CIRCULAR ECONOMY APPLIED TO PLASTIC WASTE: REDESIGN OF A LOW-COST EXTRUDER

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DOI: https://doi.org/10.6036/10653

1. - INTRODUCTION

According to the World Wide Fund for Nature and the WWF association, plastics represent 95% of the waste in open sea. Furthermore, Spaniards consume 10% of the single-use plastics in Europe, where plastic recycling only reaches 33% of the 27 million tons produced and only 6% of the demand for plastics in this continent comes from recycled plastics. It is estimated that by 2050, humans could be ingesting the equivalent of one credit card of plastic particles a week [1]. Another study from the University of Victoria (Canada) adds that the average person, depending on where they come from, may ingest 126-142 microplastics and inhale 132-170 particles daily [2].

The World Economic Forum has eight proposals to put an end to all the plastic that floods the oceans and the European Union is committed to the circular economy, every year hundreds of ideas try to improve the current conditions. Encouraging this type of habits is a priority and failure to do so condemns the planet. The change of paradigm and the improvement in awareness will allow to establish a methodology that can help future generations develop new projects through recycling. People like Dave Hakkens and Boyan Slat, founders of Precious Plastic and The Ocean Cleanup, respectively, are pioneers in marking the path that society must take to help eliminate waste in the sea, classify plastics and reuse them in different ways, looking for the solution that offers the most benefits [3], [4].

This is how the "MAREA Plastic" project came about at the University of Malaga. A group of students and professors met together with the aim of joining the set of measures to reduce plastic waste, developing such proposals under "the Extended Producer Responsibility" (EPR) statement. Therefore, based on the Precious Plastic movement and with the aim of reducing plastic consumption at the time of production, MAREA Plastic tries to contribute by recycling plastic objects that allow to extend the useful life of the material; by transforming them, they can offer longer time of service to all users. In this sense, waste management is improved by giving society, and in this case the university community, a new source of raw materials and the possibility of creating and designing new objects based on recycling, using the principle of circular economy. By doing so, many containers sent to the yellow bin after use would never become waste, but new objects ready to be used and enabling the material to continue in the productive chain. In order to turn them into new objetcs, a number of machines or devices are needed.

In other words, MAREA Plastic proposes the creation of a portable urban laboratory that allows the university community, and society in general, to get closer to the process of plastic recycling and reuse, being able to experience first-hand the transformation of packaging or plastic waste into new objects for everyday use. As mentioned above, the laboratory requires several machines to operate. They have been manufactured by the MAREA team employing already disposed components, thus applying the principle of circular economy in all its phases. The machines developed are: a shredder, a washing machine, an extruder, an injector and a winder. Each of them fulfils a specific function in the process of converting plastic waste into new objects that makes possible for the raw material to be reintroduced into the production chain.

This document presents the work developed for the construction of the extrusion machine which, by means of a worm screw and the application of heat, is able to transform recycled plastic into filament. The extrusion of this filament can be stored on spools or coils for 3D printing through a winding machine. In addition, through the action of pressing, pushing, melting and molding of the melted plastic chips (previously crushed in the shredder), it is also possible to obtain new objects in the desired shape. Thus, the extruder is one of the fundamental prototypes of the project, as it can provide either coils of recycled plastic filament or new longitudinal products such as a table or stool leg.

In brief, the extruder prototype proposed by MAREA Plastic starts studying and analyzing the basic model of Precious Plastic in order to identify its weak points, especially those related to the machine's safety and operability, since the main goal of the project is that each prototype developed can be operated by anyone and employed as mere tools within the reach of society as a whole, thus raising awareness and directly sensitizing about the countless possibilities offered by plastic waste that is generated every day.

2. - BACKGROUND

Currently, there are models of large plastic extruders on the market that are designed for an industrial environment. These are large machines that can only be operated by trained technical personnel, and therefore cannot be compared with the idea of extruder pursued by the aforementioned project, since industrial-type extruders are difficult to transport due to their high volume and weight.

In addition, they are not machines designed to promote recycling among the public, so their 'opacity' prevents people from seeing what is happening inside, inhibiting the user's participation in the process. Since 'Precious Plastic' was created, many individuals have taken the plunge to build their own recycling devices, either to contribute to the community or to make a profit by selling an end product or the machine itself. Thereby, many individuals and small companies have started to sell the different parts of the extruder machine. On the official website the shop shows different users offering products for its construction or even the complete set.

Other projects similar to Precious Plastic and MAREA Plastic include the 'OneArmy' project which delves into the construction of Precious Plastic's extruder; the 'Crescent Plastics' initiative [5] which extrudes second-hand plastic, more specifically HDPE, to manufacture new industrial products; Similarly, the 'EcoForged' project [6] developed by a Dakota-based non-profit organisation proposes the creation of a plastic extrusion system capable of converting recycled plastic into sustainable building materials; similar to the 'Interreg-TRANSFORM-CE' project [7] in Northwest Europe that aims to transform single-use plastic and create a business model based on the Circular Economy (CE).

2.1 INNOVATION AND NEEDS OF THE NEW DESIGN

As mentioned above, the starting point of the work presented here is the basic model from Precious Plastic whose components and values can be found in the supplementary material (*Tabla SU- 1*). Improvements made on the MAREA Plastic's extruder are grouped according to their specific function in three different categories: structural, mechanical or electronics and will be explained further in this work (

Fig. 1). All improvements were made paying attention to MAREA Plastic main purpose and target user.

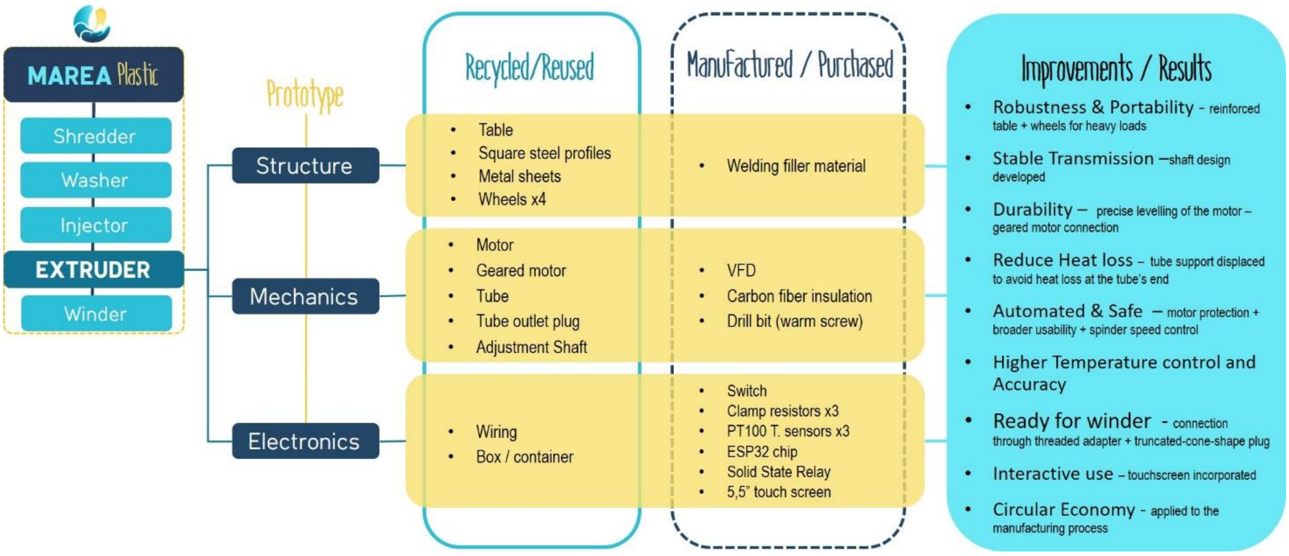

Fig. 1 Chart of the innovations required and/or implemented

3. - METHODS

From the basic model of extruder offered by Precious Plastic (*Fig.SU- 1*), MAREA team intends to provide improvements to this machine especially regarding the prototype's safety and operability in order to achieve the goals previously mentioned.

Therefore, FMEA (Failure Mode and Effects Analysis) methodology has been applied where the quality, reliability and safety of a product or process is improved during the development itself. It analyses where potential failures can occur, their cause and their

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

probability of occurrence. With the FMEA methodology in mind and after studying the previous model, it is possible to focus on the safety of the machine and the health of the user/customer, anticipating the dangers to which the user may be exposed, going one step ahead in case that it is not totally safe, either because of its mechanical or electronic part.

Once the project is finished, the implemented improvements will be shared with the Precious Plastic community, thus, keeping in mind the principles of Design for Manufacture and Assembly, DFMA becomes useful since manufacturing can be eased and a smaller number of parts and lower costs required. In addition, this makes the implementation of these improvements feasible for a larger number of users.

Supporting the circular economy concept involved, during the extruder construction, as many reused materials as possible were used. Besides that, in order to make easier the reuse and recycle of newly designed components in the future, design for the environment (DfE)[8] concept is kept in mind at all times, making them easily disassembled and separable according to their different materials.

4. - PROTOTYPING

The first step consists in searching and providing the required materials to start building the prototypes. As one of the main goals of the project that develops the work presented here is to apply the circular economy philosophy, the use of as many as possible reutilized components during the prototypes construction is constantly sought. In this sense, they have mostly been loaned by different warehouses of the University which receive, almost daily, obsolete material from the different centres and departments. This is the case of the motor, the table that supports the structure, its wheels, the sheet metal of the hopper, the tube, the supports and various electronic components. In this way, it is possible to apply the principle of circular economy whereby these components extend their useful life and remain longer in the production cycle. The only materials that have been procured externally are a Variable Frequency Drive (VFD), the worm screw (actually a drill bit), three thermal resistors and various electronic components.

4.1 STRUCTURE

The extruder main structure consists of a recycled table that has been reinforced at the base also installing four wheels for the sake of transportation since the final purpose of the machine is to be part of a portable lab. Each wheel is able to support up to 150kg/ud, more than enough in this case (

Fig.SU- 2).

For anchoring the geared motor assembly to the table (Fig. 2), a welded structure of two profiles, which is bolted to the table and to the base of the gearbox, is used. Thus, the geared motor assembly remains firmly fixed while can be removed at any time.

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

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Fig. 2. Geared motor assembly for MAREA Plastic extruder with supporting structure (two welded quadrangular section profiles).

Once the gear motor assembly is fixed to the table, supports are designed to bridge the gap between the motor and the gearbox, facilitating the work of the spindle and postponing its deterioration due to the friction of the spindle with the inside of the tube where, due to the increase in temperature, the plastic will melt. The tube is also fitted with fastenings at two points, allowing the heat generated by the heating elements to be isolated and preventing heat from returning to the hopper. With the installation of double nuts and bolts (Fig.SU- 3), the height of the tube support can be adjusted, which will facilitate its future modifications due to the weight. Finally, the upper tube lock and anti-rotation tabs must be added and welded to the previously designed supports (Fig. 3).

Fig. 3. Design of the tube support

Fig. 4 Hopper design. Left - surface alignment on a sheet (Step 1); right - cutting and bending of the sheet (Step 2).

Another fundamental element of the structure is the hopper, which allows the shredded plastic to enter the pipe in a convenient and simple way. This is designed from recycled metal sheets and obtained by cutting, bending and folding (Fig. 4). It is then joined using spot welding.

4.2 MECHANICS

To start up and keep the required movement, electric motors are the essential part. In order to achieve a correct operation of the machine, the prototype initial point of design and construction is established by the torque and force needed to obtain the results required in the project. Once the study of these parameters has been carried out to obtain the initial values, the motor that offers similar characteristics to those is selected among the available motors provided by the University or nearby scrapyards. Besides, any imperfections that may be present are assessed first-hand. Further information about the motor can be found in the suplementary material.

In order to attach all components correctly, different parts had to be designed and manufactured in the School of Engineering workshops. According to PP (*Precious Plastic*), the alignment of the motor and couplings is very important, as any error could lead to subsequent wear. In the elaboration of the general design of the extruder for plastic recycling, the mechanical design is described in detail through drawings and parts, as well as the components belonging to the electronic system, justifying the use of these for the

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

operation and good performance of the machine. Meanwhile, the MAREA Plastic team has developed its own code for the machine control and automation. The aim at this point is to be able to verify and control the temperature and operation of each resistance separately, as different temperature values are required for each resistor depending on the type of plastic employed, as can be seen in Table SU-1 of the supplementary material.

A piece that transmits the movement of the gearbox shaft to the spindle is also needed and designed using, as far as possible, recycled material. A series of requirements are established for this design: the dimensions, the anchoring system by means of threaded tightening screws (Fig. SU-4) in the reducer shaft keyway and the screws for fastening the drill bit that will act as the extruder worm screw. This design starts from a sketch which results in the piece shown in Fig. 5.

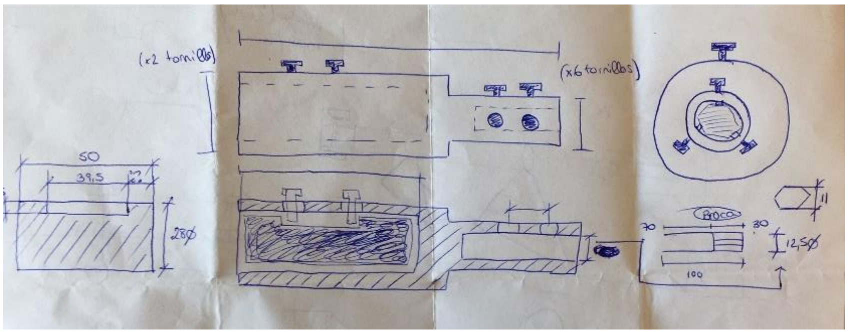

Fig. 5. Left - Sketch of the shaft and spindle anchored part; Right - shaft transmission part made of steel.

On the other hand, in order to extrude a specific diameter of plastic filament, the action of a winder is required. To enable the work that will later be carried out by the winder, a threaded adaptor can be incorporated at the extruder pipe outlet to provide a reduction in diameter at the end of the extrusion process. In addition, to prevent the generation of unwanted plastic burrs, a hollow cylinder with a tapered inner section is installed inside the plug. This will help to compress the plastic at the outlet, leaving a final welded and threaded joint that will facilitate compression. Finally, to ensure thermal insulation and safety of use against possible burns, the pipe must be covered with fibreglass insulation (Fig. SU-5).

4.3 ELECTRONICS

A start/stop button is located between the single-phase socket and the VFD to ensure that there is no room for misinterpretation by the user. The VFD allows to control the output speed of the gearbox shaft and becomes the first element required for the machine's automation.

The installed VFD has a single-phase input and output towards the three-phase motor which makes it easily pluggable to any single-phase socket at hand. However, the internal configuration of the three-phase motor (Fig.SU- 6) needs to be positioned rightfully first, connecting its components in delta-shape instead of star-shape so that it can operate in single-phase mode.

A microprocessor controls the whole machine according to a pre-configuration that covers all elements. In addition, a non-invasive intensity sensor is installed next to the motor, connected to the microprocessor. This is an improvement made by MAREA Plastic that Precious Plastic does not include and becomes of considerable value as it protects the machine in the event of current spikes by reducing or stopping the movement automatically. This also prevents the motor from working beyond its possibilities, thus extending its useful life.

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

In terms of the electronics, the resistors are the only components that remain the same from the PP extruder machine. All other components of the extruder developed by MAREA Plastic are the following:

1) Wiring
2) Switch
3) (x3) Clamp resistors, 275 W/ud
4) (x3) PT100 Temperature sensors
5) (x3) Adafruit MAX 38165 Board
6) ESP32 chip
7) Solid State Relay
8) 5.5" touch screen

The resistors are placed in the extrusion tube, as shown in Fig.SU- 7, and are connected to the power cable and the solid state relay, which, in turn, is connected to the ESP32 chip, responsible for controlling the different processes. Also connected to the board are: the display and the 3 MAX31865 boards (Fig. SU-2). The latter are responsible for amplifying the signal from the PT100 temperature sensors and are attached to the resistors by means of thermal tape; these are used to record the temperature. Once the whole circuit is assembled, it is verified that everything works correctly. Then, the resistor control is programmed. A protoboard is used for the initial assembly, and once all tests have been completed and the circuit is deemed to be good, it is moved to a soldering prototyping board.

An Arduino PID controller library has been adapted to be used with PT100 sensors. This control is governed by 3 constants; K_p, K_i *and* K_d (proportional, integral and derivative, respectively, Tabla 1); these must be adjusted for each system in order to obtain accurate control. A poor choice of constants can result in the system not stabilising accurately enough, not reaching the desired temperature or even going out of control.

Controlador	KP	TI	TD
P	0,5* K_u	∞	0
PI	0,5*K_u	P_u /1,2	0
PID	0,6*K_u	P_u /2	P_u /8

Tabla 1. Controlador PID

For a first approximation and adjustment of these constants, one of the well-known heuristic methods is used, the Ziegler-Nichols (ZN) method [9], which consists of leaving the integral and derivative constants at 0 and gradually increasing the proportional one until an output stable oscillation around the target point is obtained. Thus, the critical gain and period of oscillation are obtained, from where the different constants can be obtained based on the formulae described by ZN [9]. Further discussion on this is reported in the supplementary material.

5. – RESULTS

After assembling all components and different parts of the machine, and completing the preliminary configuration of the electronics, various operating tests were carried out. The first problem encountered as related to a heat loss in the outlet area, causing an accumulation of molten plastic in around the spindle, right where one of the tube supports is located (Fig. 3, Fig.SU- 7 , *Fig.SU- 9*). Although this accumulation does not cause clogging, it is found that heat cannot stay steady around this area. The solution consists in restructuring this specific tube support by moving it from the end of the tube to the central part, bringing it closer to the other existing support so that the structure stays stable but also allows all the temperature of the heating elements to be concentrated at the outlet end.

Secondly, resistors vacuum tests are also carried out, reaching temperatures of up to 400ºC, much higher than those required for the plastics to be worked with according to D. M. Bryce [10]. The accuracy obtained during these tests reaches ±0.5ºC, a higher accuracy than that from the PP original design. PP users and developers report a temperature swing of between 10 and 20ºC, which may vary depending on the electronic components used. In the case of the present work, the above configuration achieves an accuracy of ±0.5ºC with a single resistor in operation, and ±2ºC when all three resistors are in operation.

Tests are also carried out with different types of plastic. In the case of PET, it manages to melt after a few minutes. However, some gases can be seen coming out of the machine. This time, the flakes come together as they melt and manage to be ejected through the exit orifice without any intermediate accumulation once the tube support has been displaced. At this point, if the plug is put back into position, the rotational speed must be reduced with the help of the VFD. Besides, at all times, the temperature must be controlled according to the type of plastic as shown in Table SU-1.

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

6. – CONCLUSIONS

To date, a 100% functional prototype has been obtained. However, it still needs to be improved in some areas to reach the expected performance.

Regarding the original design and considering the improvements that have already been implemented, the following is achieved:

- Taking the circular economy concept one step further, by ensuring that most of components employed come from disposed devices, that is to say, they are recycled and/or reused, thus extending their useful life and minimising their impact on the immediate environment.
- Greater precision in terms of temperature control, as each resistor's temperature can be managed individually. This translates into better control of the plastic consistency at the time of injection and also, greater Temperature accuracy than the original PID controllers from PP.
- Simplifying the communication with the extruder, by implementing the code on an interactive touch screen, which avoids the tedious connection and control from the computer (Fig.SU-4). The "Next Edition" program allow us to add the touch screen to the final design of the extruder. Its functions and visualisations help the machine's operation by non qualified personnel, namely, society in general.
- A safer use by any user profile thanks to the incorporation of protections to avoid burns, such as the aforementioned fibreglass tubes (Fig. SU-5).
- Greater speed and precision when feeding plastic to the machine due to the automation of this process.

Safety is key in MAREA Plastic designs due the main goal of the project being raising awareness and promoting all public interaction with the machines. This is the reason why serious thinking has been given to the user and public environment, as well as to optimising the machine operability, both in terms of production and consumption.

Yet, one of the improvements that remains unfinished is the gas/fume extractor, which is essential for the correct and safe operation in order to avoid possible concentrations and humidification due to condensation of these gases. Moreover, the colour code has not been implemented on the prototype yet.

The work presented here results in a tool that facilitates and enables that people with less or none technical knowledge can operate these kind of machines, thus being able to create a culture of recycling and working with plastics for anyone, especially young students and school children. In addition, MAREA Plastic website will provide open access to all this knowhow so that anyone interested can reproduce it anytime anywhere.

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ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

MATERIAL SUPLEMENTARIO

1* INTRODUCTION

Despite the ban on the single-use plastic production, more and more plastic objects are being produced, and not just biodegradable ones. Only 9% of all plastic produced and consumed worldwide has been recycled, 12% incinerated and the vast majority, 79%, has ended up in landfills or in the environment itself. The sea is the main container where plastic waste ends up being deposited, not only by people but also by the environment action itself: e.g. thousands of waterways, due to rainfall, transport all kinds of waste to the sea. This results in the so-called "plastic soups", that is to say, plastic concentrations on the sea surface of the Atlantic, Pacific and Indian Oceans. These represent only the tip of the iceberg, accounting for 15% of all plastic [11], [12].

This type of waste does not only affect the Mediterranean which already accounts for between 20% and 54% of microplastics in the planet. Plastic makes up 80% of the rubbish in the oceans, a figure that will reach 12 billion tons by 2050. This kills thousands of animals and already threatens 700 species [13].

2* BACKGROUND

There are a wide variety of options for the bulky and heavy industrial version, however, on a small scale, the range of lightweight and portable extruders is not so large. Among them, the "filament maker" from 3Devo is found and marketed from 5.350€ by this Dutch company dedicated to 3D printing since 2016 [14]; the American brand Filabot also shows on its website different versions of extruders such as the EX6 whose price is around $12. 000 [15] or the EX2, its cheapest version which costs around $2750; another of the cheapest options is the Filastruder extruder [16] available from $300; on the Felfil website [17], they also offer open source solutions and sell the necessary accessories and components already pre-configured. All of them have in common that their function fulfils a single objective, to manufacture filament. Meanwhile, the main objective of the prototypes designed within the MAREA Plastic project is to make the user participate and see the inner workings of the machines, involving the user at all times in the converting process in order to educate and raise awareness on sustainability, recycling and circular economy.

In this sense, there are other projects or works that pursue one or the following, either to produce filament cheaply or to raise awareness in society, or both. Some examples of this are: the work of Mosquera et al. [18] that presents a redesign of a low-cost filament 3D printer based on a pellet extruder; other researchers at the Department of Applied Sciences and Technology in Turin, Italy, are using a twin-screw extruder [19] to recycle discarded face masks and reuse them as printing filament; meanwhile, at the Federal University of São Carlos, Brazil, they study how the configuration parameters of a single nozzle extruder, such as the one presented here, influence the manufacturing process and the final result [20]; also worth mentioning is the work of Budiyantoro et al. [21] who developed an extrusion and pultrusion system to produce carbon fibre 'pellets'.

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

Fig.SU- 1. Basic model of Precious Plastic extruder

Components of the basic model from Precious Plastic

- Geared motor assembly.
- Hopper, pipe and screw
- Frame and support.
- Resistors.
- Outlet orifice.
- Electrical and electronic components.

4.1* STRUCTURE

Fig.SU- 2 Welded reinforcement + wheels employed on the recycled table

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

Fig.SU- 3 Sujeción en mesa de los soportes

4.2* MECHANICS

Starting with the calculation and design of the mechanical part, the power of the motor to be reused is 1 CV, equivalent to 0.74 kW, with a frequency of 50 Hz and a rotation speed of 1400 rpm. Initially, the motor is configured to be used at three-phase current, by connecting its wires in a star configuration, so it has a current of 2.1 A and a voltage of 380 V. Given that portability is one of the main characteristics defined as essential in the MAREA prototypes together with the fact that three-phase socket are not available everywhere, a delta connection is finally employed. Hence, a current of 3.5 A, at a voltage of 220 V is achieved. The phase and line voltage are balanced (120º) and are related by *Uf* = *U·L* . The phase current with respect to the line current (Eq. 1) will be maintained as follows:

$$\sqrt{3} \cdot I_f = I_L \qquad \text{(Eq. 1)}$$

The construction and commissioning process takes as its starting point the values used on the Precious Plastic website. The power of the extruder should be 1.5 kW, equivalent to 2 hp, and a rotational speed of between 40 and 140 rpm, i.e. the equivalent torque of 109 N·m. In the information collected on extruders, the required power often varies between 0.5 kW and 1 kW, so the 0.74W of the recycled motor is considered valid. Anyhow, the torque calculation equation (Eq.2) is proposed for both options, seeking to bring the torque as close as possible to the recommendation.

$$\boldsymbol{Par\ Nominal} = \frac{HP * 5252}{rpm\ (out)} \qquad \text{(Eq. 2)}$$

This results in:

- For a 1 hp engine, T_q = 151,557 Lb·Ft,
- For a 2 hp engine, T_q = 303,115 Lb·Ft,

where 1 Lb·ft represents 1,3558 N·m, and *rpm* refers to the output shaft rotational speed which using the gearbox will remain as 35 rpm.

Precious Plastic (PP) states in the instructions for its extruder that a minimum of 109N·m is required to guarantee the correct operation of the extruder. The torque obtained from the Somex Bilbao 1 HP motor (rescued from the university warehouse and reused for the extruder) offers 151.557Lb·ft, equivalent to 205,48N·m, thereby ensuring the minimum set by PP.

Naturally, it is possible to look for another gearbox offering a higher rotational speed, e.g. a gearbox with i=1/20 would result in a speed of 70 rpm. Henceforth, an average value that complies with Precious Plastic's specifications would be obtained, giving a nominal torque of 102.908 N·m. In addition, by adding a VFD, the frequency could be reduced, therefore the speed would be reduced and the torque increased. In other words, this gear unit might not be the ideal. However, it is suitable for the construction of the extruder, as the lower speed will, to some extent, reduce the energy supplied to the resistors, thus reducing their working temperature.

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

Fig.SU- 4 Roscado del eje

Fig.SU- 5 Aislante fibra de vidrio para tubo

Fig.SU- 6 Cableado estrella-triángulo motor

4.3* ELECTRONICS

The Ziegler-Nichols (ZN) method [9] yields constants close to the final values. However, further adjustment is still required. For this, the output temperature must be analysed with regard to the target temperature. Deviations in each constant from its optimum value generate characteristic behaviour. For example, a stable temperature but below the target temperature, is indicative of too low K_p, while very large oscillations around the target temperature may be caused by larger K_i value than needed, and if an anomalous and unstable behaviour of the signal is observed as it approaches the setpoint, something

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

known as "porpoising" occurs. This implies that a very large K_d has been used. All these effects can overlap, this is the reason why it is important to know how to distinguish them in order to, by means of an iterative process, manually increase or decrease the different constants until the correct ones are obtained, which are certainly ascertained by performing tests on the machine and the closer study values on the tables.

Fig.SU- 7. Resistors on MAREA Plastic's extruder

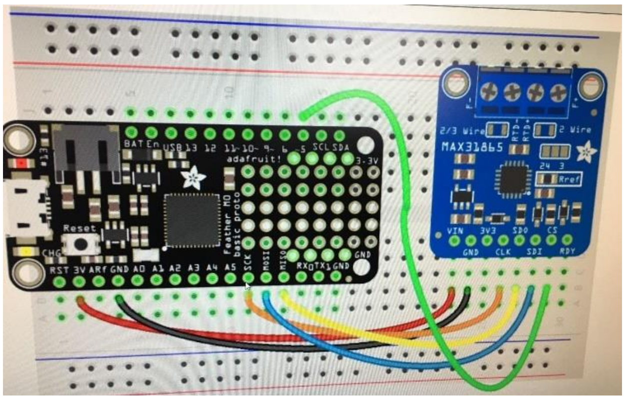

Fig.SU- 8. Conjunto ESP32 y Adafruit MAX 38165

Fig.SU- 9. Izq. - Concentración de plástico fundido en el husillo; Dcha - Escamas fundidas de PET

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

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Fig.SU- 10. Pantalla Nextion NX8048T070

Fig.SU- 11. Funcionamiento Extrusora MAREA Plastic

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

Fig.SU- 12 Izq. Extrusora básica de Precious Plastic; Dcha. Extrusora en desarrollo de MAREA Plastic

Tabla SU- 1 *Values according to the experience of the basic model. Pros and cons of the basic model.*

Potencia Nominal	Par Nominal	Velocidad de salida
1,5 kW = 2 CV	109 Nm	± 40 a 140 rpm

Pros	Cons
Light and small	Low processing charge
Possibility to extrude different sizes	Slow extrusion
Relatively cheap	High maintenance
Portable	

Tabla SU- 2. *Características según tipo de plástico*

Polímero	**Índice de consistencia**	**Coeficiente de ley de potencia**	**Rango de Temperatura (ºC)**
PP	7,5 x 10^3	0,38	200
PLA	1,7 x 10^3	0,39	180
HDPE	2,0 x 10^4	0,41	180
LDPE	6,0 x 10^3	0,39	160
PC	6,0 x 10^2	0,98	300

Tabla SU- 3. Kp, Ki, Kd calculado para extrusora

Controlador	**KP**	**TI**	**TD**	**T (periodo)**	
K_p	K_i	K_d	Tª MÍN/MÁX	P_u(periodo)	Valor medio
10,5	0:00:38	0:00:10	112,60 ºC	0:01:12	
			120,80ºC	0:01:16	0:01:16
				0:01:21	
6,6	0:00:50	0:00:12	111,69ºC	0:01:37	
			124,70ºC	0:01:46	0:01:40

ISSN: 0012-7361 eISSN: 1989-1490 / DYNA Vol.87, n.1 DOI: https://doi.org/10.6036/10653

				0:01:37	
5	0:00:36	0:00:09	112,5ºC	0:01:10	
			124,04ºC	0:01:16	0:00:13
				0:01:12	

5* RESULTS

All improvements made will be published on the web in open source, in order to contribute to the community by offering the possibility for anyone to reproduce it, as Precious Plastic does. This includes the developed code for the electronic control of the machine together with images and alternatives to some specific pieces that can be harder to obtain. The main purpose is to contribute establishing a research community that will allow all those who have doubts or suggestions to easily access a huge amount of instructions and help to complete or improve these tools.

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ACKNOWLEDGEMENT

The work presented here has been carried out within the MAREA Plastic Project, funded by the *II Plan Propio* of the SMART CAMPUS vice-rectorate from the University of Malaga.

The authors would also like to thank the INGEGRAF association.