Hardware Article

Instrumented open-source filament extruder for research and education

Maurício de Oliveira Filho *, Matheus Cerqueira de Jesus, Anderson Zenken Nakazato, Marcel Yuzo Kondo, Luis Rogerio de Oliveira Hein

Materials and Technology Department, School of Engineering, São Paulo State University – UNESP, Av. Ariberto Pereira da Cunha, 333 Guaratinguetá, SP, Brazil

ABSTRACT

Extruders are necessary equipment for 3D filament manufacturing, which is considered a clean technology because it has less scrap and can reuse materials, increasing its life cycle. Open source extruders are less expensive than industrial extruders. However, they have little instrumentation, which limits processing analysis and thus the development of new materials, screw design and process control. Therefore, this project aims to develop a low-cost extruder with a high degree of instrumentation for in-situ process analysis. To achieve this, equipment was developed with an integrated circuit board, both with modularity, machine and peripheral control, process stability, and data acquisition. To validate the equipment, processing was done at constant temperature and with flow variation. The data obtained were the temperatures at different points in the barrel, the rotation speed of the extruder motor, the current consumed by the motor and the resistances, and the speed of the extruder motor. Thermal images of the components were obtained during processing, validating the type of material used in the parts manufactured by additive manufacturing. The ABS filament produced was analyzed by flow and surface analysis using a confocal microscope. Higher flow rates had a better surface quality of the filament.

(continued on next page)

Specifications table

| Hardware name | Integrated and modulated system for extruder machine |
|---------------|------------------------------------------------------|
| Subject area  | Engineering and materials science                   |
|               | Educational tools and open-source alternatives to existing infrastructure |
| Hardware type | Measuring physical properties and in-lab sensors      |
|               | Field measurements and sensors                       |
| Closest commercial analog | There are several commercial extruders. The integrated circuit is designed to connect and control the machine and external elements. With it, you can control and analyze the process simultaneously and in real-time. This circuit can be applied in commercial extruders. |

* Corresponding author.
E-mail address: mauricio.oliveira@unesp.br (M. de Oliveira Filho).

https://doi.org/10.1016/j.ohx.2022.e00362
2468-0672/© 2022 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Unconscious use of the planet’s natural resources makes society less egalitarian and has a greater impact on society. Therefore, ideas such as green fablab and increasing the life cycle of materials are imperative and necessary [1–3]. Additive manufacturing is presented as a great alternative for reducing disposal and thereby increasing the circular economy [4,5]. This is because the manufacturing process produces less scrap, compared to other manufacturing processes, can use a wide range of polymer types and some works analyzed remanufacture these materials. This is because the manufacturing process produces less scrap compared to other processes, can use a wide range of polymer types, and some works have analyzed the reprocessing of these materials [6–9]. Moreover, this is a promising process to be widely used in the automotive, medical, and aerospace industries, and for the same reason, new materials have been emerging to suppress these requirements [10,11]. However, producing the filament requires an extruder, which is expensive and the industrial one has a considerable size.

Industrial extruders are expensive equipment and difficult to modernize [12]. The screw is usually the most expensive part of the machine because it is designed for the polymer to be processed. However, after 2012, thanks to an open-source patent, open filament extruder designs began to emerge [13]. They are machines with smaller sizes and reduced costs compared to industrial ones. Some of them are developed for the laboratory, according to commercial portfolios [14–17]. They have little instrumentation and none of them have data acquisition systems or data processing capabilities [18]. As they come from closed projects, this limits the research, development and validation of new materials and mechanisms.

Open design extruders, developed for FDM, have four characteristic components similar to commercials: the extruder and out systems [19,20]. The extrusor system is usually divided into three functional regions: the extrusion system, which is the drill and motor, the feeding zone, with printed designs in general and the heating zone, which is usually with resistances only in the barrel, therefore with only one heating zone. The structural part of the extruder has several types of constructive forms, some designs use printed parts locked into a wooden board, and others use metallic plates [19,21,22]. However, these machines have little instrumentation, using heater controller and potentiometer for motor control. This consequently limits them about process analysis and, consequently, the control of the produced filament quality or the phenomena generated in the material during the process [23,24].

The peripheral mechanisms are the cooling system, puller, diameter analysis and spooling. Cooling systems for the filament can be of two types, water and air. These two systems are present in either, commercial machines or open-source projects [25,26]. Diameter analysis is obtained in several ways, according to various projects in the literature: using caliper, optical sensor or using cameras [20,27–30]. The analysis with the caliper and optical sensor is simple. The caliper has the advantage that it is easily purchased, there is virtually no calibration, and the operator can monitor the measurement from his display during the process. The camera has the advantage of analyzing the material in different positions and being able to evaluate the roundness of the filament, for example. The optical sensor can produce consistent measurements but must be calibrated and the background illumination must be stable. The puller system is necessary in both horizontal and vertical extruders [31]. However, in the vertical, it assists the winding system, and in the horizontal, it is responsible for pulling
the filament, especially as it gets rigid. The most common designs resemble rolling mills, where the filament passes through rollers connected to a motor [19–32]. The winder system is present in all designs of desktop extruders. They prevent contamination of the filament and make the material ready to be used in 3D printers. The systems usually have two support parts, a shaft for positioning the spool, a spool stopper, which 3D printers usually have, and a motor, which can be a stepper or DC. In these designs what differs most is the system for directing the wire during spooling and systems for control, using mechanical or optical switches [33].

However, adding instrumentation for open source machines would improve the quality of the processed material and make it possible to manufacture new types of filaments as composite materials, considerably enhancing their mechanical and other properties [34–39]. The acrylonitrile butadiene styrene is a polymer that can be recycled, can make new types of materials, for example, blends and used in extrusion studies [40–45]. The most common problems in extrusion processes are: flow variability, insufficient energy capacity for melting, temperature fluctuations during the process, screw wear, and also polymer drying issues [23,46,47]. Irregular flow can be improved with more stable particle size, making the extrusion more stable, for this requires variability reduction and particle size analysis [48,49]. The ability to homogenize depends on the screw design and the extruded polymer. Analysis of the processed polymer can evaluate the mixing capacity of the designed screw. Increased flow rate can lead to process instabilities, resulting in visual defects such as stick–slip [42,50]. It is reported that equipment instrumentation is vital to diagnose and ultimately act more effectively on the problem [47]. Recycled materials have physicochemical changes, such as chain reduction with primary and secondary bond breakage, causing a reduction in molar mass and a drop in physical–mechanical properties [51]. This can reduce the homogeneity and quality of the processed material, showing the need for process monitoring and data analysis [52].

The extrusion process has great economic importance, being the most used technique for polymer processing in the world [53]. Consequently, several studies report the instrumentation of industrial extruders to reduce the energy consumption of the process and subsequently the quality of the material. As industrial extruders have considerable cost usually external instruments are used and in general, I not much change is made in the initial machine design, occasioned by the cost of the machine [24,54]. The equipment instrumentation helps in the development of process controls, thus reducing the energy consumed and defects of the extruded material [46,54,55]. The most used parameters for process analysis and control are extrusion temperature and flow, dimensional variation, load consumed by the motor, load consumed by the resistors and pressure in nozzle [24,30,53–61]. The analysis of the data not only serves to know and understand the process phenomena, but they are used as parameters for control systems, anticipating the effects [57,61].

Therefore, this work proposes to design a modular extruder, with a degree of instrumentation compatible with industrial ones, and with a modular integrated circuit for data analysis and control. Thus, it is compatible with the need of a machine for research and teaching. The user interface for command and data acquisition is the Arduino’s command prompt. The circuit board is a shield for Arduino Mega. The material used to validate the equipment in the first recycle is ABS. During the process, the following parameters were analyzed in situ: the radial temperature in the nozzle’s chamber, the energy consumption by the heaters and the extruder motor, extruder motor speed. In the peripherals, the diameter of the extruded filament was measured and controlled. The filament will be validated by diametrical variation and roughness, using the confocal technique.

**Hardware description**

The hardware is designed for research and for use in the classroom, so the focus is on process analysis. It has to be robust, lightweight, stable, with easy and fast modification of process parameters, and with reliable and continuous data analysis. The equipment can be divided into three different parts. The first is the extruder, where the material is processed and extruded. The second is the external components, where the material is cooled, tensioned, diameter measured and finally spooled. The third is an integrated circuit that controls and obtains data from the first two systems. The first two parts are practically common to all extruders and are smaller in size at a lower cost when compared to industrial extruders. However, in this equipment a 3⁄8” wood drill was used, instead of a 5/8” one as is usually found in conventional open source extruders [19,20]. Another significant change is the third system, a circuit that integrates, records and acts on the machine. For the development of new materials, drill geometry and process control systems, a system that acts and monitors is needed. This circuit was developed so that the operator has this information and can better comprehend the material process, in real-time. The circuit board was the component created to act quickly and safely in the machine and its components, controlling the whole equipment with a computer and the Arduino command board. It is possible to control the speed of the extrusion motor, puller motor and spooler, set a working temperature, where the control temperature is the average of the two thermocouples located in the polymer, and analyze the radial temperature of the nozzle chamber. Through the Arduino’s command prompt, it is possible to acquire the temperature of the five thermocouples, the speed of the extruder motor (since it oscillates during the process), the current consumed by the resistances and the extruder motor, and the diameter of the extruded filament. In the code it is possible to modify the PWM (pulse width modulation) signal sent to the resistors Mosfet, increasing or not the heating ramp inclination and the data acquisition time. The wiring harness has the purpose of facilitating the assembly and disassembly of the equipment, being shielded to reduce noise, and having the possibility of placing more sensors, if the user wishes. Therefore, CAT6 cables with RJ45 plugs were used for it.
Design files summary

Bill of materials

The bill of materials was divided into several tables, in which Table 2 is the extruder structure, Table 3 is the extruder system, Table 4 is the cooler system, Table 5 is the puller system and diameter analysis, Table 6 is the spooler system, Table 7 is the electrical of extruder and peripherals, and Table 8 is the PCB machine components.

| Design file name | File type | Open-source license | Location of the file |
|------------------|-----------|---------------------|----------------------|
| Extruder (structural and extrusion part) | SLDPRT, SLDDRW, SLDASM STL, pdf, tiff | https://www.doi.org/10.17632/2fp47vg2w9.4 | |
| Puller | SLDPRT, SLDDRW, SLDASM STL, pdf, tiff | https://doi.org/10.17632/2fp47vg2w9.4 | |
| Spooler | SLDPRT, SLDDRW, SLDASM STL, pdf, tiff | https://www.doi.org/10.17632/2fp47vg2w9.4 | |
| Board | PDF, PcbDoc, xlsx and tiff | OSHWA Certification | https://certification.oshwa.org/br000009.html and https://github.com/MauricioOfilho/Integrated-and-modulated-circuit-for-extruder-machine |

| Name | Code | Number | Cost per unit | Total cost | Source of materials | Material type |
|------|------|--------|--------------|------------|---------------------|---------------|
| Profile 2020 (306 mm) | A | 2 | USD 2.45 | USD 4.90 | https://produto.mercadolivre.com.br/MLB-1902658947-perfil-estrutural-aluminio-v-slot-20x20-openbuilds-cnc-3d-1m-_JM#position=1&search_layout=stack&type=item&tracking_id=8127f63b-0dfb-40f3-8e99-babba4017d72 | Aluminum |
| Profile 2020 (240 mm) | B | 6 | USD 1.92 | USD 11.52 | https://produto.mercadolivre.com.br/MLB-1902658947-perfil-estrutural-aluminio-v-slot-20x20-openbuilds-cnc-3d-1m-_JM#position=1&search_layout=stack&type=item&tracking_id=8127f63b-0dfb-40f3-8e99-babba4017d72 | Aluminum |
| Profile 2020 (260 mm) | C | 4 | USD 2.08 | USD 8.32 | https://produto.mercadolivre.com.br/MLB-1902658947-perfil-estrutural-aluminio-v-slot-20x20-openbuilds-cnc-3d-1m-_JM#position=1&search_layout=stack&type=item&tracking_id=8127f63b-0dfb-40f3-8e99-babba4017d72 | Aluminum |
| Profile 2020 (485 mm) | D | 2 | USD 3.88 | USD 7.76 | https://produto.mercadolivre.com.br/MLB-1902658947-perfil-estrutural-aluminio-v-slot-20x20-openbuilds-cnc-3d-1m-_JM#position=1&search_layout=stack&type=item&tracking_id=8127f63b-0dfb-40f3-8e99-babba4017d72 | Aluminum |
| Aluminum corner | E | 23 | USD 0.30 | USD 6.79 | https://pt.aliexpress.com/item/4000190579760.html?spm=a2g0o. | Aluminum |
| Plate machined (190x45mm) | F | 1 | USD 0.00 | USD 0.00 | | Steel |
| Plate machined (190x45mm) | G | 1 | USD 0.00 | USD 0.00 | | Scrap |
| Angle bracket (machined 20x60) | H | 1 | USD 0.00 | USD 0.00 | | Local store |
| Profile 2040 (200 mm) | I | 2 | USD 2.86 | USD 5.72 | https://produto.mercadolivre.com.br/MLB-1276060174-perfil-de-aluminio-estrutural-v-slot-20x40-tipo-openbuilds-_JM#position=1&search_layout=stack&type=item&tracking_id=617355a3-6f8a-472f-88eb-bf61aca28839 | Aluminum |
| Profile 2020 (140 mm) | J | 1 | USD 1.12 | USD 2.24 | https://produto.mercadolivre.com.br/MLB-1902658947-perfil-estrutural-aluminio-v-slot-20x20-openbuilds-cnc-3d-1m-_JM#position=1&search_layout=stack&type=item&tracking_id=8127f63b-0dfb-40f3-8e99-babba4017d72 | Aluminum |
Table 3
List of components of the extrusion part of the extruder.

| Name                                      | Code | Number | Cost per unit | Total cost | Source of materials          | Material type |
|-------------------------------------------|------|--------|----------------|------------|------------------------------|---------------|
| Nozzle (1.75 mm machined hole)            | K    | 1      | USD 3.00      | 3.00       | Local store                  | Brass         |
| Plate 0.5 mm (500X110x155mm)              | L    | 1      | USD 1.40      | 1.40       | Local store                  | Stainless steel 304 |
| Resistor 15 O 10 w                        | M    | 16     | USD 0.17      | 2.72       | https://produto.mercadolivre.com.br/MLB-1618385873-resistor-de-porcelana-10w-15-ohms-_JM?matt_tool=63064967&matt_word=&matt_source=google&matt_campaign_id=14303413826&matt_ad_group_id=125984298957&matt_match_type=&matt_network=&matt_device=&matt_creation_date=539354957022&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=495454905&matt_product_id=MLB1618385873&matt_product_partition_id=1404934605530&matt_target_id=pla-1404934605530&gclid=Cj0KCQiA09eQBhCxARIsAAYRikBOty6Ph0Fj0p0GiEzDDeclDFa7TAHoE5XDtqshlTaf8QFyrsaAqmpEAkLyw_wCB | Ceramic       |
| Octagonal coupler                          | N    | 1      | USD 0.00      | 0.00       |                             | Aluminum      |
| K-type thermocouple M6 screw-type (M6 thread. 1 mm pitch) | O    | 3      | USD 0.00      | 0.00       | https://www.baudaelronica.com.br/modulo-sensor-de-temperatura-max6675-termopar-tipo-k.html | Stainless steel |
| Flange (nipple)                           | P    | 1      | USD 0.00      | 0.00       |                             | Stainless steel |
| M6 nut                                     | Q    | 6      | USD 0.08      | 0.45       |                             | Stainless steel |
| Allen screw (M6x25mm)                      | R    | 6      | USD 1.30      | 7.80       | https://produto.mercadolivre.com.br/MLB-930562086-parafuso-m6x25-625-Allen-cabeca-inox-10-pcs-_JM?matt_tool=63064967&matt_word=&matt_source=google&matt_campaign_id=14303413826&matt_ad_group_id=125984298957&matt_match_type=&matt_network=&matt_device=&matt_creation_date=539354957022&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=495454905&matt_product_id=MLB1618385873&matt_product_partition_id=1404934605530&matt_target_id=pla-1404934605530&gclid=Cj0KCQiA09eQBhCxARIsAAYRikBOty6Ph0Fj0p0GiEzDDeclDFa7TAHoE5XDtqshlTaf8QFyrsaAqmpEAkLyw_wCB | Stainless steel |
| Wood block                                 | S    | 1      | USD 0.00      | 0.00       |                             | Wood          |
| Wood drill 1/2"                            | T    | 1      | USD 12.00     | 12.00      | Local store                  | Steel         |
| Double flange                              | U    | 1      | USD 0.00      | 0.00       |                             | Stainless steel |
| Optical encoder disk (photolithography)     | V    | 1      | USD 0.00      | 0.00       | Local store                  | Transparency film paper |
| M3 Allen grub screw (8 mm)                  | W    | 6      | USD 0.23      | 1.40       | https://produto.mercadolivre.com.br/MLB-1275215986-parafuso-Allen-sem-cabeca-inox-m3-x-8mm-pacote-c20-pacas-_JM?matt_tool=63064967&matt_word=&matt_source=google&matt_campaign_id=14303413826&matt_ad_group_id=125984298957&matt_match_type=&matt_network=&matt_device=&matt_creation_date=539354957022&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=495454905&matt_product_id=MLB1618385873&matt_product_partition_id=1404934605530&matt_target_id=pla-1404934605530&gclid=Cj0KCQiA09eQBhCxARIsAAYRikBOty6Ph0Fj0p0GiEzDDeclDFa7TAHoE5XDtqshlTaf8QFyrsaAqmpEAkLyw_wCB | Stainless steel |
| Optical disc locker (3 g)                   | X    | 1      | USD 0.05      | 0.05       | https://3dfila.com.br/produto/filamento-abs-premium/ | ABS           |
| Machined Coupling                          | Y    | 1      | USD 0.00      | 0.00       |                             | Aluminum      |
| Hex flat head bolt (M6.5x60mm)              | Z    | 3      | USD 0.00      | 0.00       |                             | Steel         |
| Bearing (72x90x28.5 mm)                     | AA   | 1      | USD 11.00     | 11.00      | https://produto.mercadolivre.com.br/MLB-1926629750-rolamento-nico-32306-30x72x2875-mm-capa-e-cone-_JM?matt_tool=63064967&matt_word=&matt_source=google&matt_campaign_id=14303413826&matt_ad_group_id=125984298957&matt_match_type=&matt_network=&matt_device=&matt_creation_date=539354957022&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=495454905&matt_product_id=MLB1618385873&matt_product_partition_id=1404934605530&matt_target_id=pla-1404934605530&gclid=Cj0KCQiA09eQBhCxARIsAAYRikBOty6Ph0Fj0p0GiEzDDeclDFa7TAHoE5XDtqshlTaf8QFyrsaAqmpEAkLyw_wCB | Steel         |
| Printed bearing support 1 (298 g)           | AB   | 1      | USD 4.86     | 4.86       | https://3dfila.com.br/produto/filamento-abs-premium/ | ABS           |
| Printed bearing support 2 (157 g)           | AC   | 1      | USD 2.56     | 2.56       | https://3dfila.com.br/produto/filamento-abs-premium/ | ABS           |
| Windshield wiper motor bosc                | AD   | 1      | USD 77.80    | 77.80      | https://produto.mercadolivre.com.br/MLB-20734034141-motor-do-limpador-do-parabrisa-mercedes-benz-caminhones-12v-_JM?matt_tool=63064967&matt_word=&matt_source=google&matt_campaign_id=14303413826&matt_ad_group_id=125984298957&matt_match_type=&matt_network=&matt_device=&matt_creation_date=539354957022&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=495454905&matt_product_id=MLB1618385873&matt_product_partition_id=1404934605530&matt_target_id=pla-1404934605530&gclid=Cj0KCQiA09eQBhCxARIsAAYRikBOty6Ph0Fj0p0GiEzDDeclDFa7TAHoE5XDtqshlTaf8QFyrsaAqmpEAkLyw_wCB | Steel         |
| M4 steel screw                             | AE   | 69     | USD 0.11     | 7.63       | https://produto.mercadolivre.com.br/MLB-1272150467-parafuso-Allen-cabeca-cilindrica-m4-x-10-aco-liga-50-pacas-_JM?matt_tool=63064967&matt_word=&matt_source=google&matt_campaign_id=14303413826&matt_ad_group_id=125984298957&matt_match_type=&matt_network=&matt_device=&matt_creation_date=539354957022&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=495454905&matt_product_id=MLB1618385873&matt_product_partition_id=1404934605530&matt_target_id=pla-1404934605530&gclid=Cj0KCQiA09eQBhCxARIsAAYRikBOty6Ph0Fj0p0GiEzDDeclDFa7TAHoE5XDtqshlTaf8QFyrsaAqmpEAkLyw_wCB | Steel         |

(continued on next page)
### Table 3 (continued)

| Name                          | Code | Number | Cost per unit | Total cost | Source of materials | Material type |
|-------------------------------|------|--------|---------------|------------|---------------------|---------------|
| T-nut M4                      | AF   | 69     | USD 0.09      | USD 6.24   | https://pt.aliexpress.com/item/10050023757778002.html?spm=a2g0o.6041010.0.0.378d9005bQx&algo_pvid=9c529764-a4fb-426e-a67f-fbe655473c38&algo_exp_id=9c529764-a4fb-426e-a67f-fbe655473c38&0dpd_ext_f%7B%22sku_id%22%3A221200020416820982%22%7D&dpd_pie%3A138%45%3B1-138%15%40salePrice%3B%BRL%3BSearch-mainSearch        | Steel          |
| M4 gasket                     | AG   | 69     | USD 0.02      | USD 1.10   | https://produto.mercadolivre.com.br/MLB-1177723618-arruela-lisa-zincada-m4-zincada-500-pecas-_JM#position=6&search_layout=stack&type=item&tracking_id=544def39-68a0-41c5-9630-67317a0f7fd9 | Steel          |
| Tachometer sensor             | AH   | 1      | USD 1.84      | USD 2.22   | https://www.baudaeloetronica.com.br/catalogsearch/result/?q=M%BC%3B3dulo%2BSensor%20de%20Velocidade%20%2B%20Encoder                           | PLA            |
| Support tachometer sensor (7 g) | AI   | 1      | USD 0.18      | USD 0.22   | https://3dfila.com.br/produto/filamento-pla-easy-fill/                                                         | PLA            |
| Superior part printed funnel (173 g) | AJ  | 1      | USD 2.82      | USD 2.82   | https://3dfila.com.br/produto/filamento-ABS-premium/                                                            | ABS            |
| Inferior part printed funnel (81 g) | AK  | 1      | USD 1.32      | USD 1.32   | https://3dfila.com.br/produto/filamento-ABS-premium/                                                            | ABS            |
| Phillips screw (M5 x 40 mm)    | AL   | 2      | USD 0.13      | USD 0.26   | https://3dfila.com.br/produto/filamento-ABS-premium/                                                            | Steel          |

### Table 4

Components of cooler system.

| Name                          | Code | Number | Cost per unit | Total cost | Source of materials | Material type |
|-------------------------------|------|--------|---------------|------------|---------------------|---------------|
| Cooling barrel (75 g)         | A    | 1      | USD 1.22      | USD 1.22   | https://3dfila.com.br/produto/filamento-ABS-premium/                                                            | ABS            |
| Water tank                    | B    | 1      | USD 0.00      | USD 0.00   | Waste material       | PVC           |
| Bomb                          | C    | 1      | USD 13.60     | USD 13.60  | Local store          | PVC           |
| Sealing cap (31 g)            | D    | 1      | USD 0.51      | USD 0.51   | https://3dfila.com.br/produto/filamento-ABS-premium/                                                            | ABS            |

### Table 5

List of puller system components and diameter analysis.

| Name                          | Code | Number | Cost per unit | Total cost | Source of materials | Material type |
|-------------------------------|------|--------|---------------|------------|---------------------|---------------|
| Nema 17 step motor            | 1    | USD 13.44 | USD 13.44   |            | https://produto.mercadolivre.com.br/MLB-1699089992-motor-de-passo-nema-17-17hs401-42kpcm-cabo-1-metro-_JM#match_tool=562915298&matt_word=material_source=google&matt_campaign_id=1430341364&matt_ad_group_id=125994287157&matt_match_type=&matt_network=&matt_device=&matt_keyword=539354956218&matt_language=pt&matt_ad_position=matt_ad_type=pla&matt_merchant_id=279126063&matt_product_id=MLB1699089992&matt_product_partition_id=1404886571258&matt_target_id=pla-1404886571258&gclid=Cj0KCQiA09eEQhBvARIsAAYRiyin8POX2vzr6C9yzzYD-OxVj6zt0hOnZ-wMjHlilUlguqKHjmpRZ38eAvppEALw_wc8 | Steel          |
| Hex flat head bolt M6x40 mm    | B    | 1      | USD 0.77      | USD 2.32   | https://produto.mercadolivre.com.br/MLB-1676655022-kit-parafusos-suporte-tv-philco-sextavado-m6-x-40mm-_JM#match_tool=562915298&matt_word=material_source=google&matt_campaign_id=1430341364&matt_ad_group_id=125994287157&matt_match_type=&matt_network=&matt_device=&matt_keyword=539354956218&matt_language=pt&matt_ad_position=matt_ad_type=pla&matt_merchant_id=279126063&matt_product_id=MLB1676655022&matt_product_partition_id=1404886571258&matt_target_id=pla-1404886571258&gclid=Cj0KCQiGo9eQhBvARIsAAYRixi8POX2vzr6C9yzzYD-OxVj6zt0hOnZ-wMjHlilUlguqKHjmpRZ38eAvppEALw_wc8 | Steel          |
| Superior puller systems (39g) | C    | 1      | USD 0.64      | USD 0.64   | https://3dfila.com.br/produto/filamento-ABS-premium/                                                            | ABS            |
| Bearing 608zz                  | D    | 3      | USD 0.32      | USD 0.95   | https://produto.mercadolivre.com.br/MLB-1425559218-kit-100-rolamentos-608zz-aceb-1-8x22x7-skate-patinssemmaco-_JM#match_tool=562915298&matt_word=material_source=google&matt_campaign_id=1430341364&matt_ad_group_id=125994287157&matt_match_type=&matt_network=&matt_device=&matt_keyword=539354956218&matt_language=pt&matt_ad_position=matt_ad_type=pla&matt_merchant_id=279126063&matt_product_id=MLB1425559218&matt_product_partition_id=1404886571258&matt_target_id=pla-1404886571258&gclid=Cj0KCQiGo9eQhBvARIsAAYRIyin8POX2vzr6C9yzzYD-OxVj6zt0hOnZ-wMjHlilUlguqKHjmpRZ38eAvppEALw_wc8 | ABS            |
| Name                                      | Code | Number | Cost per unit | Total cost | Source of materials                                      | Material        |
|-------------------------------------------|------|--------|---------------|------------|----------------------------------------------------------|----------------|
| Machined steel axe (M8x52 mm)             | E    | 2      | USD 0.00      | USD 0.00   | Waste material                                           | Steel           |
| Rubber tires of recycled printers         | F    | 2      | USD 0.00      | USD 0.00   | https://3dfila.com.br/produto/filamento-pla-easyfill/    | Rubber          |
| Filament guide and caliper holder (98 g)  | G    | 1      | USD 2.53      | USD 2.53   | https://produto.mercadolivre.com.br/MLB-766878742        | PLA             |
| Caliper                                   | H    | 1      | USD 0.00      | USD 15.38  | https://produto.mercadolivre.com.br/MLB-2084350836       | PLA             |
| Inferior caliper holder (17 g)            | I    | 1      | USD 0.44      | USD 0.44   | https://3dfila.com.br/produto/filamento-pla-easyfill/    | PLA             |
| Puller base (114 g)                       | J    | 1      | USD 2.94      | USD 2.94   | https://produto.mercadolivre.com.br/MLB-2084350836       | PLA             |
| Phillips screw (M3x12mm)                  | K    | 6      | USD 0.10      | USD 0.59   | https://produto.mercadolivre.com.br/MLB-2084350836       | Steel           |
| Inferior puller systems (42 g)            | L    | 2      | USD 1.08      | USD 2.17   | https://3dfila.com.br/produto/filamento-pla-easyfill/    | PLA             |
| M6 nut                                    | M    | 2      | USD 0.02      | USD 0.07   | https://produto.mercadolivre.com.br/MLB-2065676528       | Steel           |
| Aluminum flexible coupling                | N    | 1      | USD 2.27      | USD 2.27   | https://www.baudaeleronica.com.br/acoplamento-flexivel-para-motor-de-passo-6-35-x-8mm.html?gclid=EAIaIQobChMI16SM_qqg9gVikRCh0Mmw91EAQYAiABg0EOkKd_BwE | Aluminum        |
| Phillips screw (M3x25)                    | O    | 5      | USD 0.05      | USD 0.27   | https://produto.mercadolivre.com.br/MLB-1528778452       | Steel           |
| Allen screw (M8x35)                       | P    | 2      | USD 0.44      | USD 0.87   | https://produto.mercadolivre.com.br/MLB-1934301939       | Steel           |
| Hex lock nuts M8                         | Q    | 2      | USD 0.10      | USD 0.20   | https://produto.mercadolivre.com.br/MLB-1286378768       | Steel           |
Table 6
Spooler System Components List.

| Name                                      | Code | Number | Cost per unit | Total cost | Source of materials                                                                 | Material type |
|--------------------------------------------|------|--------|---------------|------------|-------------------------------------------------------------------------------------|---------------|
| M4 steel screw                             | A    | 14     | USD 0.11      | 1.55       | [Source](https://produto.mercadolivre.com.br/MLB-1272150467-parafuso-allen-cabeza-cilindrica-m4-x-10-aco-liga-50-pecas-JM#position=5&search_layout=stack&type=item&tracking_id=d7e3194b-fa72-45ba-8153-bc91717fe76) | Steel         |
| Nema 17 step motor                         | B    | 1      | USD 13.44     | 13.44      | [Source](https://produto.mercadolivre.com.br/MLB-1699089992-motor-de-passo-nema-17-17hs4401-42kgfcm-cabo-1-metro-JM#position=50#search_layout=stack&type=item&tracking_id=d7e3194b-fa72-45ba-8153-bc91717fe76) | Steel         |
| Timing pulley 2gt 8                        | C    | 2      | USD 0.74      | 1.48       | [Source](https://pt.aliexpress.com/item/1005003238020029.html?spm=a2g0o.productlist.0.0.6df332d0e20c8q&algo_pvid=7797006e-36a1-4d2c-a1e3-262bbd3de78abkm_df_detail=2022022506465606968743128360012494818&algo_exp_id=7797006e-36a1-4d2c-a1e3-262bbd3de78abkm_df_ext_f=787%22sku_id%22%3A%22512100002479378262527%22%D&dpd_pi=13B3.1%235%2B113%2BN19%26%2B4nalePrice%3B3B%3Bsearch-mainSearch) | Aluminum      |
| Motor step support (66 g)                  | D    | 1      | USD 1.08      | 1.08       | [Source](https://3dfila.com.br/produto/filamento-abs-premium/)                      | ABS           |
| Bore bearing housing vertical block mounted KP08 | E    | 2      | USD 1.70      | 3.40       | [Source](https://pt.aliexpress.com/item/32903705568.html?spm=a2g0o.productlist.0.0.1cf312d26d47pxq&algo_pvid=9d0d78d8-3db7-449d-b5c3-0e263bca1948&algo_exp_id=9d0d78d8-3db7-449d-b5c3-0e263bca1948&algo_ext_f=%78%72sku_id%22%3A%22512100002479378262527%22%D&dpd_pi=13B3.1%235%2B113%2BN19%26%2B4nalePrice%3B3B%3Bsearch-mainSearch) | Aluminum      |
| Aluminum extruded profile 20x20 (210 mm)   | F    | 2      | USD 1.68      | 4.48       | [Source](https://produto.mercadolivre.com.br/MLB-1902658947-perfil-estrutural-aluminio-v-slot-20x20-openbuilds-cnc-3d-1m-JM#position=1&search_layout=stack&type=item&tracking_id=812763b-0dfb-40f3-899b-babb4017d72) | Aluminum      |
| Spool holder (53 g)                        | G    | 2      | USD 0.87      | 1.73       | [Source](https://3dfila.com.br/produto/filamento-abs-premium/)                      | ABS           |
| M8 steel threaded rods bar (380 mm)        | H    | 1      | USD 2.58      | 2.58       | [Source](https://pt.aliexpress.com/item/1005002375778002.html?spm=a2g0o.productlist.0.0.43b13169cBfQxr&algo_pvid=9c5f7264-a4bf-ba7b-fbde55473cd8d8g&algo_exp_id=9c5f7264-a4bf-ba7b-fbde55473cd8d8g&algo_ext_f=78%72sku_id%22%3A%22512100002479378262527%22%D&dpd_pi=13B3.1%235%2B113%2BN19%26%2B4nalePrice%3B3B%3Bsearch-mainSearch) | Steel         |
| T-nut M4                                   | I    | 14     | USD 0.09      | 1.27       | [Source](https://pt.aliexpress.com/item/1005002375778002.html?spm=a2g0o.productlist.0.0.43b13169cBfQxr&algo_pvid=9c5f7264-a4bf-ba7b-fbde55473cd8d8g&algo_exp_id=9c5f7264-a4bf-ba7b-fbde55473cd8d8g&algo_ext_f=78%72sku_id%22%3A%22512100002479378262527%22%D&dpd_pi=13B3.1%235%2B113%2BN19%26%2B4nalePrice%3B3B%3Bsearch-mainSearch) | Steel         |
| M4 phillips steel screw (40 mm)            | J    | 6      | USD 0.30      | 1.80       | [Source](https://produto.mercadolivre.com.br/MLB-2158283746-porca-sextavada-m8-zinco-branco-passo-125-c50-pecas-JM#position=6&search_layout=stack&type=item&tracking_id=3418052456&meta&adapter_id=MLB2158283746&meta_campaign_id=1403978954696&meta_target_id=aud-395642386021:pla-1403978954696&gclid=EAIaIQobChMIVo4lqY86aAIVABEgBIPFdBwE) | Steel         |
| M8 steel hex nut                           | K    | 4      | USD 0.09      | 0.36       | [Source](https://produto.mercadolivre.com.br/MLB-2158283746-porca-sextavada-m8-zinco-branco-passo-125-c50-pecas-JM#position=6&search_layout=stack&type=item&tracking_id=3418052456&meta&adapter_id=MLB2158283746&meta_campaign_id=1403978954696&meta_target_id=aud-395642386021:pla-1403978954696&gclid=EAIaIQobChMIVo4lqY86aAIVABEgBIPFdBwE) | Steel         |
| Name                     | Code | Number | Cost per unit | Total cost | Source of materials                                                                 | Material type |
|-------------------------|------|--------|---------------|------------|---------------------------------------------------------------------------------------|---------------|
| M4 steel gasket         | L    | 6      | USD 0.02      | USD 0.10   | https://produto.mercadolivre.com.br/MLB-1177723618-opala-lisa-zincada-m4-zincada-500-pecas?&search_layout=stack&type=item &tracking_id=544def9f-68db-41c5-9630-67317a0f7f9d | Steel         |
| M4 steel hex nut        | M    | 18     | USD 0.03      | USD 0.58   | https://produto.mercadolivre.com.br/MLB-1782968438-opora-sextavada-m4-zincada-pacote-com-100-pecas- &JM#position=1&search_layout=stack&type=pad &tracking_id=ac79fe20-895f-4026-aee0-55cd429b96 216&s_is_advertising=true&ad_domain=VQCATCORE_ LST&ad_position=1&ad_click_id=NzUzZDRhZGQzZTZhMQ00NDBuLWE3OGQyVGxhMzU0QGxMMmNm | Steel         |
| Aluminum corner         | N    | 6      | USD 0.30      | USD 1.77   | https://pt.aliexpress.com/item/40001905797976.html?spn=a2g0o.productlist.0.0.30fd26db1c1kw9&algo_pvid=ba9068d4-1917-4121-adc7-8aa1c777f128&algo_exp_id=ba9068d4-1917-4121-adc7-8aa1c777f128-16&ppd_ext_f=s7b2%22sku_id%22%3A%2210000000071 1777300%22%7D&pdp.p=1%3B82.84%3B-1%3B-1%3BPrice%3BRL%5B3%5Bsearch-mainSearch | Aluminum      |
| Allen screw (M3X10 mm)  | O    | 4      | USD 0.09      | USD 0.37   | Local store                                                                            | Steel         |
| 2020 Extrusion profile(400 mm) | P | 1    | USD 3.20      | USD 2.24   | https://produto.mercadolivre.com.br/MLB-1902638947-perfil-esturtrual-aluminio-v-slot-20x20-openbuilds- &cnc-3d-1m- &JM#position=1&search_layout=stack&type=item &tracking_id=812763b-0dfb-40f3-8e99-babb4017672 | Aluminum      |
| Piece of wood (215x220mm) | Q | 2    | USD 0.00      | USD 0.00   | Waste material                                                                          | Wood          |
| M8 steel threaded rods bar (300 mm) | R | 2    | USD 2.58      | USD 5.17   | Local store                                                                            | Steel         |
| RJ45 coupler holder (15 g) | S | 1    | USD 0.39      | USD 0.39   | PLA                                                                                     |               |

Table 6 (continued)

| Name                     | Number | Cost per unit | Total cost | Source of materials                                                                 | Material type |
|-------------------------|--------|---------------|------------|---------------------------------------------------------------------------------------|---------------|
| Arduino mega 2560       | 1      | USD 25.11     | USD 25.11  | https://www.baudaeletronica.com.br/arduino-mega-2560-compativel-cabo-usb.html?gclid=EAIaIQobChMI052Tus Ogs5IGDwKRCr1BQVoEAAAYAAsAgL0-ID_BwE |               |
| Axial Resistor. 1KOhm. +/- 5%. 0.25 W | 2    | USD 0.01      | USD 0.02   | https://www.baudaeletronica.com.br/resistor-1k-5-1-4w.html                            |               |
| Axial Resistor. 10      | 12     | USD 0.01      | USD 0.14   | https://www.baudaeletronica.com.br/resistor-10k-5-1-4w.html                           |               |
| KOhm. +/- 1%. 0.25 W    | 1      | USD 0.01      | USD 0.01   | https://www.baudaeletronica.com.br/resistor-100 k-5-1-4w.html                         |               |
| Axial Resistor. 100     | 1      | USD 0.01      | USD 0.01   | https://www.baudaeletronica.com.br/resistor-1000 k-5-1-4w.html                        |               |
| Axial Resistor. +/- 1%. 0.25 W | 1     | USD 0.01      | USD 0.01   | https://www.baudaeletronica.com.br/resistor-100k-5-1-4w.html                         |               |
| Ohm. +/- 1% 0.25 W     | 2      | USD 5.66      | USD 11.32  | https://www.baudaeletronica.com.br/sensor-de-corrente-acs712-30a-a-30a.html           |               |
| ACS712 IC               | 1      | USD 0.04      | USD 0.04   | https://www.baudaeletronica.com.br/led-difuso-5mm-vermelho.html                       |               |
| LED 5 mm                | 6      | USD 10.40     | USD 62.39  | https://www.baudaeletronica.com.br/modulo-sensor-de-temperatura-max6675-termopar-tipo-k.html |               |
| Thermocouple module MAX6675 IC | 1    | USD 0.34      | USD 0.34   | https://www.baudaeletronica.com.br/regulador-de-tens-o-1-8v-ams1117-smd.html         |               |

Table 7

| Name                     | Number | Cost per unit | Total cost | Source of materials                                                                 | Material type |
|-------------------------|--------|---------------|------------|---------------------------------------------------------------------------------------|---------------|
| Arduino mega 2560       | 1      | USD 25.11     | USD 25.11  | https://www.baudaeletronica.com.br/arduino-mega-2560-compativel-cabo-usb.html?gclid=EAIaIQobChMI052Tus Ogs5IGDwKRCr1BQVoEAAAYAAsAgL0-ID_BwE |               |
| Axial Resistor. 1KOhm. +/- 5%. 0.25 W | 2    | USD 0.01      | USD 0.02   | https://www.baudaeletronica.com.br/resistor-1k-5-1-4w.html                            |               |
| Axial Resistor. 10      | 12     | USD 0.01      | USD 0.14   | https://www.baudaeletronica.com.br/resistor-10k-5-1-4w.html                           |               |
| KOhm. +/- 1%. 0.25 W    | 1      | USD 0.01      | USD 0.01   | https://www.baudaeletronica.com.br/resistor-100 k-5-1-4w.html                         |               |
| Axial Resistor. 100     | 1      | USD 0.01      | USD 0.01   | https://www.baudaeletronica.com.br/resistor-1000 k-5-1-4w.html                        |               |
| Axial Resistor. +/- 1%. 0.25 W | 1     | USD 0.01      | USD 0.01   | https://www.baudaeletronica.com.br/resistor-100k-5-1-4w.html                         |               |
| Ohm. +/- 1% 0.25 W     | 2      | USD 5.66      | USD 11.32  | https://www.baudaeletronica.com.br/sensor-de-corrente-acs712-30a-a-30a.html           |               |
| ACS712 IC               | 1      | USD 0.04      | USD 0.04   | https://www.baudaeletronica.com.br/led-difuso-5mm-vermelho.html                       |               |
| LED 5 mm                | 6      | USD 10.40     | USD 62.39  | https://www.baudaeletronica.com.br/modulo-sensor-de-temperatura-max6675-termopar-tipo-k.html |               |
| Thermocouple module MAX6675 IC | 1    | USD 0.34      | USD 0.34   | https://www.baudaeletronica.com.br/regulador-de-tens-o-1-8v-ams1117-smd.html         |               |

(continued on next page)
### Table 7 (continued)

| Name | Number | Cost per unit | Total cost | Source of materials |
|------|--------|---------------|------------|---------------------|
| Shield Motor VNH2SP30 simple | 1 | USD 13.00 | USD 13.00 | https://produto.mercadolivre.com.br/MLB-1038624798-ponte-h-30a-amerpes-arduino-monster-vnh2sp30_-JM?matt_tool=52691529&matt_word=&matt_source=google&matt_campaign_id=14303413604&matt_ad_group_id=12598428715&matt_match_type=&matt_network=&matt_device=c&matt_creative=539354956218&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=109543422&matt_product_id=ML8103862479&matt_product_partition_id=1435016894331&matt_target_id=aud-1414365823100:pla-1435016894331&gclid=EAIaIQobChMI0Ojw-Mmg9gVIUwvrCh0LAljEAQYASABEglBx_D_BwE |
| Linear Trimpot(R) 10KOhm. 300 V. –55 to 125 degC. 3-Pin controller; A4988 IC | 1 | USD 0.35 | USD 0.35 | https://www.baudaeletronica.com.br/trimpot-linear-horizontal-de-10k-10000.html |
| Linear Trimpot(R) 10KOhm. 300 V. –55 to 125 degC. 3-Pin | 2 | USD 3.14 | USD 6.29 | https://www.baudaeletronica.com.br/driver-de-motor-de-passo-a4988.html |
| Stepper motor; A4988 IC | 2 | USD 3.14 | USD 6.29 | https://www.baudaeletronica.com.br/driver-de-motor-de-passo-a4988.html |
| Electrolytic Capacitor, 100μF, 35 V, +/- 20%, SMD | 2 | USD 0.05 | USD 0.10 | https://www.baudaeletronica.com.br/capacitor-eletrolitico-100uf-35v.html |
| Electrolytic Capacitor, 10μF, 35 V, +/- 20%, SMD | 5 | USD 0.13 | USD 0.65 | https://www.baudaeletronica.com.br/capacitor-eletrolitico-smd-10uf-35v.html |
| Operational Amplifier LM741 IC 8-PDIP | 1 | USD 0.33 | USD 0.33 | https://www.baudaeletronica.com.br/amplificador-operacional-lm741.html |
| Transistor PNP 2N3906 IC TO-92 | 2 | USD 0.04 | USD 0.08 | https://www.baudaeletronica.com.br/transistor-pnp-2n3906.html |
| Ceramic Capacitor 100nF, 50 V, +/-10% | 4 | USD 0.03 | USD 0.10 | https://www.baudaeletronica.com.br/capacitor-ceramico-100nf-50v.html |
| Tantalum capacitor 220nF 35 V RADIAL | 1 | USD 0.33 | USD 0.33 | https://www.baudaeletronica.com.br/capacitor-tantalto-0-22uf-35v.html |
| Ceramic Capacitors 10nF, 50 V, +/-10% | 2 | USD 0.02 | USD 0.04 | https://www.baudaeletronica.com.br/capacitor-ceramico-10nf-50v.html |
| Single Timer LM555 IC, 8-Pin PDIP | 1 | USD 0.22 | USD 0.22 | https://www.baudaeletronica.com.br/circuito-integrado-lm555.html |
| HEXFET® Power MOSFET IRF3205, 55 V, 110A | 2 | USD 1.25 | USD 2.49 | https://www.baudaeletronica.com.br/transistor-irf3205-mosfet.html |
| Fast-switching Diode 1 N4148, | 2 | USD 0.02 | USD 0.04 | https://www.baudaeletronica.com.br/diodo-1n4148.html |
| 75 V, 0.3A, DO-35 | 15 | USD 0.15 | USD 2.22 | https://www.baudaeletronica.com.br/borne-2-polos-kf-301-2t.html |
| Blue Terminal Block, 2, 300 V, 10 A, 26 AWG, 16 AWG, 1.5 mm | 2 | USD 0.22 | USD 0.45 | https://www.baudaeletronica.com.br/miniborne-kr2-kf301-10x10mm-preto.html |
| Black Terminal Block, 2, 300 V, 16 A, 26 AWG, 16 AWG, 1.5 mm | 4 | USD 0.06 | USD 0.22 | https://www.baudaeletronica.com.br/transistor-2n3904.html |
| NPN Transistor 2N3904, 40 V | 1 | USD 0.32 | USD 0.32 | https://www.baudaeletronica.com.br/regulador-de-tensao-17805.html |
| Positive-voltage Regulator LM7805 IC | 5 | USD 5.87 | USD 29.35 | https://jlcpcb.com/ |

---

### Table 8

| Designator | Name | Number | Cost per unit | Total cost | Source of materials |
|------------|------|--------|---------------|------------|---------------------|
| Responsible for connecting the circuit board to the tachometer module, code AH of the extruder system (Fig. 2). It wasn't used in this cable plug RJ45, the cable was connected as referenced in the respective datasheets. | Cable CAT6 A (250 mm) | 1 | USD 0.02 | USD 0.02 | https://produto.mercadolivre.com.br/MLB-2152190517-cabo-de-rede-furukawa-cat6-cmx-cx-305m-azul-uutp-sohoplus_-JM?matt_tool=31508429&matt_word=&matt_source=google&matt_campaign_id=14303413595&matt_ad_group_id=125984286637&matt_match_type=&matt_network=&matt_device=c&matt_creative=539354956068&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=191699217&matt_product_id=ML2152190517&matt_product_partition_id=1457960502647&matt_target_id=pla-1457960502647&gclid=EAIaIQobChMI0Ojw-Mmg9gVIUwvrCh0LAljEAQYASABEglBx_D_BwE |
Table 8 (continued)

| Designator | Name | Number | Cost per unit | Total cost | Source of materials |
|------------|------|--------|---------------|------------|--------------------|
| Responsible for sending information and power to the caliper, code H of the puller system (Fig. 4). It connects the board to the RJ45 female plug, via an RJ45 male plug, located on the cable. The female plug is located on the part, code J of the puller system (Fig. 4). | Cable CAT6 B (950 mm) | 1 | USD 0.07 | USD 0.07 | https://produto.mercadolivre.com.br/MLB-2152190517-cabo-de-rede-furukawa-cat6-cmx-cx-305m-azu-utop-sohoplus-_JM?matt_tool=31508429&matt_word=&matt_source=google &matt_campaign_id=14303413595&matt_ad_group_id=125984286637&matt_match_type=&matt_network=&matt_device=&matt_creative=539354956068&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=191699217&matt_product_id=MLB2152190517&matt_product_partition_id=1457960502647 &matt_target_id=pla-1457960502647&gclid=CjwKCAiApfeQBhAUEiwA7K_UH3X-BmlgLxKgEM1_1sti60RORi8wX1HJRwU35viW9653udZQC67xocM_cQAdV_BwE |
| Responsible for sending information and power to the puller motor, code A of the puller system (Fig. 4). It connects the board to the RJ45 female plug, via an RJ45 male plug, located on the cable. The female plug is located on the part, code J of the puller system (Fig. 4). | Cable CAT6 C (950 mm) | 1 | USD 0.07 | USD 0.07 | https://produto.mercadolivre.com.br/MLB-2152190517-cabo-de-rede-furukawa-cat6-cmx-cx-305m-azu-utop-sohoplus-_JM?matt_tool=31508429&matt_word=&matt_source=google &matt_campaign_id=14303413595&matt_ad_group_id=125984286637&matt_match_type=&matt_network=&matt_device=&matt_creative=539354956068&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=191699217&matt_product_id=MLB2152190517&matt_product_partition_id=1457960502647 &matt_target_id=pla-1457960502647&gclid=CjwKCAiApfeQBhAUEiwA7K_UH3X-BmlgLxKgEM1_1sti60RORi8wX1HJRwU35viW9653udZQC67xocM_cQAdV_BwE |
| Connect the caliper, code H of the puller system (Fig. 4) to the RJ45 female plug, held on the code J part of the puller system (Fig. 4). This cable connects to the female plug by using an RJ45 plug at one end of the cable, the other end is connected to the caliper. | Cable CAT6 D (120 mm) | 1 | USD 0.01 | USD 0.01 | https://produto.mercadolivre.com.br/MLB-2152190517-cabo-de-rede-furukawa-cat6-cmx-cx-305m-azu-utop-sohoplus-_JM?matt_tool=31508429&matt_word=&matt_source=google &matt_campaign_id=14303413595&matt_ad_group_id=125984286637&matt_match_type=&matt_network=&matt_device=&matt_creative=539354956068&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=191699217&matt_product_id=MLB2152190517&matt_product_partition_id=1457960502647 &matt_target_id=pla-1457960502647&gclid=CjwKCAiApfeQBhAUEiwA7K_UH3X-BmlgLxKgEM1_1sti60RORi8wX1HJRwU35viW9653udZQC67xocM_cQAdV_BwE |
| Connect the motor, code A of the puller system, to the RJ45 female plug by attaching it to the code J part of the puller system (both Fig. 4). This cable connects to the female plug by means of an RJ45 plug at one end of the cable, the other end is connected to the motor. | Cable CAT6 E (100 mm) | 1 | USD 0.01 | USD 0.01 | https://produto.mercadolivre.com.br/MLB-2152190517-cabo-de-rede-furukawa-cat6-cmx-cx-305m-azu-utop-sohoplus-_JM?matt_tool=31508429&matt_word=&matt_source=google &matt_campaign_id=14303413595&matt_ad_group_id=125984286637&matt_match_type=&matt_network=&matt_device=&matt_creative=539354956068&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=191699217&matt_product_id=MLB2152190517&matt_product_partition_id=1457960502647 &matt_target_id=pla-1457960502647&gclid=CjwKCAiApfeQBhAUEiwA7K_UH3X-BmlgLxKgEM1_1sti60RORi8wX1HJRwU35viW9653udZQC67xocM_cQAdV_BwE |
| Responsible for sending information and power to the spooling motor, code B of the spooling system (Fig. 5A). It connects the board to the RJ45 female plug, via an RJ45 male plug, located on the cable. The female plug is located on the part, code R of the spooling system. | Cable CAT6 F (1250 mm) | 1 | USD 0.09 | USD 0.09 | https://produto.mercadolivre.com.br/MLB-2152190517-cabo-de-rede-furukawa-cat6-cmx-cx-305m-azu-utop-sohoplus-_JM?matt_tool=31508429&matt_word=&matt_source=google &matt_campaign_id=14303413595&matt_ad_group_id=125984286637&matt_match_type=&matt_network=&matt_device=&matt_creative=539354956068&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=191699217&matt_product_id=MLB2152190517&matt_product_partition_id=1457960502647 &matt_target_id=pla-1457960502647&gclid=CjwKCAiApfeQBhAUEiwA7K_UH3X-BmlgLxKgEM1_1sti60RORi8wX1HJRwU35viW9653udZQC67xocM_cQAdV_BwE |
| Connect the motor, code B of the puller system to the RJ45 female plug, attached to the code R part (both Fig. 5). This cable connects to the female plug by means of an RJ45 plug at one end of the cable, the other end is connected directly to the motor wires. | Cable CAT6 G | 1 | USD 0.26 | USD 0.26 | https://produto.mercadolivre.com.br/MLB-2152190517-cabo-de-rede-furukawa-cat6-cmx-cx-305m-azu-utop-sohoplus-_JM?matt_tool=31508429&matt_word=&matt_source=google &matt_campaign_id=14303413595&matt_ad_group_id=125984286637&matt_match_type=&matt_network=&matt_device=&matt_creative=539354956068&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=191699217&matt_product_id=MLB2152190517&matt_product_partition_id=1457960502647 &matt_target_id=pla-1457960502647&gclid=CjwKCAiApfeQBhAUEiwA7K_UH3X-BmlgLxKgEM1_1sti60RORi8wX1HJRwU35viW9653udZQC67xocM_cQAdV_BwE |

(continued on next page)
### Table 8 (continued)

| Designator | Name | Number | Cost per unit | Total cost | Source of materials |
|------------|------|--------|---------------|------------|---------------------|
|            | RJ45 plugue | 6      | USD 0.10      | USD 0.59   | Local store         |
|            | Power supply | 1      | USD 15.61     | USD 15.61  |                     |
|            | Maintenance | Switch two position | 1 | USD 5.32 | USD 5.32 |
|            | Emergency | Push Button | 1 | USD 5.53 | USD 5.53 |
|            | 10 A Double Pole circuit Breaker | 1 | USD 5.57 | USD 5.57 |                     |
|            | Adapter coupler RJ45 | 3 | USD 9.10 | USD 27.30 |                     |
|            | Silicon wire | to high temperature (2.5 mm) | 4 | USD 0.00 | USD 0.00 |                     |
|            | K-type thermocouple | 3 | USD 4.51 | USD 13.54 |                     |
|            | PVC case, located on the side wall, opposite to the extrusion process, in it is positioned the power supply, the circuit breaker and the AC mains input. | | | | |
|            | Power case | 1 | USD 19.52 | USD 19.52 |                     |
|            | Control Case | 1 | USD 19.52 | USD 19.52 |                     |

The three were mounted by interference, two on the code part J of the puller system (Fig. 4) and, on the part R of the winder system (Fig. 5).

They connect the two resistor circuits, code M of the extruder system (Fig. 2), to the circuit board. PVC case, located on the front view of the machine.
Bill of materials summary

Table 2 is the list of components used to assemble the structural part of the extruder. Here you can observe the components with their respective codes, shown in Fig. 1.

Table 3 is the list of components required to assemble the extrusion part. Here you can observe the components with their respective codes, as shown in Fig. 2.

Table 4 is the list of components used to assemble the cooler part of the system. Here you can see the components with their respective codes, as shown in Fig. 3.

Table 5 is the list of materials used to assemble the puller system and filament diameter analysis. Here you can observe the components with their respective codes, shown in Fig. 4.

Table 6 is the list of components required to assemble the structural and mechanical parts of the spooler system. In this, it is possible to observe the components with their respective codes, as shown in Fig. 5A mechanical system of the spooler, and Fig. 5B structural part of the spooler system.

Table 7 is the bill of materials for the components used to assemble the integrated circuit, the same reported in OSWHA [61].

Fig. 1. Structural part of the filament extruder.

Fig. 2. Extrusion part of the extruder.
Fig. 3. Cooler system.

Fig. 4. Puller system and diameter analysis.
Table 8 is the list of materials used to assemble the electrical part of the machine and the cable to connect the components.

**Build instructions**

The structural part of the extruder serves to assemble the components, such as the electrical boxes, from Table 7, as well as some components from Table 2, the extruder system. To assemble the structural part, it is necessary to mount the aluminum profiles (A, B, C, D, J, and I) with corners (E), using components from Table 2, by using M4 screws (AE), with M4 T-nut (AF) and M4 gasket (AG). Two components (AE, AF, and AE) are used in each corner (E). Finally, the parts from Table 1 (F, G, and H) are assembled using components from Table 2, such as M4 steel screws (AE), with M4 t-nuts (AF) and M4 gaskets (AG). Plate (F) uses five sets (AE, AF, and AG), three fitting it to Profile 2020 and two mounting it to profile 2020(B). Plate (G) uses two sets (AE, AF, and AG), fitting it to profile 2020(B) and angle braked (H) uses two ones (AE, AF, and AG), assembling it to another profile 2020(B).

The extruder system was assembled and held to the structural part of the machine. In this way it supports the mechanical stresses of the process, distributing these loads on the machine structure. It can be assembled or disassembled in two ways. Starting with the hot part of the machine, K, L N P Q and R, or the motor AD, AC AB, using components AE, AF, and AG, all from Table 2. In this assembly explanation, we will explain only from the hot part of the machine to the motor (AD). Therefore, to assemble this system it is interesting to assemble the entire heating system first. The thermocouples (O) are screwed into the octagonal coupler (N) and then the resistors (M) are positioned with thermal paste. To stabilize the sixteen resistors, two per face, it is interesting to use three steel wires, embracing and pushing them against the face of the octagonal coupler (N). Subsequently, the type K thermocouples, shown in Table 7, are positioned in the five 6 mm holes, one on each face of the coupler (N). The depth of the thermocouple positioning is decided by the operator during assembly. In this part (N) the five holes are eighteen millimeters deep in relation to the face where the resistors (M) are placed. It is now necessary to reserve this assembly. The flange (P) will be held to the first structural component of the machine, the plate (F). There, using four Allen screws (R) and M6 nut (Q), attach the flange (P) to the plate (F), block wood (S), and the double flange (U). The double flange will be held by two Allen screws (R) and M6 nut (Q) to the plate (G) and the angle braked (H). This is the second attachment of the components of the extrusion part to the machine. So now it is possible to position the wood drill (T). At this point, this already assembled system should be stabilized and not moving. Now the first assembled system, components N, M, O, and the type K thermocouples, are screwed onto the flange (P). At this point, the electrical part of the two resistor circuits, Kawool BK thermal blanket, Plate 0.5 mm (L), and the nozzle (K) can be assembled, finishing the hot part of the extruder system. Now the mechanical part of the extrusion process must be assembled. The motor (AD) is attached by screws (Z) to the printed bearing Support 2 (AC) and the printed bearing Support 1 (AB). Here the bearing (AA) and the machined coupling (Y) are placed on the printed bearing support (AB) and the motor axle (AD). The motor axis (AD) is centered and locked with three M3 Allen grub screws (W). Now it is possible to install the optical disc locker (X) and the optical encoder disk (V) in the machined coupling (Y). They are placed by interference. They are needed to analyze the speed of the motor. Afterward, this assembled system (AD, AC, AB, Z, AA, Y, X, W, and V) is positioned, using the wood drill shaft (T) and will be attached to the profile (I) by means of six M4 steel screws (AE), M4 t-nuts (AF) and M4 gaskets (AG). So this is the third attachment to the structural part of the extruder. Finally, the lower part printed funnel (AK) is plugged into the upper slot of the Double flange (U), using two Phillips screws (AL) the system is locked. The upper part
printed funnel (AJ) can be plugged or glued into the lower part printed funnel (AK). Now the mechanical and structural parts of the machine are ready.

The cooling system is assembled in the following steps, using the components shown in Table 3. First, the sealing cap (D) is attached to the bottom of the water tank (B). To improve the attachment and the water tightness, it is recommended to apply silicone to the fitting of the parts. Afterward, it is interesting to rub, with your fingers, more silicone on the inside, between the water tank (B) and the sealing cap (D). It is necessary to connect a plastic tube between the pump (C) and the plug, located in the lower central part of the cooling barrel (A). Finally, the cooling barrel (A) is positioned on top of the water tank (B), and water can be poured into the water tank (B).

The puller system, with the measuring system, uses components from Table 4. In it, four Phillips screws (K) attach the NEMA 17 (A) to the lower puller system (L) and also to the filament guide and caliper holder (G). The aluminum flexible coupling (N) can be attached to the axis of the NEMA 17 motor (A). The machined axle (E) and the rubber tires (F) can be attached to the aluminum flexible coupling (N). The upper puller system (C) is attached to the lower puller system (L) by means of a hex apartment head bolt (B) and two m6 nuts (M). With this system mounted, you can see that it works by making a biting motion. To bite or, for a rubber tire (F) to lean against, it is necessary to mount it to the upper puller systems (C), using a 608zz bearing (D) and a machined steel axle (E), all mounted with interference. This assembled system is positioned on top of the puller base (J) and is secured with three Phillips screws (O), locking the puller base (J) to the base of the lower puller systems (L). The caliper (H) is positioned using the internal measurement, normally used in drilled holes. One of the rods of the caliper (H) is inserted into the hole of the filament guide and caliper holder (G), in a rectangular section slot. In it, the caliper (H) is locked by three Phillips screws (O). The other rod of the caliper (H) is positioned in the rectangular section slot of the lower pulley system (L) and to hold it, two Phillips screws (O) are used. For measuring the filament, two 608zz (D) bearings were used. One locked on the filament guide and caliper holder (G) and one on the lower caliper holder (I). Both are held by Allen screw (P) and hex lock nuts (Q). The base puller (J) was used as a fixture for the cables coming from the circuit board but also raised the system at the height of the extrusion process.

The spooler is assembled using parts reported in Table 5. Four M3 Allen screws (O) secure the NEMA 17 step motor (B) to the step motor support (D). To secure this assembly to the extruded profile (P), four M4 steel screw (A) with four M4 t-nut (I) were used. Holding the axle (H), where the spool will be positioned, was done using the center hole of the spool holder (G) in the M8 threaded rods bar (H), subsequently, four M8 hex nuts (K) were used to lock the spool holders (G). This system was mounted on the extruded profile (F) with two bearing houses mounted kp08 (E), four M4 screws (A), and four M4 t-nuts (I). At the axle end of the step motor support (D) and the M8 threaded rods bars (H) is a locked timing pulley (C). The system is designed in this way so that the distance between the motor (B) and the M8 threaded rods bars (H) adjusts to stretch the belt. The assembled systems are held on two pieces of wood (Q). For this purpose, four aluminum corner (N), four M4 steel screw (A), four M4 t-nut (I) bolts locking the corner (N) to the profile (F), and four M4 Phillips steel screw (J), four M4 steel gasket (L) and four M4 steel hex nut (M) were used to lock the other face of the corner (N) to the piece of wood (Q). To increase the rigidity at the bottom of the frame, the M8 steel threaded rods bar (R) were attached by four M8 steel hex nut bars each. Of these, two M8 steel hex nuts (K) are on the inner face of the piece of wood (Q) and two are on the outer face of the piece of wood (Q). Also, to increase the rigidity at the top of the structure, a 2020 extruded profile (P) is attached to two corners (N), one at each end of the profile. They were attached to the profile by one M4 steel screw (A) each. To attach the corner (N) to the pieces of wood (Q), an M4 Phillips steel screw (J) is used on each, with an M4 steel gasket (L) and an M4 steel hex nut (M). It is important to note that this system does not use optical sensors that turn on or turn off the system, only using a preset speed, as used in other projects [10]. Another point is that the height of the piece of wood (Q) and the positioning of the M8 steel threaded rods bar (R) and the extruded profile 2020 (P), were defined using the diameter values of the filament rolls existing in the Brazilian market.

The machine has two plastic cases, shown in Table 8. Each was locked using four M4 screws (AE), with nuts (AF) and lock washers (AG), all reported in Table 2. In the power box, located on the side, opposite the extrusion mechanism, the 12 V 50A switched supply and a two-phase circuit breaker are attached. The three-way PP cable enters the power box, the power wires go to the circuit breakers and the ground wire goes to the source ground and the machine frame. From the circuit breaker, they go to the emergency button and then into the selector switch, and finally feed the source. From the power supply, the VCC and two GND wires are connected to the control board, located at the front of the machine. These two ground wires are connected one to the H-bridge driver and one to the board’s input. From the board come four 2.5 mm wires for the two resistance circuits. To power, control, and get data from the external components, CAT6 cables with RJ45 plugs were used. They go straight out of the respective terminals on the board and are plugged into female RJ45 plugs in the case of the peripherals.

To use the equipment, plug the board’s terminal block to the module’s terminal block. The choice of separating power from control and using CAT6 cables was to reduce noise on the sensors and make the equipment more stable.

**Operation instructions**

To use the equipment, plug the board’s USB cable into the computer. On the computer, open the main docs program. With the program open, use the Arduino application. In it, load the program into the machine. After loading the program, open the command prompt. There you can already see the temperatures. The current (A) consumed by the resistors and the motor, and also the filament diameter.
To start the process, it is recommended to start with the temperature, to melt the polymer and avoid unnecessary wear on the equipment components. The machine was designed to reach temperatures of up to 400 °C, higher than other designs [14]. The program has six standard codes. All were reported in the Code Definition tab.

G1- to send a desired speed information to the extruder motor, in this case in 8bit PWM. To avoid damage to the machine, in the original code, the extruder motor was not set to clockwise rotation, only counterclockwise (A). Example: G1A30 extruder motor with 30 of PWM sent to the motor in a counterclockwise direction.

G2AP- to send information about the speed desired by the puller motor and the letter A. means counterclockwise. Example G2AP10 puller motor with 10 rpm counterclockwise. If you want to use clockwise rotation. Just replace the letter A with C.

G2AB- to send information about the desired speed from the winding motor and the letter A means counterclockwise. Example G2AB20 winding motor with 20 rpm counterclockwise. If you want to use clockwise rotation just replace the letter A with C.

**G3A- to send the desired temperature information. Example: G3A230, with 230 °C service temperature.**

G3 50 - To send 50 PWM to the resistors. With this tool, it is possible to increase or reduce the heating ramp.

G4 - Changes the printing time at the command prompt. Example G4 2 prints every 2 s.

With the machine at the correct process temperature, the cooling system, puller motor, caliper and winder can be turned on using the electrical harness properly assigned.

**Validation and characterization**

The equipment validation was done by processing ABS Premium Black material purchased from 3Dfila®, in its first recy-cling cycle. The material was cut, using an Aviation Snips and analyzed by image processing. The analysis was done using NIH Imagej software. In it was possible to identify the filament particles and the size distribution. As shown in Fig. 6. The size is superior to than reported in other works, near to 3 mm [48,49]. But for this machine works using these sizes.

The granulated material was processed in the machine at a temperature of 205 °C, varying the PWM sent to the motor from 10 to 10, starting at 40 and ending at 90. The material was processed for 15 min and then weighed. With this, it was possible to obtain the average flow rate for each PWM as can be seen in Table 9. There it is also possible to observe that for each extrusion speed the speed of the puller motor was standardized. The standardization was obtained empirically aiming for diameter values closer to 1.75 mm diameter.

The temperature distribution, in some components of the machine can be observed in 11. In Fig. 7, it is possible to observe that the use of the stainless-steel flange (P), present in Table 3, was interesting. Stainless steel is a low thermal conductivity material, compared to normal steels. Subsequently, the use of Allen screw(R) and M6 nut(Q) stainless steel, wood block (S) and double flange (U), protected the addition funnel, which is made of ABS.

In Fig. 8, with elements from Table 3, the use of ABS in printed bearing support 1 (AB) and printed bearing support 2 (AC) was appropriate. This is shown by the temperature of the windshield wiper motor (AD) during the process, which was above 50 °C, making it impossible to use PLA, for example.

The extruder had a behavior compatible with the open source and the benchtop extruders, reaching a flow rate of up to 227 g/h at a temperature of 205 °C, a value close to those reported [19]. The metal profile structure was used to facilitate the adaptability of the structure to the components found by those who wish to assemble the equipment. This made the machine more expensive, compared to open source projects [18,19]. However, this helped in the modularity of the equipment and made it possible for the machine to have the division of the electrical system into power and control, with the assembly of an integrated circuit in the machine, something not observed in other projects. Modularity is reported as an important tool in the equipment since it adapts to different polymers and process characteristics [16]. Compared to less instrumented commercial machines, where the initial price is usually only presenting the extrusion part, the cost of this equipment was lower, since the current values are over US 3000 [14–16,18,25]. Another point is that in this work no pressure transducers were used. This sensor is an important tool for process analysis, has a high cost and is presented in some commercial equipment [16].

The Fig. 9 shows the printed circuit board of the machine during the process. In this one the highest temperature was at the 12 V input of the board, which feeds the resistors. This temperature reached close to 60 °C. This picture was taken without the board ventilation system and using Blue Terminal Block 10 A. In order to reduce the temperature in this region of the machine, it is recommended to replace it with Blue Terminal Block 16 A and use CPU cooler. The terminal was changed in the design before it was accepted into OSHWA, board V 2.0 [62]. This circuit made it possible, for example, to change the extrusion flow rate in a more stable and accurate way, since it is modified by PWM. These digital signals, in this circuit, are more accurate, regarding repeatability, compared to those with a potentiometer [19–22].

The step motor (A) from Table 5, reaches a temperature higher than 60 °C and, for this reason. It is interesting that the parts connected to it support this temperature. Therefore, the lower puller systems (L) and the upper puller systems (C) are made of ABS. The filament guide the caliper holder (G) and also the puller base (J) are made of PLA because they stay at temperatures below 50 °C, as can be seen in Fig. 10.
The puller system and diameter analysis were assembled together, which in some designs is separate. This reduced the degrees of freedom of the filament, causing less downtime and errors during the process, and made the system simpler and leaner. The caliper fixture was idealized and modified based on the project presented by Russ, because the need for increased rigidity was perceived, and thus, parts (G) and (I) of Table 5 [27] were developed. Another point to be addressed is that in the machine program, the caliper analysis code was modified, not generating negative numbers as presented by Russ [27,62]. The choice of the caliper as a diameter analysis system facilitated the validation of the equipment, the non-calibration, low cost, and it already has a display with the measurement, helping the operator during the process. However, it is difficult the development of process control models. The polymer comes out softened and needs to be cooled before diameter anal-

---

**Table 9**

Average flow rate for each PWM sent to the extruder motor.

| PWM | Flow rate (g/h) | Puller motor speed rpm |
|-----|-----------------|------------------------|
| 40  | 73              | 3                      |
| 50  | 114             | 4                      |
| 60  | 146             | 5                      |
| 70  | 166             | 6                      |
| 80  | 188             | 8                      |
| 90  | 227             | 10                     |

---

*Fig. 6. Particle size analysis. (A) Image of the particulates. (B) Conversion of the particulates to objects in the image and (C) sample size analysis.*
Fig. 7. Thermal analysis extrusion and feeding region.

Fig. 8. Thermal analysis of the extrusion motor during the process.

Fig. 9. Thermal analysis of the integrated circuit during the process.
ysis because to obtain the diameter the system uses bearings touching the polymer. This makes the system, mandatorily, after the cooling system. The consequence of this is that the response of the puller motor speed variation is delayed and, for this reason, in this project only constant puller motor speeds were used for each machine flow. Therefore, for a closed loop system with the puller motor, it is interesting to use other systems to obtain the diameter, such as optical and camera sensors near the output region [20,28–30]. Another important point was the use of a stepper motor in the puller motor system. In the project this motor was chosen because it has constant speed, precision and easy acquisition. However, the load to pull the softened filament is low and other motors can be used. DC motors are easier to control, and can have lower speed ranges, which would make it easier to obtain diameters closer to 1.75 mm. Therefore, for developing a control system to obtain more stable diameters with variable speed of the puller system, the DC motor chosen is more suitable.

The parts observed in Fig. 11 are shown in Table 6. In this, the step motor (B) remains at a temperature over 60 °C during the process. Therefore, the stepper motor support is designed in ABS.

For the spooling system, we did not use sensors or a system for positioning the filament on the spool. The use of sensors associated with the filament positioning system is a great tool for the correct winding of the filament [33]. However, in the local filament roll market, there is no standardization of the roll. This makes the use of the system unfeasible and for this reason it was chosen that the speed was adjusted by the operator using the command prompt.

During the processing of the material the variation of the machine flow rate was analyzed as shown in Table 9. This way it was possible to observe the behavior of this type of thread in the filament manufacturing process and if it can generate excessive shear stress in the polymer. In Fig. 12 it is possible to observe the influence of the flow rate on the radial heat distribution. It is possible to observe that the drill generates heat and in it was the highest average temperature recorded followed by the thermocouple at 12 mm depth and finally at 6 mm from the face and then at 0 mm. This is different to that presented in literature, where in extruders the drill generates considerable amount of heat in the process [24,54,60]. At flow rates close to 170 g/h the drill was able to heat the material. To the point that the temperature in the polymer is much higher than the other thermocouples. After 170 g/h the energy generated by the drill and the resistances was consumed by the increased flow of material reducing the temperature in all thermocouples.
The current consumed by the process can be seen in Fig. 13. The sum of this increases considerably after a flow rate of 113 g/h. This gain was more influenced by the increase in consumption at the resistors, than that of the motor. Consequently, the heat generation by the drill was higher at lower flow rates. This shows a lack of mixing efficiency of this auger design for

Fig. 11. Thermal analysis of the winder system during the process.

Fig. 12. Graph of temperature averages × different flow rates and in different regions of the nozzle chamber.

The current consumed by the process can be seen in Fig. 13. The sum of this increases considerably after a flow rate of 113 g/h. This gain was more influenced by the increase in consumption at the resistors, than that of the motor. Consequently, the heat generation by the drill was higher at lower flow rates. This shows a lack of mixing efficiency of this auger design for
the processed polymer, this differs from commercial extruders, where the motor current rises considerably with increasing flow rate [19].

The relationship between diameter variation and increase in the extruder motor speed and therefore increase in the flow rate can be seen in Fig. 14. The motor varies between 7 and 14 rpm and that these variations interfere with the dimensional stability of the filament. Therefore, it is important to create control models to predict and reduce the effect on the filament. To this end, the analysis of motor current and resistances are tools used in the literature for predicting flow variability, but even these tools have been used in the development of the equipment, with the standardized distance between extruder and diameter analysis (270 mm), it was not possible to correlate the variations of the process to the filament, needing to use other analysis tools.

The processed polymer was analyzed with confocal microscopy. Using a LEICA DCM3D microscope. As can be observed in Fig. 15(A). Ten elevation maps for roughness analysis of each process setting were taken using 20X lens. To standardize the positioning of the filament in the microscope a filament analysis stand was designed. As can be seen in Fig. 15(B).

**Fig. 13.** Analysis of the average current consumed by the resistors and the extruder motor, for different flow rates.

**Fig. 14.** Variation of filament diameter and extruder motor speed by time.
The design of the support is on the Thingverse platform [63]. In it the position of the filament image is practically stable. And it is only necessary to pull the filament to change the analyzed region. To analyze the surfaces obtained, Gwyddion software was used as can be seen in Fig. 16. In this it is possible to examine the influence of the process parameters on the material roughness, using ten images per filament. The filaments can be observed in Fig. 16, where from the manufacturer (A)
and produced in the first recycling cycle in the extruder of this work were analyzed. In which (B) 73 g/h. (C) 114 g/h. (D) 146 g/h. (E) 166 g/h. (F) 188 g/h and (G) 227 g/h.

For each process parameter ten measures of the topography were taken. All at different positions. With these measurements, and analyzing by median. It was possible to obtain the data shown in the Table 10. In it is presenting relationship between the flow rates, average diameter. Coefficient of variation of the diameters. Projected area/surface area and the median roughness (Sq). From this, higher flow rates made filament production more stable since the coefficient of variation was lower than at lower ones. In addition, the higher flow rates had average diameters closer to 1.75 mm. Even with increasing flow rates no influence on roughness was noted. As reported, showing that the wood screw does not generate the shear stress necessary to cause deformation of the filament surface [24,42,50]. This is also seen by the reduced load on the motor when the flow rate is increased.

### Table 10

| PWM | Average Diameter (mm) | Coefficient of variation (%) | Projected area (μm²)/Surface area (μm²) (median) |
|-----|------------------------|-------------------------------|-----------------------------------------------|
| As received filament | 0.93 | 9.79 | 0.97 |
| 40 | 1.85 | 9.79 | 0.97 |
| 50 | 1.67 | 7.83 | 0.92 |
| 60 | 1.79 | 2.57 | 0.92 |
| 70 | 1.83 | 2.01 | 0.96 |
| 80 | 1.76 | 1.73 | 0.92 |
| 90 | 1.74 | 1.06 | 0.96 |

### Conclusion

The equipment produced and analyzed the process in-situ, enabling the design of drills and new materials. Something limited on desktop machines. Modularity was respected in both the registered circuitry and the equipment, possibility this machine adapts to different processes and materials. It was observed that the use of other types of sensors for diameter analysis, such as those by optical analysis, is more suitable for the development of closed-loop control models for the puller motor. Also, the use of DC and brushed puller motor will help in the development of these models. For the design of this drill and extruder model, using ABS in the first recycling cycle and at 205 °C, higher flow rates generated lower surface ratios, therefore better roughnesses. This parameter also generated less diameter variability during the process.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Acknowledgments

Acknowledgement to the funding agencies CNPq process 168694/2018-2 and 305959/2017-4. Fapesp process: 2019/14694-0.

### References

[1] ONU, 17 Objetivos para transformar nosso mundo, Nações Unidas, 2015 https://nacoesunidas.org/pos2015/ 2015 accessed October 16, 2018.  
[2] Precious_Plastic, Set up a Shredder Workspace, 3, 54–67 https://community.preciousplastic.com/how-to/set-up-a-shredder-workspace 2020 accessed June 10, 2020.  
[3] D.J. Byard, A.L. Woern, R.B. Oakley, M.J. Fiedler, S.L. Snabes, J.M. Pearce, Green fab lab applications of large-area waste polymer-based additive manufacturing, Addit. Manuf. 27 (2019) 515–525, https://doi.org/10.1016/j.addma.2019.03.006.  
[4] Z. Liu, Q. Jiang, Y. Zhang, T. Li, H.C. Zhang, Sustainability of 3D printing: A critical review and recommendations, ASME 2016 11th Int. Manuf. Sci. Eng. Conf. MSEC 2016. 2 (2016). https://doi.org/10.1115/MSEC2016-8618.  
[5] F.A. Cruz Sanchez, H. Boudaoud, M. Camargo, J.M. Pearce, Plastic recycling in additive manufacturing: A systematic literature review and opportunities for the circular economy, J. Clean. [2] Prod. 264 (2020) 121602. https://doi.org/10.1016/j.jclepro.2020.121602.  
[6] D.A. Anderegg, H.A. Bryant, D.C. Ruffin, S.M. Skrip, J.J. Fallon, E.L. Gilmer, M.J. Bortner, In-situ monitoring of polymer flow temperature and pressure in extrusion based additive manufacturing, Addit. Manuf. 26 (2019) 78–83, https://doi.org/10.1016/j.addma.2019.01.002.  
[7] F. Cruz, S. Lanza, H. Boudaoud, S. Hoppe, M. Camargo. Polymer recycling and additive manufacturing in an open source context: Optimization of processes and methods, in: Proc. - 26th Annu. Int. Solid Free. Fabr. Symp. - An Addit. Manuf. Conf. SFF 2015, 2020: pp. 1591–1600. http://link.springer.com/10.1007/978-3-319-57078-5.  
[8] X. Tian, T. Liu, Q. Wang, A. Dilmurat, D. Li, G. Ziegmann, Recycling and remanufacturing of 3D printed continuous carbon fiber reinforced PLA composites, J. Clean. Prod. 142 (2017) 1609–1618, https://doi.org/10.1016/j.jclepro.2016.11.139.  
[9] F.A. Cruz Sanchez, H. Boudaoud, S. Hoppe, M. Camargo, Polymer recycling in an open-source additive manufacturing context: Mechanical issues, Addit. Manuf. 17 (2017) 87–105, https://doi.org/10.1016/j.addma.2017.05.013.
A. L. Woern, J. R. McCaslin, A. M. Pringle, J. M. Pearce, RepRapable Recyclebot: Open source 3-D printable extruder for converting plastic to 3-D printing filament. HardwareX, 12 (2022) e00362.

[13] H. M. L. Jr., Lyman Filament Extruder II, 2012. http://creativecommons.org/licenses/by-sa/3.0/.

[15] Zhangjiagang-Friend-Machinery-Company, Monofilament machinery /PET plastic filament extruding machine /broom making machine, Alibaba.

[16] DiamondAmerica, Table Top Extrusion Equipment, (2022). https://daextrusion.com/equipment/extruders/table-top-extruders/ (accessed July 9, 2022).

[19] L. B. Silva, R. O. de Oliveira, G. F. Barbosa, S. B. Shiki, K. Fu, Influence of the single-screw extruder nozzle diameter on pellet-based filaments for additive manufacturing, J. Brazilian Soc. Mech. Sci. Eng. 44 (2022) 286, https://doi.org/10.1007/s40430-022-03590-z.

[22] J. Deng, K. Li, E. Harkin-Jones, M. Price, N. Karnachi, A. Kelly, J. Vera-Sorroche, P. Coates, E. Brown, M. Fei, Energy monitoring and quality control of a single screw extruder, Appl. Energy. 113 (2014) 1775–1785, https://doi.org/10.1016/j.apenergy.2013.08.084.

[24] A. Petsiuk, J. M. Pearce, Open Source Filament Diameter Sensor for Recycling, Winding, and Additive Manufacturing Machines, J. Manuf. Sci. Eng. 143 (2021), https://doi.org/10.1115/1.4050762.

[25] FILMAQ3D, Máquinas, 2021https://www.filmaq3d.com.br/index.php?route=product/category&path=172021 accessed October 24, 2021.

[26] R. Gries, Russ’s Home Brewed Filament Extruder For 3D Printer. First Look. Built From Recycled Material, (2013). https://www.youtube.com/watch?v=jXuUgUL0X6M (accessed November 1, 2018).

[27] R. Gries, #5 Russ’s Filament Extruder: Air Cool Jig Test. “This is Just A Test” time laps, Youtube. (2013). 5. https://www.youtube.com/watch?v=0hKosVs91i&index=38&list=PLs1lK9pZLEkEmIwPVScMR5w2mvsFl (accessed January 14, 2019).

[28] R. Gries, #15 Russ’s Filament Extruder: Digital Caliper Filament Measuring Device Finished, (2015) 2015. https://www.youtube.com/watch?v=R2DJrR9tw (accessed January 14, 2018).

[29] A. Petsiuk, J. M. Pearce, Open Source Filament Diameter Sensor for Recycling, Winding, and Additive Manufacturing Machines, J. Manuf. Sci. Eng. 143 (2021), https://doi.org/10.1115/1.4050762.

[30] D. Mosklin, Filament Width Sensor with Arduino uno and Thickness-Gauge. Thingverse. (2018). https://www.thingiverse.com/thing:398087 (accessed January 14, 2019).

[31] H. M. L. Jr., Lyman Filament Extruder V6, (2014). https://www.thingiverse.com/thing:1199870 (accessed October 17, 2018).

[32] F. G. Wingmaster for Filament Extruder Puller, Thingiverse, 2015. https://www.thingiverse.com/thing:681880 2015 accessed September 20, 2020.

[33] H. Lyman, Extruder Y with Spool Winder – video 2, Youtube. (2015). https://www.youtube.com/watch?v=6HyLYDoPNMU (accessed November 1, 2018).

[34] V. Mirón, S. Ferrándiz, D. Juárez, A. Mengual, Manufacturing and characterization of 3D printer filament using tailoring materials, Procedia Manuf. 13 (2017) 888–894, https://doi.org/10.1016/j.promfg.2017.09.151.

[35] A. Bhaskar, J. Butt, H. Shrivani, Experimental analysis of plastic-based filaments for fused filament fabrication, J. Manuf. Mater. Process. 5 (2021) 69, https://doi.org/10.1186/s42730-021-00165-x.

[36] V. Dikshit, G. D. Goh, A. P. Nagalingam, G. L. Goh, W. Y. Yeong, Recent progress in 3D printing of fiber-reinforced composite and nanocomposites, INC Poly. 45534 (2020) 455344, https://doi.org/10.1016/j.indconeng.2019.12.038.

[37] V. Mirón, S. Ferrándiz, D. Juárez, A. Mengual, Manufacturing and characterization of 3D printer filament using tailoring materials, Procedia Manuf. 13 (2017) 888–894, https://doi.org/10.1016/j.promfg.2017.09.151.

[38] R. Gries, #5 Russ’s Filament Extruder: Air Cool Jig Test. “This is Just A Test” time laps, Youtube. (2013). 5. https://www.youtube.com/watch?v=0hKosVs91i&index=38&list=PLs1lK9pZLEkEmIwPVScMR5w2mvsFl (accessed January 14, 2019).

[39] A. Petsiuk, J. M. Pearce, Open Source Filament Diameter Sensor for Recycling, Winding, and Additive Manufacturing Machines, J. Manuf. Sci. Eng. 143 (2021), https://doi.org/10.1115/1.4050762.
Maurício de Oliveira Filho

Maurício de Oliveira Filho has a degree in Mechanical Engineering from Universidade Federal Fluminense (2015), a Master in Mechanical Engineering from Unesp, Area of Materials Processing (2017), and a Ph.D. in Mechanical Engineering from Unesp, Area of Materials Processing (2022). He has experience in Mechanical Engineering, with emphasis on manufacturing processes, materials characterization, and design equipment. He works especially on the following topics: digital image processing, foam production via liquid route, and equipment design/build (open source).

Matheus Cerqueira de Jesus

Matheus Cerqueira de Jesus Electrical Engineering undergraduate student at the Faculdade de Engenharia de Guaratinguetá, Universidade Estadual Paulista “Júlio de Mesquita Filho” (UNESP). He is interested in the area of Electrical Engineering, Electronics and Control.

Andersen Zenken Nakazato

Andersen Zenken Nakazato PhD student in the Postgraduate Program in Mechanical Engineering in the Materials area at UNESP Guaratinguetá Campus, working in the research line of Design and Development of Scientific and Didactic Equipment of Open Design. Master also from the Post-graduation program in Mechanical Engineering in the Materials area from UNESP Guaratinguetá Campus. Bachelor in Mechanical Engineering from Universidade Federal Fluminense - University of Volta Redonda. Where he acted as Captain of the Project and Construction team of a Battle Robot for National and International Interinstitutional Competitions founded by Professor Ivaldo Leão Ferreira. He was a CNPq Scientific Initiation scholarship holder, oriented by Professor Jefferson Fabricio Cardoso Lins in composites of the sandwich type Metal/Polymer/Metal.

Marcel Yuzo Kondo

Marcel Yuzo Kondo PhD in Mechanical Engineering at Paulista State University Júlio de Mesquita Filho since 2019, Master in Mechanical Engineering in Mechanical Engineering at Paulista State University Júlio de Mesquita Filho since 2015. He has a Bachelor’s degree in Industrial Wood Engineering from Paulista State University Júlio de Mesquita Filho (2011). Researcher in the area of machining of materials, machining of superalloys and planning of experiments. He is currently conducting a Post-Doctoral project at Paulista State University Júlio de Mesquita Filho, in the area of machining of materials.

Luis Rogerio de Oliveira

Luis Rogerio de Oliveira Hein Bachelor's degree in Mechanical Engineering from the State University of Campinas (1989), a master's degree in Mechanical Engineering from the State University of Campinas (1993), a doctorate degree in Mechanical Engineering from the State University of Campinas (1996), and a livre docência degree in Mechanical Properties of Materials from the Paulista State University (2002). He is currently Professor of the chair “Microscopy and Characterization of Structures” at the Materials and Technology Department of the Engineering School of Guaratinguetá, Júlio de Mesquita Filho State University (UNESP). He was responsible for the conception of the curricular structure of the Materials Engineering Undergraduate Course at UNESP. He also created and equipped, for the Department of Materials and Technology, the Laboratories of Ceramic Materials and Optical Microscopy, Microscopy and Microanalysis, Surface Characterization, Digital Image Processing, and the Sample Preparation Room, which compose LAIMat (Materials Imaging Laboratory), a multi-user center in Scanning Electron Microscopy, Atomic Force Microscopy, Optical Microscopy and Digital Image Processing that serves research and academic institutions throughout the Vale do Paraíba (São Paulo and Rio de Janeiro) and southern Minas Gerais, being its creator and coordinator since 1997. Experience in materials for the aerospace industry, with an emphasis in Microscopy and Digital Image Processing of materials for aeronautic use, working mainly on the following topics: fracture, mechanical tests (metals, ceramics and polymeric matrix composites), digital image processing, quantitative fractography, correlative microscopy, quantitative micrography, quantitative metallography and quantitative ceramography. He is currently working on open source projects for low-cost equipment for technical education and advanced research. His hobby is electronic instrumentation for low-level measurements, including repairing, restoring, and upgrading measuring instruments.