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# Design and Manufacture of a Smart Desktop Rotational Moulding Machine

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## Abstract.

Motion control capabilities within rotational moulding machines have remained relatively unchanged for the past 60 years. However, driven by Industry 4.0, this is showing signs of change and the potential of rotational moulding machines which can provide more agile movements and rotations is beginning to be realized.

This paper therefore proposes a novel desktop sized rotational moulding machine that can provide the user with more flexibility and control over mould rotation by incorporating a smart control system. This lifts the current restriction with conventional machines where the rotational speeds of the two motors remain constant throughout a cycle. The benefit of having improved control over the mould rotation is that recent research has shown that by varying the rotational speeds throughout the cycle can improve product quality and process efficiency.

**Keywords.** Rotational Moulding, Motion Control, Machinery

## 1. Introduction

Rotational moulding is a polymer forming process that uses heat and rotation (usually about two axes) to produce hollow stress free parts. Both the rotational path and rotational speed of the mould highly influence the product quality and process efficiency [1], [2]. Recent research has found through simulation modelling that the optimization of rotational moulding processes through motion control parameters can be achieved by varying these parameters during the moulding cycle [3].

However, the state of the art in terms of rotational moulding machines prohibit these novel motion control schemes being used and tested due to limitations within current machine control systems to provide a more flexible and agile means of mould rotation. Current bi-axial machines currently provide rotation about two at constant speeds, i.e. they lack the ability to vary rotational speed and/or speed ratios during a cycle.

Furthermore, Industry 4.0 is driving a change in the rotational moulding industry. This has led to the emergence of the RoboMould [4] rotational moulding machine which improves the rotational capabilities of the process by providing multi-axis rotation beyond the two axis provided by conventional machines. A restriction with RoboMould is that only one of its axis (end effector) provides continuous rotation. All other potential axes of rotation are restricted to a maximum of  $\pm 360^\circ$ .

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The conventional machinery and motion control capabilities are limited. Recent work in motion control shows the potential to improve product quality and reduce waste by using an agile and flexible motion control system. This level of motion control is currently not available, therefore the focus of this study is to design and manufacture a desktop sized rotational moulding machine that can be controlled by a smart programmable motion control system.

## 2. Design

### 2.1. Specifications

Table 1 defines the key specifications for a smart desktop rotational moulding machine.

Table 1 Product Design Specifications

Factor	Specification	Reason
Axis of rotation	2 (Infinite rotation)	Conventional machine biaxial
Size	<300x300x300mm	Ease of mobility
Programmable motors	Controlled through Arduino control system and motor shields.	To achieve new novel rotational paths.
Maximum temperature	>200 °C	To ensure powder will melt.
Weight	<5 kg	Ease of mobility
Payload size	<100mm diameter	Ease of mobility
Payload mass	<1 kg	Testing requirement
Safety	User protection from all hot and moving parts.	Prevention of injuries
Cost	<£600	Project budget

### 2.2. Mechanical Design

Several concepts were proposed and assessed against the machine specifications using a concept selection matrix. The chosen mechanical design of the machine is shown in Figure 1. The two axes of rotation are provided by two motors which are situated at the base of the machine to reduce the payload mass. Through the use of bevel gears, a hollow external shaft and a solid internal shaft, one motor will provide rotation to provide motion about two axes, while the second motor provides independent control of the secondary axis of rotation. A key advantage with this design was the accessibility provided to the mould, making it easy to load the mould to the machine and demould the products. Furthermore, the base design allows for easy attachment to the end of a robotic arm to provide at least two axes of infinite rotation.

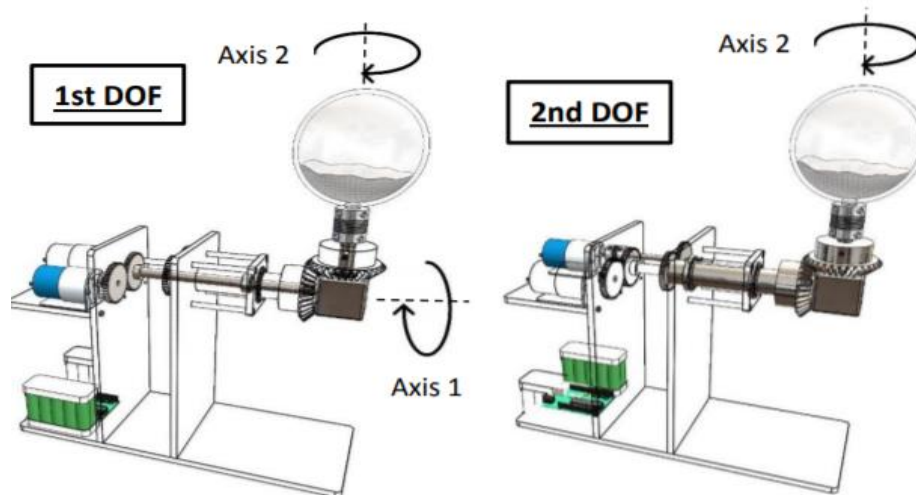


Figure 1 Rotational Moulding Machine Mechanical Design [5]

### 2.3. Motors

Direct current (DC), stepper and servo motors were evaluated for their suitability for this project, with the key factors being cost and their ability to provide the user with accurate agile control over the mould rotation. Although the cheapest option, it was found that DC motors (brushed and brushless) were challenging to control and provide a constant angular velocity due to the changing torque provided from the rotating mould.

Stepper and servo motors provide more accurate, repeatable rotations through the use of pulsed command signals and feedback loops. Two bi-polar stepper motors with a  $1.8^\circ$  step size were chosen as they provided the required level of accuracy and control needed for this project and were also less expensive than servo motors.

### 2.4. Motion Control System

An Arduino UNO development board was chosen as this has been a proven method for electronic projects involving stepper motors. These boards can be programmed on a computer using Python, MatLab or Arduino IDE coding language. The code can then be uploaded onto the board via its USB port. This system gives the user increased control over the direction and speed of the mould rotation. A limitation of the Arduino Uno board is its five volts' capacity which is insufficient for the required motors. To accommodate this, we used two Adafruit motor shields to provide a higher voltage of up to 12 Volts to the motors.

### 2.5. Heating System

The conventional heating method within rotational moulding is through a convection oven. However, this is an energy inefficient method and electrical heating methods has been proven to be up to 13 times more efficient [6]. Therefore, an electrical heating

system was chosen for energy saving and also financial reasons. Several electrical heating options were investigated including quartz heating elements, silicon heating mats, Kapton film heaters and electromagnetic induction heating. These options were assessed on weight, cost, ability to heat to 200°C, ability to provide uniform heat transfer to mould and flexibility to wrap around and heat complex mould geometries.

Although not a specification for the project Kapton film heaters had an advantage in that it is a translucent film meaning that if a glass mould was used the user could visual the motion and position of the powder up until the point of it sticking to the mould wall. This option can be very useful for research and development purposes where a range of process variables can be analyzed and studied. However, due to financial restrictions this method was not investigated further for this project. The silicon heating mat was chosen as it was one of the least expensive options investigated, is lightweight, very flexible and can be produced to suit any profile. For a spherical shaped mould, two heating mats were manufactured with the profile needed to cover this shape, which were mathematically described by Demaine et al. [7] and shown in Figure 2.

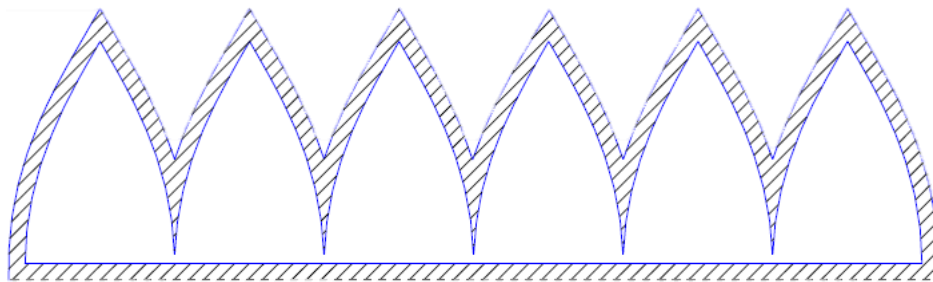


Figure 2 Profile for wrapping hemisphere

Supplying electrical power to the heating mats was a challenging task due to the bi-axial rotation of the mould. This was completed through the use of two Adafruit slip-rings which were channeled through the bevel gear box and enabled electrical power to be transferred from a stationary power supply to the mould which can be rotated infinitely about two axes.

## 2.6. Moulds

Conventional rotational moulding moulds are manufactured largely from aluminum or steel. For this project however, it was decided to utilize borosilicate glass material to allow for better visualization of the powder flow during the mould rotation, enabling powder flow research and improving the users understanding of the process. For a spherical mould, the bottom halves of two round bottom flasks were removed using a lathe and a diamond cutter. A metal flange was then attached to the open end of each of the two hemisphere using high temperature silicon. The metal flanges allowed for a secure attachment of the two mould halves (Figure 3).

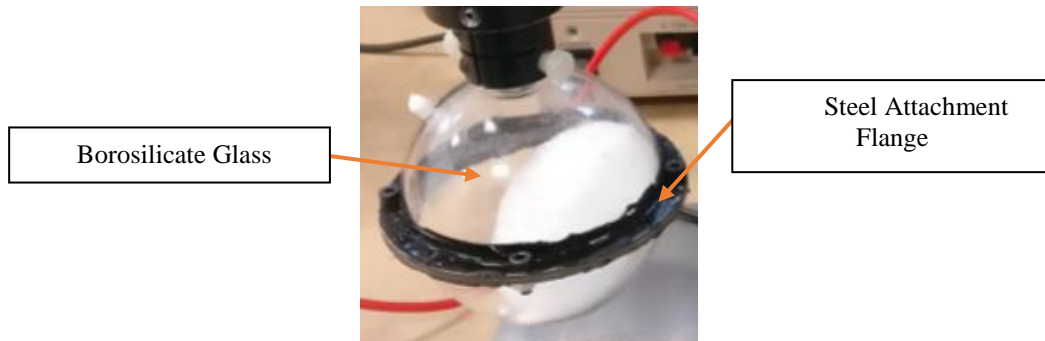


Figure 3 Glass Sphere Mould

### 2.7. Temperature Monitoring

The most commonly used method of tracking the key stages of the rotational moulding process is to monitor the internal air temperature inside the mould. For a desktop scale machine, a small, lightweight and wireless data logging option was required. A suitable data logger was purchased and mounted to the outside of the mould and fitted with a K-type thermocouple which measures the internal air temperature of the mould. This data logger provides the user with real-time progress via Wi-Fi connectivity. This allows the user to track the progress without the need of being beside the machine and also alarms can be setup to notify the user of key points in a cycle (For example, when to begin the cooling process).

### 2.8. Safety

The key safety concerns with this machine lies with the heat from the exposed heating mats around the mould and the rotation of the mould and gears (although only slow rotational speeds are required). To compensate for these risks, it was decided to enclose all the rotating gears and area travelled through by the rotating mould within two transparent Perspex guards (See Figure 4). A magnetic reed switch was installed between the machine base and Perspex guard to ensure the safety guard is securely fitted. The reed switch was wired to ensure no power can be supplied to the motors or the heating system unless the guard is securely in place.

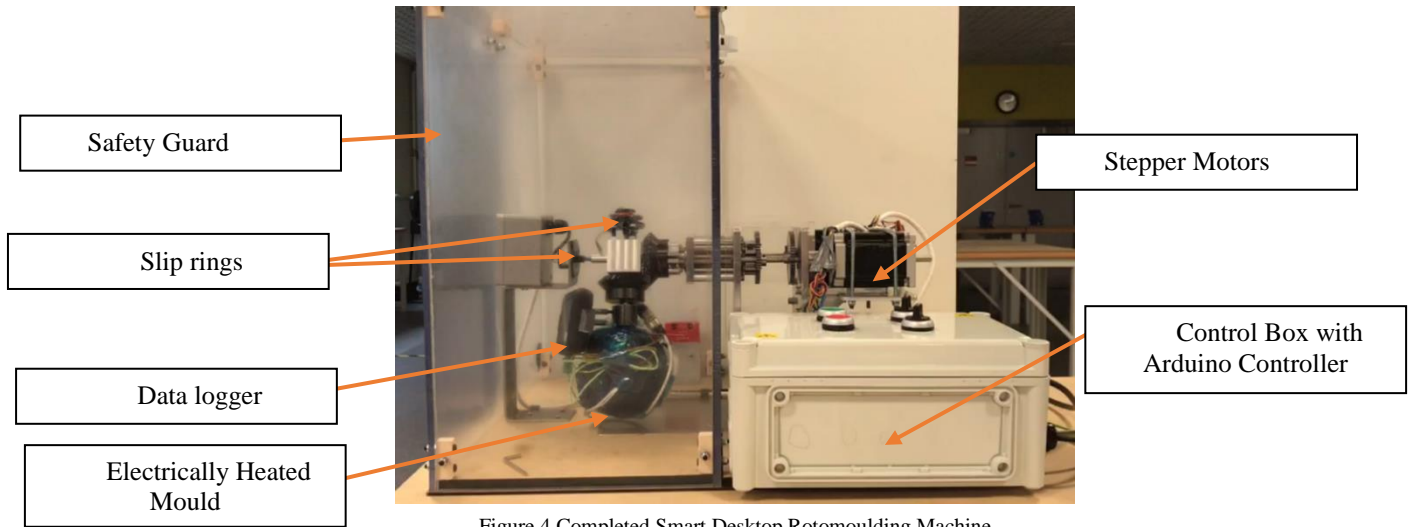


Figure 4 Completed Smart Desktop Rotomoulding Machine

### 3. Testing

#### 3.1. Conformance to product specification

The produced machine was tested against the product specifications in Table 1. The products met all specifications except for the machine size which measured 320x160x360mm. Further refinements can be made in the next iteration to ensure the size of the machine can be kept within the specified range.

#### 3.2. Functionality Testing

The machine was successfully used to produce hollow plastic shapes and allow for testing of a range of rotational speeds and rotational paths (which includes paths not achievable on conventional machines) to be completed. Figure 5 show a samples and a sample air temperature trace which allows the key stages of the rotational moulding process to be identified and monitored.



Figure 5 (a)Rotationally Moulded Polyethylene Sphere Sample (b)Sample Internal Air Temperature Trace

#### 4. Conclusion

A fully functional smart desktop rotational moulding machine was designed, manufactured and tested. This machine replicates the rotational moulding capabilities of conventional moulding machines but also enhances the motion control capabilities. This allows for more agile rotation of the mould to be studied and investigated. Through using this machine, it is hoped that motion control optimization in rotational moulding can be achieved by lifting the current rotational restrictions.

Other features of this machine that are unique to rotational moulding that were successfully utilized are the use of flexible silicon heating mats (which can heat complex mould geometries), glass moulds (which provide better visualization of the process) and the use of a Wi-Fi connected temperature data logger (which enables the user to track a moulding cycle remotely).

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