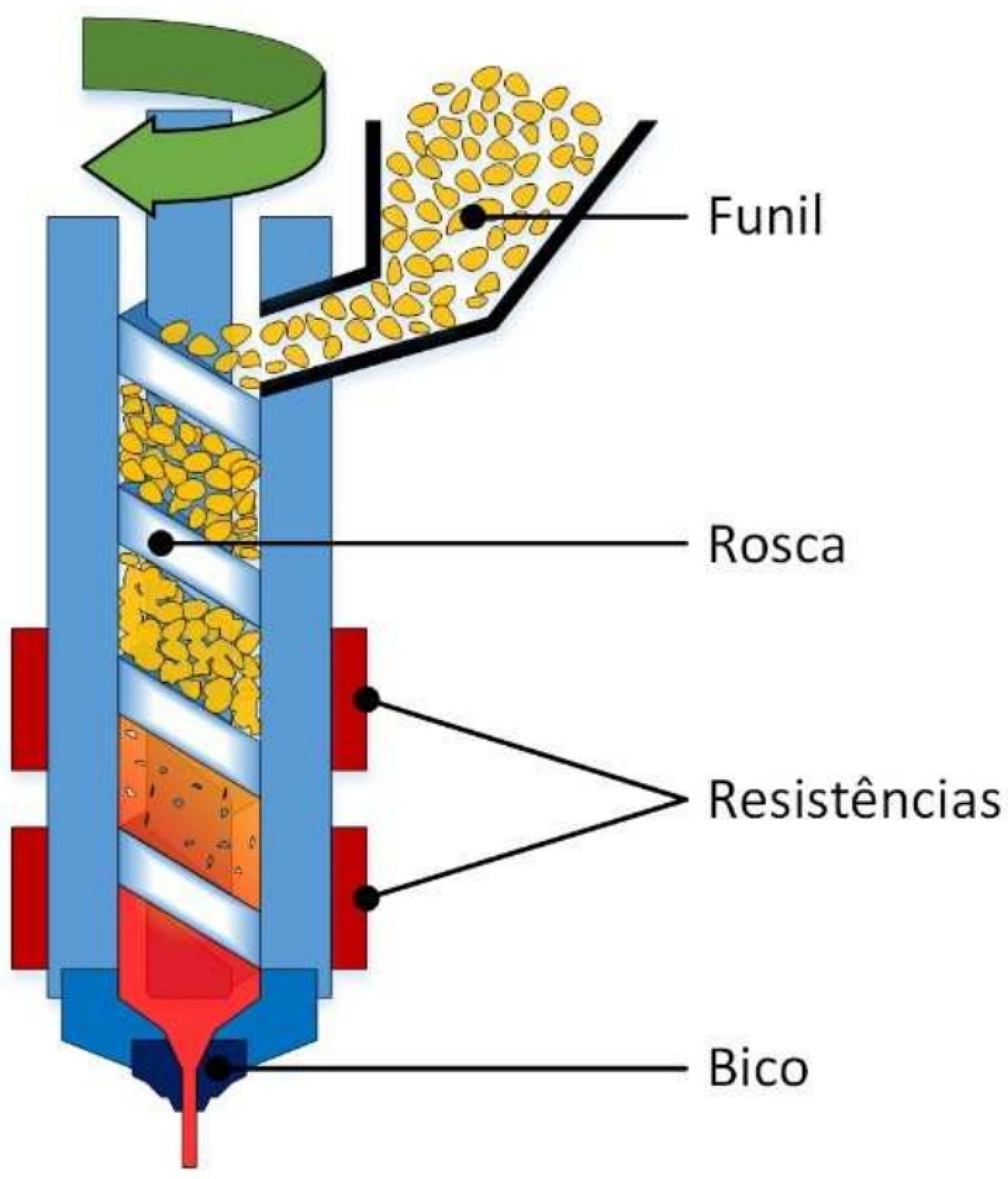

Figure 2: Schematic of the extruder module with the main components.

Granulated materials are stored in a hopper positioned at the top of the system. A vertical extruder screw transports the granulated material along the barrel containing electrical heating elements in two zones. After the second heating zone, the material passes through an extrusion die that adjusts the filament diameter and maintains the temperature of the material with a third heating element.

It was initially decided to use a screw with only the transport zone. The diameter chosen for the screw was 15 mm, allowing a flight height compatible with the particle size of virgin materials. The screw length chosen was 300 mm, giving a L/D ratio of 20, normal in thermoplastic extrusion. To manufacture the prototype screw, an 18 mm concrete drill bit was used. The tip with the carbide insert was removed and the screw diameter was machined to reach the final dimension.

Based on the screw, the extruder barrel was designed from a 36x16 drawn seamless steel tube with internal diameter of 15.3 mm. Two mica clamp-type heating resistors and two J-type thermocouples were mounted to the barrel.

The electrical power for heating the system was calculated based on equations 1, 2 and 3.

(1)

$$Q = m \cdot c\,p \cdot \Delta T \quad (2)$$

$$Q = m \cdot \Delta h \quad (3)$$

Where: P = electrical power; Q = heat quantity; t = time; m = mass; cp = specific heat; ΔT = variation between final and initial temperatures and Δh = variation between final and initial enthalpies.

For this calculation it was necessary to consider the various components and different materials making up the assembly. Through estimated approximations of each component mass, using *software* CAD, the required value was obtained so that the assembly could reach the working temperature. Using a maximum heating time of 10 minutes as reference, it was obtained that the required electrical power would be 300W. However, two 200W resistors were used each as safety margin and to allow a faster heating response.

As an extrusion die, a nozzle for 3D printers, Merlin model, with 3 mm inlet diameter and 0.5 mm outlet diameter, was adopted. The nozzle contains a 12V cartridge-type resistor with 30W of power and a 100kΩ thermistor for controlling the filament output temperature.

To drive the screw, a system composed of pulleys/timing belt was designed,

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a reducer and stepper motor. The pulleys were chosen to provide safety in case of a screw jam. A planetary reducer with 15:1 ratio was used to provide greater torque and precision to the system. The stepper motor used was a NEMA 23 with 15 kgf.cm.

Based on the aforementioned components, the 3D modeling of the extruder module was performed in Solidworks software, as shown in figure 3.

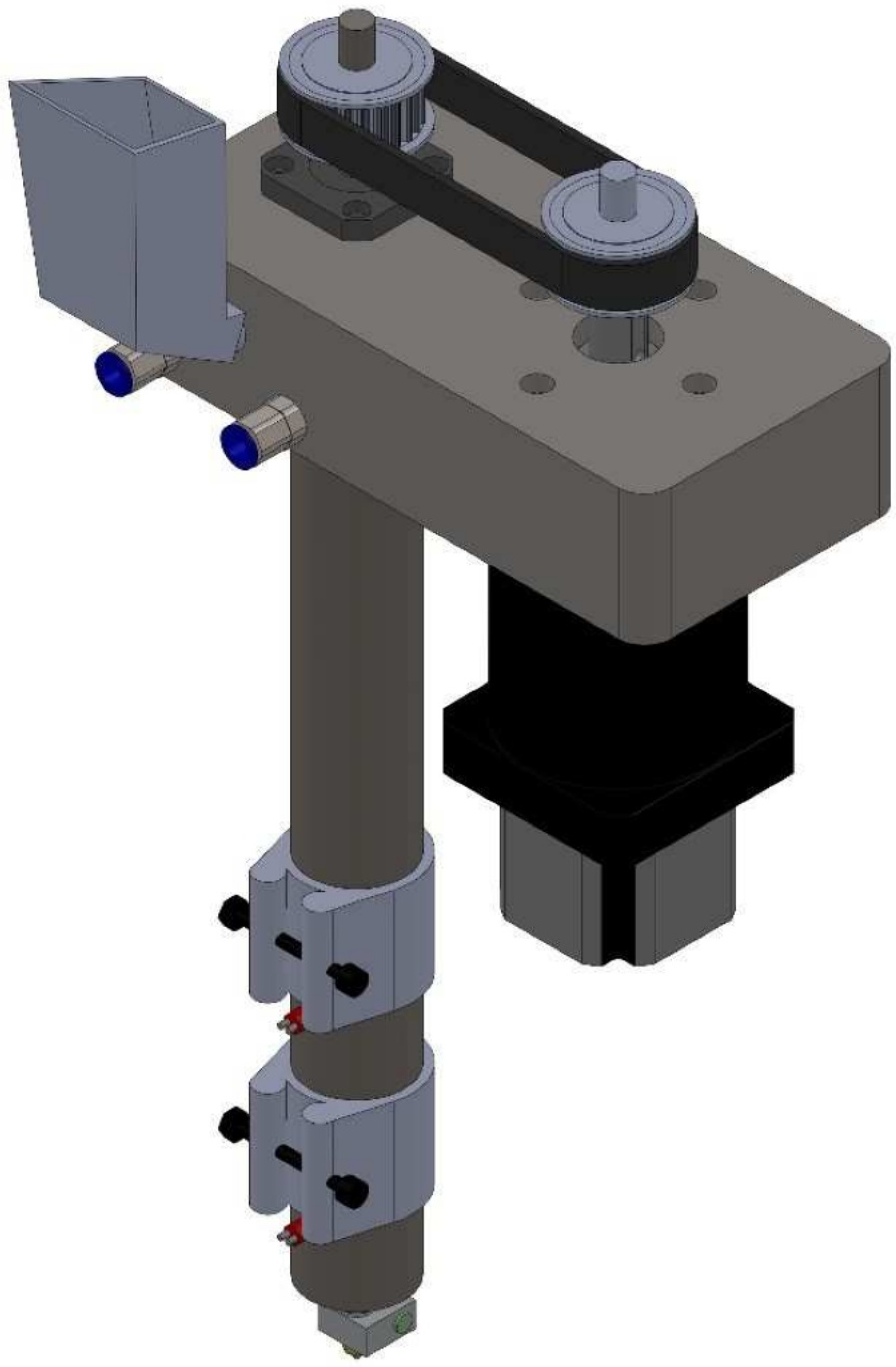

Figure 3: CAD assembly of the extruder module.

Development of the Electro-electronic Module

The equipment control system is responsible for interfacing between programming and machine. For this, it was necessary to develop a control cabinet using electronic components with various functionalities.

Four power supplies were used in the project for the electro-electronic systems, all with direct current outputs.

The C10 controller board, powered separately by a 5V supply, was chosen for its low cost, parallel port use, and for being commonly used for developing CNC machines with Mach3 software interface. The second supply has an output of 36V used to power the KL4030 motor control drivers from Keling Inc., capable of driving a wide variety of stepper motors; their advantages include the high actuation precision offered, with microstepping up to 1/64 steps providing greater movement resolution and relatively high driving power capacity. A third 24V supply was used to power a 24V/25A contactor controlling the entire interlock circuit, providing greater safety for the system. A fourth supply with a 12V output was also used to power the extruder nozzle.

To control temperatures in the two barrel zones and in the nozzle, three PID C304 controllers from Contemp were employed, which feature a high-performance RISC microcontroller technology enabling execution of mathematical operations and algorithms in 32-bit floating point, ensuring speed and precision in process control.

The software option for control and HMI of the equipment was Mach3, for its flexibility, quality and low cost; the software is widely used in the development of standalone CNC machines. Another factor that led to this choice was its use as a teaching platform for machine construction, making the researchers more familiar with this platform.

RESULTS AND DISCUSSION

The PRODIP methodology was fundamental in performing the selection and choice of the most suitable components to constitute the mechanical and electro-electronic modules.

A conservative design was adopted due to the uncertainties arising from the use of small-scale extrusion concepts. Tests performed with conventional nozzles indicate that the required extrusion rate is around 0.7g/5min. It is believed that a single-profile screw, with only the transport zone, is adequate to meet this need.

The prototype is in the manufacturing phase and it is understood that the mechanical and electro-electronic modules will operate adequately. However, no tests were performed to verify the precision and accuracy of the machine as a whole, due to

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delays in the project execution schedule.

The proposed machine validation tests consist of checking the uniformity and density of the resulting filament at the end of the process, as well as repeatability, in order to define the precision and reliability of the developed equipment.

Tests for validation of the control cabinet interface and interlock with the mecânico também foram realizados, estes showed satisfactory performance by meeting expectations regarding the safety and control system. The interlock system showed excellent performance, shutting down the system when requested.

CONCLUSIONS

The prototype, in the manufacturing phase, has the initial characteristics to perform thermoplastic extrusion studies at reduced scale. It will be controlled via a computer using Mach3 software and will be capable of processing the material in granulated form through a die into a final filament form with an approximate diameter of 0.5 mm.

The next step will be to integrate the extrusion module with an XYZ movement device to conduct additive manufacturing studies and, thus proving the final purpose of the project. Given that the objective was only the development of the extruder module, it is concluded that it was a success.

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