



APRIL 13, 2018

MANUFACTURING DESIGN & TECHNOLOGY (M5X02070)

DESIGN DEVELOPMENT – POLYMER PROCESSING PLANT

ANDREW CURTIS 1706668
UNIVERSITY OF WALES TRINITY SAINT DAVID
Marie Pitson



1.0 Executive Summary

The intention of this report is to select a machine from the Precious Plastics Initiative, research relevant academic books, journal articles and websites to provide an understanding to critically analysis the selected machine against an industrial or commercial version. The critical analysis provides a starting point to design and develop a better version of the machine which is documented throughout this project.

The machine selected was the Extruder and the design transitioned through the research, planning, analysis, conceptualisation and 3D modelling stages to establish an effective design. The report concluded that the design provided flexibility and adaptability which through commissioning and testing would meet all polymer extrusion needs. However, stainless steels in a hardened condition or Nickle alloys are generally the materials selected for industry. To manufacture the machine with these suitable materials would spiral costs and over complicate the manufacture of the components. The decision was ultimately left with the customer and no material selection was given within the design.

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2.0 Introduction

The Government Office for Science estimates around 70 per cent of all the litter in the oceans is made of plastic. Plastic pollution is becoming a major concern with production of plastics globally exceeding three hundred million tonnes per annum. Ocean pollution with plastic waste is becoming a major problem and can be attributed to design, use and disposal of plastic items, particularly single-use packaging. Waste plastic becomes trapped within ocean currents, worn into smaller pieces, but never breakdown. Fish often mistake the plastic waste for food, which leads to contamination of the food chain. 'Plastic pollution may even be disrupting the biophysical systems that that keep the oceans stable and therefore, contributing to climate change' (Thompson, 2017). To combat this growing problem a paradigm shift of society's stewardship is needed in regard to generating waste and recycling. A number of volunteer groups have started to meet the challenges from plastic waste in creative ways.

'Precious Plastic is a global community of people who are working together towards a solution to plastic pollution. This has been achieved by developing and sharing open source designs for basic polymer processing machinery. It is intended that individuals or small groups can use these designs, along with readily available components and materials to facilitate their own, miniaturised polymer processing and manufacturing plant capable of transforming waste plastic into useful, saleable products' (Preciousplastic.com, 2018).

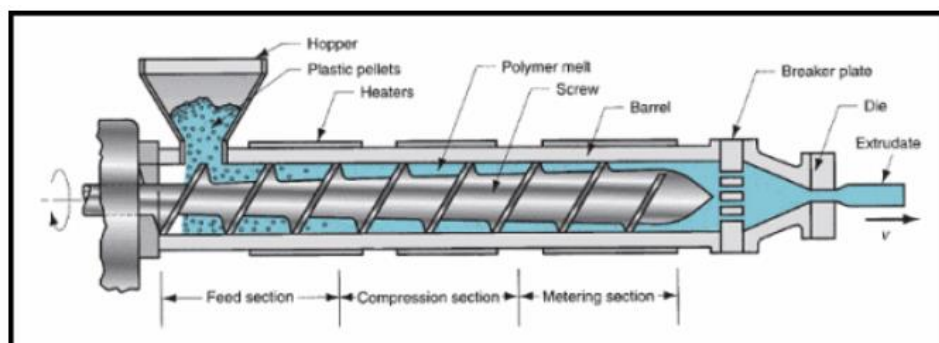
Cwmavan Council has chosen to react to this significant problem. The Council has been inspired by the Precious Plastics initiative and approached the University of Wales Trinity Saint David (UWTSD) for help to design their own miniature polymer processing plant. The University has actioned the Engineering Students to select one of the four Precious Plastics machines, research relevant academic books, journal articles and websites to provide an understanding to critically analysis the selected machine against an industrial or commercial version. The critical analysis provides a starting point to design and develop a better version of the machine for consideration by Cwmavan Council. The four Precious Plastics machines underwent high-level scoping based on their attributes for this project. From this high-level appraisal, the Extruder was chosen as the focus for this conceptual design project. The extruder was selected mainly based on the design challenges it presented.

3.0 Introduction to Polymer Extrusion

Extrusion is a process for shaping metals, ceramics and polymers. Extrusion uses compression to force material to flow through a die or orifice to produce a continuous cross-sectional shape, which is determined by the shape on the orifice. When used for polymer processing, it is predominantly utilised for thermoplastics and elastomers. A polymer extruder machine is capable of mass production of structural shapes, tube, pipe, sheet and film, continuous filament and electrical cable insulation. The process is normally continuous and the extrudate is subsequently cut to size after extrusion (Mechscience.com, 2018).

The process of polymer extrusion involves pellet or powder being gravity fed from a hopper into an extruder barrel, to which heat is applied from electrical heaters. The feedstock falls down into the rotating screw channels and frictional forces develop in the polymer during 'plasticizing'.

'Plasticating' refers to the conversion of plastic granules to flowable melt. It is the process inside the screw barrel assembly of an injection moulding or plastic extrusion machine, which moves the melt forward towards the die as illustrated bellow (Pitfallsinmolding.com).. This force pushing the melt through the passages to the die provides two essential mixing actions. The cross flow in the screw channel provides distributive mixing and the shearing action causes dispersive mixing. This mixing and mechanical working of the polymer generates supplementary heat, which maintains the melt in larger extruders. In some instances, enough heat can be applied through the mixing and shearing action that external heating is not required. In other applications it is necessary not only to heat the barrel but also provide cooling to prevent overheating of the polymer. (Rosaro, 1998; Mechscience.com, 2018).



The main two components of an extruder machine can be considered as the barrel and the screw (further research, theory and design calculations are described later into the project during Screw and Barrel Design). The die is not generally regarded as a component of the extruder and is manufactured separately dependant on the profile of the application. The internal diameter of an extruder barrel can

vary specific to the application from 25 to 150 mm. The barrel is long relative to its diameter, with $L=D$ ratios usually between 10 and 30. The higher ratios are used for thermoplastic materials, whereas lower $L=D$ values are for elastomers. (Mechscience.com, 2018).

4.0 Precious Plastics Extruder Critical Analysis

Precious Plastics' fundamental design concept of developing a basic Extruder machine for polymer processing, with the intent to inspire or motivate people into creating or using these designs to build their own recycling machines, was fundamentally successful. This is evident from the popularity and feedback Precious Plastics have received on their website from their supporters and 'global community' (Preciousplastic.com, 2018). However, Precious Plastics design concept involved using readily available components and materials, simple designs and strived to maintain low manufacturing costs. These design factors have all had a detrimental effect on the build quality, which will have a direct impact on machine reliability, life in-service and productivity. Also, no attention has been given to the Health and Safety Executive's guidance and Approved Codes of Practice for the Health and Safety at Work etc Act (Hse.gov.uk, 2018).

4.1 Health and Safety

The Health and Safety Executive (HSE) provides guidance and Approved Codes of Practice (ACOPs), which describe preferred or recommended methods of following legislation and the standards to be met. It helps organisations understand how to follow legislation and comply with their legal duties imposed by the Health and Safety at Work etc Act (Hse.gov.uk, 2018).

'Following the guidance is not compulsory, unless specifically stated, and you are free to take other action. But if you do not follow the guidance you will normally not be doing enough to comply with the law. Health and safety inspectors seek to secure compliance with the law and may refer to this guidance' (Hse.gov.uk, 2018).

Essential (health and safety) requirements (EHSRs) - The HSE provides guidelines on the essential health and safety requirements for machine or product designers. Manufacturers also have a duty to construct applicable products for safety and compliance. (Hse.gov.uk, 2018).

'Hse.gov.uk 2018 state that before any product is placed on the market, or brought into use for the first-time, designers and manufacturers must meet, to the state of the art, all essential requirements relevant to the particular product. In most cases these requirements set broad objectives for securing:'

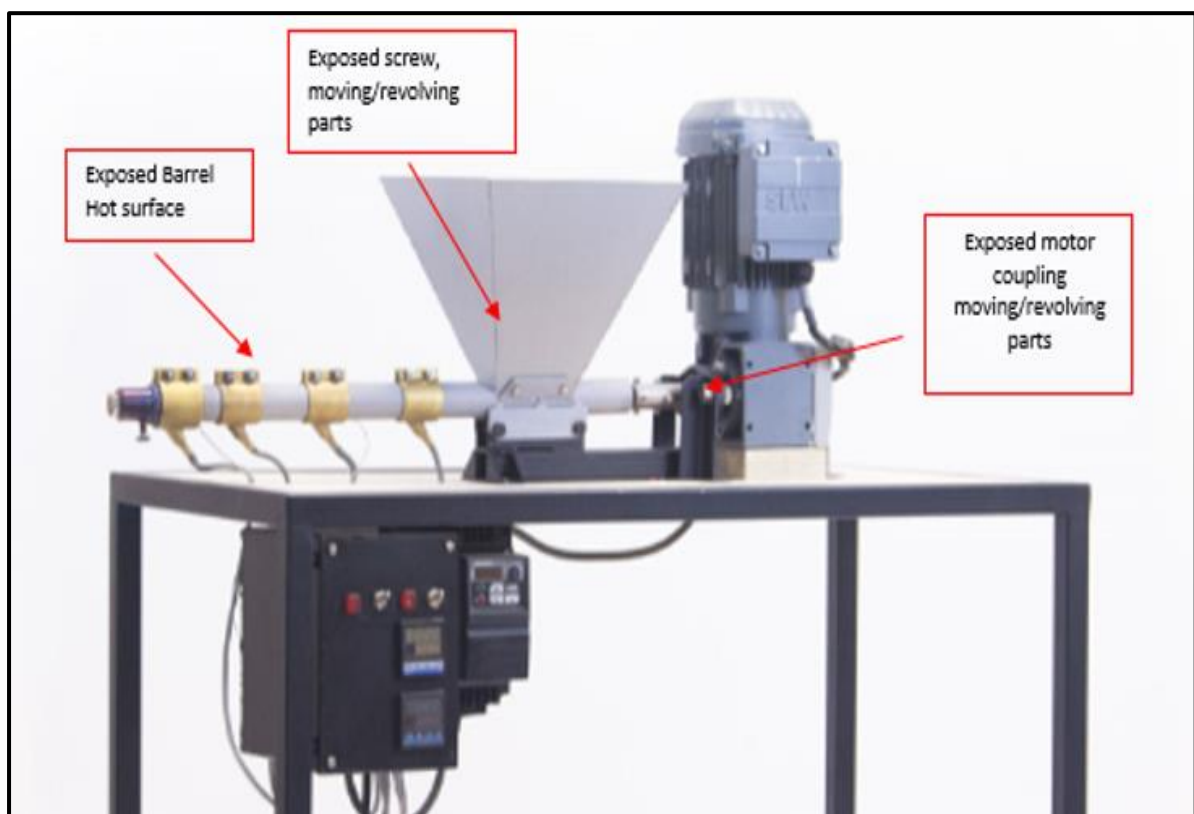
- 'The health and safety of the user of the product'

- ‘Others who may be affected, such as consumers of materials processed on certain types of machinery (eg food, cosmetics and pharmaceuticals) and in some cases the safety of domestic animals and the environment’ (Hse.gov.uk, 2018).’

Section 6 of the Health and Safety at Work Act 1974 states:

‘...any person who designs, manufactures, imports or supplies any article for use at work...to ensure, so far as is reasonably practicable, that the article is so designed and constructed that it will be safe and without risks to health...’ (Hse.gov.uk, 2018).

Precious Plastic Extruder:



(Preciousplastic.com, 2018).

Through observation it is evident that the Precious Plastic Extruder is missing vital components which would prevent harm or injury being sustained through operation. The above picture of the extruder highlights the hazards identified through the HSE guidelines on Safety at Extruder Lines. The table below highlights the hazards and recommended safeguards.

Table 1 Practical safeguards for extruders

Hazard	Safeguard
Trap at feed nip during normal operation (ie other than start-up/feeding)	Access to the rotating screws (main drive and feed) should be prevented, eg a hopper construction providing a safe distance that complies with BS EN ISO 13857. Alternatively, provide fixed guarding (eg a grille) at the openings. If the hopper and/or the feed throat is removable, then these should either be interlocked with the screw drive, or access to the screw should be prevented by a fixed grille.
Traps at other openings in the barrel	If there is access to the dangerous movement of the screw, then these should be protected by design, fixed or interlocked guards.
Burns from hot surfaces	Protect hot parts above 80 °C against accidental contact using guards or insulation. Where hot parts are necessarily exposed (eg at the die head), warning signs are required.
Burns from molten splash, in particular at start-up with material in the barrel	Where practical, use splash guards at the die. Operators will also need to wear personal protective equipment to prevent burns. Fencing, barriers or other measures may also be necessary to exclude other people from entering the area to reduce the risks when starting the machines.

(Hse.gov.uk, 2018).

Other hazards not specified in the table include:

- *Risk Related to Moving Parts:*

Moving parts on machinery must be design in such a way as to prevent contact which could lead to harm or injury, if there is any risk of exposure, fixed barrier guarding must be utilised. The fixed guarding must be secured by a system that requires tooling to remove.

- *Controlling Fume During Plastic Processing:*

The HSE provide guidance that will help you control the respiratory and other toxic hazards that plastics processing can produce. These can include respiratory sensitisers, irritants and carcinogens. The control mainly focuses on melt temperatures and cycle times, also ventilation, extraction and regular maintenance and cleaning of equipment limits risk factors (Hse.gov.uk, 2018).

- *Provision and Use of Work Equipment Regulations 1998 (PUWER):*

Based on observation the electrical system does not have an Emergency Stop device. PUWER requires that equipment provided for use at work is:

‘accompanied by suitable health and safety measures, such as protective devices and controls.

These will normally include emergency stop devices, adequate means of isolation from sources of energy, clearly visible markings and warning devices’ (Hse.gov.uk, 2018).

4.2 Precious Plastic Design Features

The Precious Plastics Extruder has many questionable design features:

- The Extruder design involves directly coupling the motor gearbox assembly to the screw. This method does not offer the bearings within the gearbox any protection from thrust or axial loading and may lead to premature bearing failure within the gearbox. The fundamental extruder screw operation does not involve any directional axial movement, and any axial forces are balanced from rotation. However, based on Newton's principle, the push or compression force acting on the polymer from the screw will cause an opposite and equal reaction. To counter this backward force, industrial extruder machines often use thrust bearings behind the feed entry or throat (Plasticstoday.com, 2018). Unfortunately, Precious plastics are reliant on the unknown or unspecified bearings within the gearbox to absorb these thrust forces. Not all bearings are designed with the same properties and the basic comparison chart below illustrates common bearing load characteristics.

AVERAGE RELATIVE RATINGS			
	Type	Capacity	
		Radial	Thrust
Ball Bearing	Conrad Type	Good	Fair
	Self-aligning	Fair	Fair
Straight/Cylindrical Roller Bearing	Separable inner ring non-locating	Excellent	0
	Self-contained two direction locating	Excellent	Poor
Tapered Roller Bearings	Self-aligning	Good	Fair
Spherical Roller Bearings	Self-aligning	Excellent	Good
Needle Bearings	Complete bearing	Good	0
Thrust Bearings	Single direction ball with grooved race	Poor	Excellent
	Single direction eye roller	0	Excellent

(Machinedesign.com, 2018).

- The Precious Plastic design consists of welded bracketry to mount and secure the hopper to the barrel and to secure the barrel to the main framework. Welding involves highly localised heat to the joint edges to enable the material to fuse together. Stress is setup within the component because of the expansion and contraction of the heated material and added stock (Twi-global.com, 2018). This process would have introduced distortion to the barrel and would have caused misalignment between the barrel and the screw. Through the research and benchmarking required for this design project there has been a consistent strong emphasis placed on extruder alignment within industrial/commercial machines.

‘Extruder barrel alignment is one of the most important aspects of a properly and efficiently operating plastics extrusion process. Whether it’s a blown film line, injection

moulding or extruded sheet process, the relationship between the rotational center of the thrust shaft in the gearbox and the rotational center of the screw are vital' (Henry, 2018).

The Precious Plastic design has provided a very basic fabricated angle section framework to secure and align the extruders components. This is mounted on a plywood base, coupled with the suspected weld distortion, this setup would provide a very poor platform that would prevent any type of accurate alignment of the machine. This misalignment would impact efficiency, life in-service and reliability. The parts would prematurely wear and lead to breakdown and high repair costs.

- The Precious plastic Extruder has been predominantly manufactured from mild steel. No consideration has been given to material selection and the properties required for the process. An injector barrel and screw are subjected to corrosive wear resultant from acids and other chemicals that are generated in plastic processing. Also, the material for the barrel and screw must be wear resistant. Failure to provide these properties during manufacture will result in abrasion and wear at a much quicker rate. Stainless steels in a hardened condition or Nickle alloys are generally the materials selected for industrial machines.

On reflection, to correct all of these negative aspects to the Precious Plastics design, the result would have had a major impact on the material cost and provided problems to the average hobbyist during manufacture from the added complexity of the components. Therefore, the Precious Plastics Extruder design is a fun, educational and a socially engaging design, which has successfully achieved its primary function.

5.0 Design and Development

A problem statement was generated which was an important part of the design process to define the design with a meaningful and actionable statement. A problem statement helps to guide and provide focus on the specific needs of the design (Interaction-design.org).

5.1 Problem Statement

Design and develop a polymer extruder machine, that can be housed along with three other machines into a large (40ft x 8ft x 8.5ft) shipping container. The machine will be functional, socially engaging

and educational. The machine will demonstrate polymer processing and manufacturing to transform waste plastic into useful saleable products.

The design will be shared through open sources with the intent to inspire or provide plans for individuals or small groups to build their own miniaturised polymer processing plant. The materials and components utilised must be easily accessible for purchase.

The design must consider and optimise the voice of the customers' demanded quality:

- Process Productivity (throughput)
- Process capability
- Health and Safety (machine operators / end users / observers)
- Social Engagement and Education
- Energy usage
- Reliability

The design must consider the voice of the engineers' following factors:

- Design for manufacture
- Cost of manufacture
- Life in-service
- Running Costs
- Design for maintainability

5.2 Quality Functional Development

Quality Functional Development (QFD) is a focused methodology for understanding the voice of the customer and effectively reacting with solutions to their needs and requirements. These needs can then be translated into specific plans in order to produce products. QFD is sometimes referred to by other names, including decision matrices, matrix product planning and customer driven engineering. The methodology was pioneered in Japan in the late 1960s as a type of cause and effect analysis and gained popularity as a result of its success in the automotive industry (Asq.org, 2018).

NPD-solutions.com (2018) states that there is a number of different ways the voice of the customer can be captured which include direct communication or interviews, surveys, customer specifications, and observation. The customer needs can then be summarized in a product planning matrix or House of Quality (HoQ). The matrices transform higher level 'what's' or needs into lower level 'how's' or product requirements and technical characteristics. In addition to the stated or spoken customer needs, unstated or unspoken needs or opportunities must be identified. Many needs may be assumed by the

customer and therefore, not communicated. However, it is important to present and include exciting opportunities or new capabilities. The unstated or unspoken needs are identified through the voice of the engineer, or from recognising opportunities for improvement.

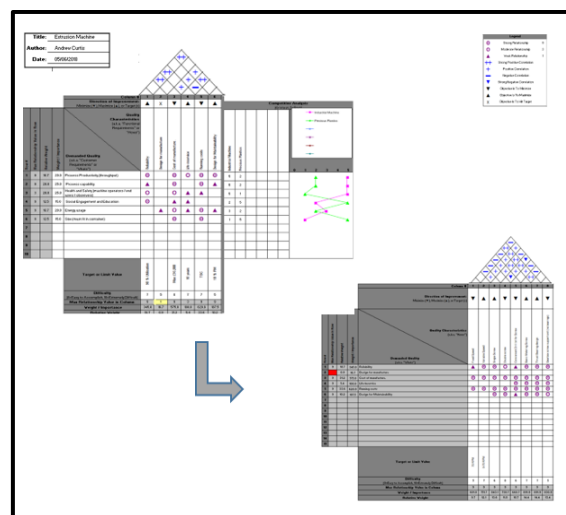
5.2.1 House of Quality

The voice of the customer or customer needs were captured for the extruder machine design through an outlined project brief and a direct communication in the form of a presentation. An affinity diagram was utilised to understand, group and summarise the customer needs. These customer needs were then entered into a HoQ matrix to establish the relationships with the product requirements. On this occasion the HoQ was concluded after two phases. However, NPD-solutions.com (2018) suggests that a normal 'Quality Function Deployment methodology involves four basic phases that occur over the course of the product development process'.

- *Phase One* – Product Planning
- *Phase Two* – Assembly/Part Deployment
- *Phase Three* – Process Planning
- *Phase Four* = Process Quality Control

Unfortunately, the customer did not communicate or specify any process target values to continue the HoQ after the second phase. This can be attributed to that the primary function of the machine is to raise awareness, educate and demonstrate as opposed to manufacture.

5.1.2 House of Quality Two Phase Flow



(Qfdonline.com, 2018).

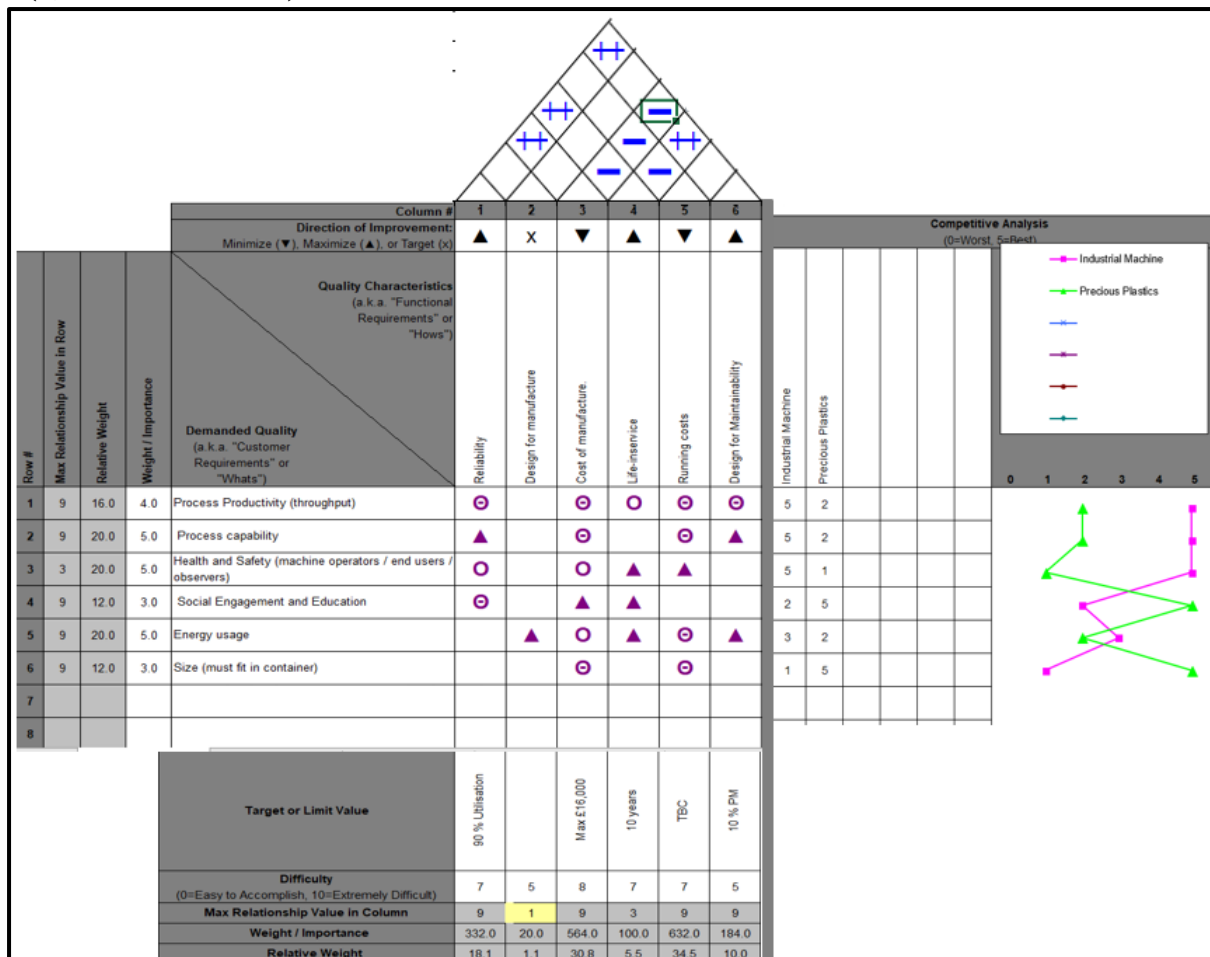
5.2.3 Phase One House of Quality Analysis - Product Planning

Phase One details customer requirements, competing or comparable product measures, and the difficulty to accomplish each customer requirement. ‘Getting good data from the customer in Phase One is critical to the success of the entire QFD process’ (Asq.org, 2018; Fme.aegean, 2018).

Title:	Extrusion Machine
Author:	Andrew Curtis
Date:	05/06/2018
Notes:	Column 2 (design for manufacture) does not appear to be a valuable requirement. This is evident by the Max Relationship Value in Column has been highlighted by the template as red.

Legend		
⊙	Strong Relationship	9
○	Moderate Relationship	3
△	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
-	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

(Qfdonline.com, 2018).



- The product requirement in Column 2 (Design for Manufacture) does not appear to be a valuable requirement as it has no bearing on customers' needs, this is evident from the HoQ

highlighting this value for concern. The reason this requirement is not applicable for the design of the Extruder Machine could be that Design of Manufacture is more associated with large production numbers, it is a methodology to reduce assembly costs. The added conceptual design and tooling costs associated with design for manufacture would be counterproductive to a one-off design such as the extruder machine.

- As evident from the HoQ there is a strong correlation between Reliability, Life in Service and Design for Maintainability. This relationship can be further explained by the need for an extensive maintenance plan to maintain machine optimisation and capability. Both of which would affect Reliability (less breakdowns) and Life in Service (prolong component life), which could all be potentially facilitated by Design for Maintainability (making maintenance quicker and easier). However, this could potentially add to the Cost of Manufacture which has resulted in a slight negative correlation.
- Running Costs and Cost of Manufacture are weighted the two highest product requirements within the matrix and special attention should be focused in this area. However, Reliability has also been weighted highly and can affect the two other requirements. If design principles are not rigorously adhered to and cheap or inexpensive parts are used, this could potentially lead to more frequent failures resulting in expensive repair costs
- To further facilitate understanding on the customer's needs, a comparison was made between the Precious Plastics extruder design and an industrial or commercial extruder. This clearly illustrated that an industrial machine has the advantage on Productivity, Capability and Safety, although Precious Plastics design appealed more to Social Engagement and education and was more size appropriate.

5.2.4 Phase Two House of Quality Analysis - Product Design

Phase two of the HoQ evaluates the design requirements and involves creativity and innovation (Asq.org, 2018; Fme.aegean, 2018). Potential product concepts components are generated and considered during this phase. Parts are evaluated for their importance to the meet the customer's needs and then deployed into early concept design.

Title:	Extrusion Machine
Author:	Andrew Curtis
Date:	05/06/2018

Legend		
⊙	Strong Relationship	9
○	Moderate Relationship	3
△	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
-	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

(Qfdonline.com, 2018).

					Column #							
					1							
					2							
					3							
					4							
					5							
					6							
					7							
					8							
					Direction of Improvement: Minimize (▼), Maximize (▲), or Target (X)							
					Quality Characteristics (a.k.a. "Hows")							
					Fixed Speed							
					Variable Speed							
					Single Screw							
					Double screw							
					Convenient Drill bit for Screw							
					Basic Metering Screw							
					Thrust Bearing design							
					Gearbox screw support unit (no bearings)							
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Whats")	1	2	3	4	5	6	7	8
1	9	18.1	332.0	Reliability	▲	○	○	○	▲	○	○	○
2	1.1	20.0		Design for manufacture								
3	9	30.8	564.0	Cost of manufacture.	○	○	○	○	○	○	○	○
4	9	5.5	100.0	Life-in-service					○	○	○	○
5	9	34.5	632.0	Running costs	○	○	○	○	○	○	○	○
6	9	10.0	184.0	Design for Maintainability			○	○	▲	○	○	○
7												
8												
					Target or Limit Value							
					Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)							
					Max Relationship Value in Column							
					Weight / Importance							
					Relative Weight							
					70 RPM	0-70 RPM	Screw Length 400 - 600mm	Screw Length 400 - 600mm	Screw Length 400 - 600mm	Screw Length 400 - 600mm	Angular Contact Bearings	
					5	7	6	8	6	7	7	5
					9	9	9	9	9	9	9	9
					605.7	750.7	841.0	732.3	664.8	890.2	890.2	829.9
					9.8	12.1	13.6	11.8	10.7	14.3	14.3	13.4

- Phase Two helps to establish more detailed design requirements and from the matrix it is evident that variable screw speed has been weighted higher than fixed speed. Variable speed and control would provide more process flexibility for different polymers with different melt temperatures.
- A single screw design has been weighted higher than a double screw. The reasoning for this evaluation can be contributed to cost. Using a single screw would drive manufacturing, running and maintenance costs down on comparison to a double screw design. However, if the machines primary function was manufacturing and output, the double screw would be favoured.
- The basic metering screw provides more efficiency, reliability and life in-service than a convenient drill bit.
- Thrust bearings within the design have been weighted higher than reliance on a gearbox. The axial load generated from the extrusion process could cause premature bearing failure within the gearbox. There is also a strong positive correlation with the basic metering screw and thrust bearings. This design feature could also be related back to HoQ one and the products requirements, not utilising these bearings could result in premature bearing failure within the gearbox which would impact Reliability and Life in-service.

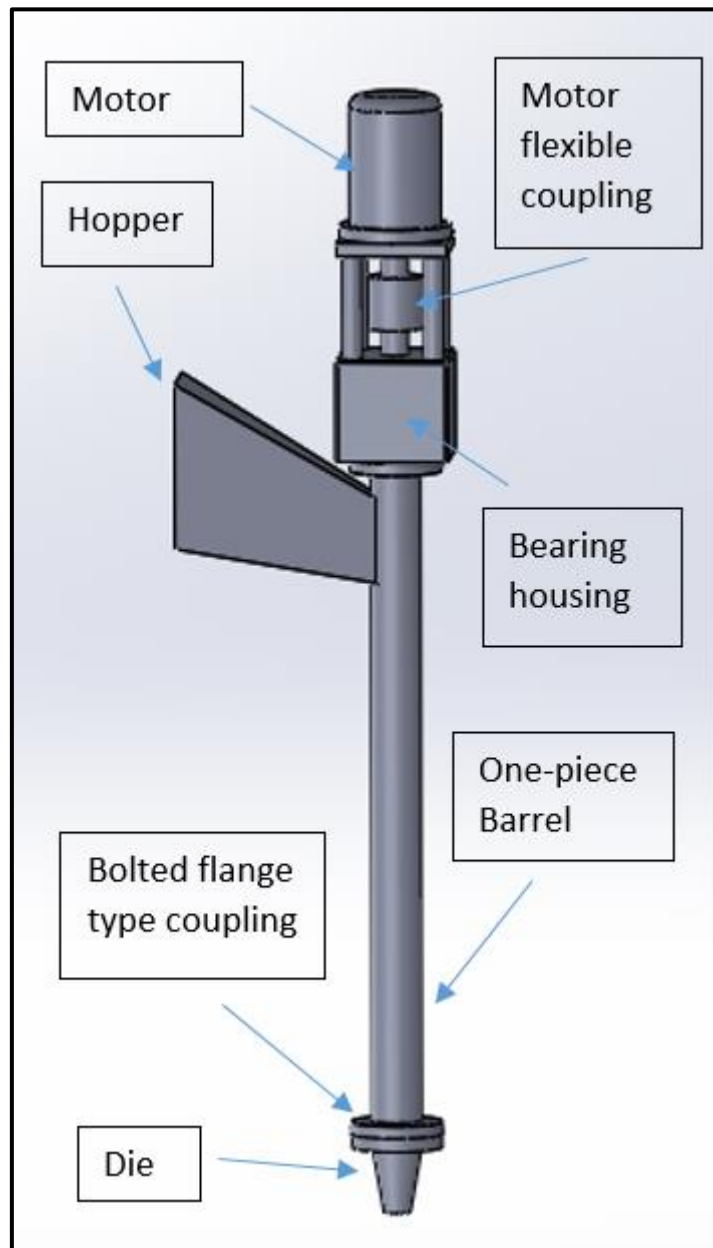
5.3 Design Specification

Once the product planning was completed, a more detailed specification was prepared to list the product requirements, technical characteristics and essential parts to include in the design. The design specification can then be used for developing design concepts.

DESIGN SPECIFICATION		
DESCRIPTION: EXTRUDER MACHINE		DATE: 06/05/18
SPECIFICATION CRITERIA	DESIGN REQUIREMENTS	
1	Function	Melt polymer and form into a continuous profile
2	Construction/build cost	Maximum permissible spend £16,000
3	Safety	Must comply with HSE Guidelines
4	Aesthetics	Primarily a demonstration machine and must be socially engaging and educational
5	Customer/Market	The customer's target market will be communities, schools, universities, etc
6	Materials	Readily available components and materials, although must be durable and fit for purpose.
7	Manufacture	The manufacturing process will involve a multitude of engineering disciplines
8	Environment	Housed within a standard shipping container
9	Maintenance	Easily maintainable with design considerations to facilitate a comprehensive maintenance program. Easily cleaned.
10	Size	To be housed and transported within a shipping container shared with three other machines
11	Ergonomics	The design must be stable and easily accessible for operation.
12	Documentation	Standard operating procedure, FMEA, Risk Assessment, Maintenance Schedule & Guide
13	Commissioning/Testing	Factory Acceptance Testing and Commissioning
14	Life in service	Ten year asset life expectancy
15	Productivity	Productive and abled to maximise throughput to make the initiative cost effective
16	Capability	Produce a continuous uniform profile dependant on the die profile, plasticate, mix and compress polymer to prevent porosity.
17	Reliability	Consistant in application and utilisation
19	Running cost	Economical running costs, potentially powered by solar panels.
20	Features	Single screw design/type, motor driven with variable speed control, variable temperature control, basic metering screw utilised within the design and thrust bearings arrangement on extruder screw.

Once the product planning stage had been completed, basic product design concepts were drafted. Information was gathered from benchmarking, product research and development to provide three conceptual designs. These concepts were then all analysed and evaluated within a concept selection or design isolation matrix.

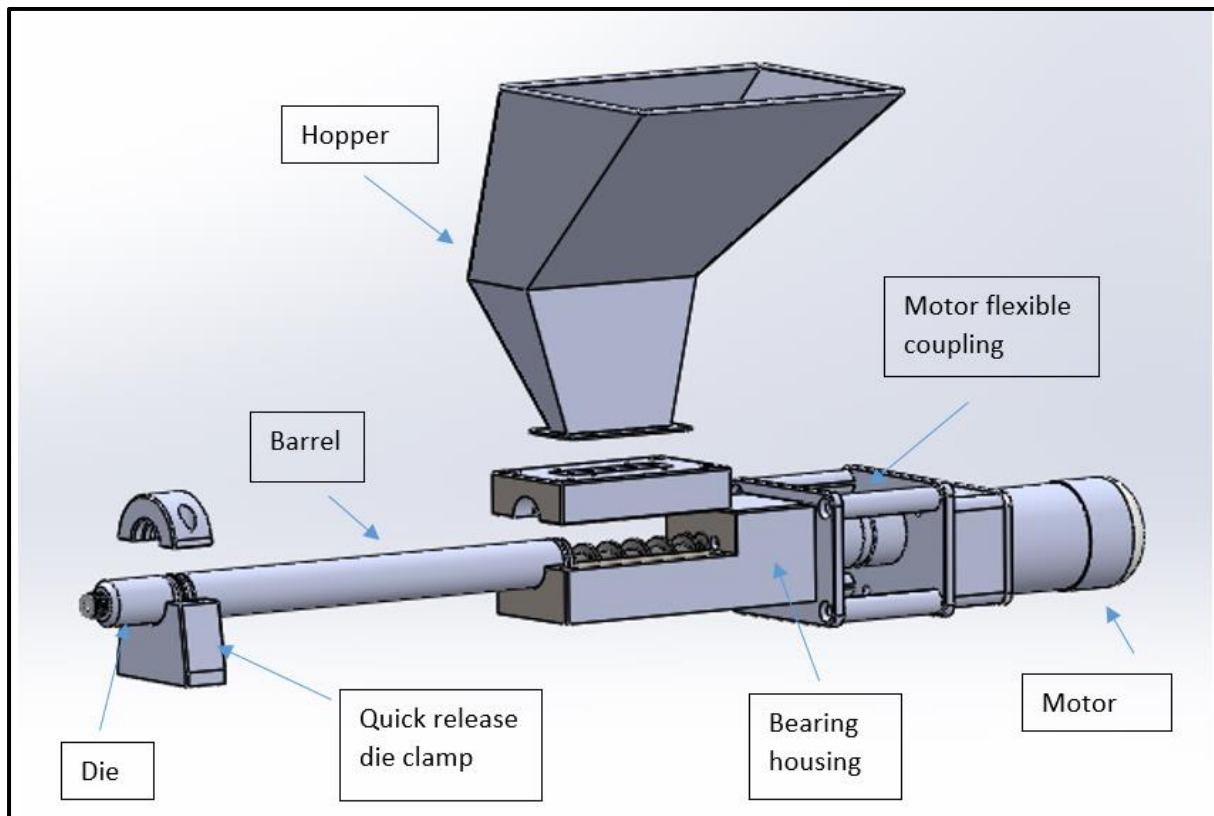
5.4 Design Concept A.



- Design Concept A. is a vertically arranged extruder.
The advantage of this orientation is that the machine has a smaller footprint and takes up less valuable space.
The disadvantages surround the design are the ergonomic factors involved in feeding the machine and a long straight run out is not possible.
- This design has a one-piece Barrel with flange connections which can slowdown maintenance and cleaning.

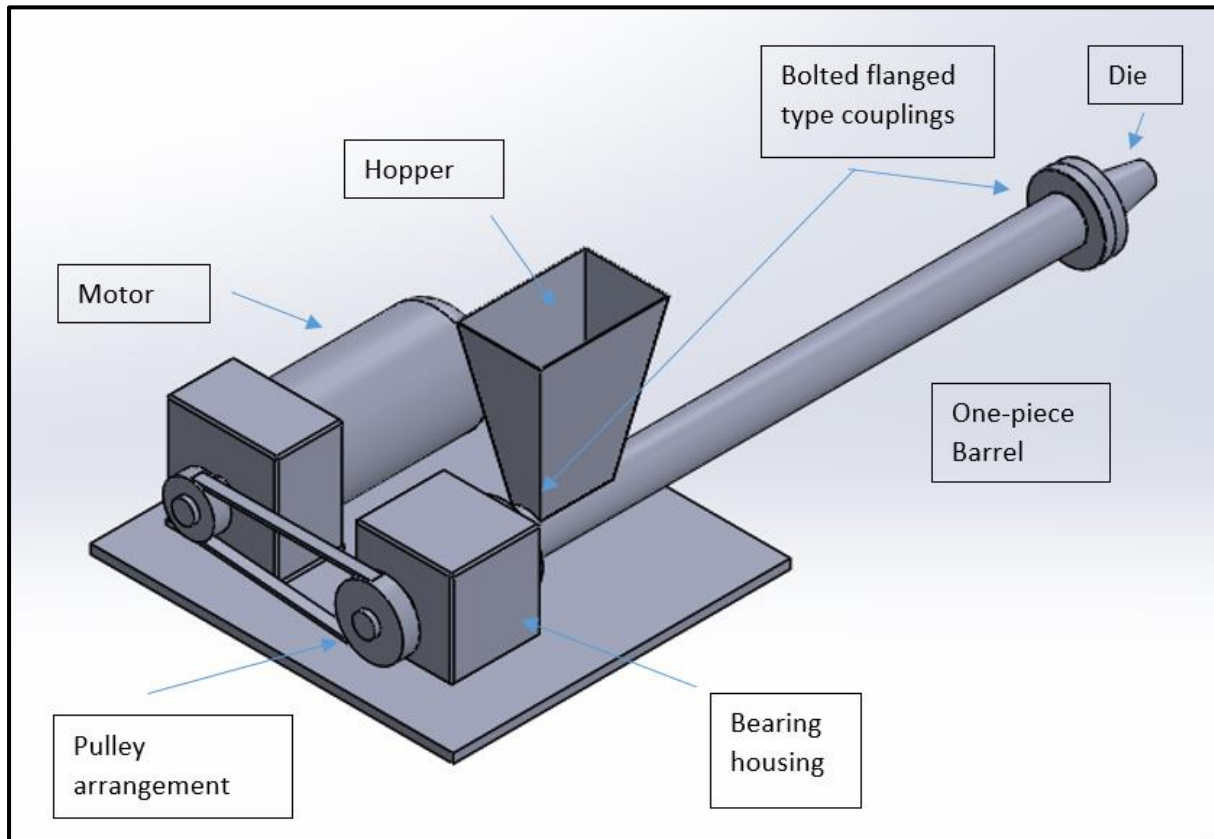
- The design incorporates a motor gearbox that couples directly to the screw. Direct coupling of motor gearbox eliminates the need for mechanical transmission elements such as timing belts, speed reducers and worm gear drives. Fewer mechanical parts minimises maintenance and reduces the system cost.

5.5 Design Concept B.



- Design Concept B. is a horizontally arrange extruder machine.
- The design once again incorporates a motor gearbox that couples directly to the screw.
- The Barrel is sectional and is easily removable for cleaning, clearing blockages and maintenance. The design has a neat clamping system to lock the sections together and the clamp at the end of the barrel also provides addition support and alignment.

5.6 Design Concept C.



- Design Concept C. is a horizontally arrange extruder machine.
- The design incorporates a motor gearbox coupled through a belt and pulley arrangement. Torque and speed can be adjusted by altering the pulley ratio. Any shock loading is also absorbed into the belt and prevented from transferring to the motor gearbox,
- This design has the same one-piece Barrel with flange connections which can slowdown maintenance and cleaning as in Design Concept A.

5.7 Design Isolation – Concept Selection Matrix

The concept selection matrix shown below lists desired design feature or technical characteristics down the left side of the matrix. An importance weighting has been applied based on a scale of 1 – 5, 1 being of little importance and 5 being very important. The concepts have then been evaluated against the design features and points can be allocated with a range of 1 – 10. Each design feature has its own key/guide to determine the correct values are added to the points system.

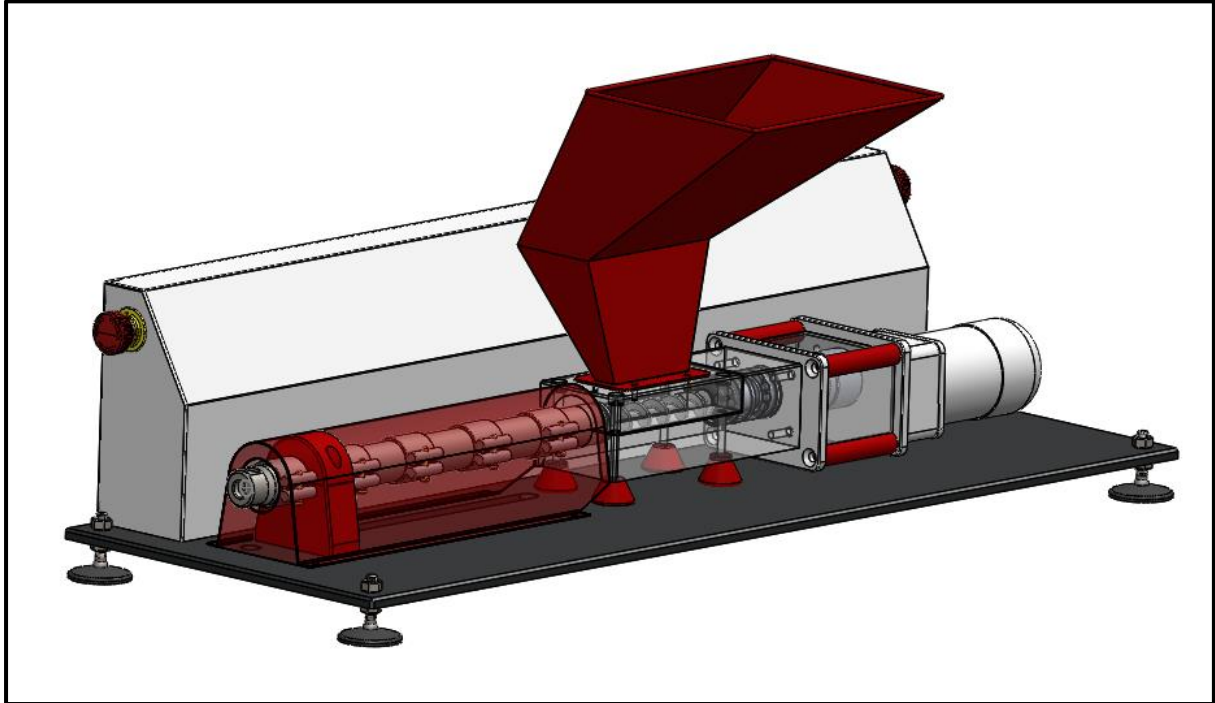
CONCEPT SELECTION MATRIX							
DESCRIPTION: EXTRUDER MACHINE				DATE: 06/05/18			
	Design Feature	Weighting	Design Concept A	Design Concept B	Design Concept C	Key	
1	Ease of Manufacture	3	7	5	7	1 = Difficult	10 = Easy
2	Ease of operation	5	4	8	8	1 = Difficult	10 = Easy
3	Life in-service	3	7	7	7	1 = Poor	10 = Excellent
4	Ease of Maintenance	4	6	10	6	1 = Easy	10 = Difficult
5	Cost of Manufacture (low cost desirable)	5	6	8	7	1 = Low	10 = High
6	Efficiency of operation	4	9	9	9	1 = Poor	10 = Excellent
7	Function	5	10	10	10	1 = Poor	10 = Excellent
Total			49	57	54		
Weighted Total			202	242	227		

CONCEPT SELECTION MATRIX KEY		
DESCRIPTION: EXTRUDER MACHINE	DATE: 06/05/18	
Importance weighting 1 - 5	1 = Little Importance	5 = Very Important

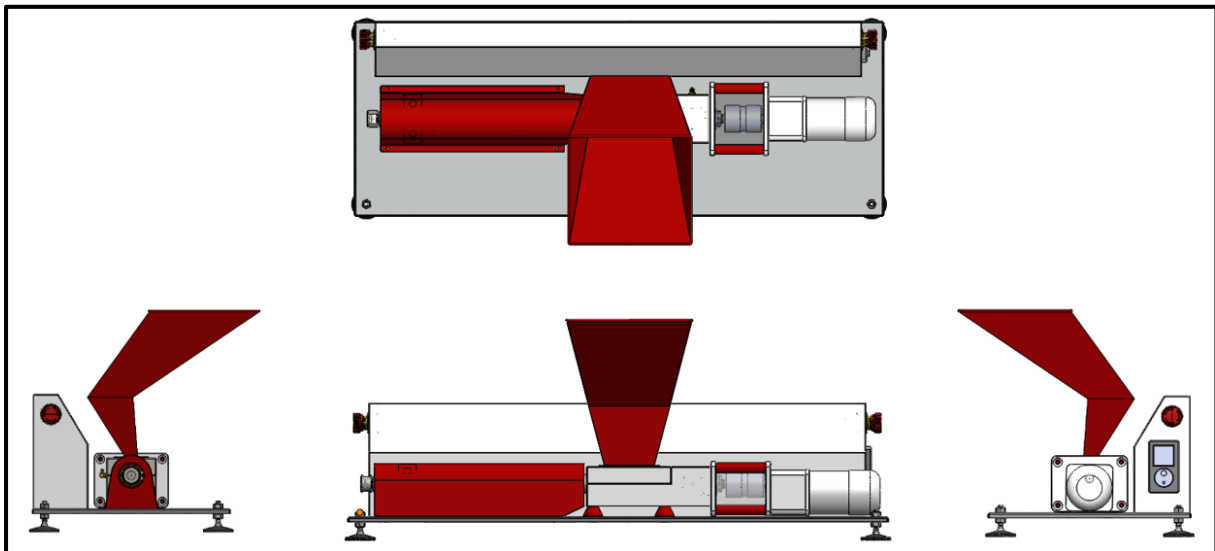
Based on the information gained from the concept selection matrix and other evaluation steps, Design Concept B. was selected. The design concept was further developed with critical components, design features and parts. The concept was modelled and critically evaluated on performance, reliability, and quality. Techniques such as failure modes and effects analysis (FMEA) have be used to determine concept reliability.

5.8 Extruder Machine Final Design

General Arrangement 3D Model:



General Arrangement Third Angle Projection:



6.0 Extruder Design Features

6.1 Screw and Barrel design

6.1.1 Extruder Screw

The fundamental mechanics of an extruder screw are simply that it revolves within a heated barrel or tube with the function to homogenise and convey polymer to the extrusion die. The screw has three resistances or forces to overcome:

- Friction of solids between the barrel wall and each other in the feed zone
- Adhesion of the melt to the barrel wall
- Resistance to flow within the melt as it is pushed forward (Plasticstoday.com, 2018).

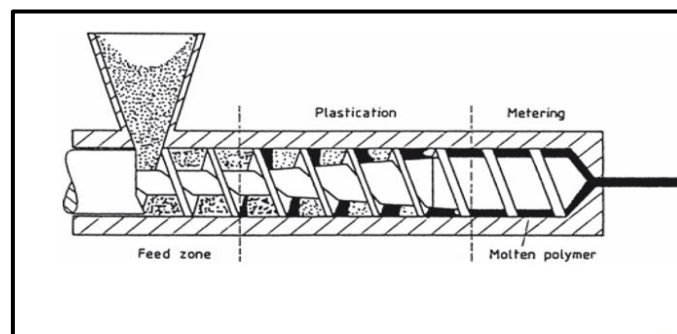
The screw does not move in an axial direction and any axial forces are balanced from rotation. However, from Newton's principle the push force acting on the screw from the polymer compression will cause an opposite and equal reaction in the other direction. Thrust bearings are often utilised behind the feed entry to absorb the backward force (Plasticstoday.com, 2018).

6.1.2 Basic Metering Three-Zone Screw

The extruder screw of a standard plasticating extruder has three different zones, whose functions can be described as follows:

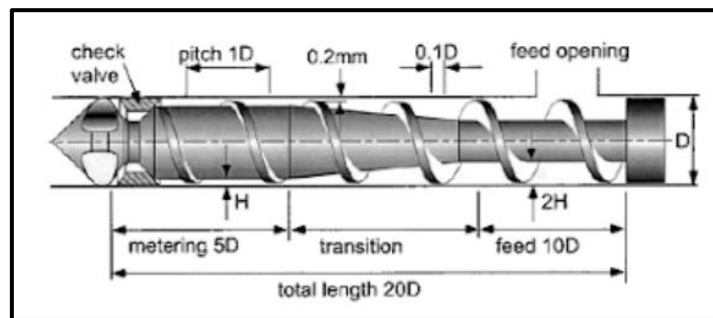
- Feed zone: Transport and preheating of the solid material
- Transition zone: Compression and plastication of the polymer (trapped air is also forced from the melt).

Metering zone: Melt conveying, melt mixing and pumping of the melt to the die. These processes often overlap and continue or occur in the corresponding zones also.



6.1.3 Screw Geometry

Below is an illustration of a general purpose solid conveying screw used in 'plasticating'. The design illustrates a screw from an injection moulding machine, as is evident from the non-return valve on the nose of the screw. However, the plasticating principle remains the same within an extruder machine. To design a screw capable for an extrusion process, the mathematical description of the screw geometry must be understood (Hanserpublications.com, 2018).



The following equations apply to three-zone screws, they can be used segment wise for designing screws of other geometries as well:

Screw diameter (D)	=	<u>25mm</u>
Total length ($20D$)	=	<u>500mm</u>
Pitch ($1D$)	=	<u>25mm</u>
Metering zone ($5D$)	=	<u>125mm</u>
Feed zone ($10D$)	=	<u>250mm</u>
Metering zone depth (H)	=	<u>2.5mm</u>
Feed zone depth ($2H$)	=	<u>5mm</u>

Womer 2000 states as a general rule of thumb typically on smooth bore extruders, the feed section of an extrusion screw should not be deeper than:

$$Fd_{\max} = 0.2 \text{ (Screw Diameter)}$$

Where $Fd_{\max}$ equates to maximum depth of feed zone. This is to prevent extruders with a 2.5-inch diameter screw or smaller from sustaining damage from torque.

6.1.4 Extrusion Machine Definition Calculations

L/D Ratio

Many manufactures define their extrusion screws with L/D Ratio (length per diameter ratio).

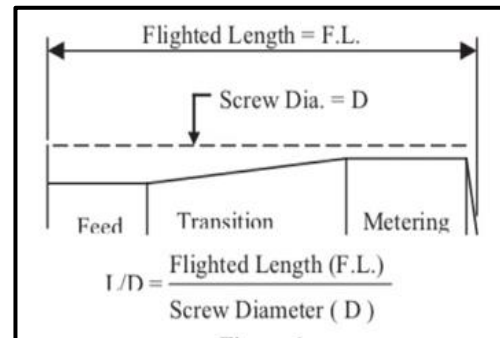
$$\text{Screw diameter } (D) = \underline{25\text{mm}}$$

$$\text{Total Length } (20D) = \underline{500\text{mm}}$$

$$L/D \text{ Ratio} = FL/D$$

$$= 500/25$$

$$= \underline{20:1}$$



(Womer, 2000).

An original equipment manufacturer would classify an extruder machine with this screw as a 20:1 L/D Extruder (Womer, 2000).

Compression Ratio

The ratio of the feed zone channel depth to the meter zone channel depth is referred to as compression ratio, typical ranges are 1.5:1 to 4.5:1 for most thermoplastic materials. Most extrusion screws classified as general purpose have a compression ratio of 2:1 to 3.:1. Thermoset screws have a 1:1 ratio. The higher the compression ratio, the greater the:

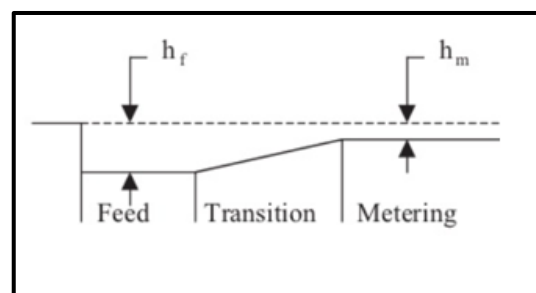
- Shear heat imparted to the resin;
- Heat uniformity of the melt;
- Potential for creating stresses in some resins;
- Energy consumption.

(Womer, 2000).

$$\text{Compression Ratio} = h_f / h_m$$

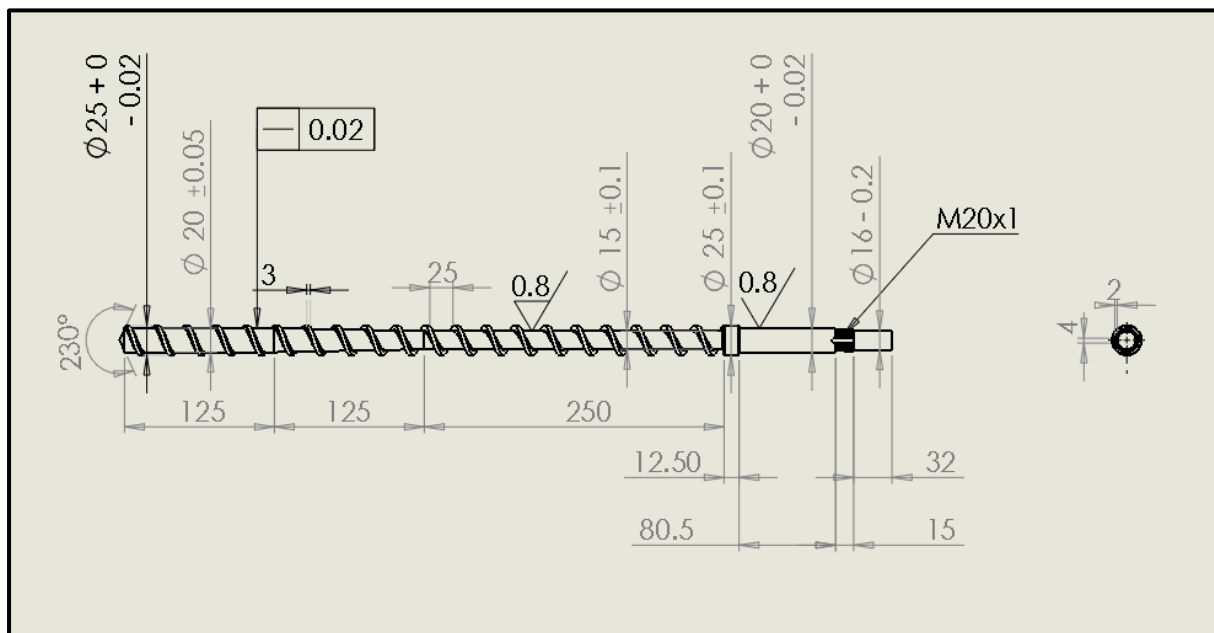
$$= 5 / 2.5$$

$$= \underline{2:1}$$



6.1.5 Extruder Screw Geometry and Size Summary

Screw Geometry Summary	
Description	Value
Screw Diameter	25
Total length (flighted Length)	500
Feed Length	250
Compression Length	125
Metering Length	125
Pitch	25
Feed Depth	5
Metering Depth	2.5
L/D Ratio	20.1
Compression Ration	2:1



6.2 Bearing Selection and Housing Design

6.2.1 Bearing Selection

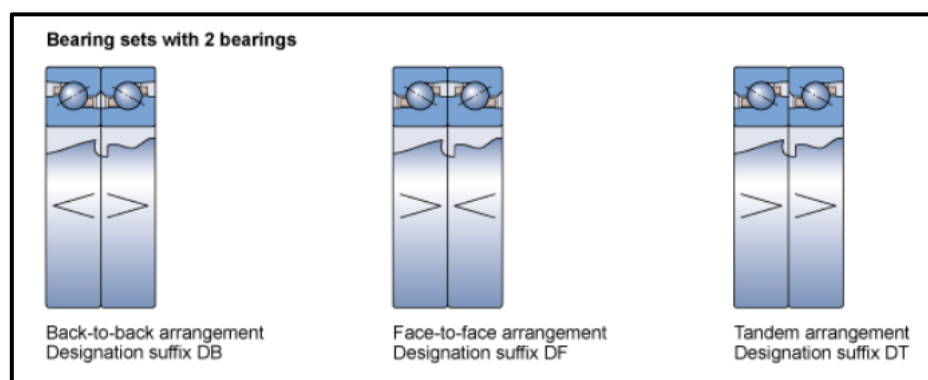
Angular contact ball bearings were chosen for this design as these bearings have inner and outer ring raceways that are displaced relative to each other in the direction of the bearing axis. This enables these bearings to accommodate combined loads, i.e. simultaneously acting radial and axial loads (SKF.com, 2018). The extrusion process creates axial forces when conveying polymer through the barrel. The characteristics of these bearings will provide the fundamental design requirements for the process and also protect the gearbox from these forces.



The single row angular contact ball bearing selected can accommodate axial loads in one direction only. The typical arrangement for this type of bearing is to provide adjustment against a second bearing. The bearing is non-separable and have rings with an upper and a lower shoulder (SKF.com, 2018).

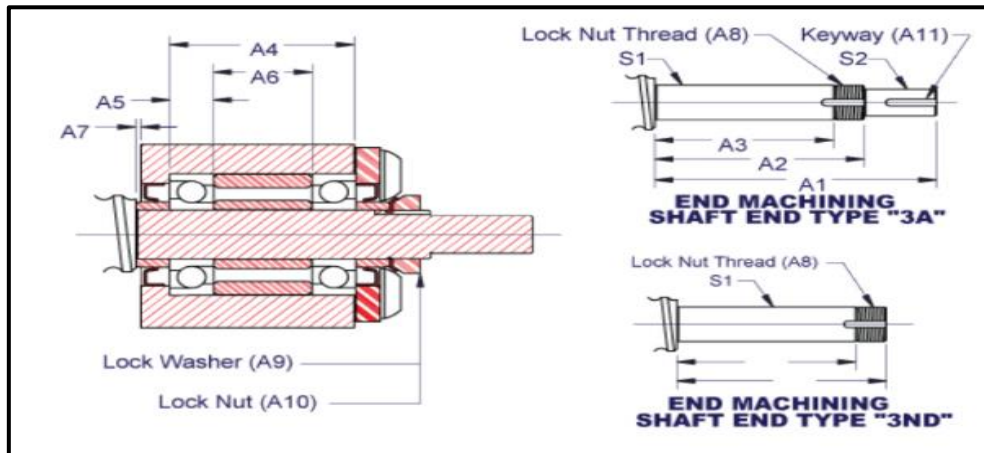
6.2.2 Bearing arrangement

Single row angular contact bearings can be arranged in different ways to meet different design applications. The possible two set bearing arrangements are shown below (SKF.com, 2018).



The back-to-back bearing arrangement was selected for the Extruder design to provide a rigid bearing arrangement. This bearing arrangement is often used on ball screw bearing mounts to provide fixed rigid support to both axial and radial load forces as illustrated below (Rockfordballscrew.com, 2018).

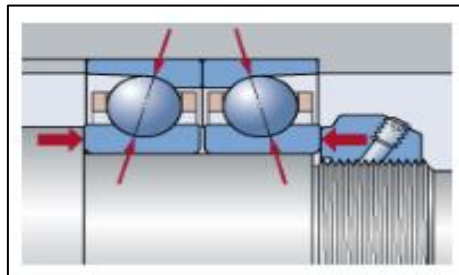
Fixed Angular Bearing Mount (Rockford Ball Screw)



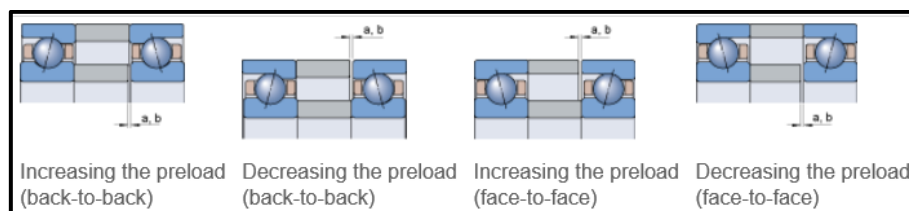
(Rockfordballscrew.com, 2018).

6.2.3 Bearing Pre-Load

Single row angular contact bearings require pre-loading during installation. The pre-load is achieved when two bearings are fitted in the face to face or back to back arrangement and one bearing ring is displaced axially relative to the other (SKF.com, 2018).

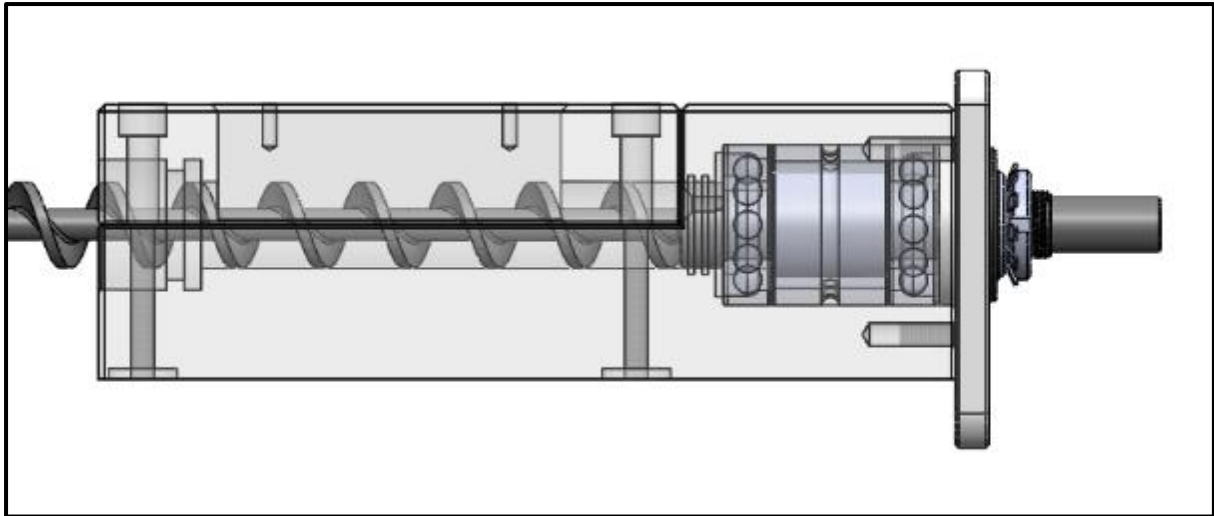


The standard pre-load is determined by the bearing manufacturer and the standard is precision ground for when two bearings are mounted adjacent to each other, a given pre-load is obtained without further adjustment. However, if further pre-loading of the bearing is required to meet a design requirement, the inner and outer spacer rings can be altered as illustrated below (SKF.com, 2018).

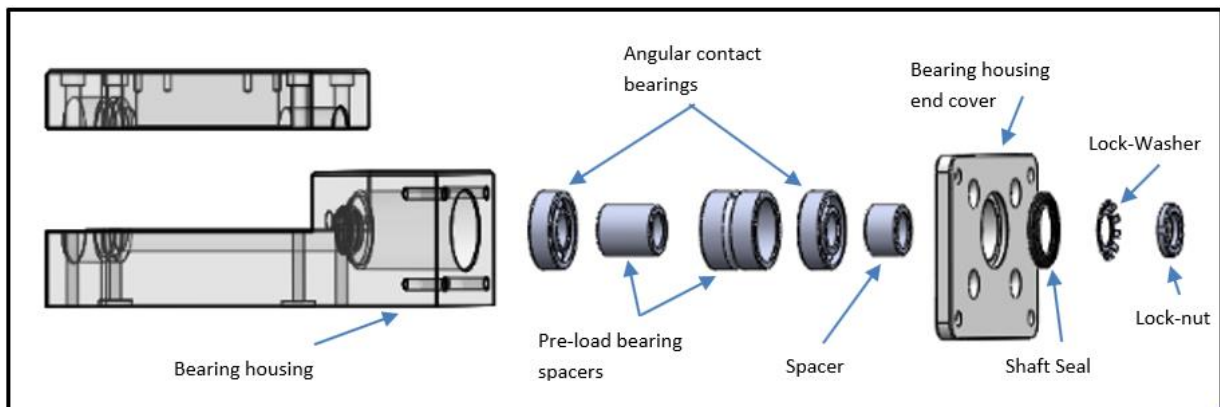


SKF.com (2018) recommend that unless preload is to be adjusted, the overall width of the inner and outer spacer rings should be identical. The most accurate way to do this is to process the width of the concentric inner and outer spacer rings in one operation.

6.2.4 Bearing Assembly



6.2.5 Bearing Assembly Exploded View

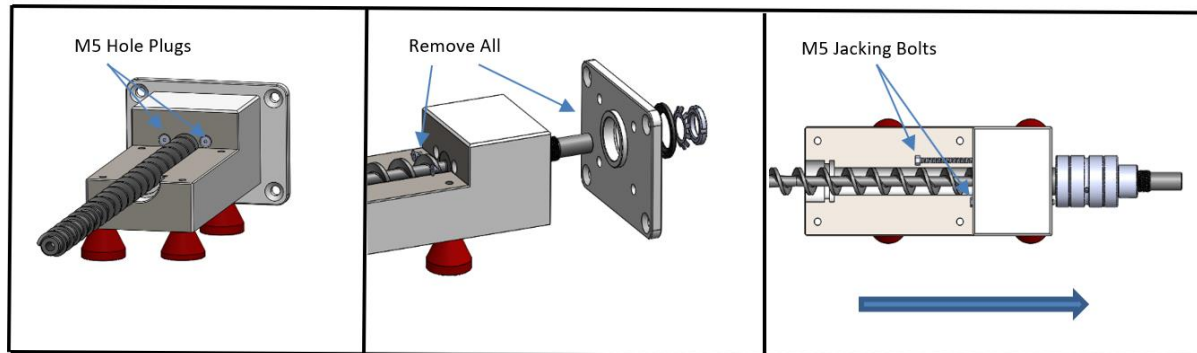


6.3 Bearing Seals

The drive side of the extruder bearing housing is sealed with a single lip rotational shaft seal to prevent ingress of contaminants and egress of the lubrication. However, the free side of the screw required extra consideration because of the additional heat and potential of contaminants from extruding. The sealing arrangement chosen was to utilise Dupont Kalrez Spectrum 7090 perfluoroelastomer o rings in a dynamic o ring arrangement and sizing. These o rings have excellent mechanical properties and can continue service in temperatures of 325°C (Dupont.com, 2018). Appendix E. O ring Data Sheets provides further information.

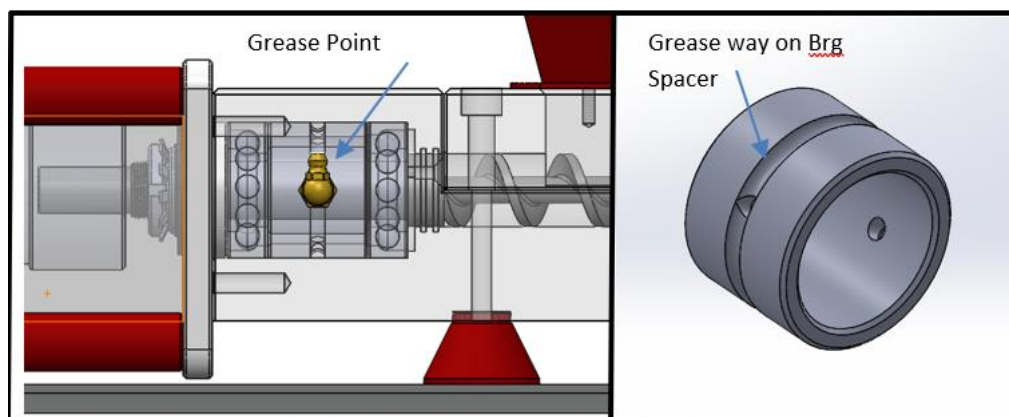
6.4 Bearing housing Maintenance

The bearing housing has a design feature to assist with bearing removal on failure or maintenance. Jacking points have been added to allow M5 bolts to drive the bearings out of the housing. In normal operation the jacking holes are plugged with M5 countersunk bolts.



6.5 Bearing Lubrication

Lubrication of the bearings can be provided through a grease point located to the rear of the housing. The grease can be applied via a manual grease gun which is directed via a grease way machined into the outer bearing spacer. The grease way will deliver the grease to both bearings.



The primary grease application on assembly should involve complete fill of the free space in the bearing. Also, the free space in the housing should be filled to 20 to 40% of its volume. A 20% grease fill is required when bearings have to be re-lubricated via the lubrication point (SKF.com, 2018).

6.5.1 Lubrication Selection

The recommended lubrication provided by SKF is ELGET 2, primarily for the high temperature application and the potential thermal conduction from the extruder screw. The Extruder Machine will operate at temperatures of 230 °C and will require a lubricant designed for this application.

Basic bearing grease selection		
Generally use if:		
Speed = M, Temperature = M and Load = M	LGMT 2	General purpose
Unless:		
Expected bearing temperature continuously >100 °C (210 °F)	LGHP 2	High temperature
Expected bearing temperature continuously >150 °C (300 °F), demands for radiation resistance	LGET 2	Extremely high temperature
Low ambient -50 °C (-60 °F), expected bearing temperature <50 °C (120 °F)	LGLT 2	Low temperature
Shock loads, heavy loads, frequent start-up / shut-down	LGEP 2	High load
Food processing industry	LGFP 2	Food processing
Biodegradable, demands for low toxicity	LGGB 2	Biodegradable

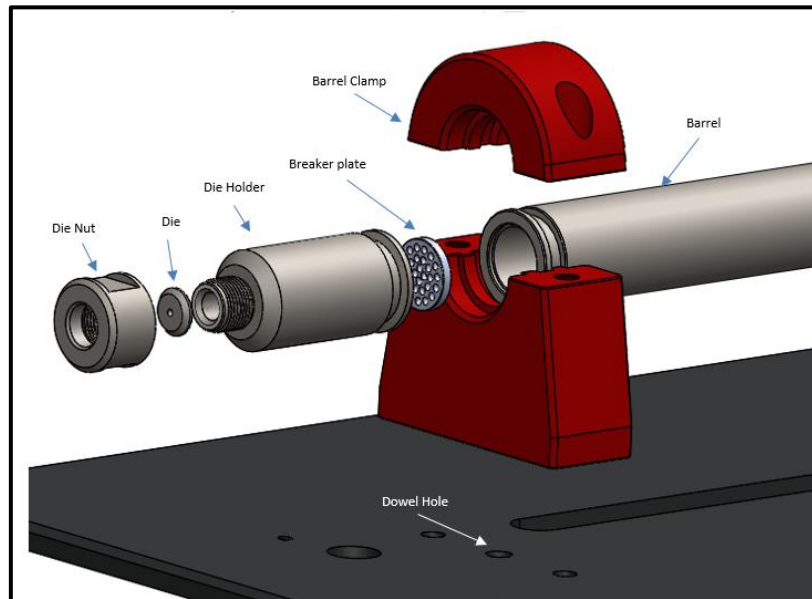
SKF LGET 2 is a synthetic fluorinated oil-based grease, using a PTFE thickener. It is especially suitable for applications at extremely high temperatures from 200 °C (390 °F) up to 260 °C (500 °F).

- Long life in aggressive environments such as very reactive areas with a presence of high purity gaseous oxygen and hexane
- Excellent oxidation resistance
- Good corrosion resistance
- Excellent water and steam resistance
- Typical applications:

Bakery equipment (ovens)	Kiln truck wheels
Load rollers in copying machines	Wafer baking machines
Textile dryers	Film stretching tenders
Electric motors running at extreme temperatures	Emergency / hot fans
Vacuum pumps	

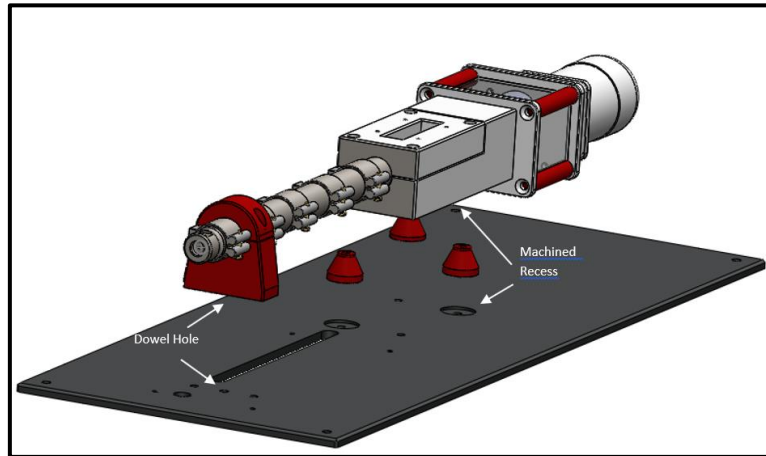
(SKF.com, 2018)

7.0 Die and Breaker Plate



- The Die is locked in place using a holder and nut.
- The Die, Holder and Nut have chamfered faces for alignment, sealing and seating.
- The breaker plate is housed in a recess between the barrel and die holder.
- The breaker plate provides the following functions:
 - It helps to further increase back pressure.
 - It turns rotational flow of the melt into floe parallel to the screw axis.
 - It holds back impurities.
 - It holds back unplasticised material (Pifallsinmoulding.com, 2018).
- The barrel clamp provides alignment of the barrel and screw through the dowelled arrangement, support and quick access to the breaker plate.

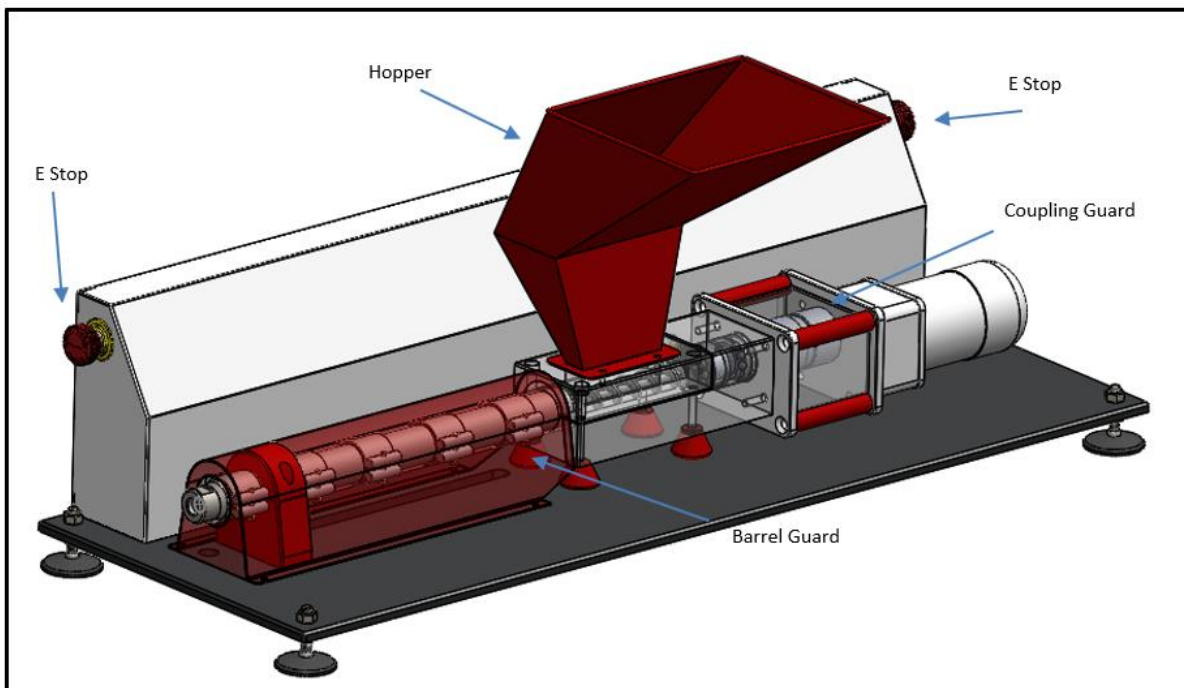
8.0 Machine Alignment



- The Design includes alignment feature to ensure after maintenance or cleaning accurate geometry and alignment is maintained.
- The feet are multifunctional and provide the correct height, anchor the machine to the base and act as dowels for alignment.

9.0 Design for Safety

Extruder Machine Safety Features:



The Extruder Machine has been designed to conform to the HSE's guidelines to include section 6 of the Health and Safety at Work Act 1974 which states:

‘...any person who designs, manufactures, imports or supplies any article for use at work...to ensure, so far as is reasonably practicable, that the article is so designed and constructed that it will be safe and without risks to health...’ (Hse.gov.uk, 2018).

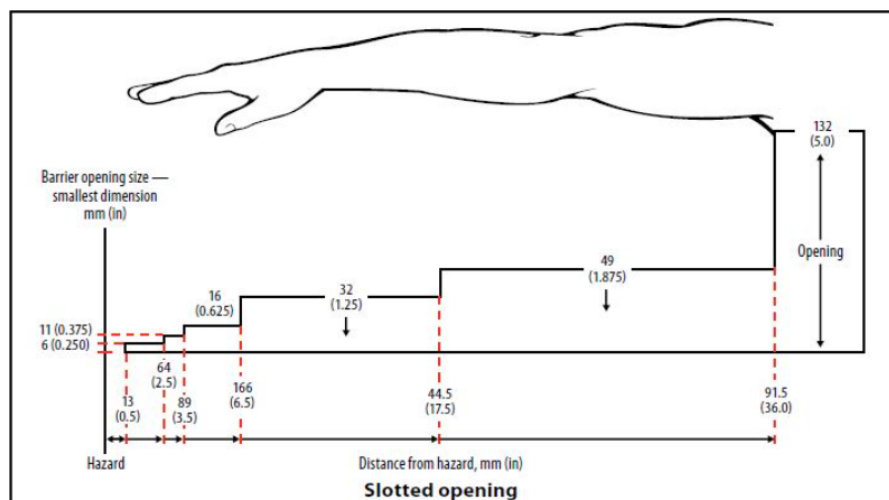
9.1 Guarding

9.1.1 Hopper

The Extruder Machine Hopper fundamentally provides two functions for the machine, the first is to funnel polymer granules to the feed screw and the second is to provide a point-of-operation guard (also known as feed guarding). Hand-feeding equipment usually presents the highest risk of injury to a worker. Feed guards must be carefully designed to ensure that an operators hand cannot access the danger point (HSEwebsite.com (2018)).

The Hopper could not be designed to provide a safe distance that complies with BS EN ISO 13857. The permissible safe distance stated by HSEwebsite.com (2018) for a slot or opening of greater than 49 mm is 915 mm. Ergonomic factors would have prevented the practicality of feeding the extruder with such a long and high hopper. Alternatively, the hopper has been designed to incorporate an angled approach to the feed zone to prevent any access to the rotating screw. HSEwebsite.com (2018) also stipulate ‘that if the hopper and/or the feed throat is removable, then these should either be interlocked with the screw drive, or access to the screw should be prevented by a fixed grille’.

HSEwebsite.com (2018) - horizontal slotted opening permissible distance illustration:



The Hopper has also been designed with edge protection - 5 mm diameter round bar is to be tack welded around the opening of the Hopper to prevent any harm from sharp edges from the 1 mm mild steel sheet that the Hopper would be manufactured from.

9.1.2 Coupling Guard

To safeguard the operator from any hazards associated with revolving parts, a fixed power transmission guard has been designed. The guard is a type of barrier guard which is the preferred method of safeguarding when access is not required during normal operation.

Rotating Motion or exposed mechanisms are dangerous unless guarded. A slow rotating shaft or coupling can grasp clothing or hair and force an arm or hand into a dangerous location. Fixed or hinged guard enclosure protects against this exposure.

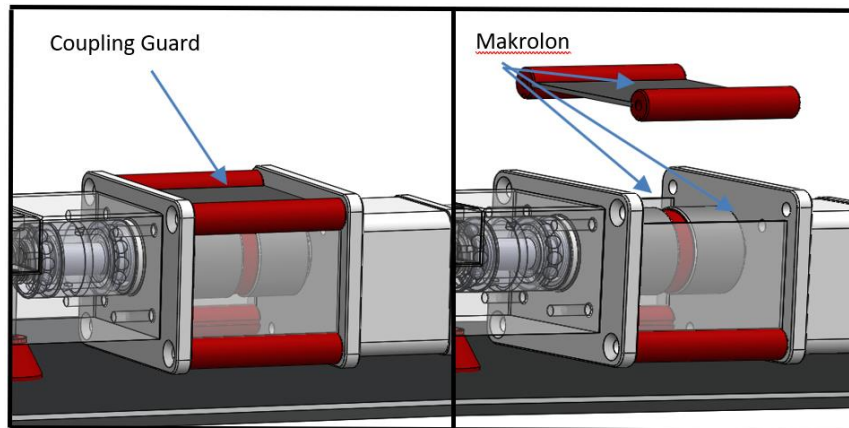
HSEwebsite.com 2018 state that a Fixed barrier guards must:

- Prevent access to the danger area from all directions (AUTO: around, under, through, over)
- Not create additional pinch points or other hazards.
- Safely contain broken parts (such as belts and chains).
- Be secured by at least one fastener requiring a tool for removal, unless properly interlocked with the machine control system.
- Allow for safe lubrication and minor adjustments.

Fixed barrier guards should:

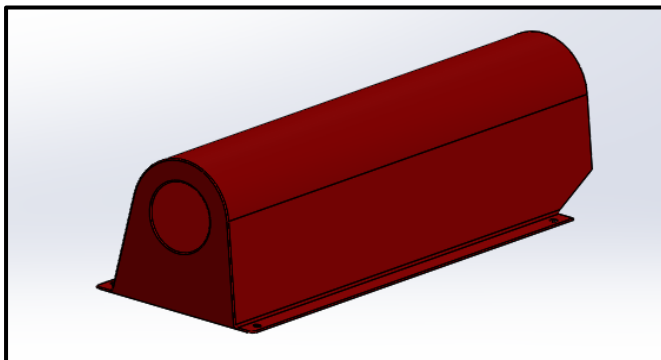
- Offer good visibility to feed points.
- Stand up to normal wear and tear.
- Meet normal production and quality needs.
- Be difficult to modify or defeat.

The coupling guard designed on the Extruder Machine consists of heat resistant polycarbonate sheet (Makrolon), which fit into machined recesses along the motor support shafts. The design is simple but functional and also provides visibility of the rotational parts.



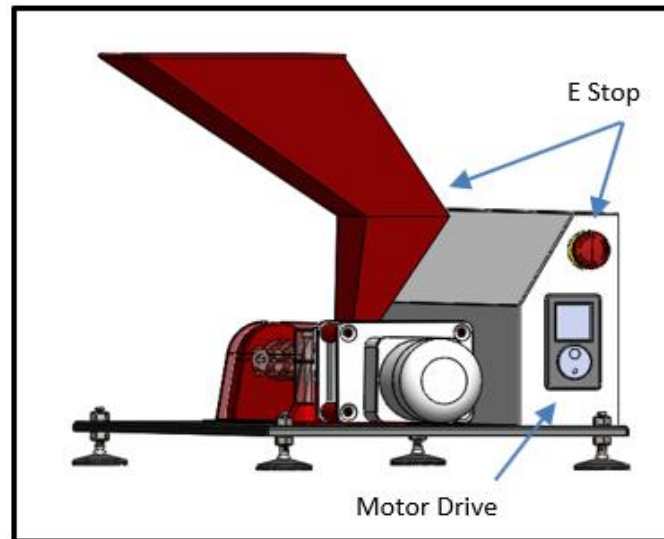
9.1.3 Barrel Guard

The barrel guard is a barrier type guard with a simple sheet metal design. HSE states that hot parts/surfaces above 80 °C require guarding or insulation against accidental contact. Where hot surfaces are necessarily exposed warning signs are required (Hse.gov.uk, 2018). The Barrel Guard design is illustrated below along with a recommended signage which can be bonded to the guard.



9.2 Electrical Safety

The Extruder Machine design concept includes two emergency stop buttons either end of the machine. Regardless to which end of the machine an operator is focusing his efforts, the machine can be stopped safely.



Motor and Drive:

The Design incorporates a motor gearbox and speed controller which can be purchased as a package to ensure there are no compatibility issues. The speed controller provides start/stop, directional control and overload features. All functions are provided from the control interface which has been mounted onto the side of the electrical enclosure. All control and operation of the screw is possible without any other systems. However, included within the design are two estops which need to be entered into the circuit. Also, additional lights and switches may be added to the system to add more appeal.

10.0 Failure Mode and Effects Analysis

FAILURE MODE AND EFFECTS ANALYSIS

Item: Extruder

FMEA number: 1

Rev: 1

Page : 1

Prepared by: Andrew Curtis

FMEA Date (Orig): 02/06/2018

Machine Component	Function	Potential Failure Mode	Potential Effect(s) of Failure	S e v	Potential Cause(s)/ Mechanism(s) of Failure	O c c u r	Current Process Controls of supplied Extruder	D e t e c	R P N	Recommended customer Action(s)	Action Results			
											S e v	O c c	D e t	R P N
Motor	Provides rotational drive	Motor electrical failure	Screw Fails to rotate	9	Over heating from incorrect setup.	3	Motor control drive overload setting. Standard operating procedure (SOP), pre-work inspection.	7	189	Training.	9	1	7	63
		Motor Mechanical Failure	Screw Fails to rotate	16	Wear	3	Standard operating procedure (SOP), pre-work inspection.	7	336	Planned Maintenance/Inspection, Replacement on manufatures recommended operating hours.	16	1	1	16
Gearbox	Provides rotational drive, reduces motor speed and increases torque.	Gearbox seized	Screw Fails to rotate,	25	Seized Bearing Gear Failure	3	Motor control drive overload setting. Operating instructions, pre-work inspection & SOP	9	675	Planned Maintenance/Inspection, Lubrication.	25	1	1	25
			Noisy operation	3	Wear, Lubrication	3	Standard operating procedure (SOP), pre-work inspection.	5	45	Planned Maintenance/Inspection, Lubrication.	3	1	1	3
Bearing	Enables shaft rotation and protects gearbox from backward thrust forces	Bearing Seized	Screw Fails to rotate,	25	Overheating, Seized.	3	Standard operating procedure (SOP), pre-work inspection.	9	675	Planned Maintenance/Inspection, Lubrication.	25	1	1	25
			Noisy operation	4	Wear, Lubrication	5	Standard operating procedure (SOP), pre-work inspection.	5	100	Planned Maintenance/Inspection, Lubrication.	4	1	1	4

Key (Pqi.org, 2018).

Probability		
Value	Description	Criteria
1	An unlikely probability of occurrence	Failure has never been seen in any relevant lab experiments, or scale-up batches yet but it is theoretically possible.
3	A remote probability of occurrence	Failure only seen once or twice in relevant lab experiments, never in scale-up batches.
5	An occasional probability of occurrence	Failure potential has been noted in several relevant lab experiments, or at scale-up. If procedures are followed the failure potential is minimal.
7	A moderate probability of occurrence	Failure potential has been noted in several relevant lab experiments, or at scale-up, in-process control maybe required to avoid failure.
9	A high probability of occurrence	Failure potential has been noted in several relevant lab experiment, or at scale-up, an active non-standard feed back control loop may be required.

Detection		
Value	Description	Criteria
1	High degree of detectability	A: Validated automatic detection system that is a direct measure of failure. B: Two or more manual operated validated detection systems, direct or indirect. (e.g. Control range and IPC)
3	Good detectability	A: Single manually operated validated detection system that is a direct measure of failure. (e.g. IPC of failure, validated PAT)
5	Likely to detect	A: Single manually operated validated detection system that is not a direct measure of failure. (e.g. PAT measurements or IPC's not directly linked to failure)
7	Fair detectability	A: Non validated (manual or automated) detection. (e.g. visual level check, visual inspection of vessels).
9	Low or no detectability	No ability to detect the failure

Severity		
Value	Description	Criteria
1	Irrelevant	No impact to product quality and process robustness
4	Slight	No impact to product quality
9	Important	Noticeable impact to product quality, but can be recovered by reprocessing
16	Critical	Definite impact to product quality that may require rework
25	Disastrous	Batch failure, not recoverable by rework

FAILURE MODE AND EFFECTS ANALYSIS

Item: Extruder

FMEA number: 1

Rev: 1

Page : 1

Prepared by: Andrew Curtis

FMEA Date (Orig): 02/06/2018

Machine Component	Function	Potential Failure Mode	Potential Effect(s) of Failure	S e v	Potential Cause(s)/ Mechanism(s) of Failure	O c c u r	Current Process Controls of supplied Extruder	D e t e c	R P N	Recommended customer Action(s)	Action Results			
											S e v	O c c	D e t	R P N
Coupling	Transitions rotation to extruder screw and corrects misalignment	Coupling wear	Screw Fails to rotate,	16	Wear, excessive misalignment	5	Standard operating procedure (SOP), pre-work inspection.	7	560	Planned Maintenance/Inspection,	16	3	1	48
			Noisy operation	4	Wear, excessive misalignment	5	Standard operating procedure (SOP), pre-work inspection.	5	100	Planned Maintenance/Inspection,	4	1	1	4
Shaft Seal	Contains lubrication within bearing housing	Worn	Lubrication leak	4	Wear through normal operation	5	Standard operating procedure (SOP), pre-work inspection.	3	60	Planned Maintenance/Inspection,	4	3	1	12
O Ring	Contains lubrication and prevents polymer or additive egress into the bearing housing	Worn	Polymer or additive egress into bearing housing causing bearing failure.	9	Wear through normal operation	5	Standard operating procedure (SOP), pre-work inspection.	9	405	Planned Maintenance/Inspection,	9	1	1	9
Screw	Plasticates and conveys polymer to die	Damage (twisted, sheared).	Screw no longer functional.	25	Incorrect setup, excessive torque	3	Motor control drive overload setting. Standard operating procedure (SOP), pre-work inspection.	5	375	Training.	25	1	5	125
		Worn	Inefficient plasticating	9	Wear through normal operation	5	Standard operating procedure (SOP), pre-work inspection.	7	315	Planned Maintenance/Inspection,	9	3	1	27
Band Heater	Provides heat to melt polymer	Electrical failure	Polymer does not melt.	16	Electrical fault	5	Standard operating procedure (SOP), pre-work inspection.	5	400	Planned Maintenance/Inspection,	16	1	1	16
Thermocouple	Measures temperature	Electrical failure	Polymer not melting or evidence of burning	16	Electrical fault	5	Standard operating procedure (SOP), pre-work inspection.	7	560	Planned Maintenance/Inspection/ Calibration.	16	1	3	48
PID Controller	Regulates temperature	Electrical failure	Polymer not melting or evidence of burning	16	Electrical fault	5	Standard operating procedure (SOP), pre-work inspection.	7	560	Planned Maintenance/Inspection/ Calibration.	16	1	1	16
Motor drive	Controls motor speed, torque and overload.	Electrical failure	Screw Fails to rotate	16	Electrical fault	3	Standard operating procedure (SOP), pre-work inspection.	5	240	Planned Maintenance/Inspection,	16	1	3	48

11.0 Conclusion

The Extruder design has offered many solutions to the voice of the customer and the design requirements established through planning, benchmarking, research and development. The machine has interesting aesthetics to appeal and socially engage members of society and can also be visually likened to a toy by design. The guarding does not only provide the essential safety aspect that conforms to the HSE's guidelines, but provides interesting angles, curves and shapes. Where possible transparent materials have been utilised to enable visualisation of the rotational components of the machine. Aesthetically, the social engagement and educational aspect of this machine is far more appealing than the Precious Plastics design.

Polymer processing and industrial extrusion machines were extensively researched to provide the necessary theory and engineering principals required to prepare an effective extruder design. Screw geometry was calculated on current technologies to design and specify the extruder screw and barrel to ensure machine capability and maximise productivity. The design focused specifically in these areas to maximise efficiency and to lower running costs when in production. The design provides flexibility and adaptability through its use of variable speed control on the screw. This feature will assist setup for different polymer types with different melt temperatures. The barrel has been designed to provide enough capacity for five band heaters, one of which can be fitted directly to the die if required. The control for the barrel heating has not been specified within the design. Further development is needed to evaluate which system would be most applicable and cost effective for this application. However, the electrical enclosure has the capacity to mount five standard sized temperature controllers, which would be visually and ergonomically practical in regard to the machine's build orientation. All cable management has been considered within the design, to include the electrical enclosure and cable routing through pre-drilled/slotted holes within the machine base.

Careful consideration has been given to the design for ease and speed of maintenance. Throughout the research required for this project, high emphasis has been constantly placed on the requirement of an intensive maintenance program, to include regular cleaning operations which are needed to sustain optimum running conditions. The machine barrel and die are easily removable with the integrated clamping feature. This quick clamping feature also provides easy access to the breaker plate when blockages occur. Re-alignment of the machine after maintenance has also been considered, two of the feet on the bearing housing also provide alignment from close tolerance fits between the machine base and the housing. The barrel clamp design is also dowelled to the machine base to provide quick and accurate alignment.

One other factor which has not been specified within the design is material selection. As previously described within the Precious Plastics Extruder Critical Analysis, the extruder barrel and screw are

subjected to corrosive wear from acids and other chemicals that are generated in plastic processing. Also, the material for the barrel and screw must be wear resistant. Failure to provide these properties during manufacture will result in abrasion and wear at a much quicker rate. Stainless steels in a hardened condition or Nickel alloys are generally the materials selected for industrial machines. However, these materials are very expensive and difficult to work with. The total costs for the components involved in manufacturing this Extruder are low, although manufacturing costs and costs for materials could be potentially high if the correct materials were used. Predominantly it would be the customer choice as the design provides flexibility and adaptability which through commissioning and testing would meet all polymer extrusion needs and could be a profitable machine.

During the commissioning and testing phase of this machine it would be necessary to develop a standard operating procedure to comply with the HSE's legislation guideline. The maintenance program would also have to be built around the material selection to factor in component wear.

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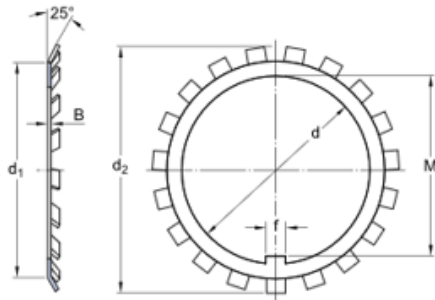
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Appendix A: Locking Nut and Washer Data Sheet

► MB 4

Dimensions



d	20	mm
d ₁	26	mm
d ₂	36	mm
B	1	mm
f	4	mm
M	18.5	mm

Mass

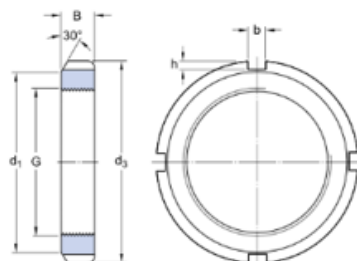
Mass lock washer

0.004 kg

<http://www.skf.com/group/products/bearings-units-housings/bearing-accessories/lock-nuts/requiring-keyway/mb-l-lock-washers/index.html?designation=MB%204>

► KM 4

Dimensions



G	M 20x1	
d ₃	32	mm
B	6	mm
d ₁	26	mm
b	4	mm
h	2	mm

Calculation data

Axial static load carrying capacity

24 kN

Mass

Mass lock nut

0.025 kg

Mounting information

Associated spanner

HN 4

Associated products

Lock washer / Locking clip

MB 4

<http://www.skf.com/group/products/bearings-units-housings/bearing-accessories/lock-nuts/requiring-keyway/kml-lock-nuts/index.html?designation=KM%204&unit=metricUnit>

Appendix B. Motor and Drive Package Data Sheet



AC Motor & Driver Packages (US2)

US2 Series
AC Motor and Driver Package

Type
US2-590EC-100

Features

- ✓ Easy handling
- ✓ Simple to install
- ✓ Many functions

Order information
All prices excluding VAT & possible shipping costs, shipping time: **approx. 7 Day(s)**

 [Characteristic](#)

 [Dimensions](#)

Online price £198.00

* Already includes the 10% discount on the list price.



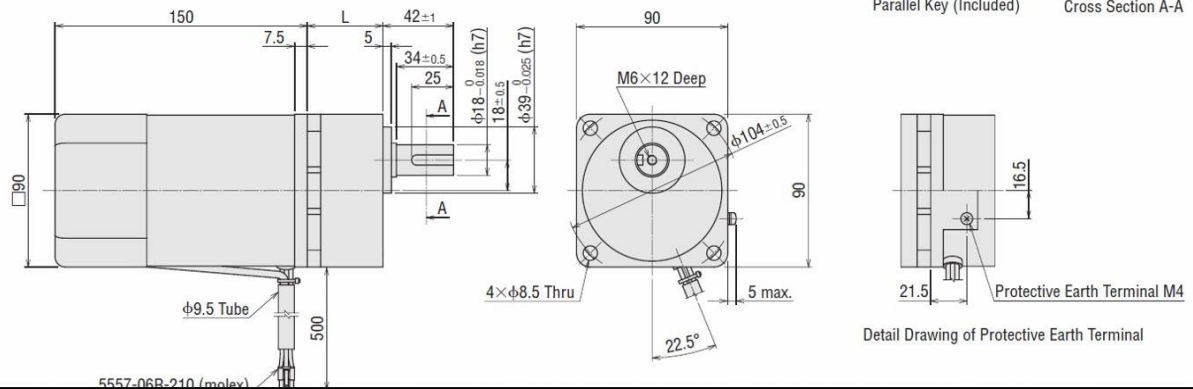
Parallel Shaft Combination Type

Maximum Permissible Torque 40 N·m

Output Power	6 W/15 W/25 W/40 W/60 W/90 W
Power Supply	Single-Phase 110 VAC/115 VAC
Voltage	Single-Phase 220 VAC/230 VAC

◇ 90 W

Product Name	Motor Product Name	Gearhead Product Name	Gear Ratio	L	Mass kg
US2-590UA -□	SCM590GVR-UA	5GVR□B	5~15	45	4.8
US2-590EC -□	SCM590GVR-EC		18~36	58	
			50~180	70	



Product Number Code

US2 - 4 25 EC - 50 - 3

① ② ③ ④ ⑤ ⑥

①	Series Name	US2: US2 Series
②	Motor Frame Size	2: 60 mm 3: 70 mm 4: 80 mm 5: 90 mm
③	Output Power (W)	(e.g.) 25: 25 W
④	Power Supply Voltage	EC: Single-Phase 220/230 VAC
⑤	Gear Ratio/Shaft Configuration	Number: Gear Ratio for Combination Type A: Round Shaft Type
⑥	Connection Cable	Number: Motor Cable is included Length -1: 1 m -2: 2 m -3: 3 m None: Cable not included

● Examples of product names that indicate connection cable availability and length

3 m connection cable included → **US2-425EC-50-3**

Connection cable not included → **US2-425EC-50**

[https://www.oriental-](https://www.oriental-motor.co.uk/Products/Ac_motors/Ac_motors_with_speed_control/Motor_driver_packages_us2/?&feld153=50+Hz%3A+40+Nm&arid=20809&dwn=artnr)

[motor.co.uk/Products/Ac_motors/Ac_motors_with_speed_control/Motor_driver_packages_us2/?&feld153=50+Hz%3A+40+Nm&arid=20809&dwn=artnr](https://www.oriental-motor.co.uk/Products/Ac_motors/Ac_motors_with_speed_control/Motor_driver_packages_us2/?&feld153=50+Hz%3A+40+Nm&arid=20809&dwn=artnr)

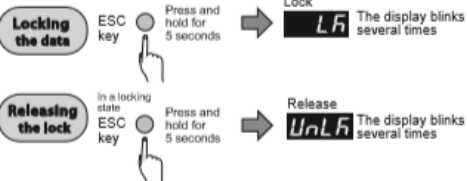
Many other useful features are also available

Various settings can be performed when removing the front panel.

When the front panel is removed



To lock so that the setting does not change



You can lock or release only when the display shows the rotation speed.

And others.....

- ▶▶ To display the rotation speed of the gearhead output shaft
- ▶▶ To limit the setting range of the rotation speed
- ▶▶ To start and stop the motor slowly



OPERATING MANUAL

Refer to "6 Convenient functions"

© Copyright ORIENTAL MOTOR CO., LTD. 2015

ORIENTALMOTOR CO., LTD.

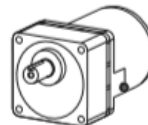
Orientalmotor



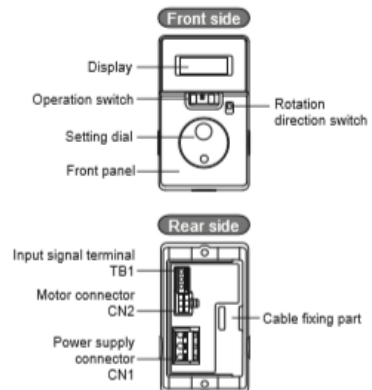
Speed Control Motor and Controller Package US2 Series

QUICK START GUIDE

Motor



Speed controller



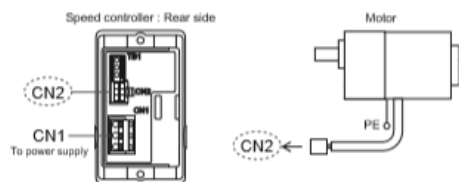
Thank you for purchasing an Oriental Motor product.

Use the product correctly after thoroughly reading the section "Safety precautions" of the operating manual. For more information about how to use the product, refer to the separate **OPERATING MANUAL**.

1 Connecting

OPERATING MANUAL
Refer to "4 Connecting"

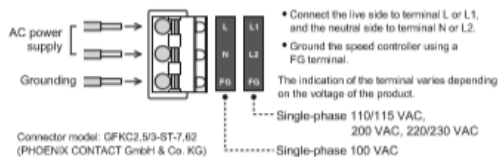
Insert the motor connector in the speed controller connector.



- Ensure that the connector plugged in securely.
- Be sure to ground a motor and speed controller using the Protective Earth Terminal (PE) and FG terminal, respectively.

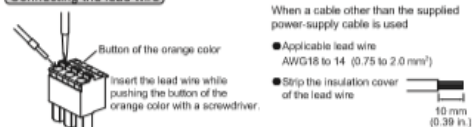
Note Ground the product securely in order to prevent electric shock or damage to the product by static electricity. The product will tend to be electrified especially in a dry environment, so it may be damaged by static electricity.

Connect an AC power supply to the CN1.



Connector model: GFKC2.5/3-ST-7 R2
(PHOENIX CONTACT GmbH & Co. KG)

Connecting the lead wire



2 Operating a motor

OPERATING MANUAL
Refer to "5 Operating"

1 Turn on the AC power supply.

Turn on the power supply after connecting. Display is lit
Indication: Rotation speed

2 Start the motor operation.

Switch the operation switch to the RUN side.
The motor starts rotating.

3 Change the speed.

Adjust the rotation speed using the setting dial of the front panel.

[Turn clockwise]

The rotation speed makes faster.

Decelerate Accelerate

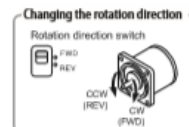
[Push]

The rotation speed has been set (stored).

The motor rotates at the set speed from the next time.

4 Stop the motor.

The motor stops when switching to the STAND-BY side.



The rotation direction varies depending on the gear ratio.

When **AL26** **AL30** etc. (alarm code) was displayed

OPERATING MANUAL
Refer to "7 Alarms"

If it did not rotate,

OPERATING MANUAL
Refer to "8 Troubleshooting"

Appendix C: Flexible Coupling Data Sheet



Flexible coupling 16 mm I 18 mm

Type
MCL551618

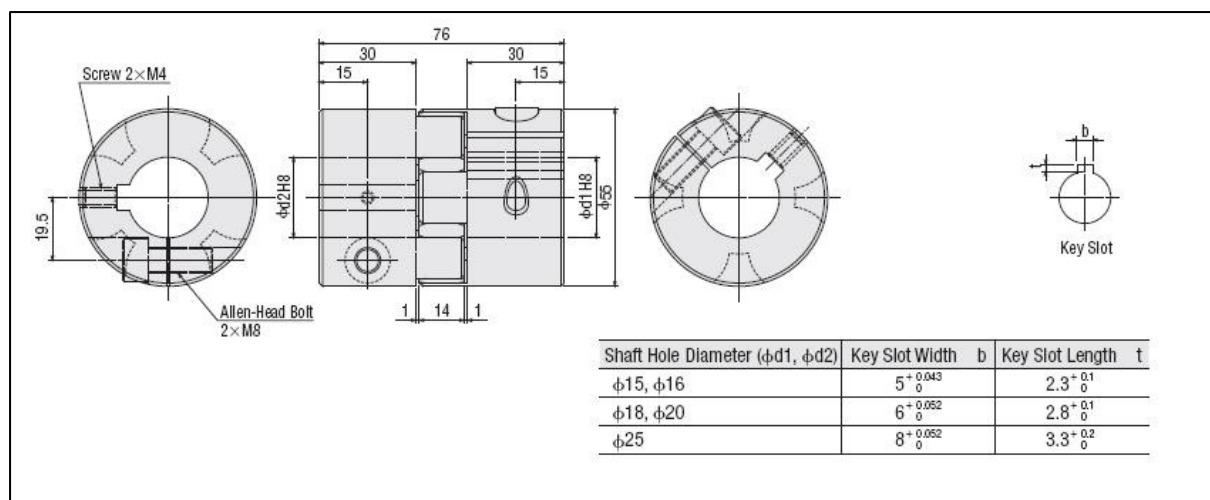
Order information
All prices excluding VAT & possible shipping costs, shipping time: **approx. 7 Day(s)**

Online price £48.60

* Already includes the 10% discount on the list price.

[Dimensions](#)

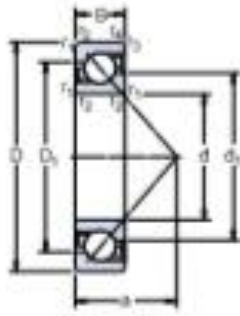
Inertial moment:	$1.6 \times 10^{-4} \text{kgm}^2$
Shaft hole diameter d1:	16 mm
Shaft hole diameter d2:	18 mm
Permissible eccentricity:	0.2 mm
Permissible declination:	1.0°



https://www.oriental-motor.co.uk/Products/Ac_motors/Accessories/Couplings/?arid=5921

Appendix D. SKF Angular Contact Bearing Data Sheet

ball bearings
d 10 – 55 mm



Principal dimensions			Basic load ratings		Fatigue load limit P_0	Speed ratings		Mass	Basic designation ¹⁾
d	D	B	C	C_0		Limiting speed min	n_L		
mm			N		N	min		kg	
10	30	9	7 000	3 350	140	19 000	28 000	0.030	T250 BE
12	32	10	7 610	3 800	160	18 000	26 000	0.036	T261 BE
	37	12	10 600	5 000	208	17 000	24 000	0.060	T261 BE
15	35	11	8 540	4 800	204	17 000	24 000	0.045	T262 BE
	42	13	13 000	6 700	290	15 000	20 000	0.080	T362 BE
17	40	12	11 100	5 100	260	15 000	20 000	0.065	T263 BE
	40	12	11 050	5 050	250	15 000	20 000	0.065	T263 BE
	47	14	15 800	8 300	355	13 000	18 000	0.11	T363 BE
20	47	14	14 000	8 300	355	12 000	17 000	0.11	T264 BE
	52	15	19 000	10 400	440	10 000	15 000	0.14	T364 BE
	52	15	19 000	10 000	425	10 000	15 000	0.14	T364 BE
20	47	14	14 000	8 300	355	12 000	17 000	0.11	T204 BE
	52	15	19 000	10 400	440	10 000	15 000	0.14	T304 BE
	52	15	19 000	10 000	425	10 000	15 000	0.14	T304 BE
30	62	16	23 800	15 600	655	8 500	12 000	0.20	T266 BE
	62	16	24 000	15 600	655	8 500	12 000	0.20	T266 BE
	72	19	34 500	21 200	900	8 000	11 000	0.34	T266 BE
	72	19	35 500	21 200	900	8 000	11 000	0.34	T366 BE
35	72	17	30 700	20 800	880	8 000	11 000	0.28	T267 BE
	72	17	31 000	20 800	880	8 000	11 000	0.28	T267 BE
	80	21	38 000	24 900	1 040	7 500	10 000	0.45	T267 BE
	80	21	41 500	26 000	1 140	7 500	10 000	0.44	T367 BE
40	80	18	36 400	26 000	1 100	7 000	9 500	0.37	T268 BE
	80	18	36 500	26 000	1 100	7 000	9 500	0.36	T268 BE
	90	23	49 400	33 500	1 400	6 700	9 000	0.63	T268 BE
	90	23	50 000	32 500	1 370	6 700	9 000	0.64	T368 BE
45	85	19	37 700	28 000	1 200	6 700	9 000	0.42	T269 BE
	85	19	38 000	28 000	1 220	6 700	9 000	0.42	T269 BE
	100	25	60 500	41 500	1 730	6 000	8 000	0.85	T269 BE
	100	25	61 000	40 500	1 730	6 000	8 000	0.83	T369 BE
50	90	20	39 000	30 500	1 290	6 000	8 000	0.47	T270 BE
	90	20	40 000	31 000	1 320	6 000	8 000	0.47	T270 BE
	110	27	74 100	51 000	2 200	5 300	7 000	1.10	T270 BE
	110	27	75 000	51 000	2 160	5 300	7 000	1.10	T370 BE
55	100	21	48 800	38 000	1 530	5 600	7 500	0.62	T271 BE
	120	29	85 200	60 000	2 550	4 800	6 300	1.40	T271 BE
	120	29	85 000	60 000	2 550	4 800	6 300	1.40	T371 BE

¹⁾ The designations of bearings belonging to the Explorer range are printed blue; information on available variants see pages 22 and 23.

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<http://www.dexis-iberica.com/ficheros/2.pdf>

Appendix E. O ring Data Sheet

[Request a Quote](#)



DuPont™ Kalrez® Spectrum™ 7090

Technical Information — Rev. 1, July 2010

Product Description

DuPont™ Kalrez® Spectrum™ 7090 perfluoroelastomer parts are specifically targeted for use in applications requiring high hardness/higher modulus properties. These specialty black parts have excellent mechanical properties including compression set resistance, seal force retention, response to temperature cycling effects and rapid gas decompression resistance. Kalrez® Spectrum™ 7090 perfluoroelastomer parts are well suited for both static and dynamic sealing applications, especially applications that require extrusion resistance at higher temperatures. They also offer outstanding thermal stability and chemical resistance. A maximum continuous service temperature of 325 °C (617 °F) is suggested. Short excursions to higher temperatures may also be possible.

Typical Physical Properties¹

Color	Black
Hardness, Shore A ²	90
50% Modulus ³ , MPa (psi)	15.51 (2250)
Tensile Strength at Break ³ , MPa (psi)	22.75 (3300)
Elongation at Break ³ , %	75
Compression Set ⁴ , %	
70 hr at 204 °C	12
70 hr at 260 °C	23
Temperature of Retraction, Tr10 ⁵ , °C (°F)	-5 (23)
Maximum Continuous Service Temperature ⁶ , °C (°F)	325 (617)

¹ Not to be used for specification purposes
² ASTM D2240 (pellet test specimens)
³ ASTM D1414 and D412 (AS568 K214 O-ring test specimens)
⁴ ASTM D1414 and D3958 (AS568 K214 O-ring test specimens)
⁵ ASTM D1329 (dumbbell test specimens/test specimens stretched 25%)
⁶ DuPont proprietary test method

Performance Features/Benefits

- Higher hardness and modulus
- Exceptional thermal stability and compression set resistance
- Outstanding seal force retention properties and response to temperature cycling effects
- Excellent mechanical properties
- Lower coefficient of thermal expansion (CTE) versus other Kalrez® parts thus minimizing the need to increase the free volume of the seal gland when upgrading from fluoroelastomers (FKM) to perfluoroelastomers (FFKM)

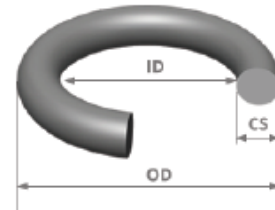


The miracles of science™

(800) 775-6525 | www.marcorubber.com**REQUEST A QUOTE**

Standard British O-Rings Sizes

Tolerances vary by use, please see our tolerance pages. Thousands of non-standard sizes are available in stock or can be made within a few weeks typically without tooling fees so no need to settle for a less than optimal fit.



Size	CS (IN)	ID (IN)	OD (IN)	CS (MM)	ID (MM)	OD (MM)
001	0.040	0.029	0.109	1.02	0.74	2.78
002	0.060	0.042	0.142	1.27	1.07	3.61
003	0.060	0.056	0.176	1.52	1.42	4.46
004	0.070	0.070	0.210	1.78	1.78	5.34
005	0.070	0.101	0.241	1.78	2.57	6.13
006	0.070	0.114	0.254	1.78	2.90	6.46
007	0.070	0.145	0.285	1.78	3.68	7.24
008	0.070	0.176	0.316	1.78	4.47	8.03
009	0.070	0.208	0.348	1.78	5.28	8.84
010	0.070	0.239	0.379	1.78	6.07	9.63
011	0.070	0.301	0.441	1.78	7.65	11.21
012	0.070	0.364	0.504	1.78	9.25	12.81
013	0.070	0.426	0.566	1.78	10.82	14.38
014	0.070	0.489	0.629	1.78	12.42	15.98
015	0.070	0.551	0.691	1.78	14.00	17.56
016	0.070	0.614	0.754	1.78	15.60	19.16
017	0.070	0.676	0.816	1.78	17.17	20.73
018	0.070	0.739	0.879	1.78	18.77	22.33
019	0.070	0.801	0.941	1.78	20.35	23.91
020	0.070	0.864	1.004	1.78	21.95	25.51
021	0.070	0.926	1.066	1.78	23.52	27.08
022	0.070	0.989	1.129	1.78	25.12	28.68
023	0.070	1.051	1.191	1.78	26.70	30.26
024	0.070	1.114	1.254	1.78	28.30	31.86
025	0.070	1.176	1.316	1.78	29.87	33.43
026	0.070	1.239	1.379	1.78	31.47	35.03
027	0.070	1.301	1.441	1.78	33.05	36.61
028	0.070	1.364	1.504	1.78	34.65	38.21
029	0.070	1.489	1.629	1.78	37.82	41.38
030	0.070	1.614	1.754	1.78	41.00	44.56
031	0.070	1.739	1.879	1.78	44.17	47.73
032	0.070	1.864	2.004	1.78	47.35	50.91
033	0.070	1.989	2.129	1.78	50.52	54.08

Afternoon Andy,

Hope you are well,

Thankyou for your recent request for Kalrez O-Rings, we are pleased to be able to offer the following :

Qty: 5pcs

BS022 Genuine Kalrez 7090 compound

Lead Time: 7/10 working days

Price validity : 30 days

Price: £32.95 each

Kind Regards

Ian Harvey

Business Development and Key account Manager

DICHTOMATIK Limited



DICHTOMATIK

Any seal. Any time.

Donington House | Riverside Road | Pride Park | Derby DE24 8HX | Great Britain

Phone: 01332 524400 | Direct: 01332 524418

ian@dichtomatik.co.uk | www.dichtomatik.co.uk [dichtomatik.co.uk]

a brand of



FREUDENBERG

https://www.marcorubber.com/kalrez-o-rings.htm?gclid=EAIaIQobChMI5N2Z8LPx2wIVicBkCh2qGQ0TEAAYASAAEglg3PD_BwE

Appendix F. Rotary Shaft Seal Data Sheet

20x52x7-R21-FPM Rotary Shaft Seal - Viton Rubber (FPM) Metric 20 x 52 x 7



 Zoom

This image shows the product type but may not be this exact part.

Brand: TTO
Measurement Unit: Metric
Material: Viton Rubber (FPM)
Inside Diameter: 20.00mm
Outside Diameter: 52.00mm
Width: 7.00mm
Lip Style: R21 Single Lip

Availability: 

Our Price: **£9.92**
 (Exc. 20% VAT)
 (£11.90 Inc. VAT)

- 1 +
ADD TO BASKET

 Like 0
  Tweet
  G+
  Share

Information | **Technical Information** | **Customer Reviews (0)**

20x52x7-R21-FPM Rotary Shaft Seal - Viton Rubber (FPM) Metric 20 x 52 x 7

Oil Seals or Rotary Shaft Seals are designed to provide a barrier to retain lubricant and to keep out contamination. They are available in metric and imperial sizes with a variety of sealing lip arrangements the most common of which are:

- R21 - Single Sprung Lip
- R23 - Single Sprung Lip with the addition of a wiper lip to help keep out contamination

Oil Seals are constructed using a steel case which is usually covered in rubber. Various materials are available the most common materials are:

- Nitrile Rubber (NBR) - Temperature Range -40 to +110 degree C - Usually coloured Black
- Viton Rubber (FPM) - Temperature Range -30 to +225 degrees C - Usually coloured Brown
- Silicone (SI) - Temperature Range -60 to +225 degrees C - Usually coloured Red

http://www.wychbearings.co.uk/20x52x7-r21-fpm_oil_seal.html

Appendix G. Band Heater Data Sheet



Datasheet
Stock No: [920-9956](#)

Nozzle Heater, 38 x 38mm, 235 W

English



Product Overview

RS Pro Nozzle heaters are designed with the highest quality materials used for optimal performance. The heaters are most commonly used in the plastic industry but are also suitable to use in applications of up to 1000°F.

Product Details

- High temperature oxidation resistance metal sheath
- Highest grade mica insulation provides excellent electrical insulation at high temperature and is resistant to moisture
- Clamping band is low thermal expansion steel construction designed to maintain clamping pressure at elevated temperatures
- Nickel/Chromium resistance wire evenly wound for uniform heat distribution and reliable accuracy
- Standard 10 in fibreglass lead wire

Product Details

Nozzle Heaters

RS Pro Nozzle heaters are designed with the highest quality materials used for optimal performance. The heaters are most commonly used in the plastic industry but are also suitable to use in applications of up to 1000°F.

- High temperature oxidation resistance metal sheath
- Highest grade mica insulation provides excellent electrical insulation at high temperature and is resistant to moisture
- Clamping band is low thermal expansion steel construction designed to maintain clamping pressure at elevated temperatures
- Nickel/Chromium resistance wire evenly wound for uniform heat distribution and reliable accuracy
- Standard 10 in fibreglass lead wire

Multi-Purpose Process Heaters

In order to obtain optimum performance from these products, it is advised that temperature sensing and control elements be used with them.

Warning

- These heaters shall only be used where adequate electrical, thermal and mechanical barriers are provided to prevent access to hazardous parts without the use of a tool.

Specifications

Attribute	Value
Band Heater Type	Nozzle Heater
Power Rating	235 W
Supply Voltage	230 V
Band Dimensions	38 x 38mm
Height	38mm
Diameter	38 mm

<https://docs-emea.rs-online.com/webdocs/14ce/0900766b814cead4.pdf>

RS Pro Nozzle Band Heater, 235 W, 230 V, 38 mm Band DiameterRS Stock No.: 920-9956 | Brand: **RS Pro**

Available to back order for despatch
25/07/2018

Price Each

£17.80

(exc. VAT)

£21.36

(inc. VAT)

Units	Per unit
1 +	£17.80
1 Units	<button>Back order</button>
	<button>☆ Add to a parts list</button>

<https://uk.rs-online.com/web/p/band-heaters/9209956/>

Appendix H. Materials/Components Price List

MATERIAL/COMPONENTS LIST									DATE: 06/05/18	
DESCRIPTION: EXTRUDER MACHINE										
	PART NAME	DESCRIPTION		MANUFACTURER	QUANTITY	UNIT PRICE	TOTAL PRICE	DRW/DATA SHEET REF.		
1	Angular Contact Bearing	7304 BE		SKF/Simply bearings	2	£22.81	£45.62		Appendix D.	
2	Locking Washer	MB4		SKF/Simply bearings	1	£4.71	£4.71		Appendix A.	
3	Locking Nut	KM4 (M20x1)		SKF/Simply bearings	1	£9.75	£9.75		Appendix A.	
4	Flexible Coupling	Type - MCL551618		Oriental Motors	1	£48.60	£48.60		Appendix C.	
5	Shaft Seal	20x52x7-R21-FPM - Viton		Wych Bearing Supplies	1	£9.92	£9.92		Appendix F.	
6	O Ring	BS022 Kalrez 7090		Dichtomatik	2	£32.95	£65.90		Appendix E.	
7	Motor & Speed Controller	Product Number Code US2-425EC-50-3		Oriental Motors	1	£198.00	£198.00		Appendix B.	
8	Makrolon	3MM Clear Lexan 305mm x 152mm palram/makrolon Polycarbonate sheet		Ebay	2	£2.79	£5.58		N/A	
9	Adjustable Feet	4 Weight Rated Heavy Duty Adjustable Feet, M10 x 100mm Tilt, 40mm Base		Ebay	1	£8.49	£8.49		N/A	
10	Band Heater	235W 230V 38mm Band Heater		RS Components	5	£17.80	£89.00		Appendix G.	
11	Thermocouple	TBC					£0.00		N/A	
12	PID Controller	TBC					£0.00		N/A	
13	E Stop	TBC					£0.00		N/A	
					TOTAL PRICE	£355.82				