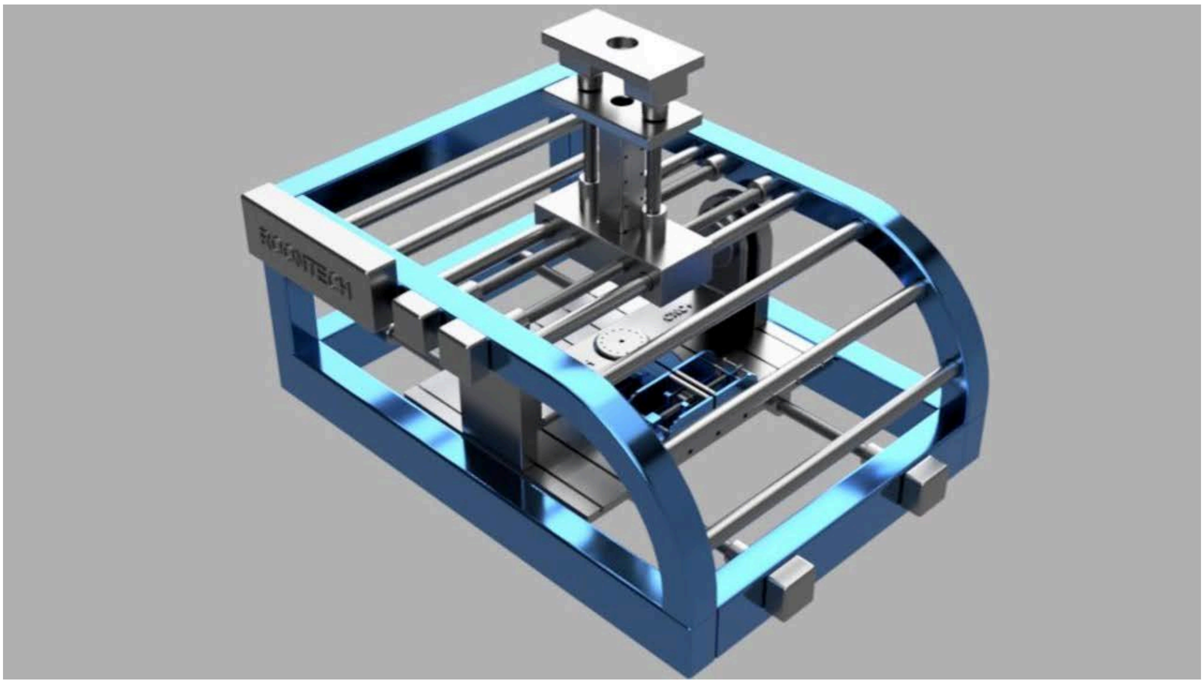
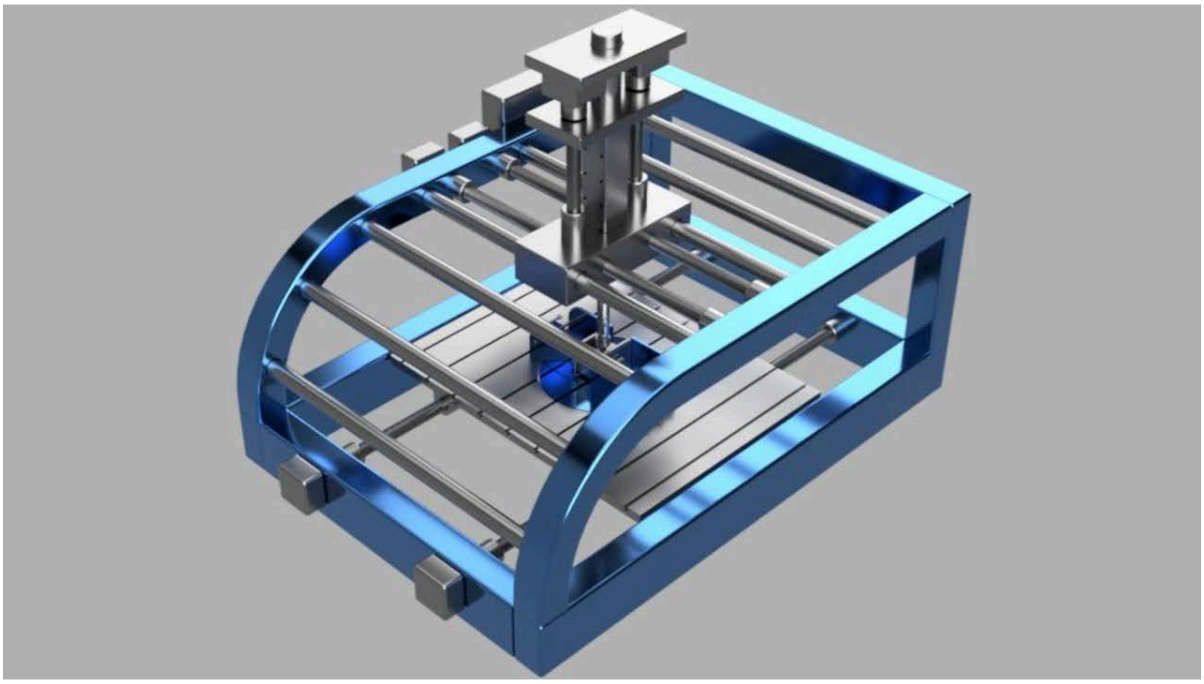
Computer Numerical Control+

CNC+

By ROONTECH





Research Document

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www.roontech.co.uk/cnc

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Summary

This report is based on the design and build of a unique Computer Numerical Control (CNC) device. The device is called the CNC+ and is aimed at Start-Up companies, hobbyists and professionals who are looking for an all-in-one affordable micro manufacturing solution. The idea is to remove expensive external time consuming manufacturing costs for those on budgets that cannot compete with the wealth of big companies. The CNC+ will be designed for space saving, making it ideal for garages or sheds. The unique combination of multiple tooling requirements not only makes it an efficient solution but also sustainable due to the reduced number of components. Utilising the basic CNC XYZ Axis as the foundation to build upon and the following tools/machines are to be implemented to form an all in one solution.

- 5 Axis End Mill
- 5 Axis Router
- 3D Printer
- Laser Cutter
- Vertical Lathe
- Injection Mould

The concentration at this point is to develop a unique End Mill and Injection Mould Machine. This Research and Development document is predominantly maths based and calculations will suggest if my Design is viable or not. It also contains attributes such as logical reason, necessity, gantt chart planning, costs, budgets, energy, efficiency, sustainability, off-the-shelf components. Unique components, program controls, CAE, CAM, CAD, hand calculations, optimisation and procurement whilst the core focus of this document is based upon permissible Axis loads and controls.

Figure 1, Axis Machine

Introduction

The CNC+, this document or report if you prefer, will take you through every aspect and every decision I make towards bringing the CNC+ to life on a budget of £3000.

My Style

This Report is not going to be conducted in an industry style robotic rhetoric, it will be done with simplicity to help those outside of the Engineering world understand how you take an idea and make that a reality. Often you will find the use of "I", "you" and "We", depending on what I am referring to. In hindsight of simplicity, please be warned that mathematical calculations for some are challenging but I will break them down with an explanation.

Designers Perspective

The CNC+ has the little man in mind, I am that "Little Man", I have big ideas, a little skill and dare I say talent, however, this is countered by lack of funds, mentors, investment and connections. It seems I have to do everything the hard way. I need a little help but there is not a person that can help me. It is a machine, the CNC+, I believe this machine will not only help me produce Moulds, Components, Prototypes and Products, it will also improve my Skill-set regarding manufacture whilst saving £1000's with limited risks. Failure is one thing, but when it comes with a hefty price tag to boot, life changing events can occur. This device is not just a fancy toy, this device helps reduce pressures and time constraints, it's the all in one solution many of us need to progress with our big tangible ideas. The only requirement is that you are committed and willing to learn.

Methodology

I will take you through the method I believe is best, to start with the basics such as the reason for existence and build upon that ultimately creating what is known as a Research Document. I will use my creativity as the driving force, ADHD for the hyperfocus and learnt skills including both Technical Mechanical Engineering Design and hands-on Electrical Installation approaches. The combination of these attributes allows me with a proven history to complete a project of this magnitude without external influence.

Ambition

To create the CNC+ to the vision I see in my mind, to use it to its maximum ability and deliver prototypes and products which I can take to shows, investors and those of interest. Hopefully this approach will enable me to advance my Start-Up company which is based on unique, sustainable and efficient designs, processes, inventions and innovations. All of which are available to view via www.roontech.co.uk.

About CNC

Computer Numerical Control is a manufacturing method that automates the control and movement of tools precisely. It operates by pre-programmed software which is embedded within the machines. The programming language for CNC is known as G-code and M-code which are metric based. G-code controls the movement and function of a machine and M-code controls the operation of external movements, for example, turning on and off specific functions such as a spindle or water coolant. You will often hear CNC associated with abbreviations CAD and CAM, these refer to Computer Aided Design and Computer Aided Manufacture. CAD is the interface, a programmable language that talks to CAM and tells it what to do and how to do it. CAM is the Machine itself and CNC is the overall process. There are many types of CNC, the 7 most common are listed below.

- CNC Milling
- CNC Lathe
- CNC Water Jet
- CNC Plasma Cutting
- CNC Laser Cutting
- CNC Drilling
- CNC 3D Printer

Manufacturers

Generally these machines are large, robust and separate, therefore you may need a number or variety of them to complete projects on mass scale. This becomes very expensive, thus, you will often find only medium to large manufacturing companies house them in numbers.

Home Use

Generally speaking the most common types of CNC for home use are the 3D Printer and Milling variants, there is no issue with strength regarding a 3D printer but there is when Milling. Due to demand and cost many of these Milling machines have been designed smaller to suit hobbyists and small businesses. However, in making them affordable a compromise in strength has arisen and whilst they perform well cutting woods and plastics they do not perform well when cutting metals.

Problem Solving

My aim is to combine multiple tooling requirements using the robustness of bigger machines whilst incorporating a space saving technique at an affordable price for individuals. Specifically aimed at those who work from small premises such as sheds and garages like me.

Initial CAD Design

To begin the initial design I need to implement the main features that separate my CNC+ from any other, and what effects this has on an overall design intent. The two dictating features are as follows.

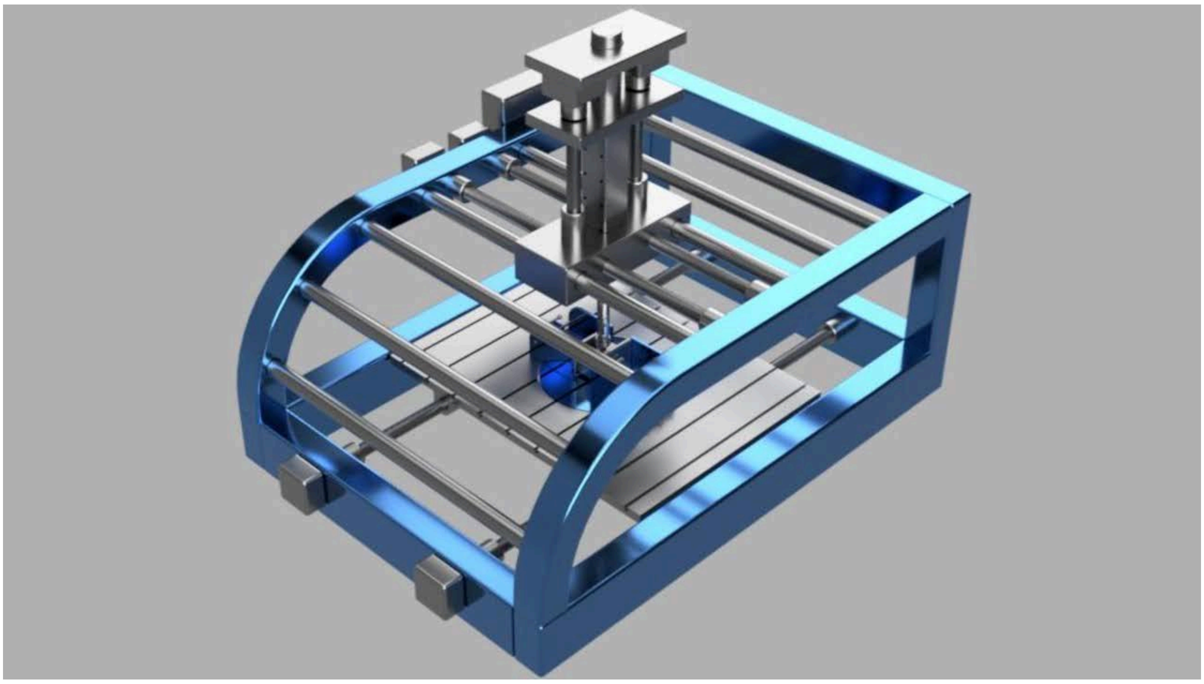


Figure 2, Injection Mould Variant

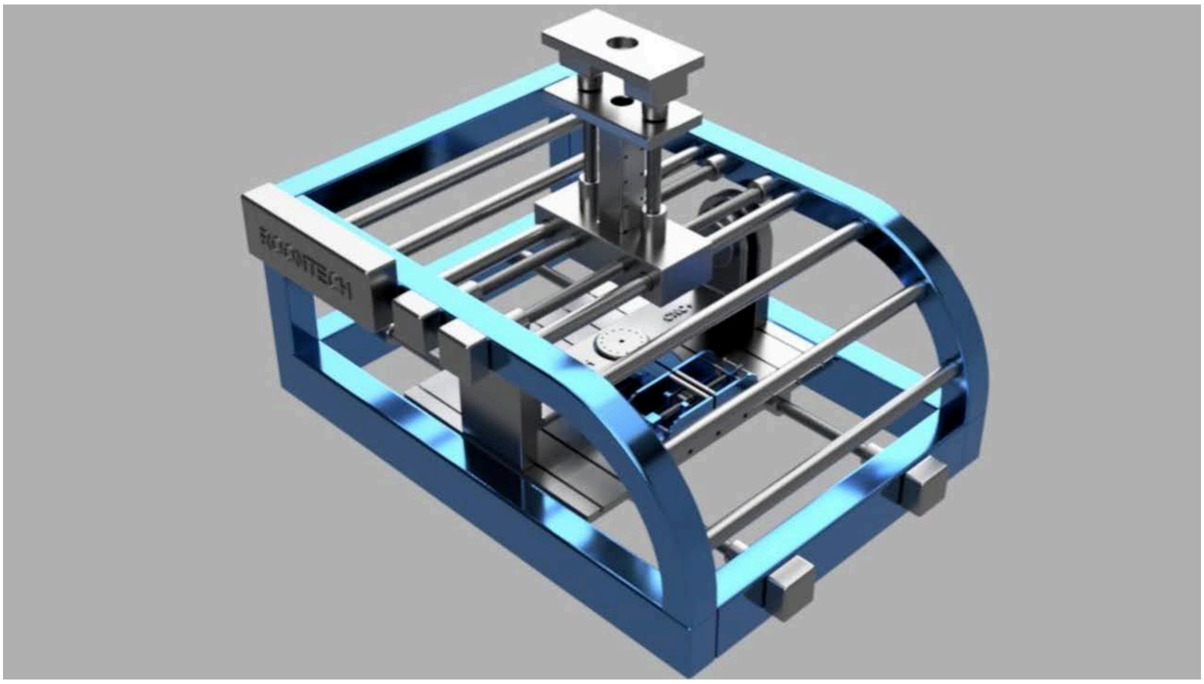


Figure 3, CNC Mill Variant

Design

These two features cannot be compromised in any way, otherwise the machine is not as versatile in solving the problem that I know to be a huge issue for those on tight budgets. The initial CAD design is just a quick conceptual vision that includes multiple tooling requirements. This simplistic design of both variants is however the basic foundation to which Research and Development (R&D) takes place. R&D dictates parameters, calculations, design, optomisation, order of assembly and the finalised prototype.

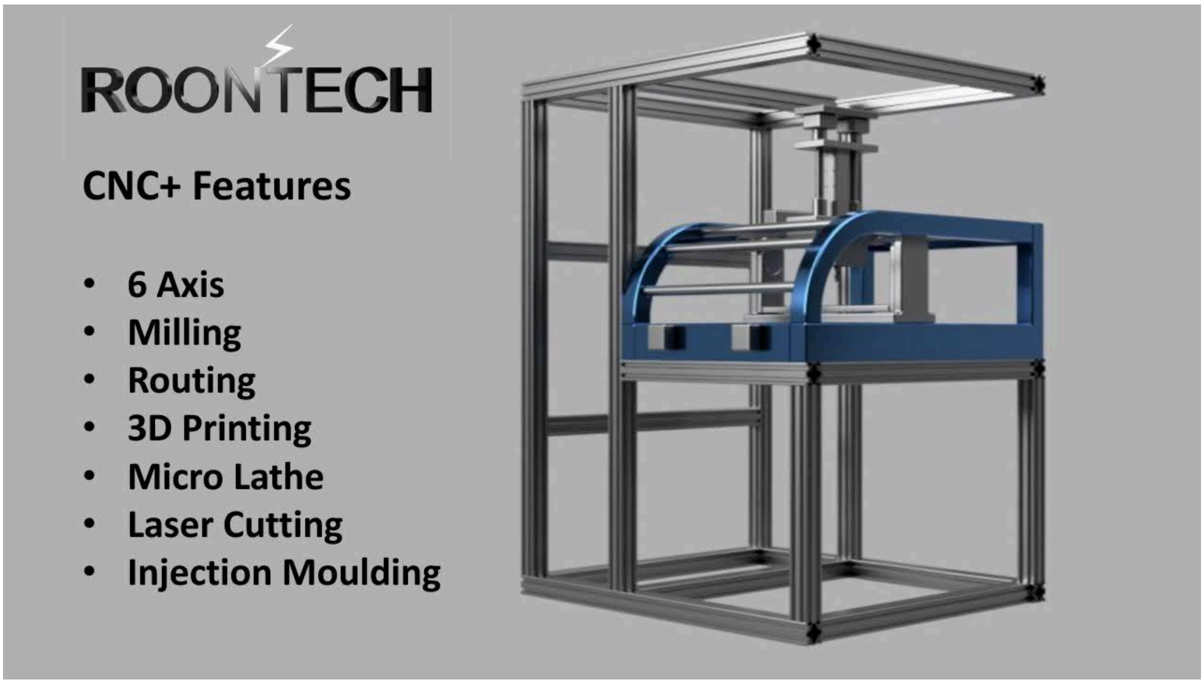
Gantt Chart

This is not set in stone but helps to organise a plan of attack, it is a simple way of keeping a timelined track of the process. It keeps you moving and hitting the targets on time, time is valuable and procrastination is not an option. I believe within 6 months a fully functioning prototype will be ready to showcase.

Plan of Attack

Table 1, Gantt Chart

2023/24	October	November	December	January	February	March
R&D	🟥	🟥	🟥	🟥	🟥	🟥
Design	🟨	🟨	🟨	🟨		
Procurement		🟪	🟪	🟪		
Assembly					🟩	🟩
Testing					🟧	🟧
Conclusion						🟪



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CNC+ Features

- 6 Axis
- Milling
- Routing
- 3D Printing
- Micro Lathe
- Laser Cutting
- Injection Moulding

Figure 4, Machines Potential Features

Research & Development

The R&D section is the most detailed part of this document, it will ultimately dictate the outcome. Thorough research leads to a better design and product, the attributes are listed below.

- Parameters
- Specification
- Calculations
- Components

Parameters

One of the main influences of this design is the Parameters, a robust rigid, compact design intended for home use is desirable. Looking online at the cost of components I have concluded that the dimension of the CNC+ will be approximately 1000mm in width and 1600mm in length. This is big enough to complete a variety of projects, it is not too small, or big, it's just right. The benefit of operating within the dimensional parameter is that many components are available in this size without being bespokely designed and manufactured. The height cannot be negotiated at this point, however, it will definitely not be as tall as it is in length.

Cost

I have a £3000 budget, all parts must be under this parameter, this will be a challenge but I believe it to be feasible.

Lead & Ball Screws

To begin we need to know and understand the main components that are involved in making the CNC+. The main components are Lead and Ball Screws. They become expensive when length and diameter are increased. Initially I was looking at two Screws per Axis. However, an issue arose where two motors would operate at the same time using the Mach3; 5 Axis PCB. The Issue is that no matter the program, 2 motors will not run at the same speed, one will always lag. Due to a tolerance of just +/- 0.1mm the accuracy of motors would cause the Aluminium block that guides the tool to position to twist. To counter, two smaller Screws could be used with just one motor driving them using a gear system to split the Load. But this then becomes expensive. So the alternative is to use 1 Screw on each Axis using 32mm Ball Screws for the X,Y and Z Axis.

Ball Screw

Ball Screws are desirable for smooth frictionless motion which is great for use on the X and Y Axis. However there is an issue with Ball Screws on a Z Axis. This issue is Back Driving due to reduced friction. This potentially could cause a problem with the Z Axis tool positioning dropping due to weight. However, weight has to be significant and this will be investigated.

Lead Screw

The Lead Screw is desirable on the Z Axis due to the design removing Back Driving. The downside of a Lead Screw is that it has increased friction. The increased friction is not a factor on the Z Axis in fact it is welcomed, but it is an issue on the X and Y.

Ball Screw Assembly

Each Axis has a select amount of components associated.

Table 2, X Axis

Axis	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6
X	Block	Spindle	Flange	Motor	Clamp	Rail

Table 3, Y Axis

Axis	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6
Y	Tool Bed	Motor	Flange	Rail	4th Axis	5th Axis

Table 4, Z Axis

Axis	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6
Z	Block	Spindle	Flange	Motor	Clamp	Rail

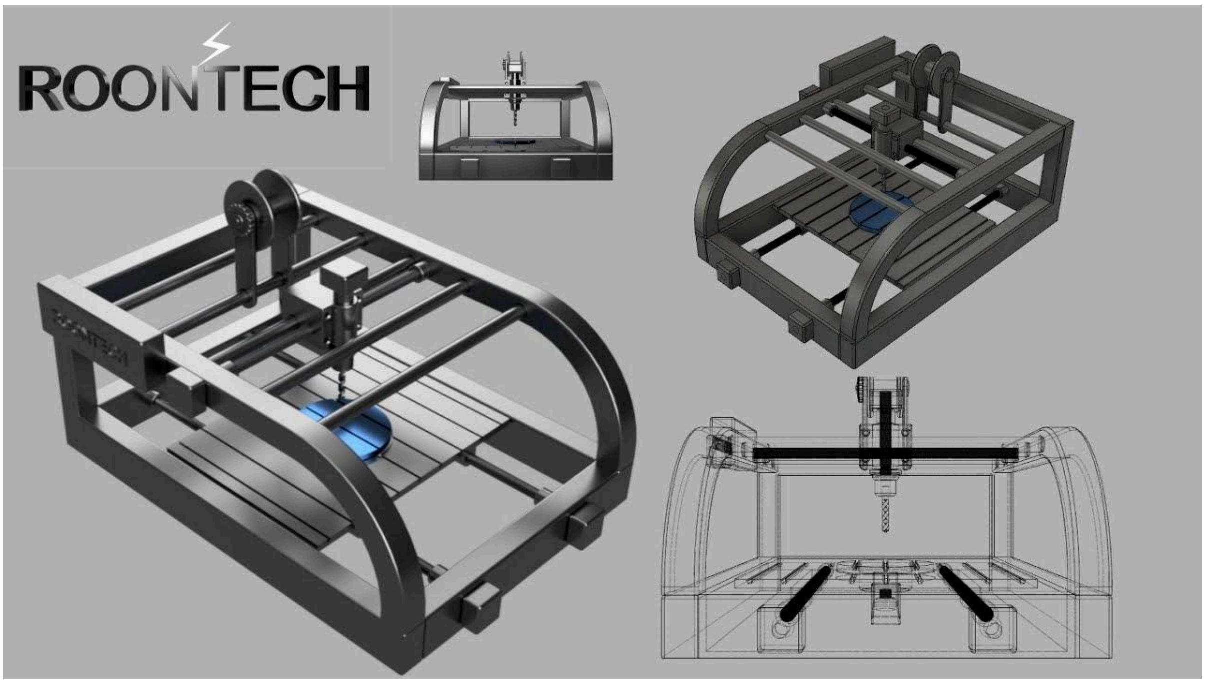

Figure 5, Potential Aesthetics

Specification

Below I have selected components based on parameters, strength, rigidity, cost, necessity and regulation.

Ball Screw

The 32mm Ball Screw is more than capable of providing strength and rigidity regarding the CNC Mill Variant (CMV). However, it comes under scrutiny when the Injection Mould Variant (IMV) is applied. Back Driving may be an issue.

Ball Screw Specification

Table 5, Ball screw

Axis	Type	Quantity	Guide Length	Diameter	Pitch	Cost
X	DFU03205	1	1000mm	32mm	5mm	£138
Y	DFU03205	1	1500mm	32mm	5mm	£150
Z	DFU03205	1	300mm	32mm	5mm	£70

Ball Screw Bearing

These Bearings offer support and frictionless operation regarding the Ball Screws, they are to be sealed and press fitted.

Ball Screw Bearing Specification

Table 6, Ball Screw Bearing

Axis	Type	Quantity	Dimension	Bore	Code	Cost
X	Sealed	2	58 x 32 x 13mm	32mm	60/32-2RS	£20
Y	Sealed	2	58 x 32 x 13mm	32mm	60/32-2RS	£20
Z	Sealed	1	58 x 32 x 13mm	32mm	60/32-2RS	£10

Ball Screw Rail Bearing

Linear Ball Screw Rail Bearings are positioned inside of the sliding block, they hug the Rails allowing for a frictionless transit. One at each end of the Sliding Block, these are press fitted into position.

Ball Screw Rail Bearing Specification

Table 7, Ball Screw Rail Bearing

Axis	Type	Quantity	Dimension	Bore	Code	Cost
X	Closed	2	35 x 25 x 40mm	25mm	5012	£30
Y	Closed	2	35 x 25 x 40mm	25mm	5012	£30

Single Flange Nut

To connect an Aluminium Sliding Block and Base Plate regarding the X and Y Axis The Ball Screws will use 2 x Single Flange Nuts on each end. This ensures unwanted movement and helps with accurate positioning and rigidity due to being preloaded against each other. The Single Flange Nuts are the only components in contact with a Ball Screw. For the Z Axis, a Single Flange Nut is preferred due to limited travel and they often come with the Ball Screw so the cost is neglected.

Single Flange Nut Specification

Table 8, Single Flange Nut

Axis	Type	Dimension	Quantity	Diameter	Standard	Cost
X	SFU03205	40 x 50mm	2	32mm	C7	NA
Y	SFU03205	40 x 50mm	2	32mm	C7	NA
Z	SFU03205	40 x 50mm	1	32mm	C7	NA

Linear Rails

Rails help guide the tools into position, they come in different shapes and sizes. For this CNC’s X Y Axis they have a 25mm diameter, for the Z Axis they have a 15mm diameter but there are 4 of them, these will use Self-Lubricating Brass Bushings with a 15mm bore and an OD of 20mm. Linear Rails remove any Loading over the Screws, they are also acting supports that stop the Sliding Block from turning. These will either be screwed directly into the CNC+ Frame or be positioned using clamps either externally or internally, they also help increase friction which limits Back Drive.

Linear Rails Specification

Table 9, Linear Rails

Axis	Type	Length	Diameter	Quantity	Cost
X	Stainless	1000mm	25mm	2	£100
Y	Stainless	1500mm	25mm	2	£140
Z	Stainless	300mm	15mm	4	£40

Linear Rail Bushings

The 15mm Rails will use Bushings to aid a controlled frictional transverse.

Linear Rail Bushings Specification

Table 10, Linear Rail Bushings

Axis	Type	Length	OD	ID	Quantity	Cost
Z	Brass	20mm	20mm	15mm	4	£10

Spindle Supports

The Supporting frame marries the Sliding Block to the Spindle and Ball Screw, it is broken down into 4 pieces and each are to be machined from Aluminum 6061 20mm thick plates.

Spindle Supports Specification

Table 11, Supporting Frame

Axis	Type	Dimension	Weight	Quantity	Cost
Large	6061	300 x 100 x 20	1.6kg	1	£30
Top	6061	80 x 100 x 20	0.3kg	1	£10
Middle	6061	80 x 100 x 20	0.4kg	1	£10
Bottom	6061	80 x 100 x 20	0.4kg	1	£10

Sliding Block

This is the component that couples the X and Z Axis components, it needs to be big enough so the X and Z Axis Screw and Rails are spaced and operate correctly. Aluminium 6061 has been selected due to being light, strong and anticorrosive. The Sliding Block will be brought as a solid and machined to the design specification using an external CNC hobbyist or manufacturer.

Sliding Block Specification

Table 12, Aluminium Block

Component	Type	Dimension (mm)	Weight	BS EN	Cost
Sliding Block	6061	150 x 100 x 50	1.3kg	755-2:2008	£100

Spindle Clamp

This component keeps the Spindle in place, 3 x 10mm screw holes secure the Spindle, perfect positioning is essential for accurate Milling. This clamp design is also bespoke and will be brought as a solid block to which it will be machined to suit the design. The bore of the clamp is 65mm, and 70mm in height. Potentially it will be the marraging component for the Injection Moulders Ram.

Clamp Specification

Table 13, Spindle Clamp

Component	Type	Dimension (mm)	Weight	BS EN	Cost
Clamp	6061	150 x 100 x 70	2.3 kg	755-2:2008	£30

Spindle

An Air Cooled Spindle will be used to Mill with initially, however, different spindles will be included and updated further down the line.

Spindle Specification

Table 14, Spindle

Component	Type	Dimension (mm)	Weight	Power	Cost
Spindle	Air Cooled	65 x 200	2.5 Kg	1.5KW	£300

Bed

The Bed is what the Workpieces are bolted or clamped to, the bed needs to be big enough to accommodate the X Axis Ball Screw Length. The Bed rides the Y Axis Ball Screw and Rails that travel forwards and backwards.

Bed Specification

Table 15, Bed

Component	Type	Dimension (mm)	Weight	BS EN	Cost
Bed	6061	750 x 750 x 5	8kg	755-2:2008	£100

Bed Clamp Rail

The Bed Clamp Rails connect the Bed to the Rails and Ball Screw. Two types are required, one to fit the Ball Screw and one for the Linear Rails.

Bed Clamp Rail Specification

Table 16, Bed Clamp Rail

Component	Type	Dimension (mm)	Bore	Quantity	Cost
Linear Rail	6061	50 x 100	32mm	2	£20
Ball Screw	6061	50 x 100	35mm	2	£20

Stepper Motors

Stepper Motors will produce the required thrust to move all tooling and components regarding the CNC+. All Axis Motors use Variable Frequency Drives (VFD) and are included in the cost.

Stepper Motors Specification

Table 17, Stepper Motors

Axis	Type	Amps	Quantity	Dimension (mm)	Weight	Torque	Cost
XYZ	34	6	3	86 x 86 x 150	5 Kg	12Nm	£240

Traversing Mass

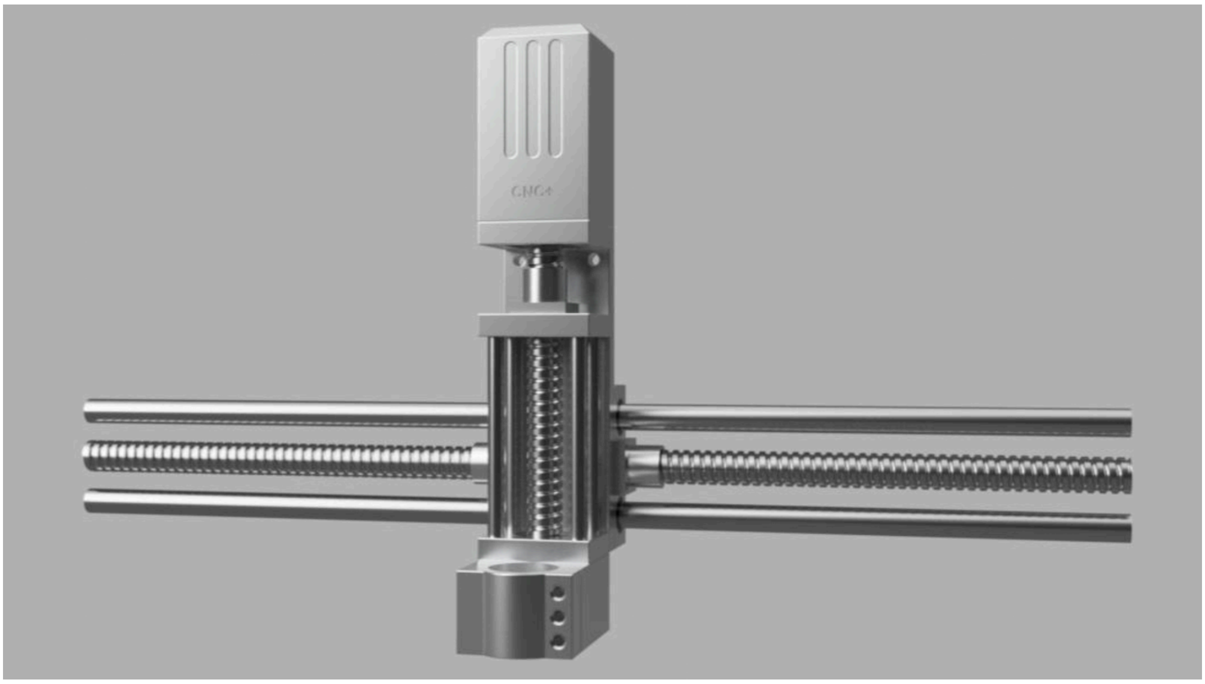

Figure 6, X & Z Axis Transversing Mass

Z Axis Weight

Table 18, Z Axis Weight

Component	Material	Weight (kg)
Ball Screw	Stainless Steel	1.7kg
Ball Screw Flange Nut	Stainless Steel	0.2kg
Spindle Support Rails	Stainless Steel	1.3kg
Top Support	Aluminium 6061	0.3kg
Middle Support	Aluminium 6061	0.4kg
Bottom Support	Aluminium 6061	0.4kg
Support Plate Long	Aluminium 6061	1.6kg
Ball Screw Bearing	Stainless Steel	0.2kg
Spindle Clamp	Aluminium 6061	2.3kg
Spindle	Aluminium 6061	2.5kg
Motor	Mix	5kg
		Total = 15.9kg

Y Axis Weight

Table 19, Y Axis Weight

Component	Material	Weight (kg)
Ball Screw	Stainless Steel	8kg
Ball Screw Rail 1	Stainless Steel	6kg
Ball Screw Rail 2	Stainless Steel	6kg
Ball Screw Flange Nut 1	Stainless Steel	0.2kg
Ball Screw Flange Nut 2	Stainless Steel	0.2kg
Rail Bearing 1	Stainless Steel	0.2kg
Rail Bearing 2	Stainless Steel	0.2kg
Bed	Aluminium 6061	8kg
Linear Rail Clamps	Aluminium 6061	0.6
Ball Screw Clamps	Aluminium 6061	0.6
		Total = 30kg

X Axis Weight

Table 20, X Axis Weight

Component	Material	Weight (kg)
Ball Screw	Stainless Steel	5.7kg
Ball Screw Rail 1	Stainless Steel	4kg
Ball Screw Rail 2	Stainless Steel	4kg
Ball Screw Flange Nut 1	Stainless Steel	0.2kg
Ball Screw Flange Nut 2	Stainless Steel	0.2kg
Rail Bearing 1	Stainless Steel	0.2kg
Rail Bearing 2	Stainless Steel	0.2kg
Sliding Block	Aluminium 6061	1.3kg
		Total = 15.8kg

Z Axis

Motor Force Requirement = **6.7kg**, the only components moved up and down via the Ball Screw is the Spindle, Spindle Clamp, Spindle Support Rails, Middle Support and Flange Nut. However, whilst this is an acceptable Torque requirement regarding the CNC Mill variant, this Motor has to produce enough force to overcome the Injection Moulding variant.

Y Axis

Motor Force Requirement = **10kg unladen**, for a Motor Force Requirement including a work piece and 4th/5th Axis including clamps = **20kg Laden**. Similar to the X Axis the Ball Screw and Rails are fixed to the frame and therefore neglected.

X Axis

Motor Force Requirement = (15.8 - 5.7 - 4 - 4) + 15.9 = **18kg**. The X Axis Motor, Rails and Ball Screw are fixed to the frame and therefore not a carried weight, it does carry the Sliding Block and Rail Bearings plus every component on the Z Axis.

Motor Solution

The XYZ Axis Stepper Motors will need to produce enough Torque to overcome the associated masses. A friction force also needs to be declared for Flange Nuts and Rail bearings.

Motor Torque Calculation

A NEMA 34 Stepper Motor will provide more than enough Torque at a 12 Nm across all Axis with a current rating of 6 Amps. The Pitch and Lead of the Ball Screws are both 5mm meaning at every revolution the load will transverse by 5mm. Torque drops off quickly, to produce the full 12 Nm of Torque the Ball Screw could only have a 20mm Diameter. For A Ball Screw with a 32mm Diameter the calculations below show the Axial Torque and Available Torque to work with.

Calculations

$X\ Axis\ Transit\ Mass\ =\ 18\ kg$

$Y\ Axis\ Transit\ Mass\ =\ 20\ kg$

$Z\ Axis\ Transit\ Mass\ =\ 6.7kg$

$Nema\ 34\ (RPM)\ =\ 3000$

$Nema\ 34\ (m/s)\ =\ 0.5,\ 1$

$Nema\ 34\ (Nm)\ =\ 12$

$Nema\ 34\ (A)\ =\ 6$

$Ball\ Screw\ Diameter/Radius\ =\ 32mm/16mm$

$Ball\ Screw\ Pitch/Lead\ =\ 5mm$

$1\ kg\ Force\ Metre\ =\ 9.81\ Nm$

$12 \div 9.81\ =\ 122.3\ kg/cm$

X Axis Motor Torque

$18\ x\ 9.81\ =\ 176.6\ N$

$0.005\ x\ 176.6\ =\ 0.9\ Nm$

$0.9 \div (2\ x\ \pi)\ =\ 0.14\ Nm$

$Motor\ Torque\ =\ 0.14\ Nm$

X Axis Available Torque

$Available\ Torque\ =\ (12\ -\ 0.14) \div 0.016\ =\ 741\ N$

$(741\ -\ 176.58) \div 9.81\ =\ 57.5\ kg\ or\ 564.4\ N$

Y Axis Motor Torque

$20\ x\ 9.81\ =\ 196.2\ N$

$0.005\ x\ 196.2\ =\ 1\ Nm$

$1 \div (2\ x\ \pi)\ =\ 0.16\ Nm$

$Motor\ Torque\ =\ 0.16\ Nm$

Y Axis Available Torque

$Available\,Torque\;=\;(12\;-\;0.16)\div 0.016\;=\;740\,N$

$(740\;-\;196.2)\div 9.81\;=\;55.4\,kg\;or\;543.8\,N$

Z Axis Motor Torque

$6.7\,x\,9.81\;=\;65.7\,N$

$0.005\,x\,65.7\;\;=\;\;0.32\,Nm$

$0.32\div(2\,x\,\pi)\;=\;0.05\,Nm$

$Motor\,Torque\;=\;0.05\,Nm$

Z Axis Available Torque

$Available\,Torque\;=\;(12\;-\;0.05)\div 0.016\;=\;746.9\,N$

$(746.9\;-\;65.7)\div 9.81\;=\;69.4\,kg\;or\;681.2\,N$

Z Axis Injection Mould Available Torque

Having built an Injection Moulder producing 650 psi, 44 Bar or 4.4 Mpa the Available Torque regarding the Z Axis is enough to produce the required Injection Pressure.

$Available\;\;Torque\;=\;12\div 0.016\;=\;750\,N$

$(746.9\;-\;65.7)\div 9.81\;=\;69.4\,kg\;or\;681.2\,N$

$69.4kg\;to\;psi\;=\;987$

$Maximum\,Available\,psi\;=\;987,\;say\;1000.$

Ball Screw & Linear Rail Material

To calculate the strength of the Ball Screw and Rails we need to know the properties associated, all Ball Screws and Support Rails are made of Stainless Steel. The weights and materials of the traversing masses are also known. Now we can begin to calculate all the Ball Screws and Supporting rails strengths and calculations will be concluded with Safety Factor values. Due to the oversizing of components I believe the Safety Factors will be overkill especially regarding the Z Axis of just 300mm. A short Solid Material can withstand far more pressure than a Large Solid Material of the same thickness.

Stainless Steel Properties

Table 21, Stainless Steel Properties

Properties	Value	Symbol
Density (x 1000 kg/m^3)	8	P or ϒ
Poisson's Ratio	0.27- 0.30	V
Modulus of Elasticity	193000 Mpa	Mpa
Yield Strength	205 Mpa	Mpa
Tensile Strength	513 Mpa	Mpa

A central load regarding the unsupported span is the weakest point and where tension and compression arises, this is why the Buckling load calculation is used. Ball Screws and Linear Rails for the XYZ Axis are all supported. Factors $n1\ and\ n2$ are used to declare the type of support. The Ball Screws are 1500mm, 1000mm and 300mm in length with an Outside Diameter of 32mm and Root Diameter of 27.33mm.

Ball Screw Buckling Load

Two equations used for the same outcome, n_1 and n_2, both are comparably valid.

$Root\ Diameter\ =\ 27.33mm$

$Elastic\ Modulus\ =\ 193000\ Mpa$

$Safety\ Factor\ (\alpha)\ =\ 0.5$

$Fixed\ Support\ (n_1)\ =\ 2$

$Fixed\ Support\ (n_2)\ =\ 10$

X Axis

$$I = \frac{\pi}{64}\ x\ D^4$$

$$I = \frac{\pi}{64}\ x\ 27.33^4 = 27386mm^4$$

$$p = \frac{\alpha\, n_1 \pi^2 EI}{L^2}$$

$$p = \frac{0.5\ x\ 2\ x\ \pi^2\ x\ 193000\ x\ 27386}{1000^2} = 52.165\ kN$$

$$\alpha = n_2 \frac{D^4}{L^2}\ x\ 10^4$$

$$\alpha = 10\, x \frac{27.33^4}{1000^2}\, x\, 10^4 = 55.790\, kN$$

Y Axis

$$I = \frac{\pi}{64}\, x\, D^4$$

$$I = \frac{\pi}{64}\, x\, 27.33^4 = 27386mm^4$$

$$p = \frac{\alpha\, n_1 \pi^2 EI}{L^2}$$

$$p = \frac{0.5\, x\, 2\, x\, \pi^2\, x\, 193000\, x\, 27386}{1500^2} = 23.184\, kN$$

$$\alpha = n_2 \frac{D^4}{L^2}\, x\, 10^4$$

$$\alpha = 10\, x \frac{27.33^4}{1500^2}\, x\, 10^4 = 24.795\, kN$$

Z Axis

$$I = \frac{\pi}{64}\, x\, D^4$$

$$I = \frac{\pi}{64}\, x\, 27.33^4 = 27386mm^4$$

$$p = \frac{\alpha\, n_1 \pi^2 EI}{L^2}$$

$$p = \frac{0.5\, x\, 2\, x\, \pi^2\, x\, 193000\, x\, 27386}{300^2} = 579.619\, kN$$

$$\alpha = n_2 \frac{D^4}{L^2}\, x\, 10^4$$

$$\alpha = 10\, x \frac{27.33^4}{300^2}\, x\, 10^4 = 619.891\, kN$$

Linear Rail Buckling Load

Two equations used for the same outcome, n_1 and n_2, both are valid.

$X\ \&\ Y\ Diameter\ =\ 20mm$

$Z\ Diameter\ =\ 15mm$

$Elastic\ Modulus\ =\ 193000\ Mpa$

$Safety\ Factor\ (\alpha)\ =\ 0.5$

$Fixed\ Fixed\ (n_1)\ =\ 4$

$Fixed\ Fixed\ (n_2)\ =\ 20$

X Axis

$$I = \frac{\pi}{64}\ x\ D^4$$

$$I = \frac{\pi}{64}\ x\ 20^4 = 7854mm^4$$

$$p = \frac{\alpha\, n_1 \pi^2 EI}{L^2}$$

$$p = \frac{0.5\ x\ 4\ x\ \pi^2\ x\ 193000\ x\ 7854}{1000^2} = 29.921\ kN$$

$$\alpha = n_2 \frac{D^4}{L^2}\ x\ 10^4$$

$$\alpha = 20\ x \frac{20^4}{1000^2}\ x\ 10^4 = 32\ kN$$

Y Axis

$$I = \frac{\pi}{64}\ x\ D^4$$

$$I = \frac{\pi}{64}\ x\ 20^4 = 7854mm^4$$

$$p = \frac{\alpha\, n_1 \pi^2 EI}{L^2}$$

$$p = \frac{0.5\ x\ 4\ x\ \pi^2\ x\ 193000\ x\ 7854}{1500^2} = 13.298\ kN$$

$$\alpha = n_2 \frac{D^4}{L^2} x\, 10^4$$

$$\alpha = 20\, x \frac{20^4}{1500^2} x\, 10^4 = 14.222\, kN$$

Z Axis

$$I = \frac{\pi}{64} x\, D^4$$

$$I = \frac{\pi}{64} x\, 15^4 = 2485 mm^4$$

$$p = \frac{\alpha\, n_1 \pi^2 EI}{L^2}$$

$$p = \frac{0.5\, x\, 4\, x\, \pi^2\, x\, 193000\, x\, 2485}{300^2} = 105.189\, kN$$

$$\alpha = n_2 \frac{D^4}{L^2} x\, 10^4$$

$$\alpha = 20\, x \frac{15^4}{300^2} x\, 10^4 = 112.500\, kN$$

Ball Screw Safety Factor

$X\ Axis\ Safety\ Factor = 55.790\ x\ 0.5 = 27.895\ kN$

$Y\ Axis\ Safety\ Factor = 24.795\ x\ 0.5 = 12.4\ kN$

$Z\ Axis\ Safety\ Factor = 619.891\ x\ 0.5 = 309\ kN$

Linear Rail Safety Factor

$X\ Axis\ Safety\ Factor = 32\ x\ 0.5 = 16\ kN$

$Y\ Axis\ Safety\ Factor = 14.222\ x\ 0.5 = 7.111\ kN$

$Z\ Axis\ Safety\ Factor = 112.500\ x\ 0.5 = 56.250\ kN$

Loaded Axis Safety Factor

$X\ Axis\ Loaded\ Safety\ Factor = 27895 \div 176.58 = 158$

$Y\ Axis\ Loaded\ Safety\ Factor = 12400 \div 196.2 = 63$

$Z\ Axis\ Loaded\ Safety\ Factor = 309000 \div 65.7 = 4703$

The values given for a Safety Factor of 0.5 seem a little excessive, however, this is the Buckling Load equation where a Safety Factor of less than 1 determines failure. The heavy/oversized design is bulletproof, not for strength reasons but for Machine

Rigidity. The heavier the machine is the less Vibration and Chatter will occur when the Spindles mounted tool contacts a Workpiece.

Ball Screw Efficiency

Optimum track conformity for ball screws is between 0.52 to 0.56, and the optimum contact angle is 45°, the Friction Coefficient is 0.01. Ball Screw Diameter is 32mm with a single Lead.

Lead Screw Angle

$$tan\,\alpha = \frac{p}{\pi d} = \frac{0.005}{\pi\, x\, 0.032} = 0.05$$

$$tan\,\alpha = \frac{l}{\pi d} = \frac{1}{\pi\, x\, 0.032} = 9.95$$

$$tan\,\alpha = 9.95 + 0.05 = 10°$$

Ball Screw Friction & Efficiency

$$\alpha = tan^{-1}(p \div u)$$

$$P = 0.005$$

$$u = \pi\, x\, 0.032 = 0.1$$

$$\alpha = tan^{-1}(0.005 \div 0.1) = 2.86°$$

$$\mu = 0.01$$

$$\eta = \frac{tan\,(2.86)}{tan\,(2.86 + tan^{-1}\,(0.01))} = 0.83$$

$$\eta = 83\%$$

Back Driving Torque

This is very important, ensuring the Loads on all Axis cannot move out of position without command is essential to correct operation. The following calculations will suggest whether Back Driving will occur. For success, Back Driving Torque needs to be much less than all of the Axis Components frictions, the frictions relate to the End Seals, Bearings and Flange Nuts vs the Initial Motor Torque using the Ball Screws Efficiency.

X Axis Back Driving

$$T_b = \frac{FP\eta}{2\pi}$$

$$T_b = \frac{176.6\ x\ 0.005\ x\ 0.83}{2\pi} = 0.12\ Nm$$

$Back\ Driving\ Torque\ = 0.12\ Nm$

X Axis Component Frictions

$2\ x\ Flange\ Nut\ = 0.06$
$2\ x\ End\ Bearings\ = 0.30$
$1\ x\ End\ Seals\ = 0.08$

$Total\ Friction\ Torque\ = 0.44\ Nm$

Y Axis Back Driving

$$T_b = \frac{FP\eta}{2\pi}$$

$$T_b = \frac{196.2\ x\ 0.005\ x\ 0.83}{2\pi} = 0.13\ Nm$$

$Back\ Driving\ Torque\ = 0.13\ Nm$

Y Axis Component Frictions

$2\ x\ Flange\ Nut\ = 0.06$
$2\ x\ End\ Bearings\ = 0.30$
$1\ x\ End\ Seals\ = 0.08$

$Total\ Friction\ Torque\ = 0.44\ Nm$

Z Axis Back Driving

$$T_b = \frac{FP\eta}{2\pi}$$

$$T_b = \frac{65.7\ x\ 0.005\ x\ 0.83}{2\pi} = 0.04\ Nm$$

$Back\ Drive\ Torque\ = 0.04\ Nm$

Z Axis Component Frictions

$1\ x\ Flange\ Nut\ =\ 0.03$

$1\ x\ End\ Bearings\ =\ 0.15$

$1\ x\ End\ Seals\ =\ 0.08$

$4\ x\ Bushings\ =\ 0.15$

$Total\ Friction\ Torque\ =\ 0.41\ Nm$

Conclusion

To pass the Back Drive Test the Components Friction for each Axis has to be >0.20 Nm with regards to the Back Drive Torque calculations, according to results obtained all Axis are Back Drive Torque proof. The Z Axis was most important due to Vertical Loads being held in position with the 15mm Supporting Rods each having their own Brass Self-Lubricating Bushings which aid additional frictional requirements.

Back Drive Torque Results

Table 22, Back Drive Torque Results

Axis	Back Drive Torque	Components Friction	Acceptable Pass >0.20 Nm
X	0.12 Nm	0.44 Nm	0.32 Nm
Y	0.13 Nm	0.44 Nm	0.31 Nm
Z	0.04 Nm	0.41 Nm	0.37 Nm

X Axis Forwards Load Torque

$$T\ =\frac{PL}{2\pi\ \eta}$$

$$T\ =\frac{176.58\ x\ 10}{2\pi\ x\ 83}=\ 3.3$$

$$T\ =\ 3.3\ Nm$$

X Axis Reverse Load Torque

$$P\ =\frac{2\pi\ T}{\eta L}$$

$$P\ =\frac{2\pi\ x\ 330}{83\ x\ 10}=\ 2.5$$

$$P\ =\ 2.5\ Nm$$

Y Axis Forwards Load Torque

$$T = \frac{PL}{2\pi\ \eta}$$

$$T = \frac{196.2\ x\ 10}{2\pi\ x\ 83} = 3.76$$

$$T = 3.76\ Nm$$

Y Axis Reverse Load Torque

$$P = \frac{2\pi\ T}{\eta L}$$

$$P = \frac{2\pi\ x\ 370}{83\ x\ 10} = 2.8$$

$$P = 2.8\ Nm$$

Z Axis Forwards Load Torque

$$T = \frac{PL}{2\pi\ \eta}$$

$$T = \frac{65.7\ x\ 10}{2\pi\ x\ 83} = 1.25$$

$$T = 1.25\ Nm$$

Z Axis Reverse Load Torque

$$P = \frac{2\pi\ T}{\eta L}$$

$$P = \frac{2\pi\ x\ 125}{83\ x\ 10} = 0.95$$

$$P = 0.95\ Nm$$

Subtle differences occur with forward and reversing Loads with the forwards motion requiring more Torque. For anyone that thinks it is the same, the evidence suggests otherwise. It is a known fact that reversing has an increased RPM therefore Torque is reduced.

Critical Speed (Nc)

$$Safety\ Factor\ s_f = 0.8$$

$$Fixed\ Support\ \lambda = 3.927^2$$

$$Density\ \Upsilon = 8\ x\ 10^{-6}\ kg/mm^3$$

$$I = \frac{\pi}{64}\ x\ 27.33^4 = 27386mm^4$$

$$A = \frac{\pi}{4}\ x\ 27.33^4 = 586.6mm^4$$

$$Nc = s_f \frac{60\ \lambda^2}{2\pi\ L^2}\ x \sqrt{\frac{EI}{\Upsilon A}}$$

X Axis

$$Nc = 0.8\ x\ \frac{60\ x\ 3.927^2}{2\ x\ \pi\ x\ 1000^2}\ x \sqrt{\frac{193000\ x\ 27386}{8\ x\ 10^{-6}\ x\ 586.6} x10^3} = 3953$$

$$Nc = 3954\ RPM$$

Y Axis

$$Nc = 0.8\ x\ \frac{60\ x\ 3.927^2}{2\ x\ \pi\ x\ 1500^2}\ x \sqrt{\frac{193000\ x\ 27386}{8\ x\ 10^{-6}\ x\ 586.6} x10^3} = 1757$$

$$Nc = 1757\ RPM$$

Z Axis

$$Nc = 0.8\ x\ \frac{60\ x\ 3.927^2}{2\ x\ \pi\ x\ 300^2}\ x \sqrt{\frac{193000\ x\ 27386}{8\ x\ 10^{-6}\ x\ 586.6} x10^3} = 43930$$

$$Nc = 43930\ RPM$$

Critical Speed is the rotational speed at which acting dynamic forces cause the machine's rotating components to resonate at their natural frequency. The Y Axis Motor cannot operate beyond 1757 RPM, this is a critical limitation therefore all Axis will be limited to 1500 RPM for safety reasons.

Power Consumption

$$Power = \frac{2\pi \, RPM \, T}{60}$$

Forward X Axis

$$Power = \frac{2 \, x \, \pi \, 1500 \, x \, 3.3}{60} = 518$$

$$Power = 518 \, Watts$$

Reverse X Axis

$$Power = \frac{2 \, x \, \pi \, 1500 \, x \, 2.5}{60} = 392.7$$

$$Power = 392.7 \, Watts$$

Forward Y Axis

$$Power = \frac{2 \, x \, \pi \, 1500 \, x \, 3.76}{60} = 590.6$$

$$Power = 590.6 \, Watts$$

Reverse Y Axis

$$Power = \frac{2 \, x \, \pi \, 1500 \, x \, 2.8}{60} = 439.8$$

$$Power = 439.8 \, Watts$$

Forward Z Axis

$$Power = \frac{2 \, x \, \pi \, 1500 \, x \, 1.25}{60} = 196.3$$

$$Power = 196.3 \, Watts$$

Reverse Z Axis

$$Power = \frac{2 \, x \, \pi \, 1500 \, x \, 0.95}{60} = 149.2$$

$$Power = 149.2 \, Watts$$

4th & 5th Axis

The 4th Axis carries the weight of the Bridge, 5th Axis Motor, Turntable and the Workpiece. The 5th Axis carries the weight of the Turntable and Workpiece only.

Figure 7, 4th & 5th Axis

4th Axis Motor Specification

Table 23, 4th Axis Motor

Component	Type	Quantity	Dimension (mm)	Weight	Torque	Cost
Motor	23	2	57 x 57 x 76	1.2 kg	2 Nm	£100

5th Axis Motor Specification

Table 24, 5th Axis Motor

Component	Type	Quantity	Dimension (mm)	Weight	Torque	Cost
Motor	23	1	57 x 57 x 56	0.8 kg	1.3 Nm	£40

4th Axis Bridge Specification

Table 25, Bridge

Component	Type	Quantity	Dimension (mm)	Weight	Motor	Cost
Bridge	6061	1	1000 x 350 x 20	5 kg	NEMA	£200

5th Axis Turntable Specification

Table 26, Turntable

Component	Type	Quantity	Dimension (mm)	Weight	Motor	Cost
Turntable	6061	1	300 x 20	1 kg	NEMA	£100

Vertical Mini Lathe

This forms the 6th Axis and is built in place of the Y Axis Bed with the Motor situated underneath. The Turntable is disconnected and removed when not in use whilst the Motor is disconnected from the coupler to which is lowered via a V-Slot Aluminium Linear Rail support. This is ideal for shaping and cutting in places a Mill even with Aggregates cannot perform. Additional tooling requirements and mounts are used with the Mini Lathe set-up.

Note

The Y Axis Ball Screw needs to be removed to avoid collisions.

Supports

Frame supports are yet to be determined but will once the basic machine is built.

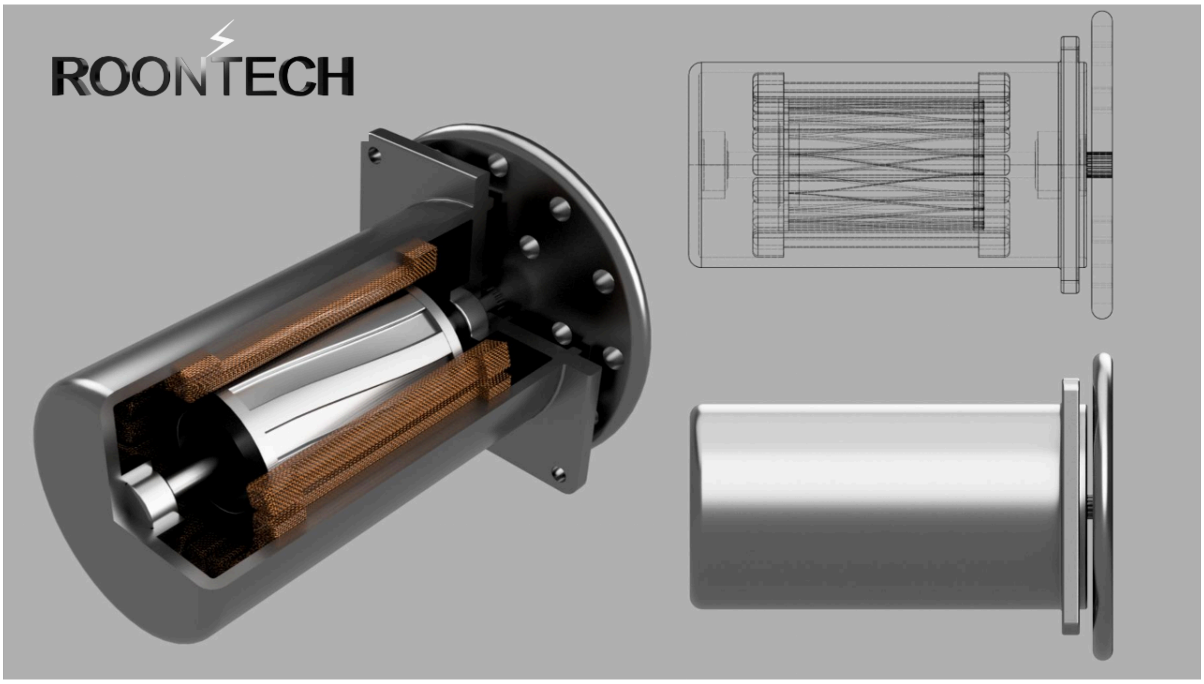

Figure 8, 6th Axis

Mini Lathe Motor Specification

Table 27, Mini Lathe Motor

Component	Power	RPM	Dimension (mm)	Weight	Torque	Cost
Motor	3 kW	3000	200 x 400 x 250	25 kg	25 Nm	£300

Turntable Specification

Table 28, Mini Lathe Turntable

Component	Type	Quantity	Dimension (mm)	Weight	Motor	Cost
Turntable	6061	1	300 x 20	3 kg	3 kW	£100

Injection Moulder

The Injection Moulder is a unique addition to the CNC+ utilising the Available Torque of the Z Axis, (1000 psi). This design style makes the conversion easy, to do so a Solid Steel Bar is threaded onto the Spindle Clamp and the Chamber is locked into position using additional supports which form part of the Frame.

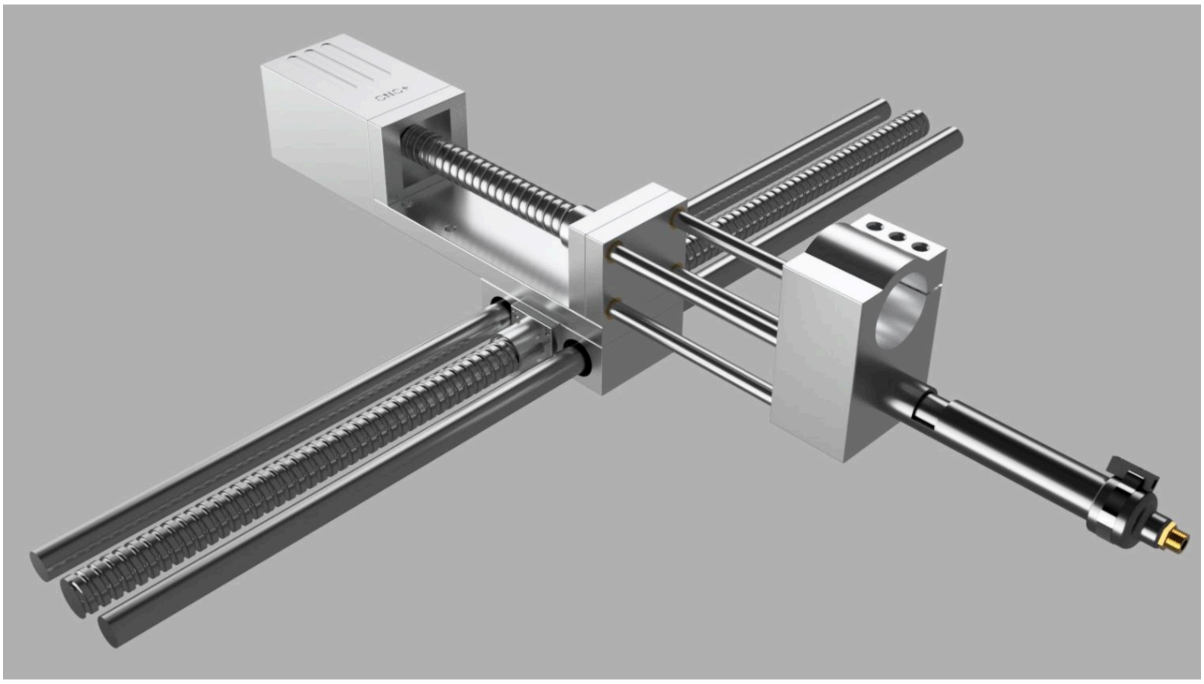

Figure 9, Extruder

Steel Tube Calculations

Technically the weakest part is the CDS Mild Steel Tube, this is where the Band Heaters sit (2 x 200 watt). They can heat up to 400℃ but will operate at less than half due to PID control. This section is where the Solid Steel Bar drives through to press the HDPE, a lot of pressure is built up here. Available psi is known to be 1000. Heat and Pressure are the main factors relating to life expectancy of the Steel Tube before deformation occurs. The following information and calculations can be used to estimate the life cycle.

What we know

$Material = CDS\ Mild\ Steel$

$Length = 195\ mm$

$Test\ Length = 125\ mm$

$BSPT\ Thread = 20\ mm$

$Hopper\ Entry = 20\ x\ 33.34\ mm$

$OD = 33.34\ mm$

$ID = 26.84\ mm$

$Wall\ Thickness = 3.25\ mm$

$Max\ psi\ =\ 1000$

$Max\ Mpa\ =\ 6.9$

$Testing\ Temperature\ =\ 200℃$

$Location\ =\ Band\ Heater$

The Steel Tube features a Hopper Entry situated 30mm from the top, cut exactly halfway through, a BSPT thread, 20mm in length, is made using a 1" die threader.

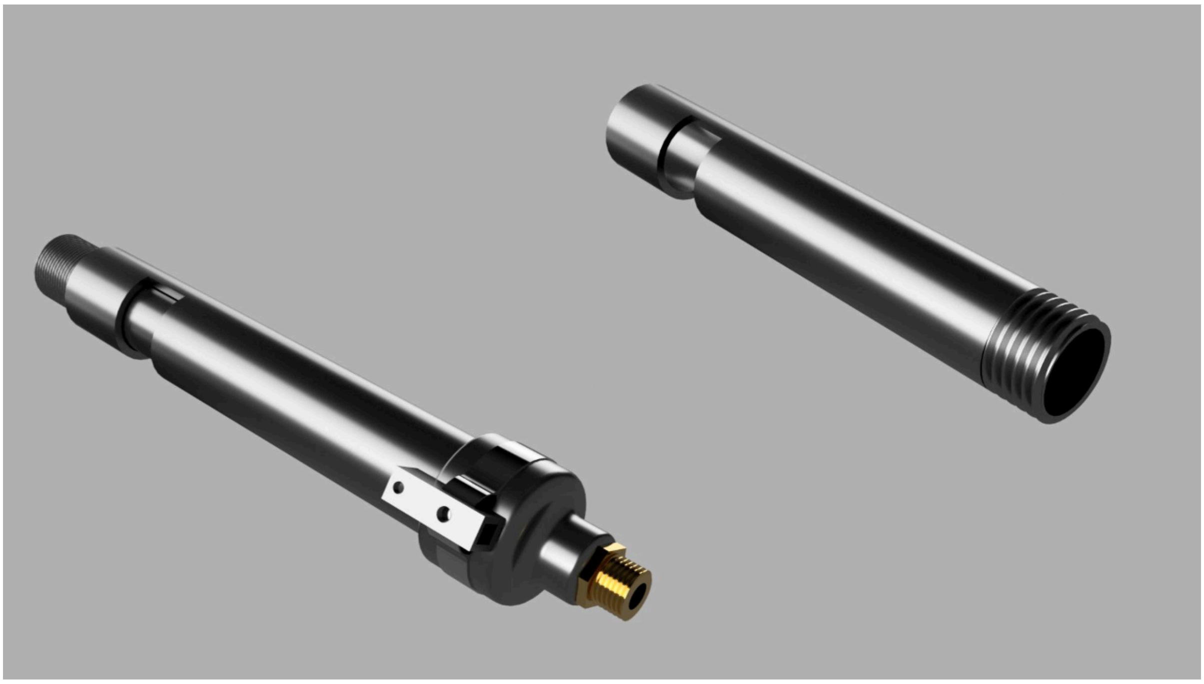

Figure 10, Barrel Design

For testing of the Steel Tube/Chamber I will neglect the area above the Hopper Entry, 30mm, the Entry Area, 20mm, and the Thread, 20mm, so the test length is now reduced, (195 - 30 - 20 - 20 = 125). This is because the two Band Heaters which are 60mm in length are situated in this space.

CAD Material Properties

$Area\ =\ 23956.862\ mm^2$

$Density\ =\ 0.008g/mm^3$

$Mass\ =\ 271.691\ g$

$Volume\ =\ 38403\ mm^3$

$Specimen\ Length\ =\ 125\ mm$

$Tensile\ Strength\ =\ 485N/mm^2$

$Yield\ Strength\ =\ 345N/mm^2$

$Melting\ Point\ =\ 1400℃$

$Modulus\ of\ Elasticity\ =\ 200\ Gpa$

$Endurance\ Limit\ =\ 242.5 N/mm^2$

$1\ N/mm^2\ =\ 1\ Mpa$

Verified Volume Calculation

$$V\ =\frac{\pi h\ (D_O^2 - D_I^2)}{4}$$

$$V\ = \frac{\pi\ x\ 125\ x\ (33.34^2 - 26.84^2)}{4} = 38403mm^3$$

$$V\ =\ 38403mm^3$$

Maximum Pressure Calculation

Allowable Stress is equal to half the Yield Strength.

$$T\ =\ 3.25\ mm$$

$$S\ =\ 345 \div 2\ =\ 172.5\ Mpa$$

$$OD\ =\ 33.34\ mm$$

$$P\ = \frac{2ST}{D_O}$$

$$P\ = \frac{(2\ x\ (172.5\ x\ 10^6)\ x\ 3.25)}{33.34} = 33.6\ Mpa$$

$$P\ =\ 33.6\ Mpa$$

Safety Factor

$Maximum\ Working\ Pressure\ =\ 33.6\ Mpa$

$Normal\ Working\ Pressure\ 6.9\ Mpa$

$$S_f = \frac{33.6}{6.9} = 4.86$$

Wall Thickness Calculation

For testing purposes the Mild Steel Tube will be calculated as if both ends are closed. First with the normal operating pressure rated at 6.9 MPa, then at maximum pressure 33.6 Mpa, both methods will use the mean radius 30.1mm. The third will use max pressure and the Outside Diameter of 33.34mm to clarify the actual wall thickness requirement. All calculations are derived from Yield Strength = 345 Mpa.

Yield Strength 6.9 Mpa

$t = \frac{6.9\ x\ 30.1}{t}$

$t = \frac{6.9\ x\ 30.1}{345} = 0.6mm$

$Minimum\ Wall\ thickness\ = \ 0.6mm$

Yield Strength 33.6 Mpa

$t = \frac{33.6\ x\ 30.1}{t}$

$t = \frac{33.6\ x\ 30.1}{345} = 2.93mm$

$Minimum\ Wall\ thickness\ = \ 2.93mm$

Yield Strength 33.6 Mpa

$t = \frac{33.6\ x\ 33.34}{t}$

$t = \frac{33.6\ x\ 33.34}{345} = 3.25mm$

$Minimum\ Wall\ thickness\ = \ 3.25mm$

Creep Calculation

Deformation based on Temperature and Pressure over a period of time, this will test the Chamber for weakness, it is the part within the most stress associated. A Warranty of 3 years is required so the Creep Calculation will determine the time before failure occurs.

$Operating\ Temperature\ = \ 200°C$

$QC\ Activation\ = \ 240\ kJ/mol$

$Gas\ Constant\ = \ 8.314$

$Temperature\ = \ 273\ k$

$Working\ Pressure\ = \ 6.9\ Mpa$

$Max\ Pressure\ = \ 33.6\ Mpa$

$Stress\ Exponent\ Metal\ = \ 5$

$$\dot{\varepsilon}_{ss} = \dot{\varepsilon}_0 (\frac{\sigma}{\sigma_0})^n \exp exp\ (-\frac{Q_c}{RT})$$

$For\ \sigma\ = \ 33.6\ Mpa$

$$\dot{\varepsilon}_{ss1} = \dot{\varepsilon}_0 (\frac{\sigma_1}{\sigma_0})^n (\left(-\frac{Q_c}{RT_1}\right))$$

$$10^6\, x\, (\frac{33.6\, x\, 10^6}{6.9\, x\, 10^6})^5 = 2738110264\, pa$$

$$Exp\,(-\frac{240\, x\, 10^3}{8.314\, x\, (200 + 273)}) = e^{61} = 3.10$$

$$\frac{\sigma_1}{exp} = \frac{2738110264}{3.10} = 883261375.5\, \frac{1}{s}$$

Ductility

Engineers Rule, 0.2% *of Original Length.*

$$\varepsilon = \frac{\Delta L}{L_O} = \frac{0.25}{125} = 0.002$$

$$t = \frac{\varepsilon}{\dot{\varepsilon}_{ss}} = \frac{0.002}{883261375.5} = \frac{\frac{\frac{2.26x10^{-12}(Sec)}{60\,(Min)}}{60\,(Hour)}}{24\,(Day)} = \frac{2.620758565\, x\, 10^{-17}(Days)}{365(1\, Year)} = 7.1\, Years$$

7.1 years creep proof at 200℃ and a pressure of 6.9 Mpa, however, it will only be in operation for 8 hours a day over 313 days.

$$t = \frac{\varepsilon}{\dot{\varepsilon}_{ss}} = \frac{0.002}{883261375.5} = \frac{\frac{\frac{2.26x10^{-12}(Sec)}{60\,(Min)}}{60\,(Hour)}}{8\,(Day)} = \frac{7.862275694\, x\, 10^{-17}(Days)}{313(1\, Year - Weekends)} = 21.4\, Years$$

Conclusion

Wall Thickness and strength under temperature and pressure has been determined that a Mild steel Tube is sufficient to house the HDPE in both solid and liquid form whilst the solid steel bar/ram applies the work done. Regarding Creep, 21.4 years at 8 hours a day over 313 days before life expectancy is fulfilled. However, it is only under pressure for 30 seconds every 6 minutes but temperature remains a constant. As previously mentioned Creep is a time dependent deformation which occurs when materials are subjected to force and heat.

Volume Shot Example

$Radius\ of\ the\ ram\ =\ 1.3$
$HDPE\ Density\ =\ 0.97$

$V\ =\ \pi r^2 h$

$V\ =\ \pi\ x\ 1.3^2\ x\ 165\ =\ 87\ cm^3$

$45 \div 0.97\ =\ 46.4\ cm^3$

$V\ =\ 46.4\ cm^3$

$A\ =\ \pi r^2$

$(\pi\ x\ 1.3^2)$

$V \div A\ =\ 46.4\ \div\ (\pi\ x\ 1.3^2)\ =\ 87\ cm^3$

$V\ =\ 46.4\ +\ 87\%\ =\ 87\ g$

An ideal Volume Shot of 46.4 grams has been determined using the parameters of the Chamber and Ram. However, we could use a factor of 20% for a max Volume Shot giving 70 grams. This is ideal for small component manufacturer, we could design a bigger Chamber and Screw to increase the Volume Shot at a later date.

Rex C100 PID Commissioning

Proportional–Integral–Derivative Controller (PID), this is the brains of the operation, this device maintains the temperature using K-type Thermocouple. It comes pre-programmed and has many functions for numerous control types. There are three settings to change regarding the IMM, the first is the (AR) setting. This setting controls the power delivered from 1-100%. Trial and era suggests that 10% solves for overshoot which is where the temperature goes far beyond the temperature selected over heating the HDPE and burns it. The PID then operates via a pulsing technique, gradually working its way up to temperature, when it hits the temperature an alarm signals the power to be cut. The alarm is the second setting to change and is set to ± 1℃.

The third setting is Auto Tuning, the tuning algorithm aims to balance performance and robustness while achieving the control bandwidth and phase margin that you specify. With these three settings configured and locked in, absolute control of the temperature is maintained. The PID operates 2 x 200 Watt Band Heaters at 200℃ which generally steps up the wattage from turning on the machine from 175, 240, 300, 360 and finally 400 watt. When the machine is up to temperature the PID sends a signal to the Solid State Relay (SSR) that energises the Band Heaters for 2 seconds, every 10 seconds, this technique is highly efficient.

Wiring Diagram

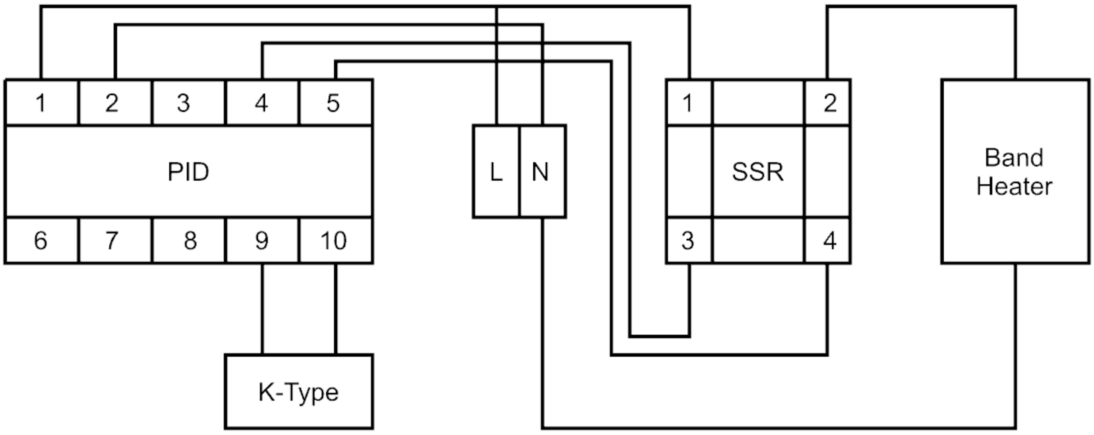

Figure 11, PID Wiring Diagram

Note: PID 1, SSR 1 are connected to L, everything else is independently connected.

Specification

Table 29, Injection Moulder

Barrel (mm)	V	Power (Kw)	psi	Capacity (g)	Temp ℃	Clamp
250 x 33.34	230	0.4	1000	46.4 - 70	140 - 200	Screw

Operation

1. Bolt Chamber to Support
2. Screw Ram to Spindle
3. Fit the Extruder Nozzle
4. Turn on PID Controllers
5. Set desired temperature
6. Check Band Heaters
7. Prepare and wear PPE
8. Leave for 15 minutes
9. Position Mould Sprue using Axis
10. Set the height of the Mould
11. Add material to hopper
12. Wait 5 Minutes to melt
13. Lower the Ram and inject the Mould
14. Hold Rams position for 20 seconds
15. Raise the Ram
16. Open Mould and remove part
17. Close Mould
18. Repeat steps 11-17

Frame Design

Below is a list of design styles, the most suitable will be selected. A simple Score Chart clearly shows the advantages and disadvantages of frame styles.

- Aluminium Machined Frame
- V-Slot Aluminum Extruded Linear Rail Frame

Table 30, Frame Score Chart

Type	Weight	Strength	Disassembly	Practicality	Cost	Score
Machined	1	5	2	1	1	10
Extruded	5	4	5	5	5	24

Aluminium Machined Frame

This would be ideal if cost, time and room for era was not an issue, it is expensive, impractical and limited regarding additional components. However, it is extra rigid due to being a solid frame, Bearings would need to be housed within the frame and this would make it difficult to replace. Or the design would have to include excessive threads and components to allow for easy removal of components. The cost of manufacture alone removes any progression towards this method.

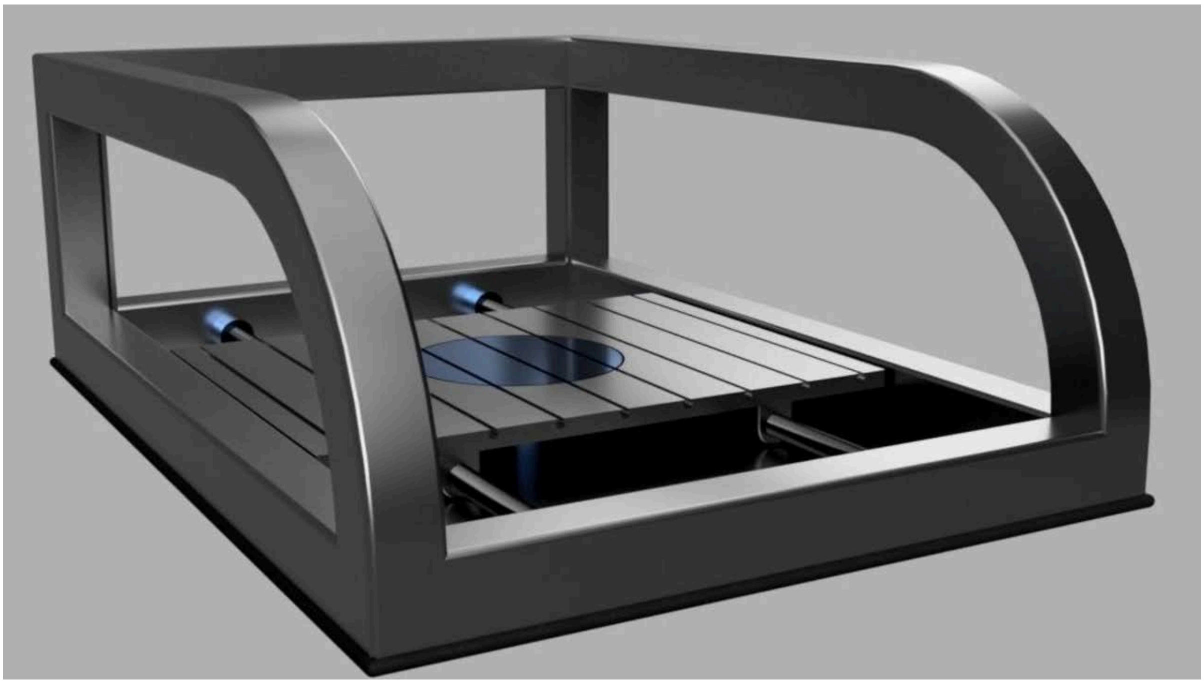

Figure 12, Machined Frame

V-Slot Aluminum Linear Rail Frame

This is what a lot of CNC machines use, this style is pre manufactured, lightweight and has attachable fixtures that are readily available allowing for easy connection of components. This method is desirable due to the design incorporating sustainable ethics, one being the need to build for disassembly. This method keeps the parts cheap and repairs easy. It has a V-Slot clamping system and is highly versatile when it comes to the assembly of multiple applications. The disadvantage is its lightweight properties due to hollowness allowing for potential vibration. However, the sheer weight of components will help prevent this whilst additional weights could be added such as Sand which would absorb any vibration.

The best thing about the V-Slot Aluminum Linear Rail Frame is the fact that not only will the CNC be made from it but the Frames Housing. The only requirement regarding dimensions is the use of a Tape Measure and an accurate Chop-Saw. Everything else is connected with V-Slot Clamps and Bolts which is a similar method to using Zebedees for unistrut. To limit any movement spacers will be used. The double V-Slot per surface allows for double fixture points regarding Ball Screws and Rails. Ultimately the 100 x 100 profile is perfect for this machine's design.

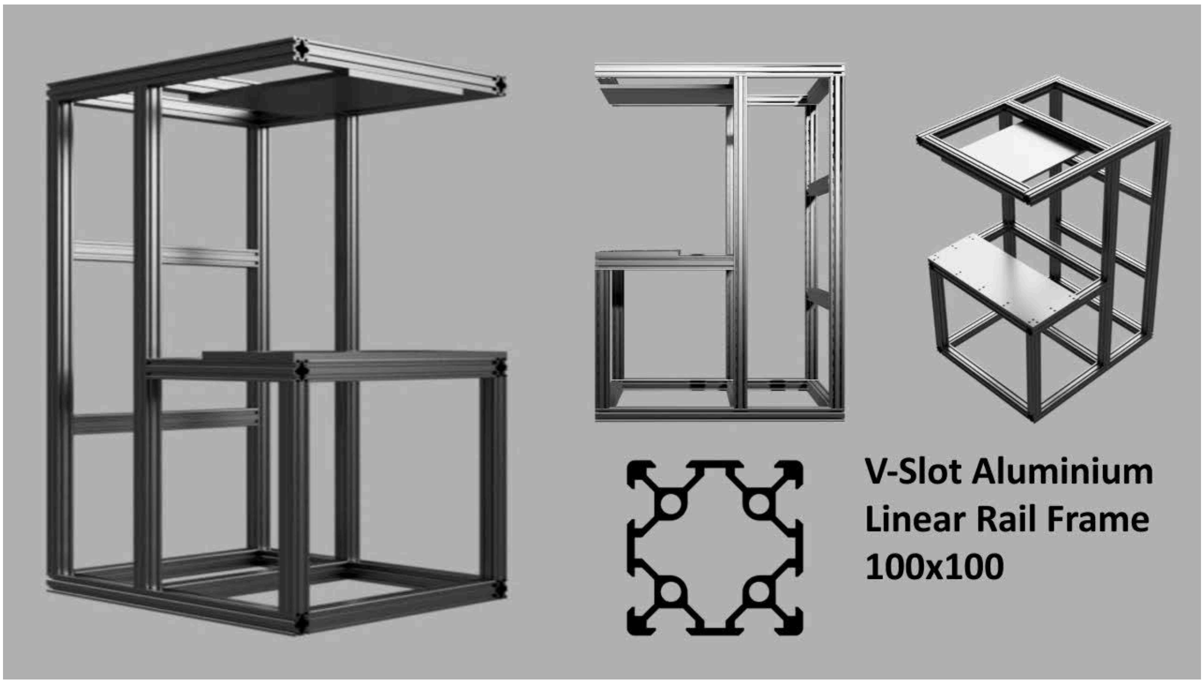

Figure 13, V-Slot Aluminum Linear Rail Frame

Safety

With the components and frame and housing accounted for safety requirements need to be implemented. Safety devices are incorporated using the PCB's control. Three aspects of safety requirements are essential.

- Emergency Stop
- Motor Cut-Out Switch
- PPE

Emergency Stop

Two Emergency Stop Buttons will be situated left and right of the front face, these are positioned for both left and right handed people and will cut the main power in the event of any risk. The Emergency stop instantly cuts the electrical supply to the machine, thus, the Spindle and Motors cease to operate until reset.

Motor Cut-Off Switches

Anything with moving or rotary parts combined with the dangers of electricity has the potential to damage equipment, maim, injure or kill. A safe isolation procedure has to be in place to prevent risk. There are a number of ways and methods to cut the power to the machines Motors.

FVD Control

All Axis Motors are controlled using Variable Frequency Drives (VFD) due to the Motors being NEMA 34's operating using Alternating Current (AC). This also includes the Spindles (VFD) that is not a NEMA 34. Isolation switches will cut the power from the Drive Units and Motherboard.

Limitation

As the Motors rotate the sliding Block, Bed and Ball Screws traverse, these need to be limited so the traversing components stop before they hit the frame of the machine. There are a number of ways to do so but the two most common for this type of Project are as follows.

Mechanical switch

This type of switch will break the power once contact has been made with an object and re-energise when there is no contact. A simple device but in my experience not the greatest due to the contact diminishing ability over time.

Proximity Switch

A Proximity Switch Senses objects within a select range, thus, a non contact switch. The switch either opens or closes when it detects the presence or absence of objects. This is preferred, the lack of physical contact ensures they last much longer.

PPE

Goggles and gloves are a mandatory requirement and to be used all of the time. When using cutting compounds heat created by the milling tool over a Workpiece induces vapours to rise. These vapours are harmful to your lungs and wellbeing, great care should be taken when applying so the use of a respiratory face mask is essential.

Equipment

The interface links the hardware of the machine with the software program, three aspects need to come together.

- Fusion 360
- Mach3
- CNC

Fusion360

Has a Manufacturing Suit that enables CAD designs to incorporate Tool Paths, these paths are to be first simulated and then created as Numerical Control (NC) files.

Mach3

This software turns a PC/Laptop into a CNC machine controller using the (NC) files created in Fusion360, speeds and feeds can be further altered here.

CNC Machine

Information given via the Software tells the Hardware to perform the given tasks.

Additional Features

- Water Cooling System
- Perspex Housing
- Blower System

Designers Guide

- Use Callipers to check tooling diameters
- Tighten screws and bolts with every use
- Maintain all equipment and dry lubricate
- Design to the machine's capability
- Calibrate travel distances

These factors are helpful guidance, tried and tested.

Ideal Design

Using the information throughout this document a detailed design of the CNC+ can be visualised.

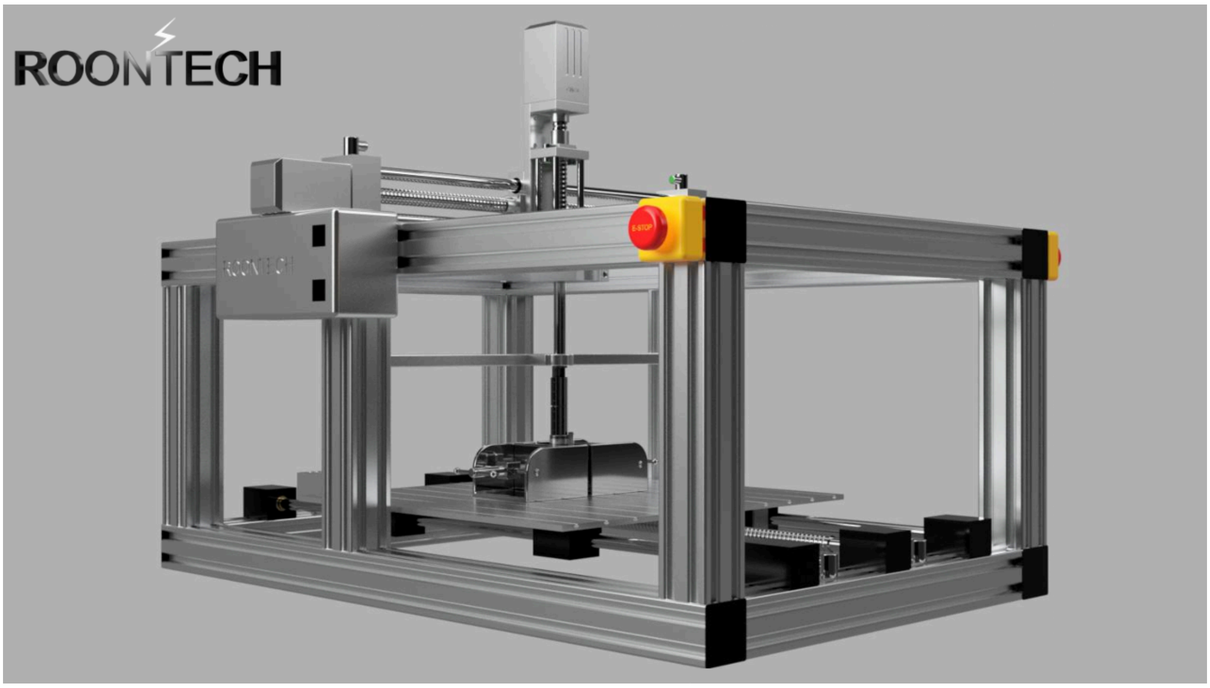

Figure 14, Injection Mould Variant View 1

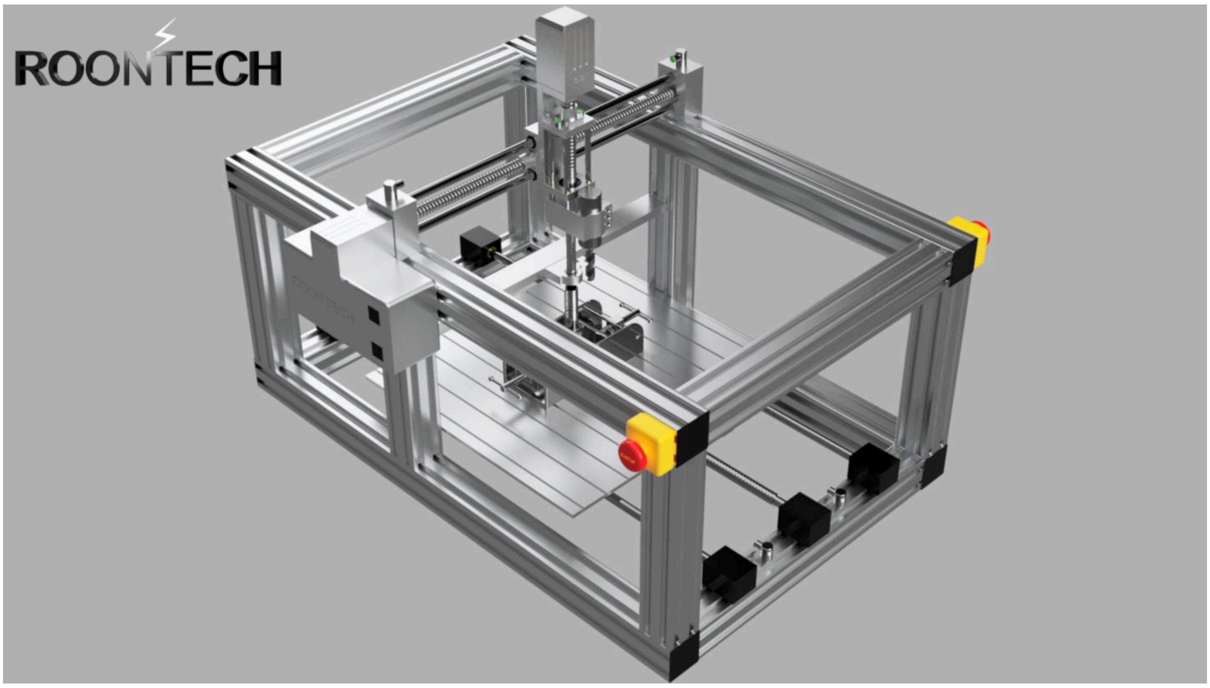

Figure 15, Injection Mould Variant View 2

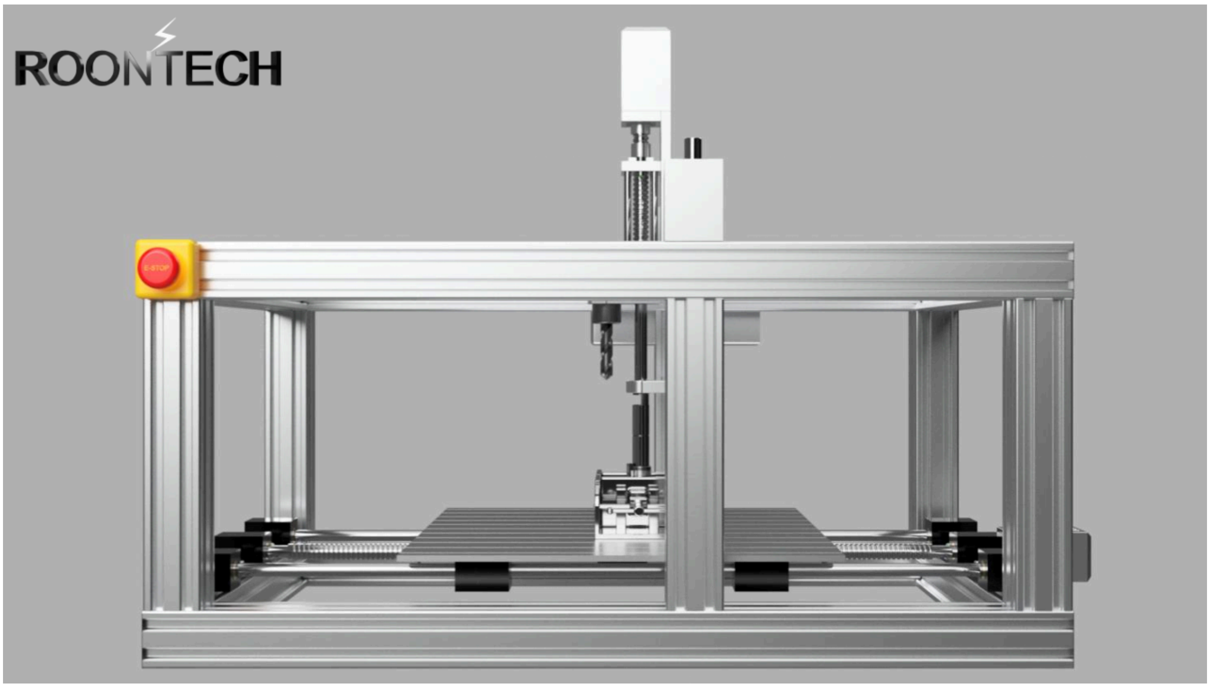

Figure 16, Injection Mould Variant View 3

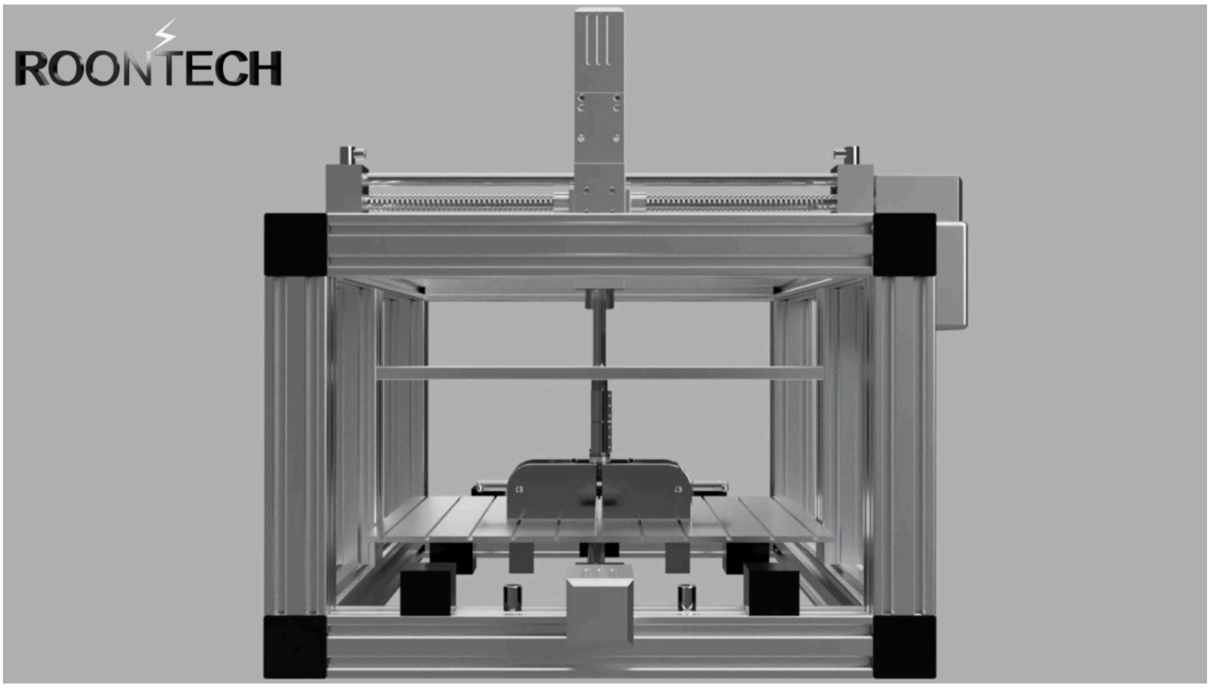

Figure 17, Injection Mould Variant View 4

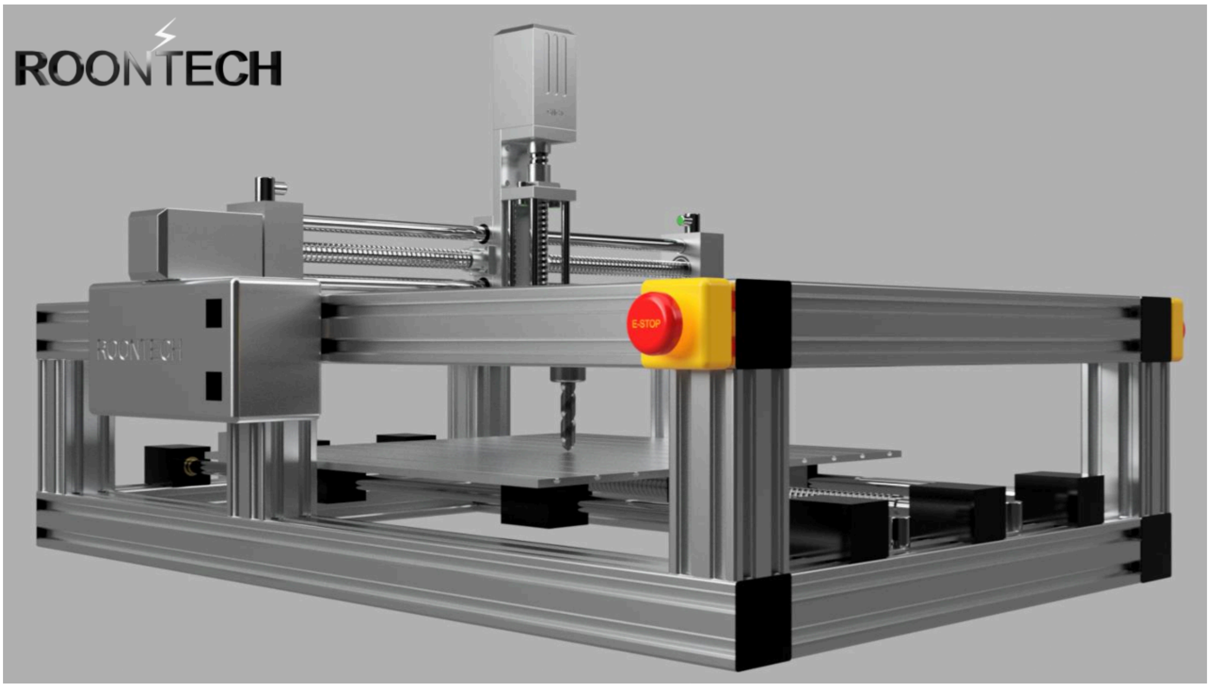

Figure 18, End Mill Variant View 1

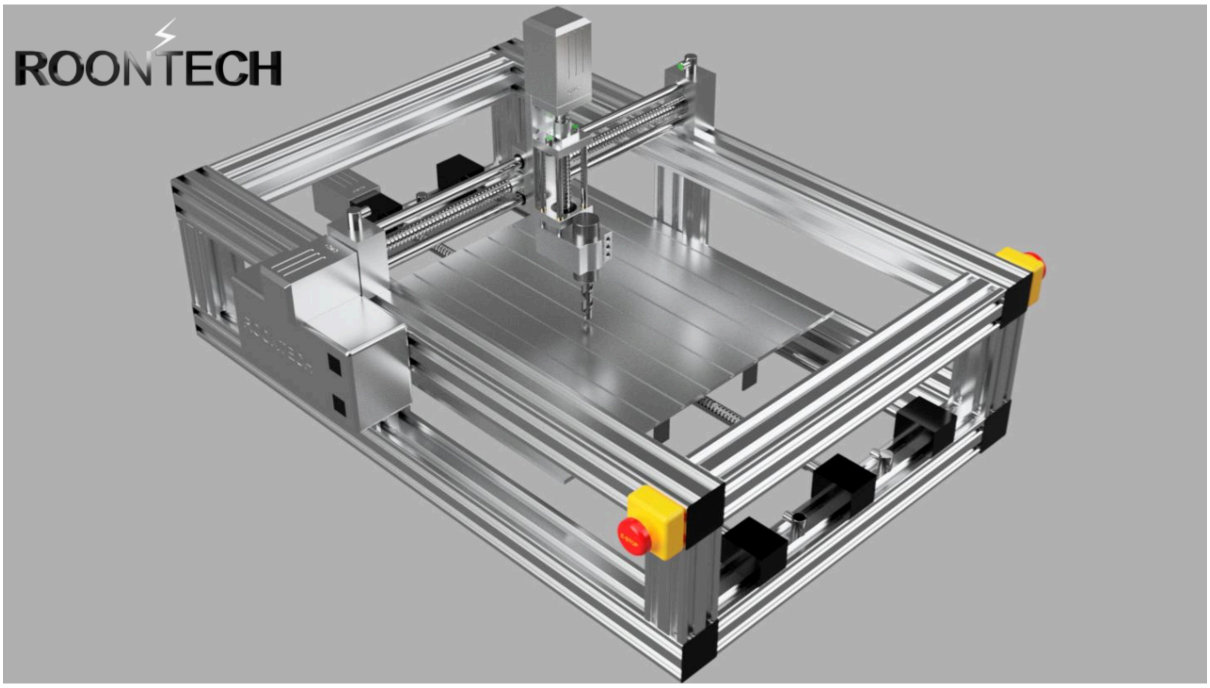

Figure 19, End Mill Variant View 2

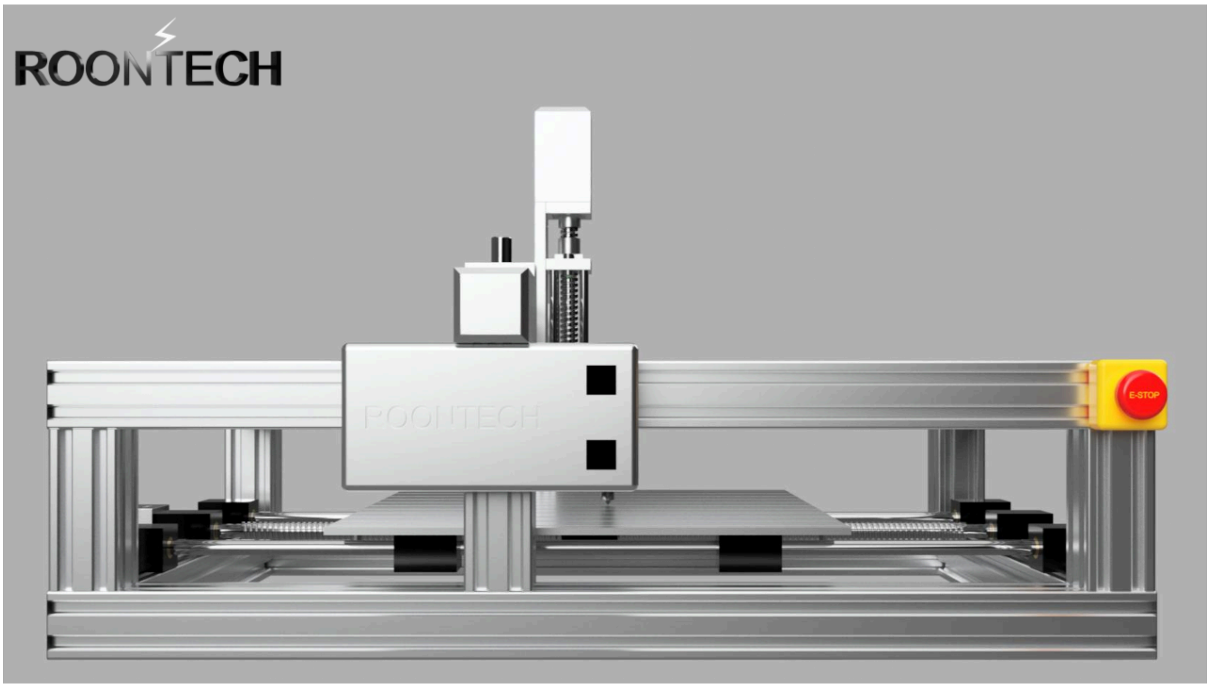

Figure 20, End Mill Variant View 3

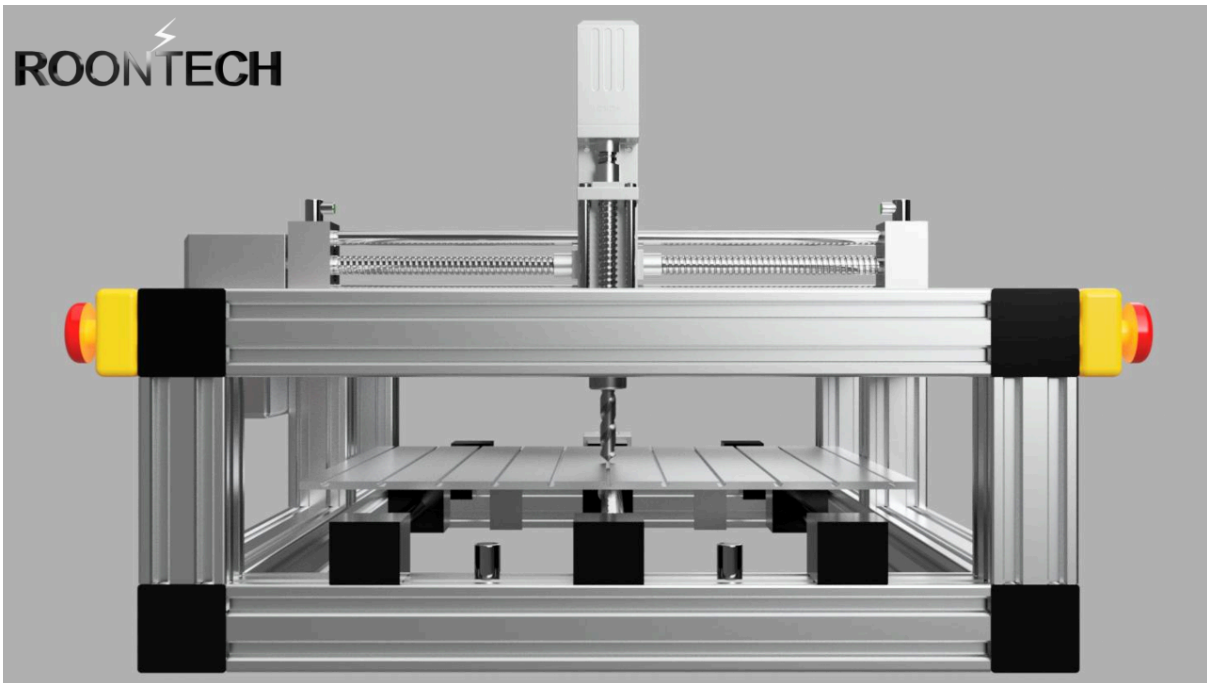

Figure 21, End Mill Variant View 4

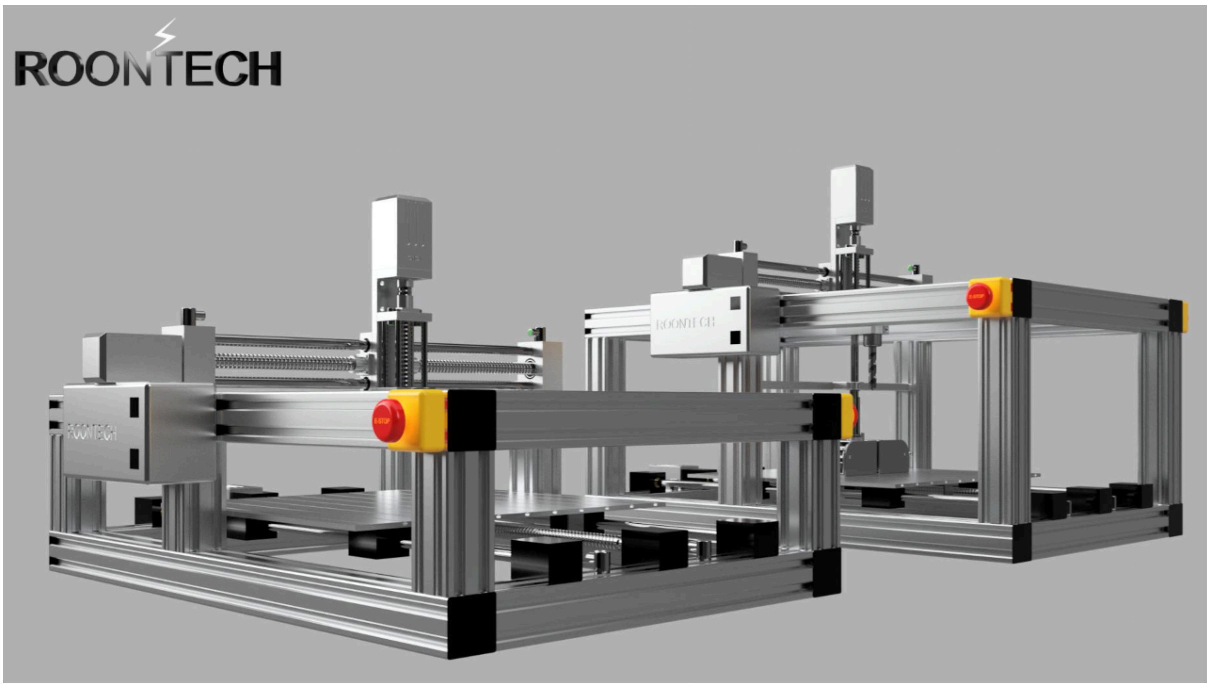

Figure 22, Side By Side

Conclusion

To bring both the End Mill and Injection Mould variants to reality two different Frame Upright Supports are necessary. A long base for the Injection Moulder and short base for the End Mill, This is a sort after method, it is quick and easy when a change of tooling is required.

I don't need to go any further, the main factors have been researched and concluded that these variations of the same machine will work. Back Driving of the Z Axis was a crucial aspect, therefore calculations were required to truly answer the question

For Now (04/02/2024), I will buy the readily available components off the shelf and I will manufacture what cannot be brought. A final design is yet to be determined as potential optomisation and component availability might affect this ideal design.

The End