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Hardware Article

Instrumented open-source filament extruder for research and education

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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.

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 Mechanical engineering and materials science
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.*

(*continued on next page*)

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(continued)

Hardware name	*Integrated and modulated system for extruder machine*
Open-source license	*MIT – for integrated circuit*
Cost of hardware	USD 47.25 – Mechanics parts of filament extruder USD 152.46 – Filament extruder system USD 15.33 – Cooler system USD 45.07 – Puller and filament measuring system USD 43.78– Spooler system USD 155.96– Integrated circuit cost USD 114.38- Electric components USD 526.99- Total equipment cost
Source file repository	Structural parts of filament extruder - https://doi.org/10.17632/2fp47vg2w9.4 Filament extruder system - https://www.doi.org/10.17632/2fp47vg2w9.4 Cooler system - https://www.doi.org/10.17632/2fp47vg2w9.4 Puller and filament measuring system - https://www.doi.org/10.17632/2fp47vg2w9.4 Spooler system - https://www.doi.org/10.17632/2fp47vg2w9.4 Integrated circuit cost - https://www.doi.org/10.17632/2fp47vg2w9.4 Electric components cost- https://www.doi.org/10.17632/2fp47vg2w9.4
OSHWA certification UID	BR000009

Hardware in context

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, l 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 ½″ 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.

Table 1
Design files summary.

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

Table 2
List of components of the extruder structural part.

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.productlist.0.0.30fd26dbiC1kw9&algo_pvid=ba9068d4-1917–4121-adc7-8aa1c777f128&algo_exp_id=ba9068d4-1917–4121-adc7-8aa1c777f128-16&pdp_ext_f=%7B%22sku_id%22%3A%2210000000711777300%22%7D&pdp_pi=-1%3B28.84%3B-1%3B-1%40salePrice%3BBRL%3Bsearch-mainSearch	Aluminum
Plate machined (190x45mm)	F	1	USD 0.00	USD 0.00	Scrap	Steel
Plate machined (190x45mm)	G	1	USD 0.00	USD 0.00	Scrap	Steel
Angle bracket (machined 20x60)	H	1	USD 0.00	USD 0.00	Local store	Aluminum
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-4837-88eb-bfd1aca28839	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	USD 3.00	Local store	Brass
Plate 0.5 mm (500X110xø155mm)	L	1	USD 1.40	USD 1.40	Local store	Stainless steel 304
Resistor 15 O 10 w	M	16	USD 0.17	USD 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=g&matt_device=c&matt_creative=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=Cj0KCQiA09eQBhCxARIsAAYRiykBOty6PhOFU0p0GiEzrODEcIdPlaJTAHoESXDtqshLTaif28QTyrsaAqmpEALw_wcB	Ceramic
Octagonal coupler	N	1	USD 0.00	USD 0.00		Aluminum
K-type thermocouple M6 screw-type (M6 thread. 1 mm pitch)	O	3	USD 0.00	USD 0.00	https://www.baudaeletronica.com.br/modulo-sensor-de-temperatura-max6675-termopar-tipo-k.html	
Flange (nipple)	P	1	USD 0.00	USD 0.00		Stainless steel
M6 nut	Q	6	USD 0.08	USD 0.45	https://produto.mercadolivre.com.br/MLB-1931961401-porca-sextavada-m6-inox-50-pecas-_JM#position=1&search_layout=stack&type=pad&tracking_id=453936c8-4266-4c37-bceb-fa4927a71a40&is_advertising=true&ad_domain=VQCATCORE_LST&ad_position=1&ad_click_id=OTY3ZWRlYTgtZDFhNi00ZTBjLThlNmEtMmI2Y2Y4ZWM3OWM3	Stainless steel
Allen screw (M6x25mm)	R	6	USD 1.30	USD 7.80	https://produto.mercadolivre.com.br/MLB-930562086-parafuso-m6x25-625-Allen-cabeca-inox-10-pcs-_JM#position=4&search_layout=stack&type=item&tracking_id=28f3c43e-cc45-4ad9-a2db-36e5b85d0625	Stainless steel
Wood block	S	1	USD 0.00	USD 0.00	Waste	Wood
Wood drill 1/2″	T	1	USD 12.00	USD 12.00	Local store	Steel
Double flange	U	1	USD 0.00	USD 0.00		Stainless steel
Optical encoder disk (photolithography)	V	1	USD 6.00	USD 6.00	Local store	Transparency film paper
M3 Allen grub screw (8 mm)	W	6	USD 0.23	USD 1.40	https://produto.mercadolivre.com.br/MLB-1275215986-parafuso-Allen-sem-cabeca-inox-m3-x-8mm-pacote-c20-pecas-_JM#position=26&search_layout=stack&type=item&tracking_id=bafc24d0-a4b6-4175-a83b-c970e8e10204	Stainless steel
Optical disc locker (3 g)	X	1	USD 0.05	USD 0.05	https://3dfila.com.br/produto/filamento-abs-premium/	ABS
Machined Coupling	Y	1	USD 0.00	USD 0.00		Aluminum
Hex flat head bolt (M6.5x60mm)	Z	3	USD 0.00	USD 0.00		Steel
Bearing (72x30x28.5 mm)	AA	1	USD 11.00	USD 11.00	https://produto.mercadolivre.com.br/MLB-1926629750-rolamento-cnico-32306-30x72x2875-mm-capa-e-cone-_JM#Calcular%20o%20prazo%20de%20entrega	
Printed bearing support 1 (298 g)	AB	1	USD 4.86	USD 4.86	https://3dfila.com.br/produto/filamento-abs-premium/	ABS
Printed bearing support 2 (157 g)	AC	1	USD 2.56	USD 2.56	https://3dfila.com.br/produto/filamento-abs-premium/	ABS
Windshield wiper motor bosch	AD	1	USD 77.80	USD 77.80	https://produto.mercadolivre.com.br/MLB-2034034141-motor-do-limpador-do-parabrisa-mercedes-benz-caminhoes-12v-_JM#position=17&search_layout=grid&type=item&tracking_id=612f0573-cf68-4e6d-a98b-5f9c73ee785d	
M4 steel screw	AE	69	USD 0.11	USD 7.63	https://produto.mercadolivre.com.br/MLB-1272150467-parafuso-Allen-cabeca-cilindrica-m4-x-10-aco-liga-50-pecas-_JM#position=5&search_layout=stack&type=item&tracking_id=d7e3194b-fa72-45ba-8153-bca91717fe76	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/1005002375778002.html?spm=a2g0o.productlist.0.0.43b13169cBfQxr&algo_pvid=9c5f2764-a4fb-426e-a6f7-fbde55473cd8&algo_exp_id=9c5f2764-a4fb-426e-a6f7-fbde55473cd8-0&pdp_ext_f=%7B%22sku_id%22%3A%2212000020416820982%22%7D&pdp_pi=-1%3B8.45%3B-1%3B-1%40salePrice%3BBRL%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=544def93-68a0-41c5-9630-67317a0f7fd9	Steel
Tachometer sensor	AH	1	USD 1.84	USD 1.84	https://www.baudaeletronica.com.br/catalogsearch/result/?q=M%C3%B3dulo+Sensor+de+Velocidade+Encoder	
Support tachometer sensor (7 g)	AI	1	USD 0.18	USD 0.18	https://3dfila.com.br/produto/filamento-pla-easyfill/	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 × 40 mm)	AL	2	USD 0.13	USD 0.26	Local store	Steel

Table 4
Components of coller 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	
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-17-17hs4401-42kgfcm-cabo-1-metro-_JM?matt_tool=56291529&matt_word=&matt_source=google&matt_campaign_id=14303413604&matt_ad_group_id=125984287157&matt_match_type=&matt_network=g&matt_device=c&matt_creative=539354956218&matt_keyword=&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=Cj0KCQiA09eQBhCxARIsAAYRiyn8POX2vzr6C9vzzYD-OxVaJt2t9OnV-wMjhIiUlguesKHJmpRZ5IEaAvppEALw_wcB	
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#position=1&search_layout=stack&type=item&tracking_id=0d710920-f6cf-48f2-b29b-a0c096e5e0c3	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-abec-1-8x22x7-skate-patinsem-aco-_JM#position=1&search_layout=stack&type=pad&tracking_id=76d7323a-389a-491e-86c7-4dd2ab40e6fa&is_advertising=true&ad_domain=VQCATCORE_LST&ad_position=1&ad_click_id=OThmNGY0NmQtMjFlZC00N2NhLWFmOGItNDdmNWZkNTRiMmIz	

Table 5 *(continued)*

Name	Code	Number	Cost per unit	Total cost	Source of materials	Material type
Machined steel axe (M8x52 mm)	E	2	USD 0.00	USD 0.00		Steel
Rubber tires of recycled printers	F	2	USD 0.00	USD 0.00	Waste material	Rubber
Filament guide and caliper holder (98 g)	G	1	USD 2.53	USD 2.53	https://3dfila.com.br/produto/filamento-pla-easyfill/	PLA
Caliper	H	1	USD 0.00	USD 15.38	https://produto.mercadolivre.com.br/MLB-766878742-paquimetro-digital-150mm-inox-profissional-c-estojo-mtx-_JM#position=1&search_layout=stack&type=item&tracking_id=a7406f9f-cead-4029-a4ef-5a2288164ccb	
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://3dfila.com.br/produto/filamento-pla-easyfill/	PLA
Phillips screw (M3x12mm)	K	6	USD 0.10	USD 0.59	https://produto.mercadolivre.com.br/MLB-2084350836-parafusos-Philips-m3-x-12mm-m3x12mm-com-100-unidades-_JM?matt_tool=73118705&matt_word=&matt_source=google&matt_campaign_id=14302215555&matt_ad_group_id=134553706788&matt_match_type=&matt_network=g&matt_device=c&matt_creative=539425529245&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=137818222&matt_product_id=MLB2084350836&matt_product_partition_id=1469248455037&matt_target_id=aud-659781599642:pla-1469248455037&gclid=EAIaIQobChMImuuVlqqg9gIVgQyRCh33OQwpEAQYByABEgKYJfD_BwE	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-porca-sextavada-m6-zincado-branco-passo-100-1000pecas-_JM#position=2&search_layout=stack&type=pad&tracking_id=efaa0a61-4737–4750-8e13-ff8b2afedbda&is_advertising=true&ad_domain=VQCATCORE_LST&ad_position=2&ad_click_id=MjEwNDI1YmMtZjI0Ni00MGJiLWE1NWUtNDAyYjJiYTgxNGFk	Steel
Aluminum flexible coupling	N	1	USD 2.27	USD 2.27	https://www.baudaeletronica.com.br/acoplamento-flexivel-para-motor-de-passo-6–35-x-8mm.html?gclid=EAIaIQobChMI16SM_qqg9gIVkIKRCh0Mmw91EAQYAiABEgIGKvD_BwE	Aluminum
Phillips screw (M3x25)	O	5	USD 0.05	USD 0.27	https://produto.mercadolivre.com.br/MLB-1528778452-parafuso-cabeca-panela-phillips-m3-25mm-com-100-pecas-_JM#position=1&search_layout=stack&type=pad&tracking_id=4ce0ba84-215d-464f-95e8-5ae8369bdf98&is_advertising=true&ad_domain=VQCATCORE_LST&ad_position=1&ad_click_id=MTU4ZjBkZjAtMWYzYS00ODU3LWFkYjQtMjQ1MmVmZWYxNGZl	Steel
Allen screw (M8x35)	P	2	USD 0.44	USD 0.87	https://produto.mercadolivre.com.br/MLB-1934301939-parafuso-Allen-cabeca-cilindrica-m8-x-35-aco-liga-20-pecas-_JM#position=9&search_layout=stack&type=item&tracking_id=5f781234-949f-4b17-ba44-a31b32e89448	Steel
Hex lock nuts M8	Q	2	USD 0.10	USD 0.20	https://produto.mercadolivre.com.br/MLB-1286378768-porca-autotravante-m8-zincado-parlok-com-500-pecas-_JM#position=2&search_layout=stack&type=item&tracking_id=c0aa1be4-3088-493d-b63e-fff0ddc2bf50	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	USD 1.55	https://produto.mercadolivre.com.br/MLB-1272150467-parafuso-Allen-cabeca-cilindrica-m4-x-10-aco-liga-50-pecas-_JM#position=5&search_layout=stack&type=item&tracking_id=d7e3194b-fa72-45ba-8153-bca91717fe76	Steel
Nema 17 step motor	B	1	USD 13.44	USD 13.44	https://produto.mercadolivre.com.br/MLB-1699089992-motor-de-passo-nema-17-17hs4401-42kgfcm-cabo-1-metro-_JM?matt_tool=56291529&matt_word=&matt_source=google&matt_campaign_id=14303413604&matt_ad_group_id=125984287157&matt_match_type=&matt_network=g&matt_device=c&matt_creative=539354956218&matt_keyword=&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=Cj0KCQiA09eQBhCxARIsAAYRiyn8POX2vzr6C9vzzYD-OxVaJt2t9OnV-wMjhIiUlguesKHJmpRZ5IEaAvppEALw_wcB	
Timing pulley 2gt 8	C	2	USD 0.74	USD 1.48	https://pt.aliexpress.com/item/1005003238020209.html?spm=a2g0o.productlist.0.0.6df332d0kvzG8q&algo_pvid=779700e6-3e8a-4d2c-a1e3-262adb3d8e67&aem_p4p_detail=202202250646569096487341283600124948184&algo_exp_id=779700e6-3e8a-4d2c-a1e3-262adb3d8e67-1&pdp_ext_f=%7B%22sku_id%22%3A%2212000024793378926%22%7D&pdp_pi=-1%3B3.71%3B-1%3B1996%40salePrice%3BBRL%3Bsearch-mainSearch	Aluminum
Motor step support (66 g)	D	1	USD 1.08	USD 1.08	https://3dfila.com.br/produto/filamento-abs-premium/	ABS
Bore bearing housing vertical block mounted KP08	E	2	USD 1.70	USD 3.40	https://pt.aliexpress.com/item/32903705568.html?spm=a2g0o.productlist.0.0.1ccf32d2MeyPXQ&algo_pvid=9dd07d4b-34b6-4ddc-b5cf-e0263bc1af94&algo_exp_id=9dd07d4b-34b6-4ddc-b5cf-e0263bc1af94-31&pdp_ext_f=%7B%22sku_id%22%3A%2265921080505%22%7D&pdp_pi=-1%3B8.5%3B-1%3B-1%40salePrice%3BBRL%3Bsearch-mainSearch	
Aluminum extruded profile 20x20 (210 mm)	F	2	USD 1.68	USD 4.48	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
Spool holder (53 g)	G	2	USD 0.87	USD 1.73	https://3dfila.com.br/produto/filamento-abs-premium/	ABS
M8 steel threaded rods bar (380 mm)	H	1	USD 2.58	USD 2.58	Local store	Steel
T-nut M4	I	14	USD 0.09	USD 1.27	https://pt.aliexpress.com/item/1005002375778002.html?spm=a2g0o.productlist.0.0.43b13169cBfQxr&algo_pvid=9c5f2764-a4fb-426e-a6f7-fbde55473cd8&algo_exp_id=9c5f2764-a4fb-426e-a6f7-fbde55473cd8-0&pdp_ext_f=%7B%22sku_id%22%3A%2212000020416820982%22%7D&pdp_pi=-1%3B8.45%3B-1%3B-1%40salePrice%3BBRL%3Bsearch-mainSearch	Steel
M4 phillips steel screw (40 mm)	J	6	USD 0.30	USD 1.80	Local store	Steel
M8 steel hex nut	K	4	USD 0.09	USD 0.36	https://produto.mercadolivre.com.br/MLB-2158283746-porca-sextavada-m8-zincado-branco-passo-125-c50-pecas-_JM?matt_tool=14372353&matt_word=&matt_source=google&matt_campaign_id=14302215552&matt_ad_group_id=134553706508&matt_match_type=&matt_network=g&matt_device=c&matt_creative=539425529230&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=341805245&matt_product_id=MLB2158283746&matt_product_partition_id=1403979574469&matt_target_id=aud-395642386021:pla-1403979574469&gclid=EAIaIQobChMItcXx16Wg9gIVCgaRCh2DzAC3EAQYAiABEgJ81PD_BwE	Steel

Table 6 *(continued)*

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-arruela-lisa-zincada-m4-zincada-500-pecas-_JM#position=6&search_layout=stack&type=item&tracking_id=544def93-68a0-41c5-9630-67317a0f7fd9	Steel
M4 steel hex nut	M	18	USD 0.03	USD 0.58	https://produto.mercadolivre.com.br/MLB-1782968438-porca-sextavada-m4-zincada-pacote-com-100-pecas-_JM#position=1&search_layout=stack&type=pad&tracking_id=ac7f9e20-895f-4026-aae0-55cd42b96216&is_advertising=true&ad_domain=VQCATCORE_LST&ad_position=1&ad_click_id=NzUzZDRhZGQtZTZhMC00NDhiLWE3OGQtYzgxMzUzOGQyMmNm	Steel
Aluminum corner	N	6	USD 0.30	USD 1.77	https://pt.aliexpress.com/item/4000190579760.html?spm=a2g0o.productlist.0.0.30fd26dbiC1kw9&algo_pvid=ba9068d4-1917–4121-adc7-8aa1c777f128&algo_exp_id=ba9068d4-1917–4121-adc7-8aa1c777f128-16&pdp_ext_f=%7B%22sku_id%22%3A%221000000071 1777300%22%7D&pdp_pi=-1%3B28.84%3B-1%3B-1%40salePrice%3BBRL%3Bsearch-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-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
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 7
Integrated Circuit Component List.

Name	Number	Cost per unit	Total cost	Source of materials
Arduino mega 2560	1	USD 25.11	USD 25.11	https://www.baudaeletronica.com.br/arduino-mega-2560-compativel-cabo-usb.html?gclid=EAIaIQobChMI052TusOg9gIVDBKRCh1B5QVoEAAYASAAEgLO-fD_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 KOhm. +/- 1%. 0.25 W	12	USD 0.01	USD 0.14	https://www.baudaeletronica.com.br/resistor-10k-5-1-4w.html
Axial Resistor. 100 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 KOhm. +/- 1%. 0.25 W	1	USD 0.01	USD 0.01	https://www.baudaeletronica.com.br/resistor-100k-5-1-4w.html
Axial Resistor. 100 Ohm. +/- 1%. 0.25 W	2	USD 0.01	USD 0.02	https://www.baudaeletronica.com.br/resistor-100k-5-1-4w.html
Current Sensor with ACS712 IC	2	USD 5.66	USD 11.32	https://www.baudaeletronica.com.br/sensor-de-corrente-acs712-30a-a-30a.html
LED 5 mm	1	USD 0.04	USD 0.04	https://www.baudaeletronica.com.br/led-difuso-5mm-vermelho.html
Thermocouple module MAX6675 IC	6	USD 10.40	USD 62.39	https://www.baudaeletronica.com.br/modulo-sensor-de-temperatura-max6675-termopar-tipo-k.html
Voltage regulator AMS1117	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-amperes-arduino-monster-vnh2sp30-_JM?matt_tool=56291529&matt_word=&matt_source=google&matt_campaign_id=14303413604&matt_ad_group_id=125984287157&matt_match_type=&matt_network=g&matt_device=c&matt_creative=539354956218&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=109543422&matt_product_id=MLB1038624798&matt_product_partition_id=1435016894331&matt_target_id=aud-1414365823100:pla-1435016894331&gclid=EAIaIQobChMI0Ojw-Mmg9gIVUwaRCh0iLAjYEAQYASABEgIBx_D_BwE
Linear Trimpot(R) 10KOhm. 300 V. −55 to 125 degC. 3-Pin	1	USD 0.35	USD 0.35	https://www.baudaeletronica.com.br/trimpot-linear-horizontal-de-10k-10000.html
Stepper motor controler; 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 0.09	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-tantalo-0-22uf-35v.html
Ceramic Capacitors 10nF, 50 V, +/-10%	2	USD 0.02	USD 0.03	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, 75 V, 0.3A, DO-35	2	USD 0.02	USD 0.04	https://www.baudaeletronica.com.br/diodo-1n4148.html
Blue Terminal Block, 2, 300 V, 10 A, 26 AWG, 16 AWG, 1.5 mm	15	USD 0.15	USD 2.22	https://www.baudaeletronica.com.br/borne-2-polos-kf-301-2t.html
Black Terminal Block, 2, 300 V, 16 A, 26 AWG, 16 AWG, 1.5 mm	2	USD 0.22	USD 0.45	https://www.baudaeletronica.com.br/mini-borne-kre2-kf301-10x10mm-preto.html
NPN Transistor 2 N3904, 40 V	4	USD 0.06	USD 0.22	https://www.baudaeletronica.com.br/transistor-npn-2n3904.html
Positive-voltage Regulator LM7805 IC	1	USD 0.32	USD 0.32	https://www.baudaeletronica.com.br/regulador-de-tensao-l7805.html
PCB fabrication	5	USD 5.87	USD 29.35	https://jlcpcb.com/

Table 8
List of components of the electrical part of the machine.

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=g&matt_device=c&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-BmLgIXkgEM1_1sti60rORDi8wX1HJRXwU3SviW96S3udZQC67xoCM_cQAvD_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-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=g&matt_device=c&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-BmLgIXkgEM1_1sti60rORDi8wX1HJRXwU3SviW96S3udZQC67xoCM_cQAvD_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-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=g&matt_device=c&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-BmLgIXkgEM1_1sti60rORDi8wX1HJRXwU3SviW96S3udZQC67xoCM_cQAvD_BwE
Connect the caliper, code H of the puller system (Fig. 4) to the RJ45 female plug, holded 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-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=g&matt_device=c&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-BmLgIXkgEM1_1sti60rORDi8wX1HJRXwU3SviW96S3udZQC67xoCM_cQAvD_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-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=g&matt_device=c&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-BmLgIXkgEM1_1sti60rORDi8wX1HJRXwU3SviW96S3udZQC67xoCM_cQAvD_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-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=g&matt_device=c&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-BmLgIXkgEM1_1sti60rORDi8wX1HJRXwU3SviW96S3udZQC67xoCM_cQAvD_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-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=g&matt_device=c&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-BmLgIXkgEM1_1sti60rORDi8wX1HJRXwU3SviW96S3udZQC67xoCM_cQAvD_BwE

(*continued on next page*)

Table 8 *(continued)*

Designator	Name	Number	Cost per unit	Total cost	Source of materials
All already explained in the previous tabs.	RJ45 plugue	6	USD 0.10	USD 0.59	Local store
	Power supply 12 V 50A	1	USD 15.61	USD 15.61	https://produto.mercadolivre.com.br/MLB-1963411876-fonte-chaveada-50a-12v-600w-bivolt-som-cameras-cftv-fita-led-_JM?matt_tool=56291529&matt_word=&matt_source=google&matt_campaign_id=14303413604&matt_ad_group_id=125984287157&matt_match_type=&matt_network=g&matt_device=c&matt_creative=539354956218&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=465715779&matt_product_id=MLB1963411876&matt_product_partition_id=1404886571258&matt_target_id=pla-1404886571258&gclid=CjwKCAiApfeQBhAUEiwA7K_UH1MT0jqnAHikhN2W8ycPvxXSf6l84GPp-HO6I6ngSFceo3UUqcUk2xoC-F0QAvD_BwE
	Maintained Selector Switch two position	1	USD 5.32	USD 5.32	https://produto.mercadolivre.com.br/MLB-2061835068-chave-seletora-metaltex-m20scr3-b-1a-_JM?matt_tool=73118705&matt_word=&matt_source=google&matt_campaign_id=14302215555&matt_ad_group_id=134553706708&matt_match_type=&matt_network=g&matt_device=c&matt_creative=539425529239&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=151764940&matt_product_id=MLB2061835068&matt_product_partition_id=1408932717052&matt_target_id=pla-1408932717052&gclid=CjwKCAiApfeQBhAUEiwA7K_UH1eb_ufsEtX0D7m4WKsAvwbF6THl4VVXdSIzEuUSVU9evdqvQv9rvhoCdw4QAvD_BwE
	Emergency Push Button	1	USD 5.53	USD 5.53	https://produto.mercadolivre.com.br/MLB-897091772-boto-de-emergncia-vermelho-c-trava-1nf-m20akr-r-1b-_JM?matt_tool=71406470&matt_word=&matt_source=google&matt_campaign_id=14302215573&matt_ad_group_id=134553711588&matt_match_type=&matt_network=g&matt_device=c&matt_creative=539425529659&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=379848079&matt_product_id=MLB897091772&matt_product_partition_id=1405369324943&matt_target_id=pla-1405369324943&gclid=CjwKCAiApfeQBhAUEiwA7K_UH-K-zPcvYW_pc56qs9wQHEPmDrBwOIAmS4DLNMwoAUOnTdcvnTrDFxoC1U0QAvD_BwE
	10 A Double Pole circuit Breaker	1	USD 5.57	USD 5.57	https://www.magazineluiza.com.br/botao-de-emergencia-tramontina-trp2-bs542-1nf-base-de-metal/p/gdckecg60d/cj/botp/?&seller_id=lspdigitalcommerce
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).	Adapter coupler RJ45	3	USD 9.10	USD 27.30	https://www.dualshop.com.br/conector-RJ45-ip65-femea-180-p-painel-tipo-c
They connect the two resistor circuits, code M of the extruder system (Fig. 2), to the circuit board.	Silicon wire to high temperature (2.5 mm)	4	USD 0.00	USD 0.00	
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.	K-type thermocouple	3	USD 4.51	USD 13.54	https://produto.mercadolivre.com.br/MLB-1942276404-sensor-termopar-tipo-k-50-400c-eza-tp-01-_JM?matt_tool=56291529&matt_word=&matt_source=google&matt_campaign_id=14303413604&matt_ad_group_id=125984287157&matt_match_type=&matt_network=g&matt_device=c&matt_creative=539354956218&matt_keyword=&matt_ad_position=&matt_ad_type=pla&matt_merchant_id=243788758&matt_product_id=MLB1942276404&matt_product_partition_id=1404886571258&matt_target_id=pla-1404886571258&gclid=CjwKCAiApfeQBhAUEiwA7K_UHxqwVmY5BFAa5xA5YbAsC00JVYnJlyKvZaU55elI9f9jtxoYipWOrBoCiI0QAvD_BwE
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	https://www.extra.com.br/caixa-de-passagem-embutir-cp-20-240x240mm-branca-plastico-pvc-ip-40-tigre/p/1501427530
Case located on the front view of the machine.	Control Case	1	USD 19.52	USD 19.52	https://www.extra.com.br/caixa-de-passagem-embutir-cp-20-240x240mm-branca-plastico-pvc-ip-40-tigre/p/1501427530

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].

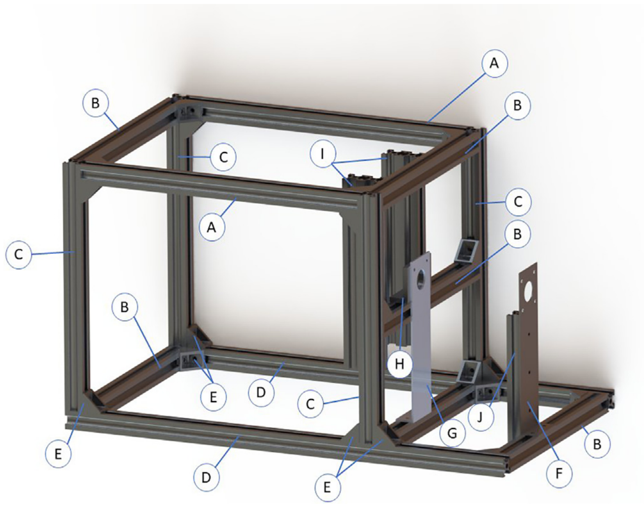

Fig. 1. Structural part of the filament extruder.

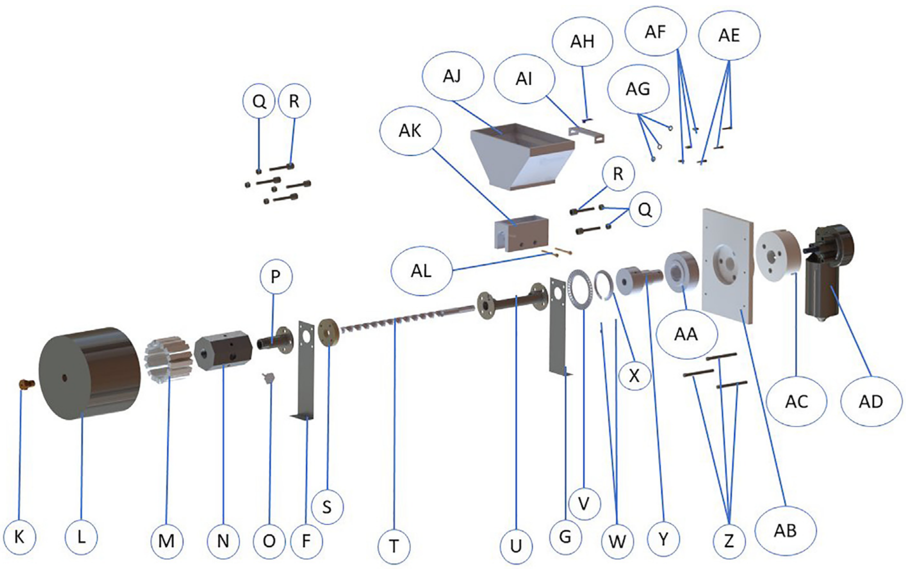

Fig. 2. Extrusion part of the extruder.

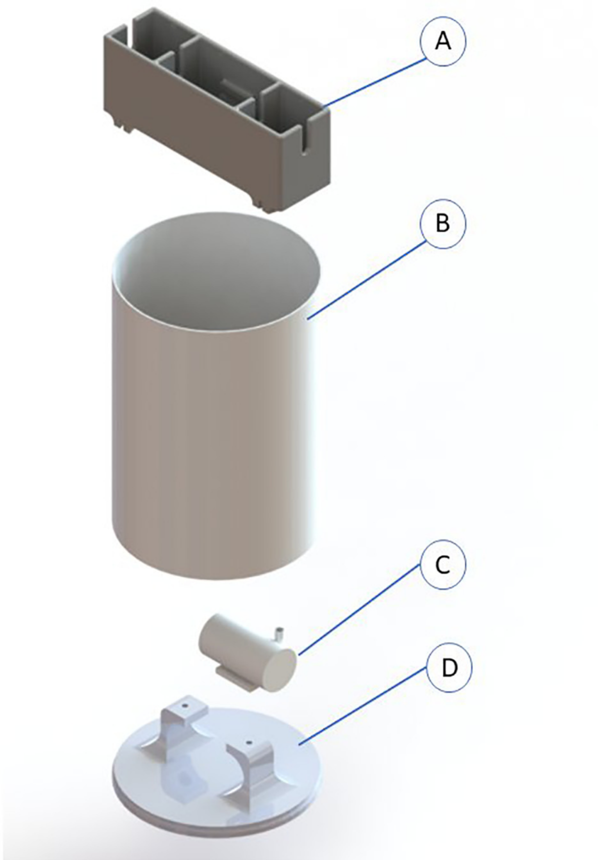

Fig. 3. Cooler system.

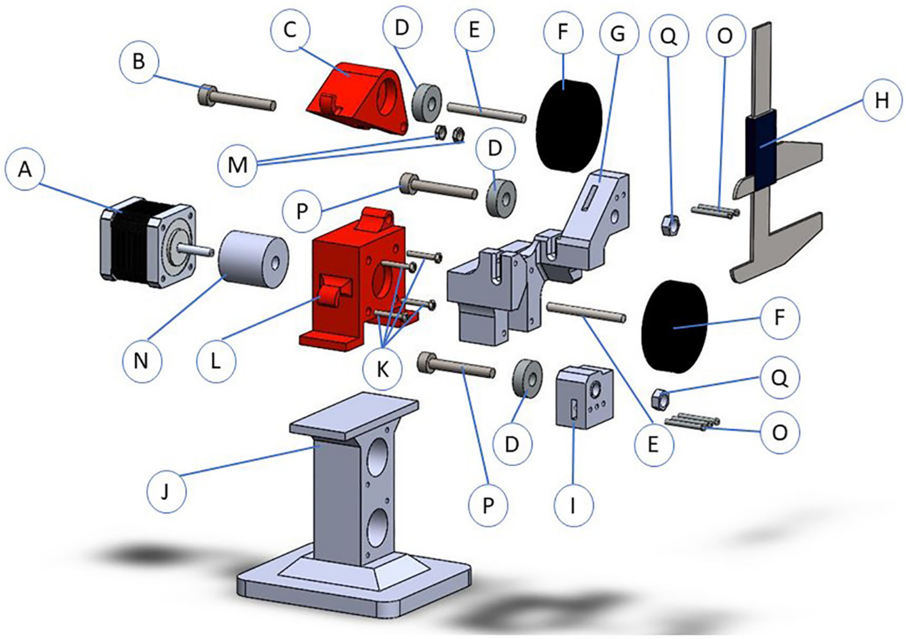

Fig. 4. Puller system and diameter analysis.

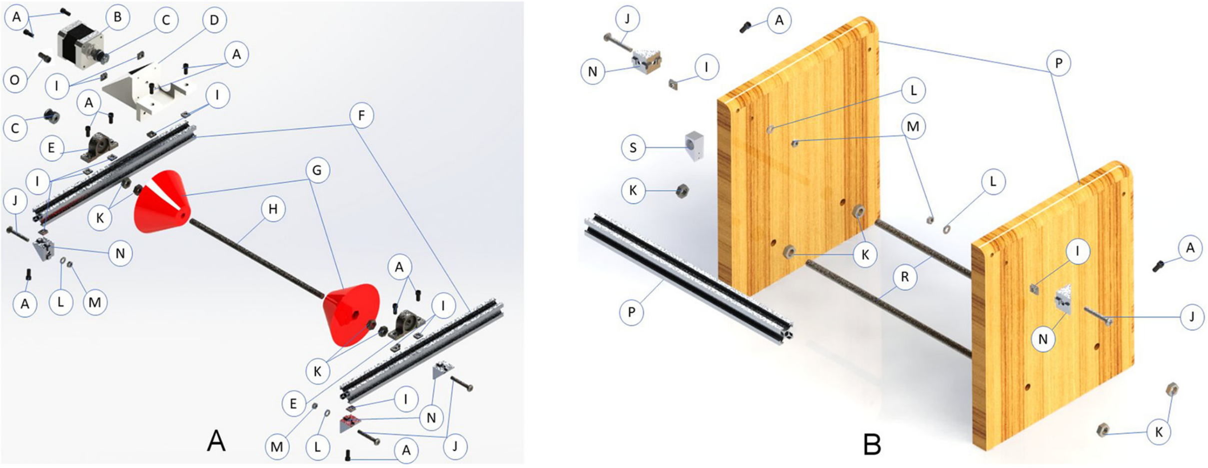

Fig. 5. Spooler system. (A) Mechanical part and (B) structural part.

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-nut s (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 holded 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 holded 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 holded 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 holded 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 holded 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 the tachometer sensor, it goes from 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 recycling 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 U$ 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 16A 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.

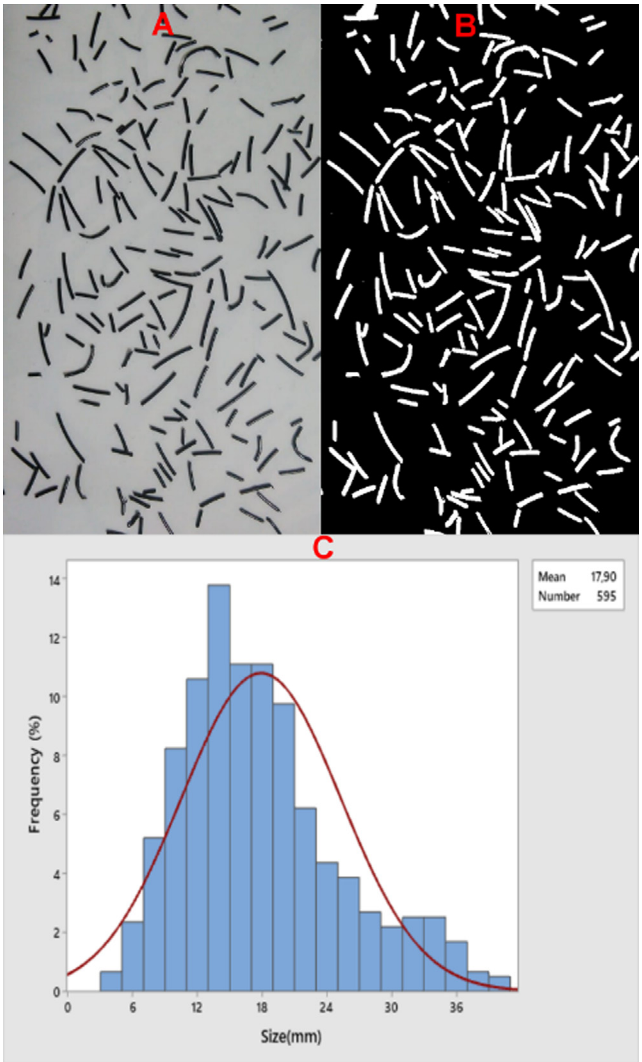

Fig. 6. Particle size analysis. (A) Image of the particulates. (B) Conversion of the particulates to objects in the image and (C) sample size analysis.

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

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-

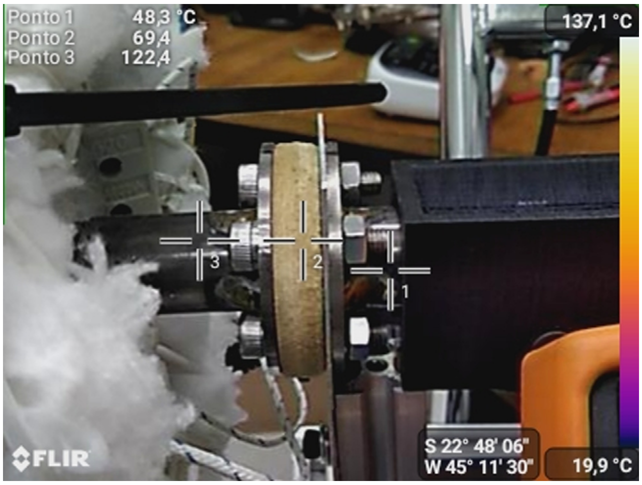

Fig. 7. Thermal analysis extrusion and feeding region.

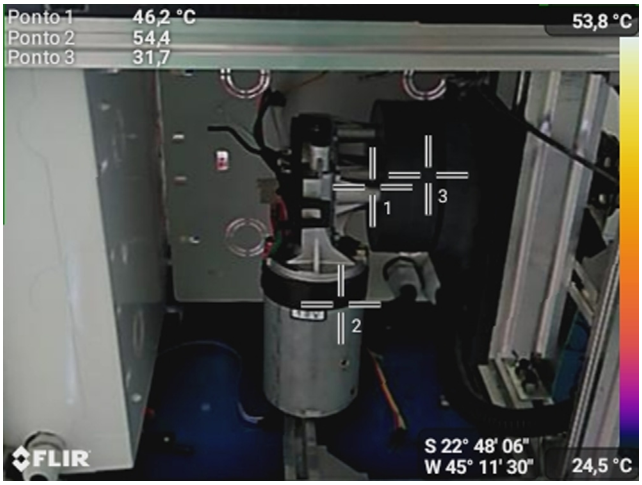

Fig. 8. Thermal analysis of the extrusion motor during the process.

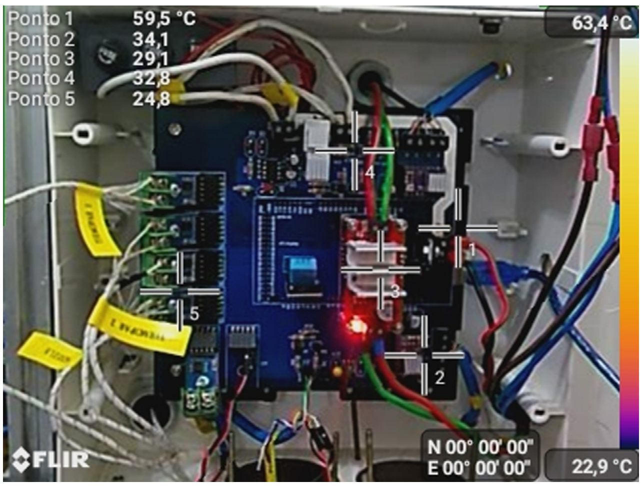

Fig. 9. Thermal analysis of the integrated circuit during the process.

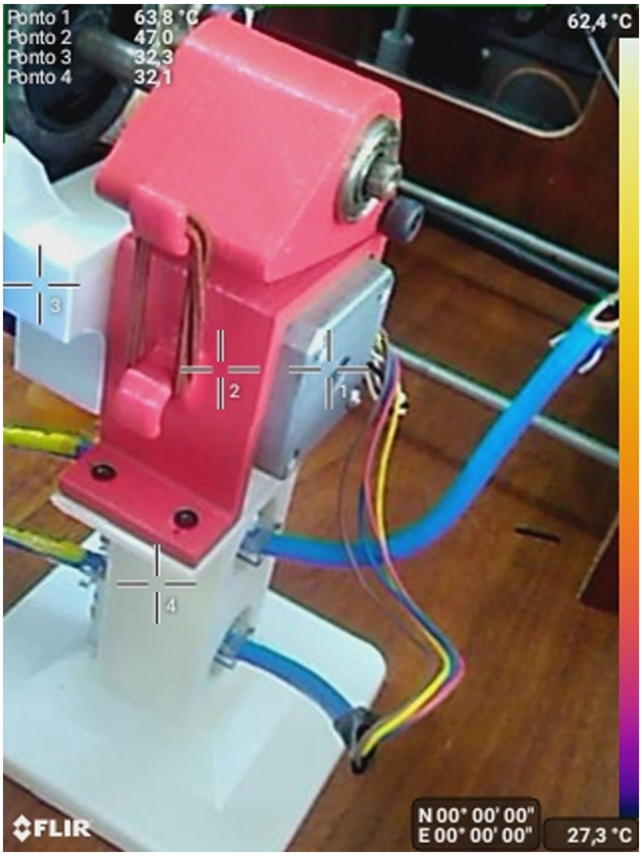

Fig. 10. Thermal analysis of the puller system during the process.

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.

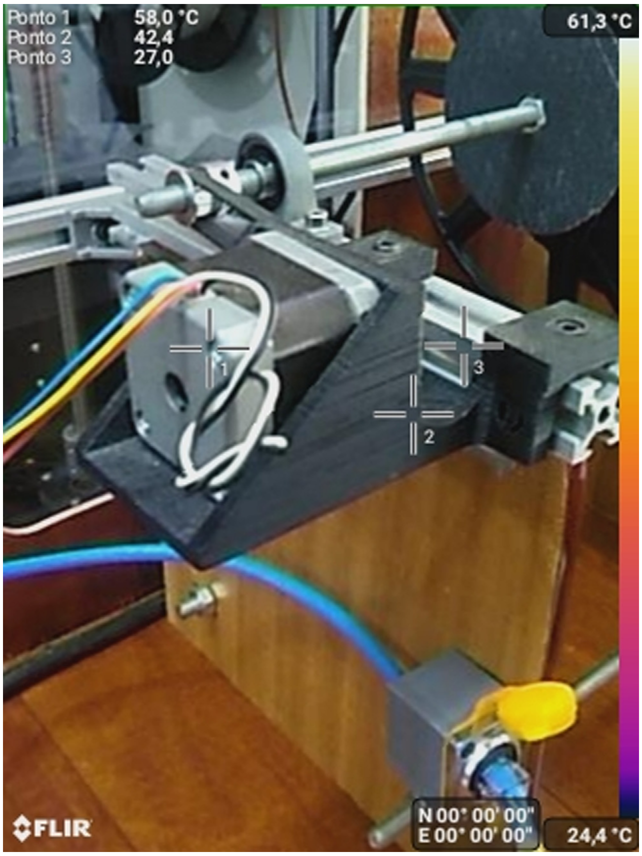

Fig. 11. Thermal analysis of the winder system during the process.

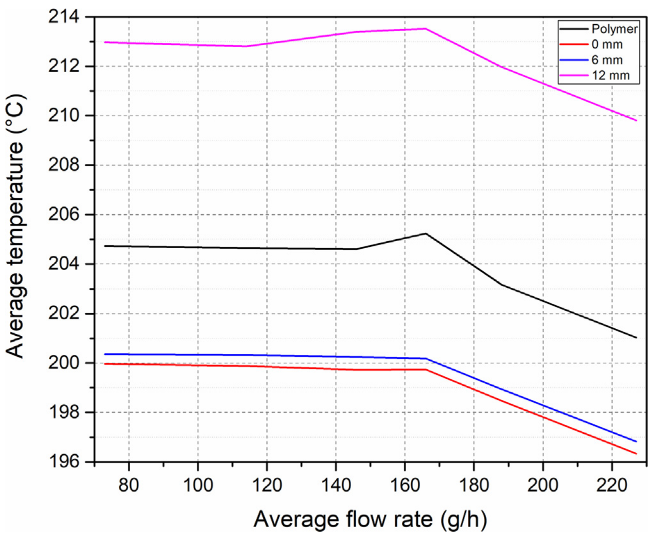

Fig. 12. Graph of temperature averages × different flow rates and in different regions of the nozzle chamber.

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

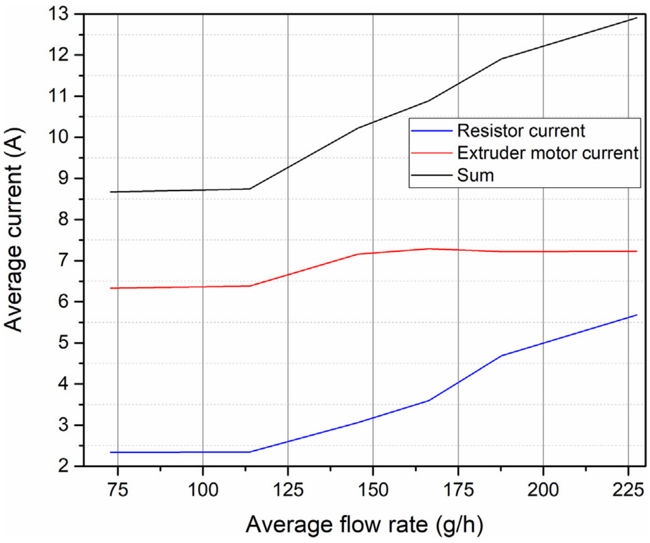

Fig. 13. Analysis of the average current consumed by the resistors and the extruder motor, for different flow rates.

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).

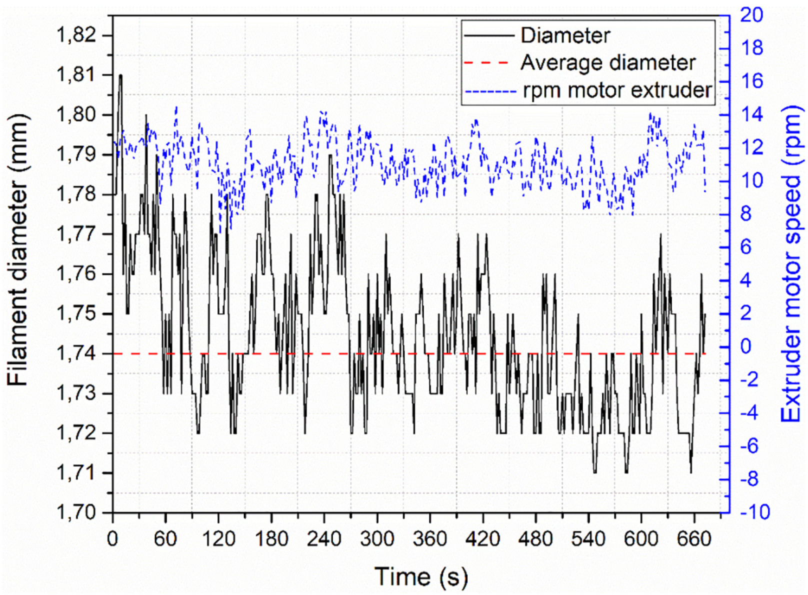

Fig. 14. Variation of filament diameter and extruder motor speed by time.

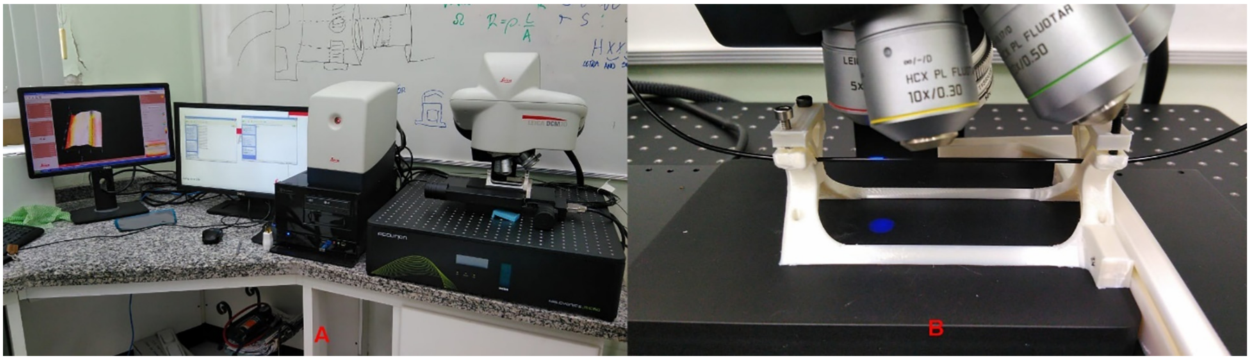

Fig. 15. Roughness analysis of the processed filament. (A) Image of the equipment during analysis and (B) image of the support used to standardize the analysis.

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 cam be observed in Fig. 16, where from the manufacturer (A)

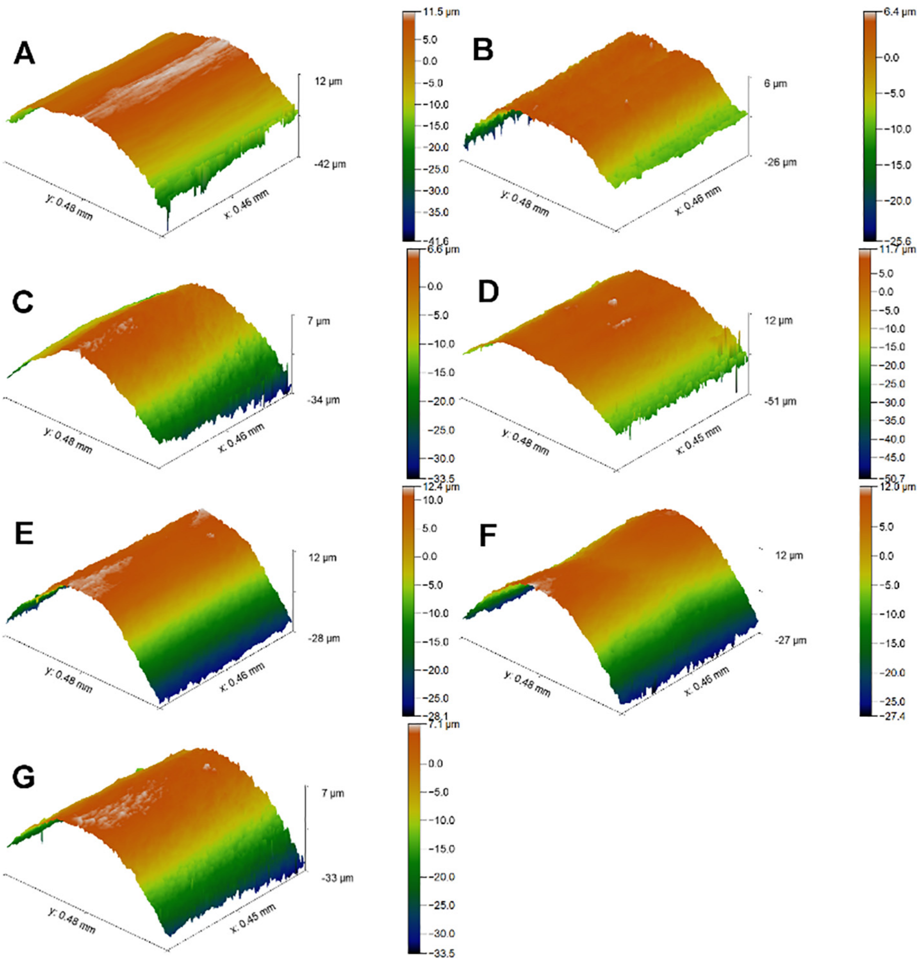

Fig. 16. Surfaces analyzed using confocal technique (A) industrial filament. (B) 73 g/h. (C) 114 g/h. (D) 146 g/h. (E) 166 g/h. (F) 188 g/h and (G) 227 g/h.

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
Influence of flow rate on the filament.

PWM	Average Diameter (mm)	Coefficient of variation (%)	Projected area (μm^2)/Surface area (μm^2) (median)
As received filament			0.93
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.

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