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Feasibility Report

ZLX_001_

Shredder Packer Machine
ZLX Ltd

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Project

Technical feasibility report on waste compactor machine.

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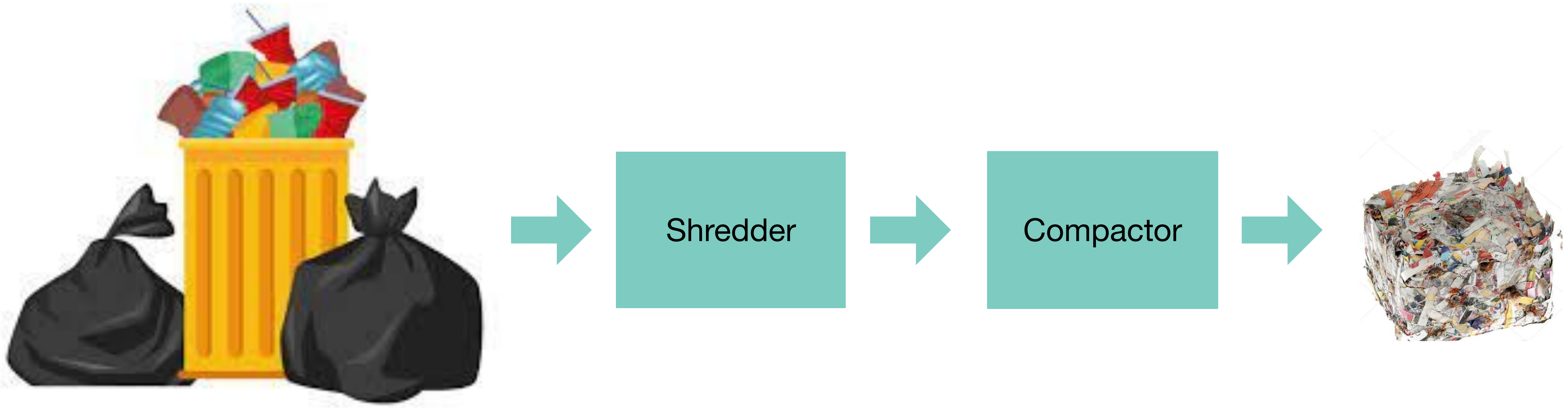
Feasibility Review

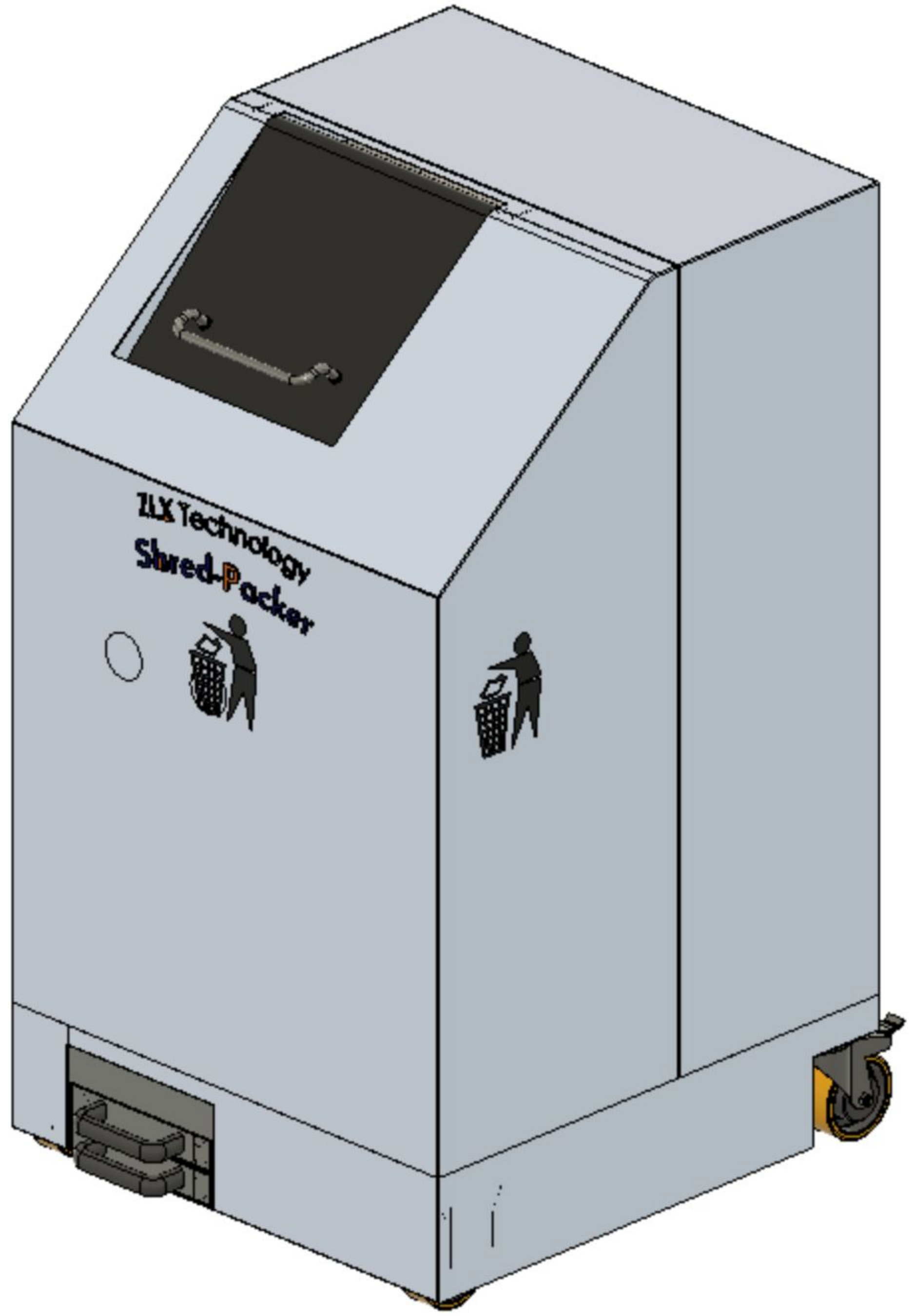
ZLX Ltd / ZLX_001

This report is a 4 day high level technical feasibility review of the clients concept design to identify gaps, risks, potential mitigations and design opportunities that can be explored as part of a more comprehensive development project.

DESCRIPTION OF CONCEPT

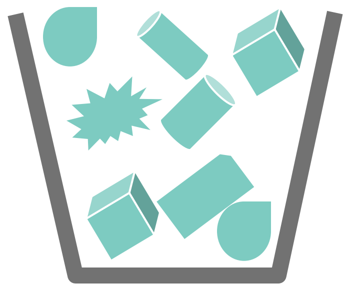
ZLX intend to develop a small-scale compactor to reduce the waste output of businesses in the retail and hospitality industries. A compactor concept has been designed to achieve a compression ratio of 10:1 via a two-stage compression process. The initial compression of the waste is achieved via an industrial shredder followed by secondary compression via a compaction ram. The waste shall be output from the prototype in the form of small briquettes.



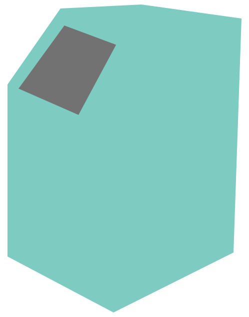


USER JOURNEY

The user journey is mapped below to identify the main user interfaces on the machine.



1. User collects uncompacted rubbish

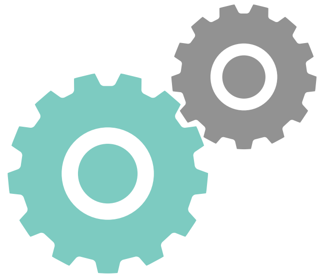


2. User takes waste to machine

3. User powers on device

4. User opens hatch and deposits rubbish until feeder area is full

5. User closes hatch and activates machine



6. Machine shreds and compacts waste producing briquette

7. User empties briquette tray

8. User either processes more rubbish or (from step 4) or user power down device

9. User removes any waste liquids and replaces collection tray

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The illustration shows a view of the machine with the outer enclosure hidden. The main components have been labeled.

Components not yet defined:
The hydraulic control system is represented by a simplified grey volume. ZLX are in discussion with hydraulic supplier who may deliver this as a complete system. The items within the hydraulic system are not yet defined.

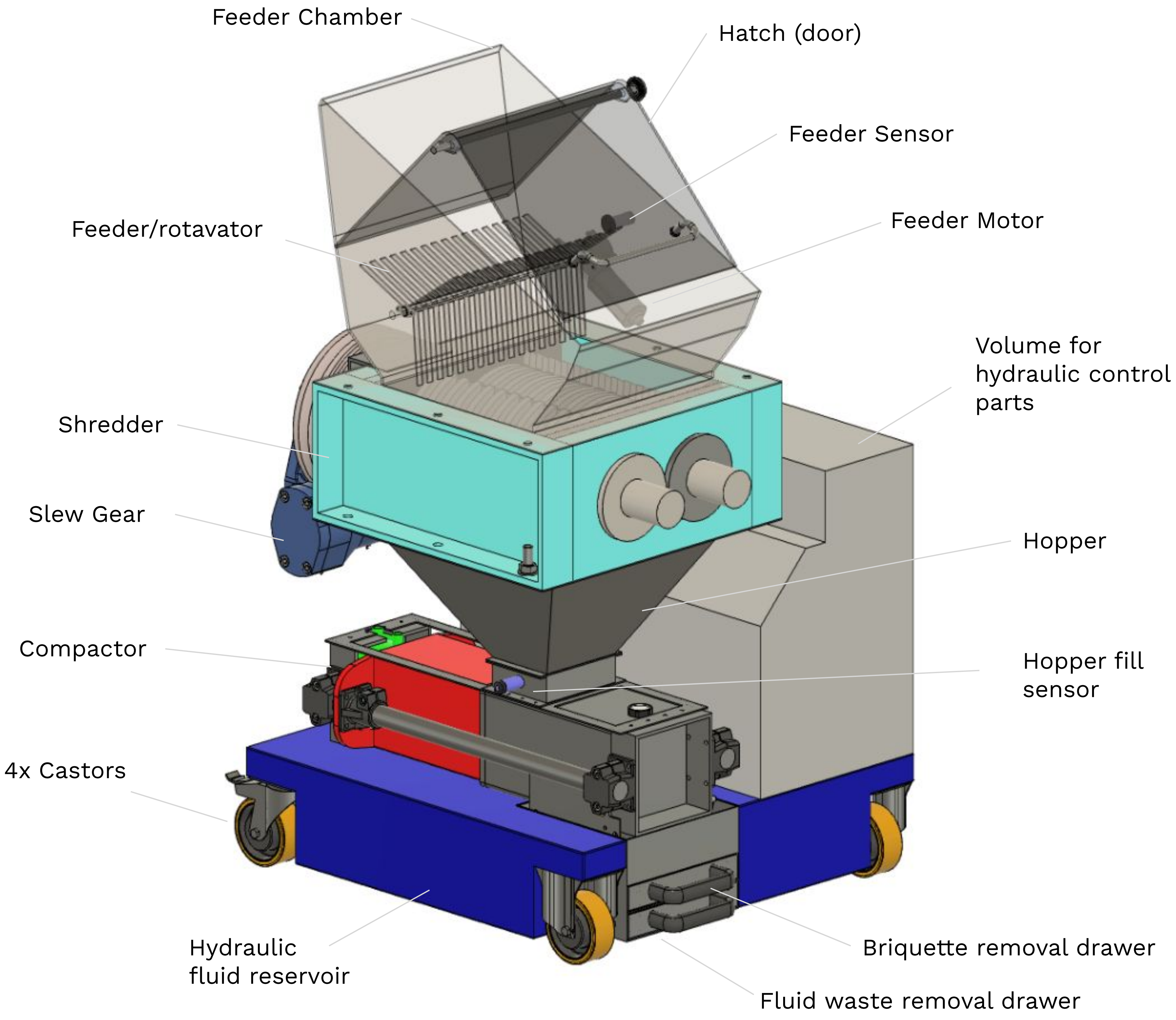
The hydraulic reservoir is respresnted by the simplified blue volume in the base.

Structural Supports are not yet defined.

Suitable positions/volumes are yet to be drawn for the control electronics.

There are currently 4 external user interfaces:

- Hatch Door
- Briquette removal drawer
- Fluid waste removal drawer
- Hinged enclosure for access to the machine

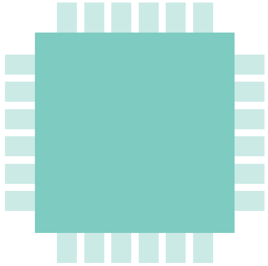


GENERAL REQUIREMENTS

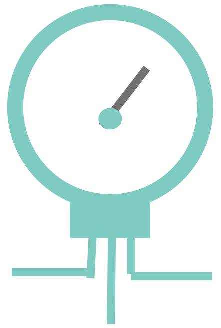
The requirements table below uses target values based on research and information provided by ZLX ltd. In some cases these are provisional values that can serve as a benchmark to evaluate the appropriateness of the design to date.

ID	What	Why	Target Value
R1	Torque	Provide sufficient torque to enable the shredder to shred material at its the maximum hardness rating (glass).	1628 Nm
R2	Speed	Provide sufficient speed to enable the shredder to run at operating speed to effectively shred	16 rpm
R3	Ram Force	To provide sufficient force to compact the waste to a ratio of 10:1.	20kN
R4	Ram Speed	To allow speedy operation of the process.	22 mm/s
R5	Accessory Power Supply	To power the solenoid lock, feeder rotor and controller	24V
R6	Hydraulic Power unit supply	To enable the hydraulic pump to provide sufficient hydraulic pressure.	380V, 3kW
R7	Electrical Supply	Sufficient to power industrial hydraulics and motor components	3 phase, 440V
R8	Hydraulic Pressure	To drive hydraulic motor and ram at operating points.	120 bar
R9	Hydraulic Volume	To drive hydraulic motor and ram at operating points.	40 L
R10	Ingress Protection level	To allow outdoor usage.	IP67
R11	Physical Size	Approximately no larger than a large domestic wheelie bin	<330 litres
R12	Weight	Machine is transportable but does not require reinforced floor	<150kg

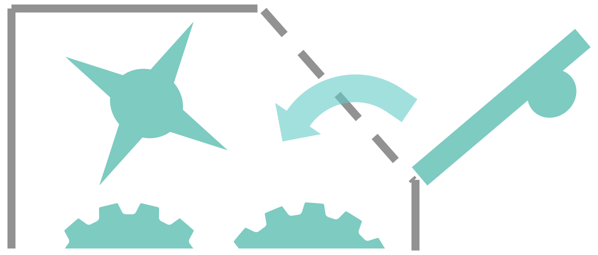
10 Functional elements of the system have been identified:



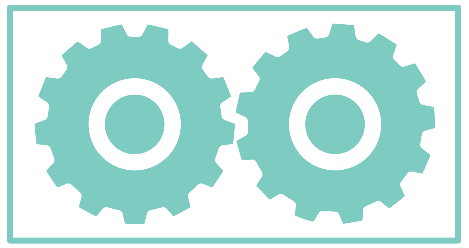
1: Control System
Process Control



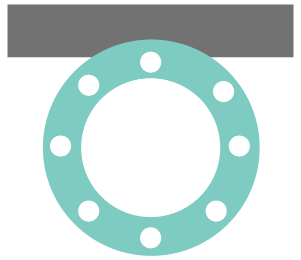
2: Hydraulic System
Provides shredder and compactor



3: Hatch & Feeder
Access point for depositing waste materials



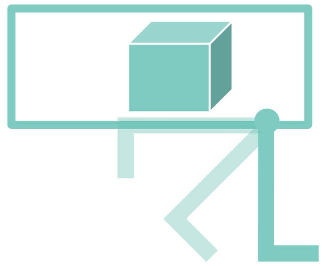
4: Shredder
Draws in waste material before crushing and shredding



5: Slew Gear
Power transmission

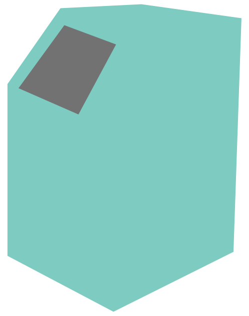
5: Hopper
Collection point for shredded waste

6: Compactor
Compresses shredded waste into bale



7: Trap Door & Drawer
Ejects waste from compactor

8: Chassis
Structural support



10: Enclosure
Exterior of the machine

CONTROL SYSTEM - PROCESS FLOW

The Process Flow Diagram identifies the main system components and maps the flow of waste from the Hatch input to the Ram output. The minimum required control inputs, power overload protection and accessory devices (solenoid etc) are also shown.

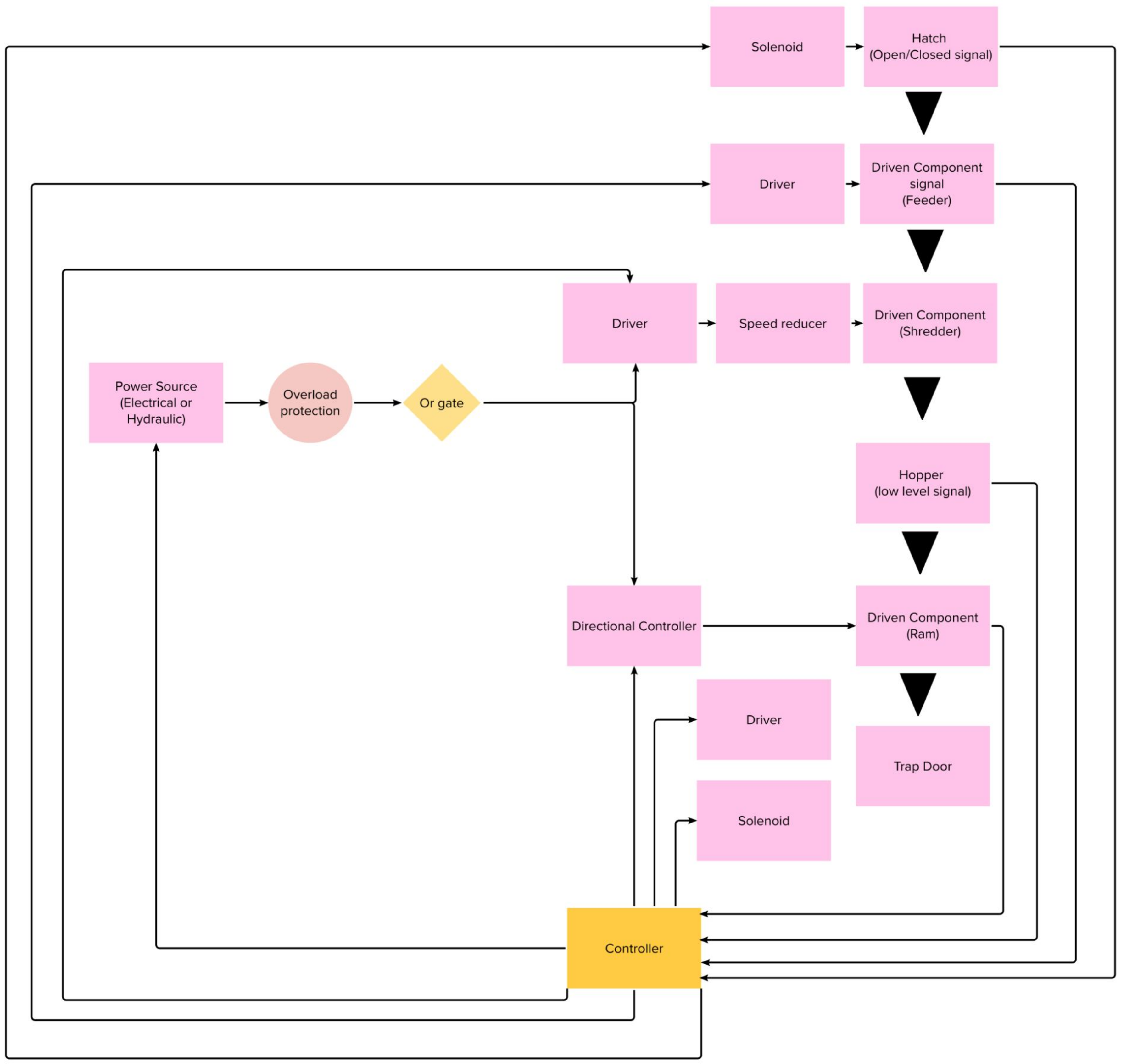
The two options for controller hardware are:

- **Automation style PLC (e.g siemens controller)**
Used for safety critical machines where high reliability is required. Customisable but expensive. Different suppliers use different logic standards

- **Semi Custom Arduino/raspberry PI PLC**
Low cost, highly customizable, wireless connectivity, easy to programme

We would recommend using an Arduino logic controller for initial proof of concept prototypes (with additional mechanical safety measures). A suitable PLC can be selected at a later stage in the product development when all the input and outputs are established.

The client may wish to consider adding sensors on the briquette drawer to prevent the machine activating the compactor if the drawer is open or full.



Hydraulic System - P&ID Diagram

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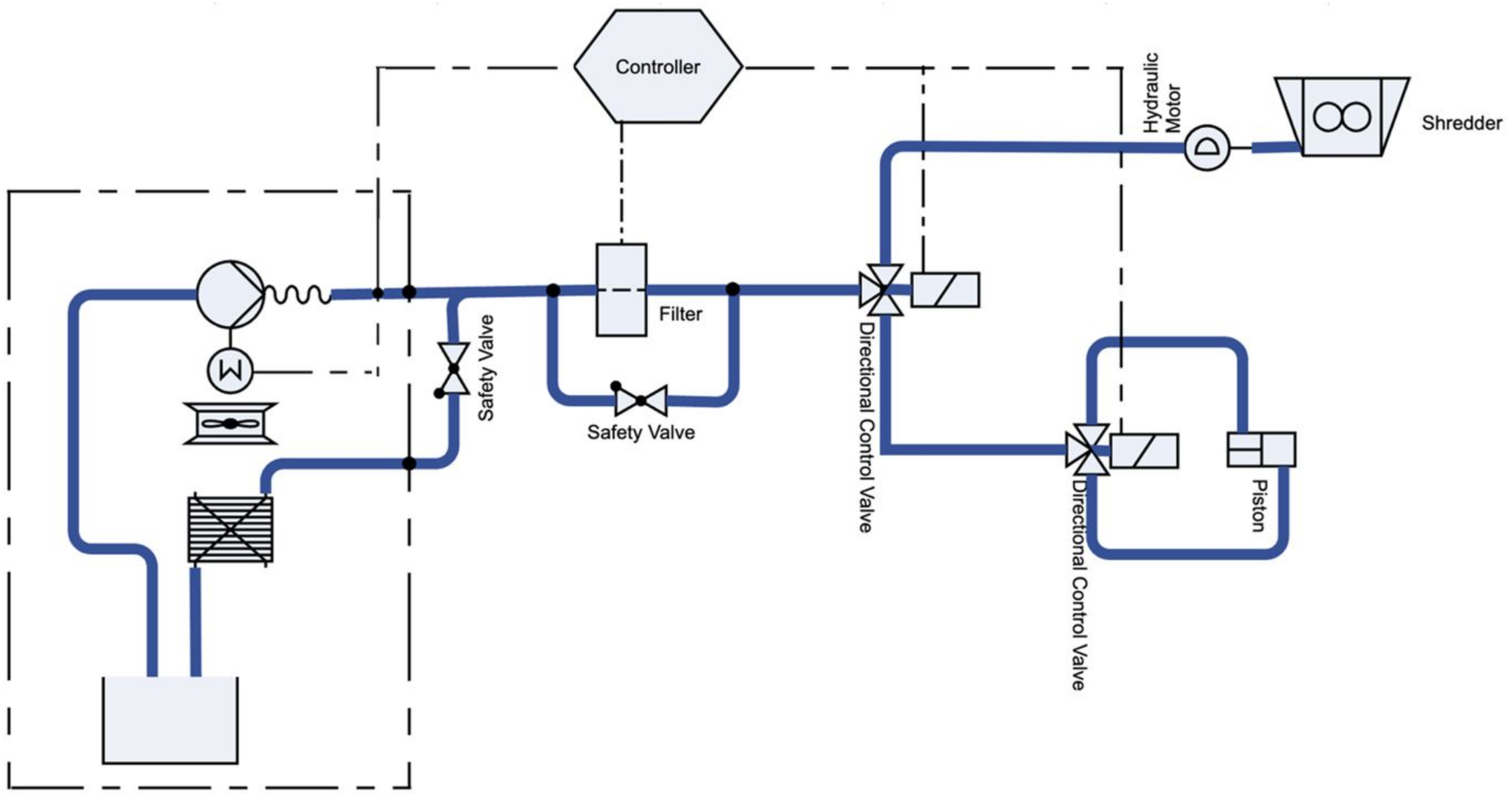
The current machine design employs a hydraulic system to power the driven components. The P&ID (piping and Instrumentation diagram) reflects the operation of the process diagram. The P&ID diagram represents the minimum components required to operate the system which have been listed in the opposite

The system is controlled via signals from the controller to the directional control valves. A main directional control valve allows switching of power between the shredder and ram. A secondary directional control valve enables extension and retraction of the piston within the ram.

A mechanical safety return valve is located downstream of the power unit to prevent over pressurisation of the system due to blockages caused by debris or failure of the control valves. The filter prompts a maintenance alert when full, however a bypass valve is included to maintain normal operation if the filter becomes blocked.

Table 2 identifies the additional hydraulic components that will be needed



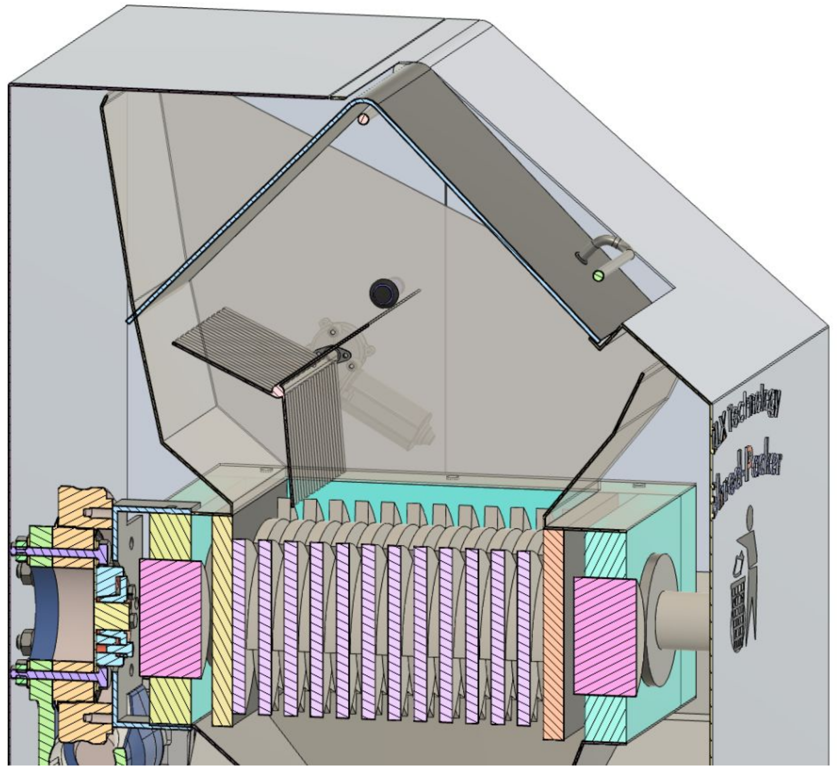
Equipment	Qty
Vendor Power Pack assembly (reservoir, motor, pump, fan, radiator, safety valve)	1
Controller (Raspberry Pi/Arduino)	1
Filter	1
Safety Valve	1
Directional Control Valve	2
Piston	1
Slewing gear assembly (hydraulic drive and worm gear)	1
Shredder	1
Connectors (estimated)	19
Tubing lengths (estimated)	11

Waste shall be deposited via an access hatch on top of the prototype. Once the hatch is shut the user shall power on the machine. To protect the user from the machine internals it is critical the hatch cannot be opened while the shredder is rotating. To prevent this it is recommended an interlock signal locks the hatch drum during shredding. It is advised that the means used to lock the hatch shall comply with the Machine Safety Standard EN.ISO13849-1.2008 [1] in particular the section below.

The SRP(Safety-related part) shall, as a minimum, be designed, constructed, selected, assembled and combined in accordance with the relevant standards and using basic safety principles for the specific application to withstand

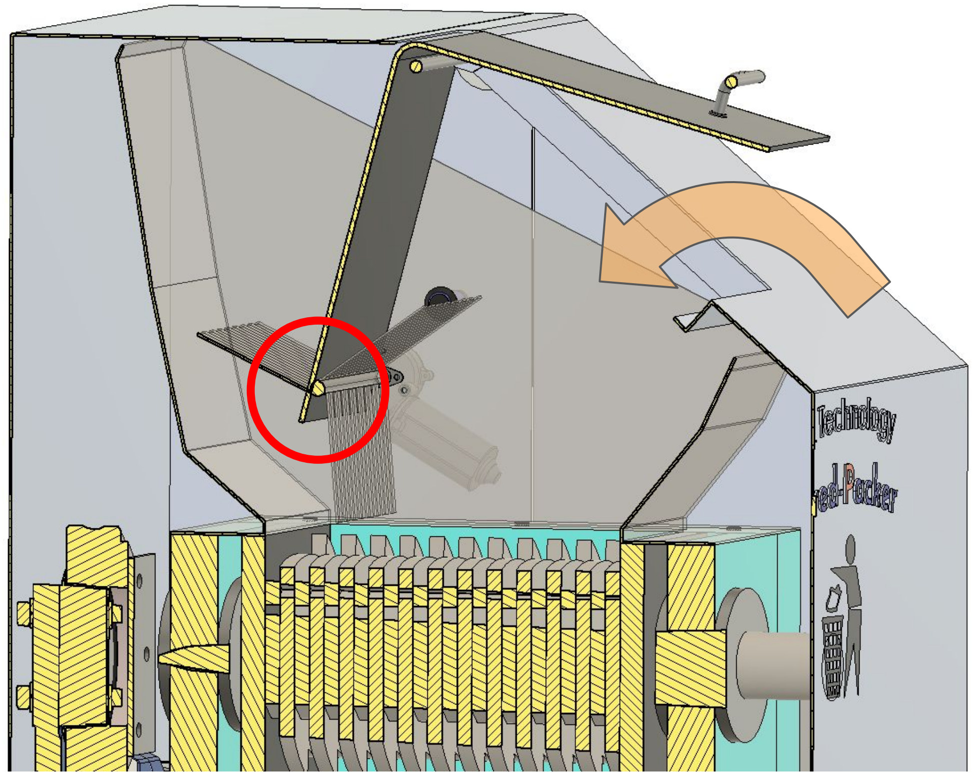
- *The expected operating stresses, e.g. the reliability with respect to breaking capacity and frequency,*
- *The influence of the processed material, e.g. detergents in a washing machine, and*
- *Other relevant external influences, e.g. mechanical vibration, electromagnetic interference, power supply interruptions or disturbances.*

One or more normally closed (NC) solenoid locks which fail in a safe condition (hatch closed) may comply with the above standard.

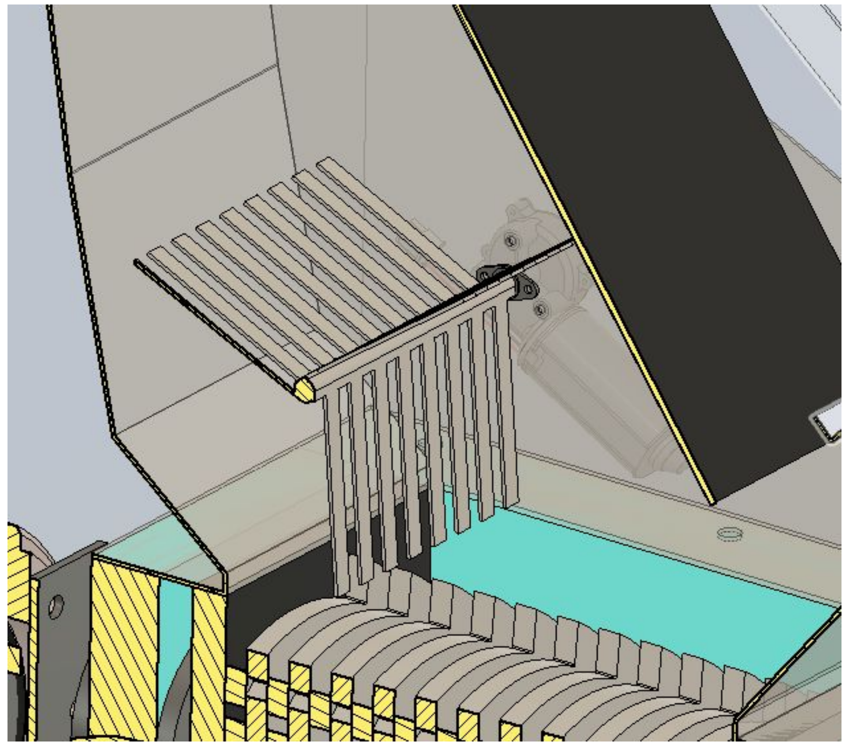


Gaps/Risks :

1. Hatch design allows user access to moving parts. In addition to interlock it would be safer to prevent direct access.
2. V shape hatch design hits feeder during opening.
3. Rope or wires can get caught around feeder rotavator fingers and it could potentially be pulled into shredder itself. The shaft diameter of the rotavator is not sufficiently large to withstand this pulling force. The feeder enclosure may not be strong enough to support the rotavator in this instance.
4. Rotavator will only covers a portion of the volume above the shredder and will miss some debris.
5. Water ingress via sloping front panel/hatch. Would require seals that then need maintenance.



Unobstructed access to moving parts



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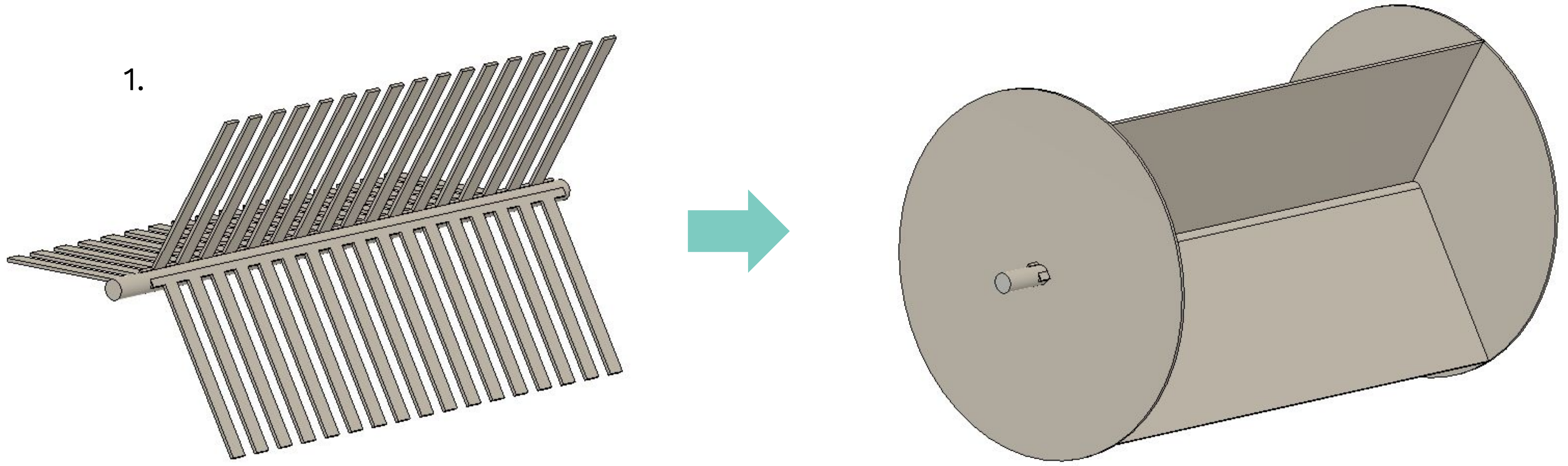
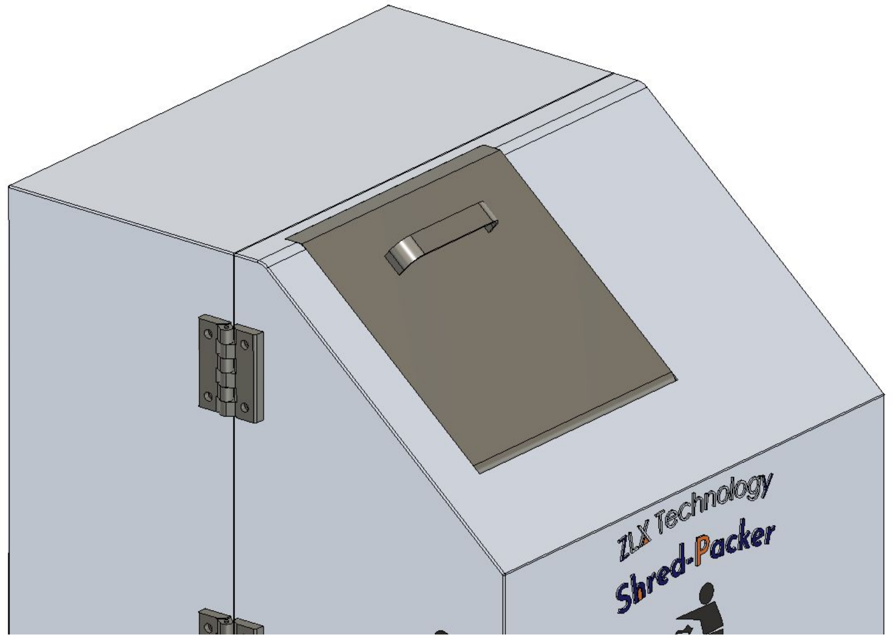
Mitigations :

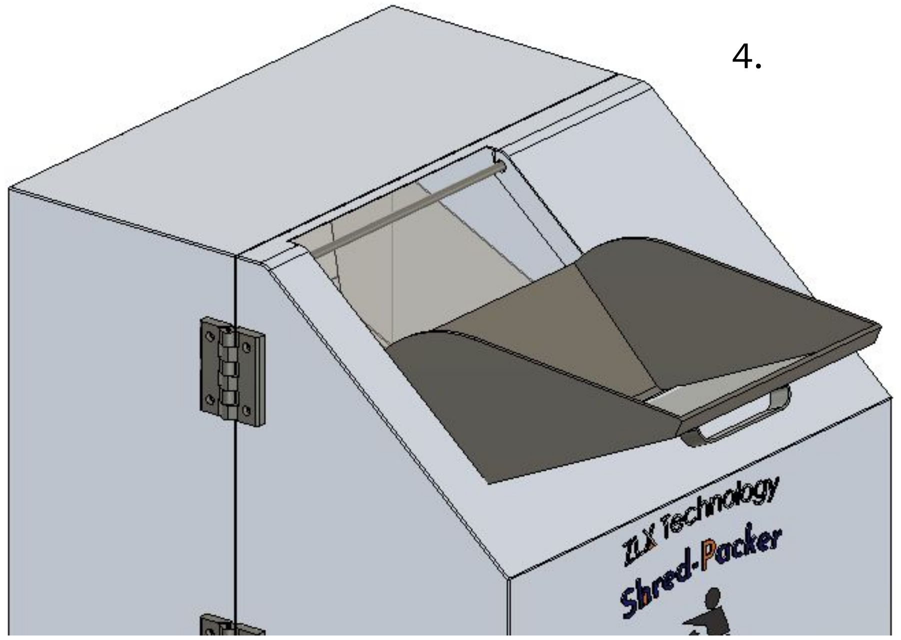
1. Remove vanes from feeder and/or increase diameter of spindle. Reinforce mounting points.
2. Replace rotavator with moving panel operated manually by lever or that is actuated by closing hatch door.
3. Offset hatch so not directly above shredder and including moving panel that blocks direct access as hatch opens
4. Move hinge point of hatch to bottom and add side walls to reduce access to moving parts.
5. Remove sloping shape - similar to clothing bins with overhang protecting door from elements.

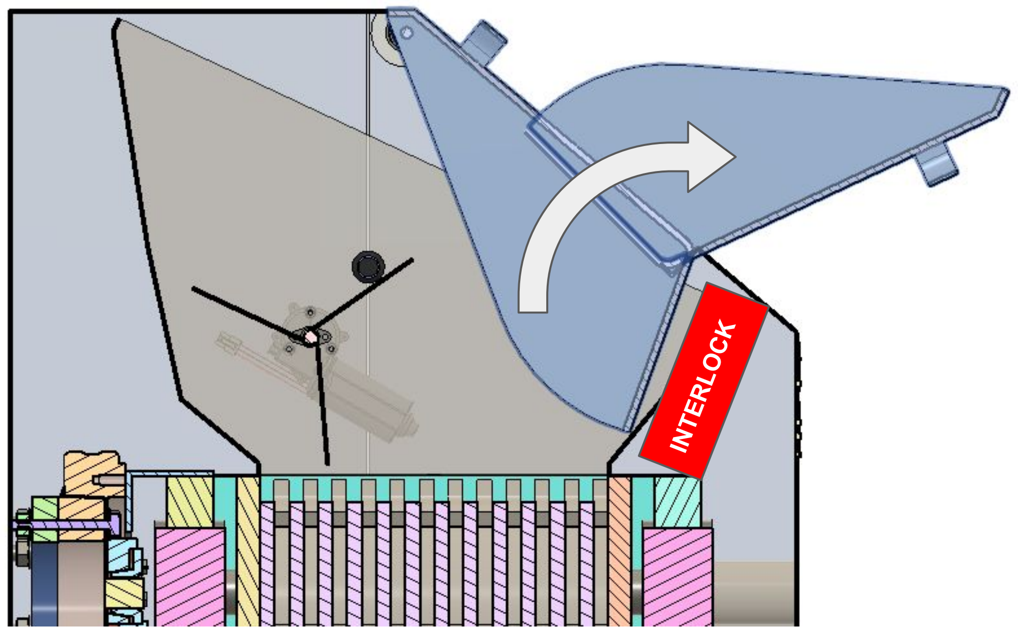
1.





4.





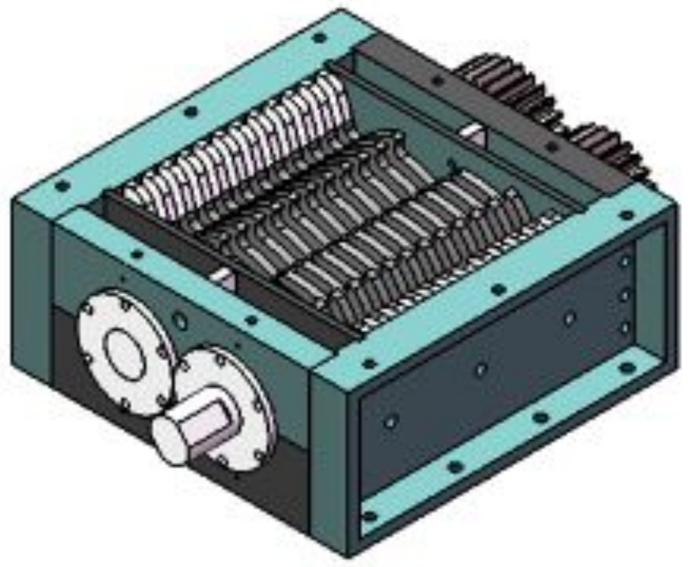
The shredder specified in the design is an EB300. The speed and torque requirement specified by the supplier datasheet is 16rpm and 1628Nm respectively. The resultant power input required to drive this shredder is 2727 watts. The datasheet for this shredder specifies the 3kW three phase electric motor. The speed reduction gearbox (JL2-16) provides sufficient speed reduction to drive the shredder at the operating speed.

Risks/Gaps:

- Our mass estimate for the shredder is 160kg. This requires significant support structure which will also contribute to the total weight of the machine
- Operating shredder at a slower speed than specified in datasheet will result in slower tip speed and therefore impact energy potentially preventing or reducing ability to shred certain materials
- Driving shredder at higher torque than specified may result in excess stress to the chassis and could potentially damage the shredder or supporting structure
- Glass is not listed within shreddable materials on datasheet

Mitigations:

- Design significant box section support structure to support weight and stress from shredder and motor system.
- Accept increased weight of machine. It may require installation of reinforced floors or the machine being situated in more industrial environment
- Use matched speed and torque input source (gearbox/motor)
- Use lower spec, lower mass shredder with lower power requirements and reduce material shredding capability
- Discuss speed and torque variations with shredder supplier

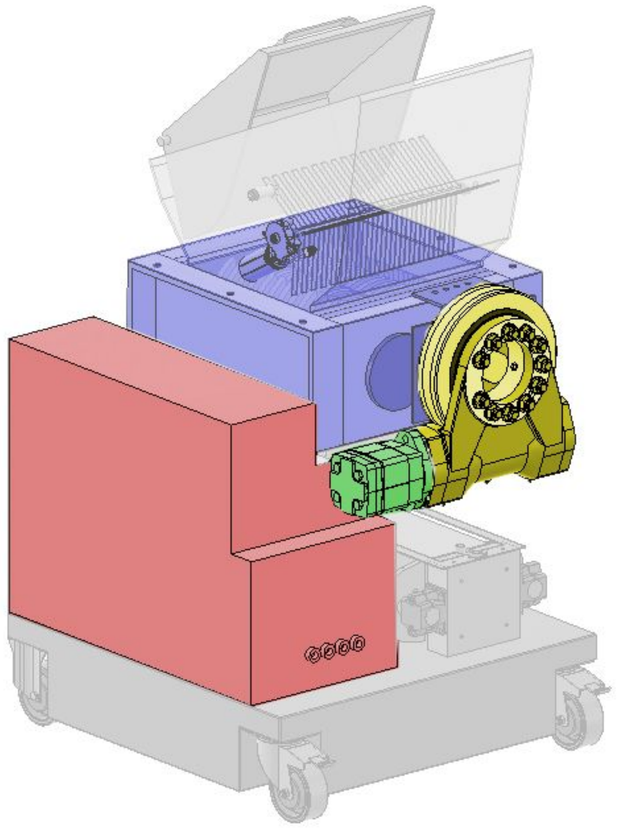


Model / Parameter Types	EB300*200
Generator	3KW4, 1 unit Three Phase 380V, 50Hz
Speed Reducer	JL2#-16, 1 set
Input speed	16 rpm
Input torque	1628Nm
Machine weight	≈ 400 kg
Scope of application	Light metal products, plastic products Kitchen waste, wooden boards, paper, etc.

Power Required	Torque (Nm)	Speed (Rpm)	Power Required(W)
	1628	16	2727.88
Power available	Motor Power (W)	Motor efficiency (%)	Power available (W)
	3000	0.9	2700

The Hydraulic Power unit (HPU) specified to power the shredder and ram features a 3kW motor providing an oil flow of 13.7 litres per minute (estimated) at a pressure of 12 Megapascal (Mpa).

This oil is fed to the slewing assembly hydraulic motor which from the table opposite shall produce a torque of approximately 141 Nm at 140 rpm.

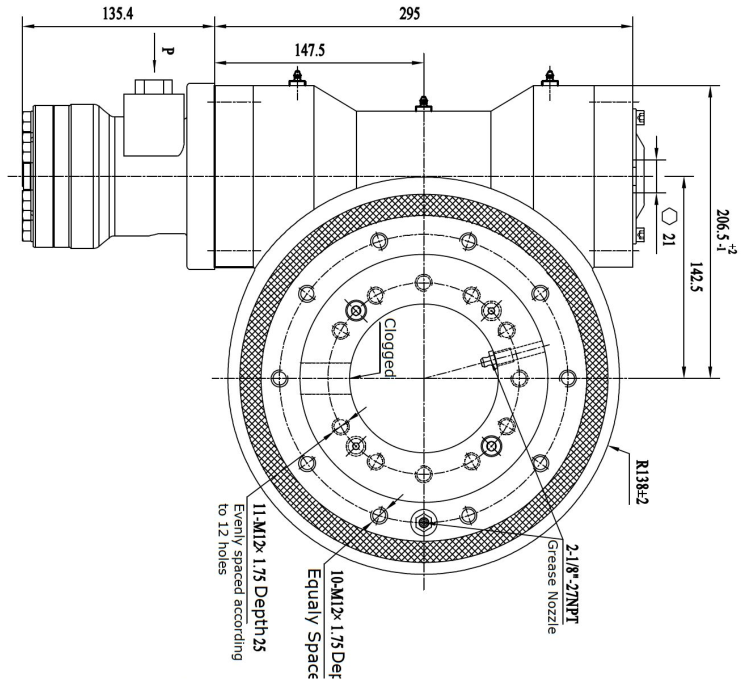


The inherent characteristics of worm gears (slew gear) is high torque but low efficiency due to the lead angle of the worm. As a result, there will be a reduction in power delivered to the shredder at the input shaft compared to the power output of the HPU.

The slew gear datasheet in the following slide gives an indication of the power losses that can be expected at a typical flowrate and pressure (based on empirical data).

The following slide compares power output vs power requirements and highlights efficiency losses.

Supplier empirical data indicates 78% power losses i.e 1.58kW input results in a 0.35kW output



Rotary reducer performance parameters	
OutputSpeed(Intermittant)	1.44 rpm
Rated Output torque	2319.5 N.m
Tipping Moment (max)	14.2 kN.m
Holding torque	20 kN.m
Axial load	220 kN
Radial load	90 kN
Reduction ratio	47:1
Accuracy class	≤ 0.15 °
Hydraulic motor performance parameters	
Pressure	12.1 MPa
Flow	8 L/min

Hydraulic motor performance parameters

WR080 [79cm^3 /rev.]

Pressure(Mpa) — Continuous max: 17.2; Intermittent max: 20.7

Flow (L/min)	1.7	3.5	6.9	8.6	10.4	12.1	13.8	15.5	17.2	19	20.7
4	18 49	38 46	77 41	94 40							
8	18 99	39 98	76 89	98 83	120 74	141 68	159 59	174 50			
15	17 189	38 187	76 177	98 170	120 161	141 151	160 144	180 131	199 122	220 112	240 100
23	17 290	37 286	79 274	97 268	119 259	140 250	160 240	182 227	202 214	222 200	243 185
30	14 374	35 368	75 357	96 349	117 339	138 330	159 321	181 307	200 296	220 284	241 268
38	11 480	34 475	73 464	94 453	116 442	138 433	158 423	177 412	199 398	218 383	238 370

Torque(N.m) 241
Speed(rpm) 268

Slewing Assembly reference values (Pressure 12.1Mpa and Flowrate 8L/min)			
	Hydraulic Motor	Worm Gear	Total power loss
Power In (kW)	1.58	1.004	
Torque (Nm)	141	2319.5	
Speed (Rpm)	68	1.44	
Power Out (kW)	1.004	0.350	
Power loss (%)	0.36	0.65	0.78

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Hydraulic motor performance parameters

WR080 [79cm³/rev.]

Pressure(Mpa) — Continuous max: 17.2 — Intermittent max: 20.7

Torque(N.m) 241
Speed(rpm) 268

Flow (L/min)	1.7	3.5	6.9	8.6	10.4	12.1	13.8	15.5	17.2	19	20.7
4	18 49	38 46	77 41	94 40							
8	18 99	39 98	76 89	98 83	120 74	141 68	159 59	174 50			
15	17 189	38 187	76 177	98 170	120 161	141 151	160 144	180 131	199 122	220 112	240 100
23	17 290	37 286	79 274	97 268	119 259	140 250	160 240	182 227	202 214	222 200	243 185
30	14 374	35 368	75 357	96 349	117 339	138 330	159 321	181 307	200 296	220 284	241 268
38	11 480	34 475	73 464	94 453	116 442	138 433	158 423	177 412	199 398	218 383	238 370
45	8 568	31 562	72 548	93 543	114 532	135 525	155 515	176 501	196 486	215 472	235 458
53	5 668	28 663	69 649	90 642	111 632	133 624	152 620	172 600	193 585	212 570	232 554
61		24 759	65 752	85 747	109 731	129 722	148 710	168 703	187 689	208 675	228 660
68		21 855	61 848	81 842	105 828	125 818	143 807	164 800	182 789	204 776	223 760
76		18 957	56 952	76 944	100 932	120 923	138 912	159 900	178 886	199 872	218 858

HPU
15 l/m (est)
12 MPa
3kW

Slew Gear Hydraulic Motor
141 Nm
151 rpm
2.23kW

Slew Gear Reduction (47:1)
2319.5 Nm
3.2 rpm
0.77kW

Shredde Input shaft
22319.5 Nm
3.2 rpm
0.77kW

Parameter Types / Model	EB300*200
Generator	3KW4, 1 unit Three Phase 380V, 50Hz
Speed Reducer	JL2#-16, 1 set
Input speed	16 rpm
Input torque	1628Nm
Machine weight	≈ 400 kg
Scope of application	Light metal products, plastic products Kitchen waste, wooden boards, paper, etc.

1628 Nm
16 rpm
2.7kW

Risk

- Due to efficiency losses across the system power delivered to the shredder shall be 29% of the supplier requirement i.e 0.77Kw v 2.7Kw

Mitigations:

- In order to match the 2.7Kw requirement using the the same pressure then flow rate should increase from 15l/min to 53l/min
- Planetary gearbox to reduce efficiency losses
- Oversized motor to account for efficiency loss
- Direct electrical drive
- Supplier engagement regarding performance at reduced power

The slewing gear assembly has been specified as WEA7-47-HR-80-R. These are typically used in crane and rotating platform applications. A few observations have been made on the CAD arrangement of this model of slew gear.

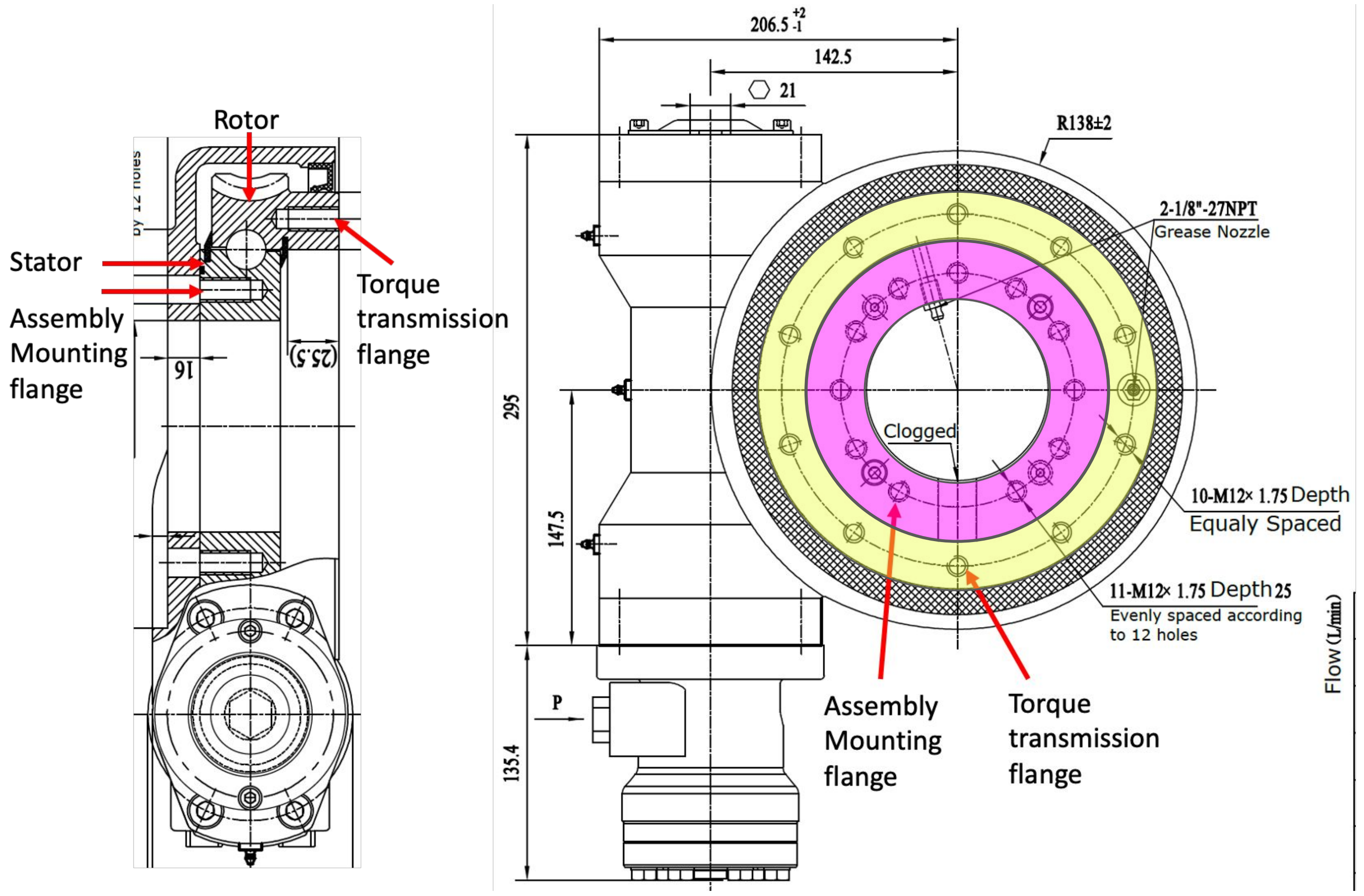
- The dimensions of the datasheet do not match the 3D CAD
- The slewing assembly housing is mounted to a static body via the flange located inboard of the bearing i.e the stator side of the assembly.
- Torque is transmitted to the driven component via the rotating flange **outboard** of the bearing i.e the rotor element.

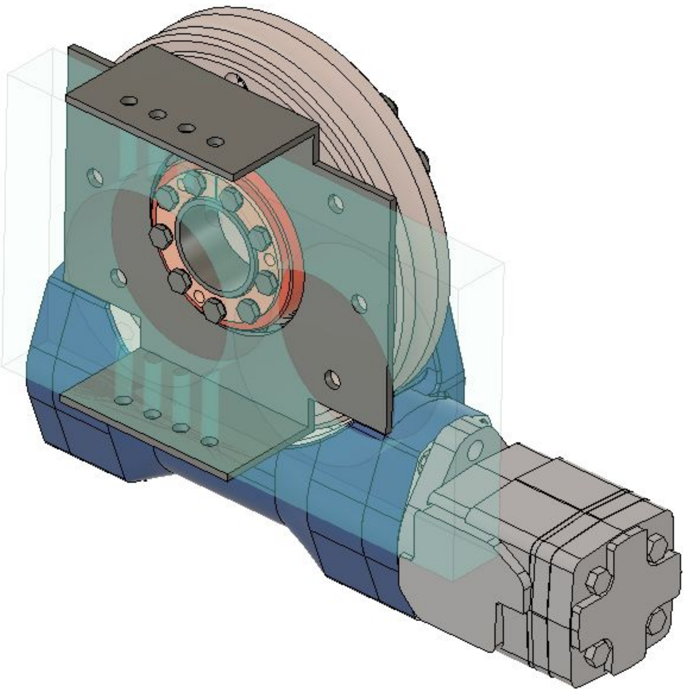
Risk/Gaps:

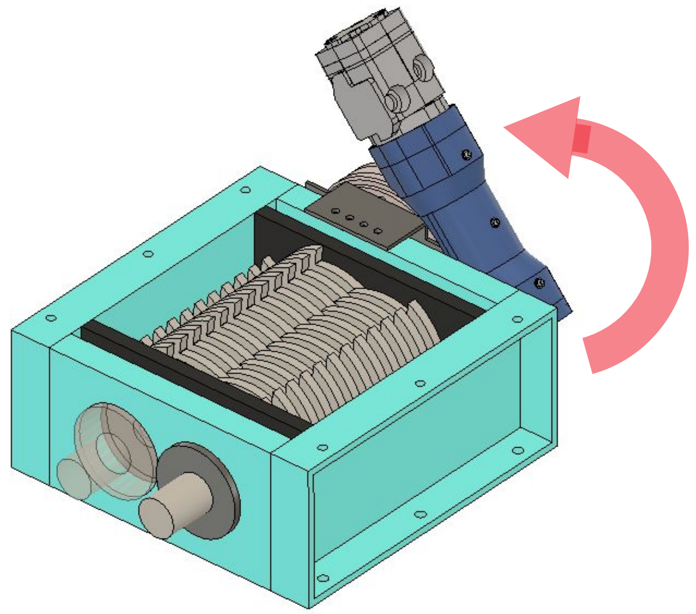
- The current bolting arrangement indicates the slewing rotor is connected to a static bracket via the gear flange.
- The torque reaction against the fixed gear will cause motor/slewing assemble to turn until the hydraulic hoses break
- Parts may not fit if not using accurate 3D CAD

Mitigations

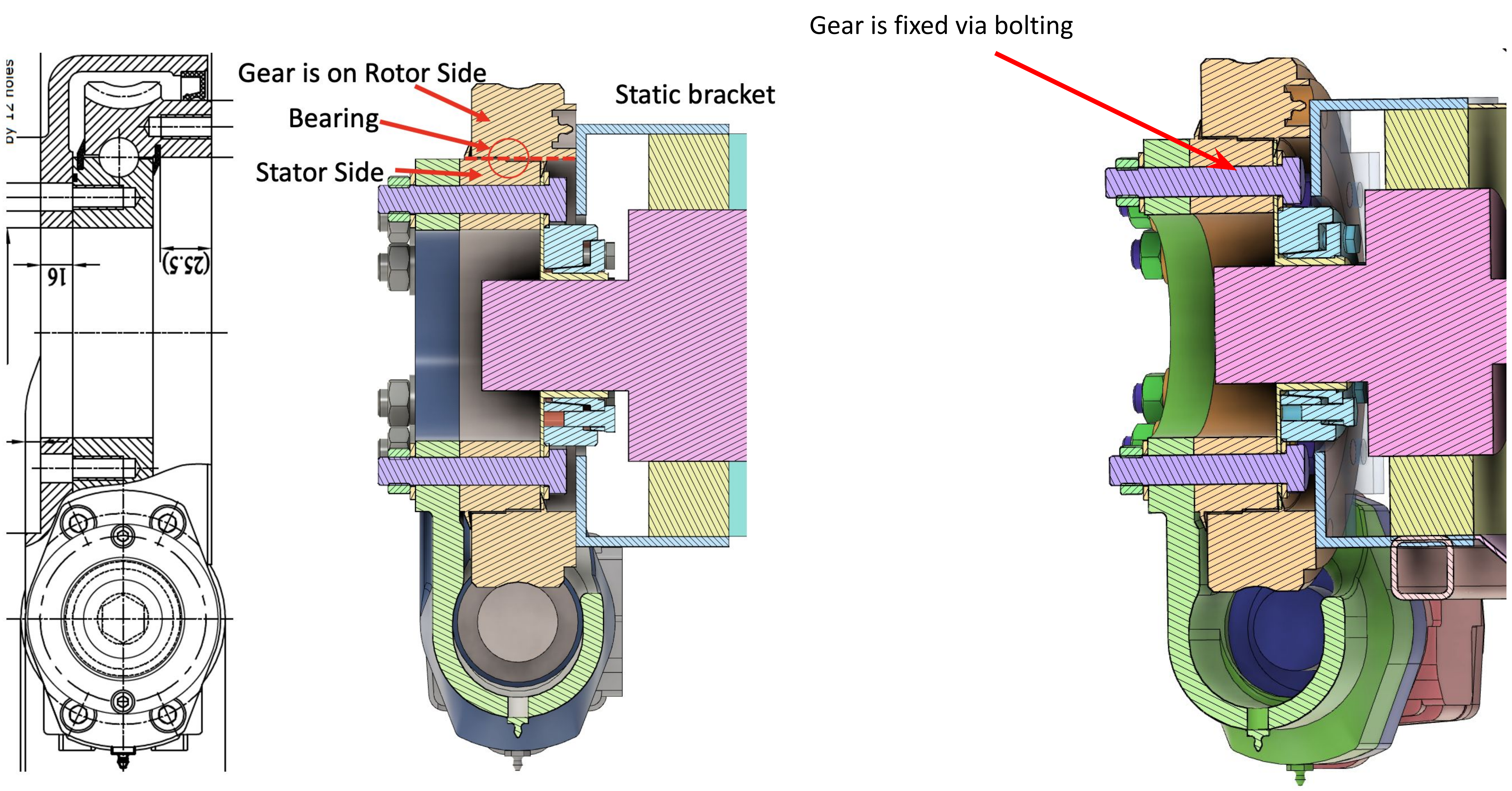
- Draw specified slew gear from scratch or get supplier CAD
- Mount slew gear to structure via inner flange (pink)
- Redesign custom shredder coupling should be fixed to outer flange (yellow)







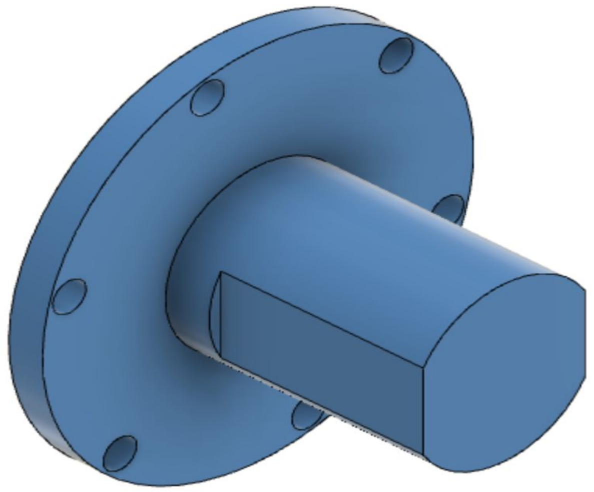
- Additional section views of current slew gear arrangement



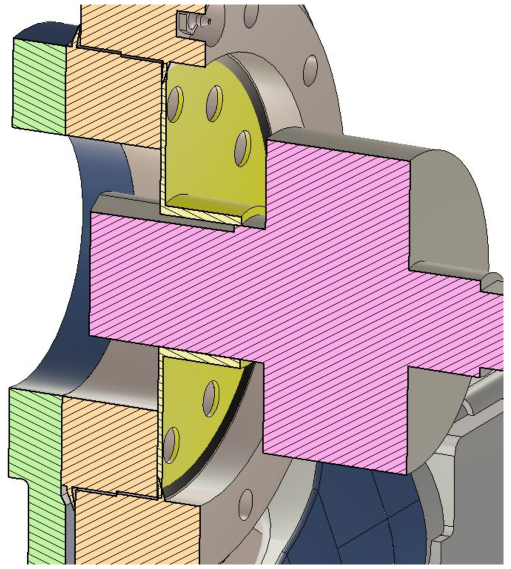
Power is transmitted from the slewing gear to the shredder via a cylindrical coupling. Some observations have been noted.

Risks/Gaps:

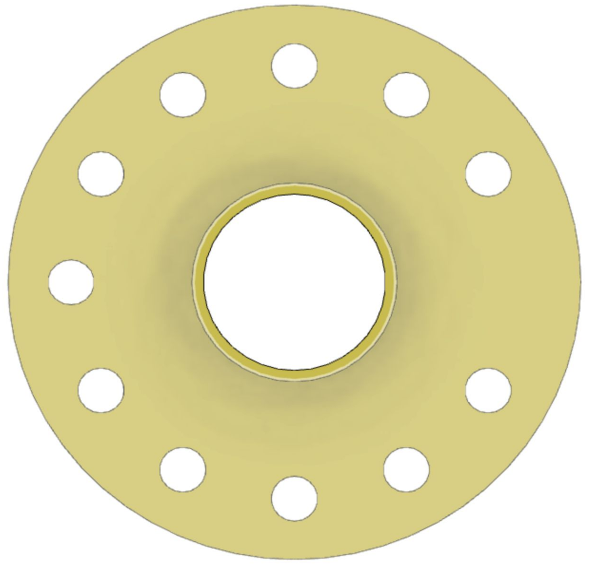
- The smooth bore of the current custom coupling design indicates power shall be transmitted through a fit rather than an abutment face. There is high potential for the coupling to slip at high torque.
- Model dimensions indicate the shaft OD and hub ID are equal. Therefore under worst case manufacturing tolerances a clearance fit can occur between shaft and hub resulting in no power transmission.
- Wall section of coupling is too low and would shear under load.
- For torque transmission fits are typically not recommended due to the risk of slippage of the components leading to wear and an eventually loss of fit between the two parts. A which point torque can no longer be transmitted.
- Not mounted to correct slew gear flange as highlighted in previous slides



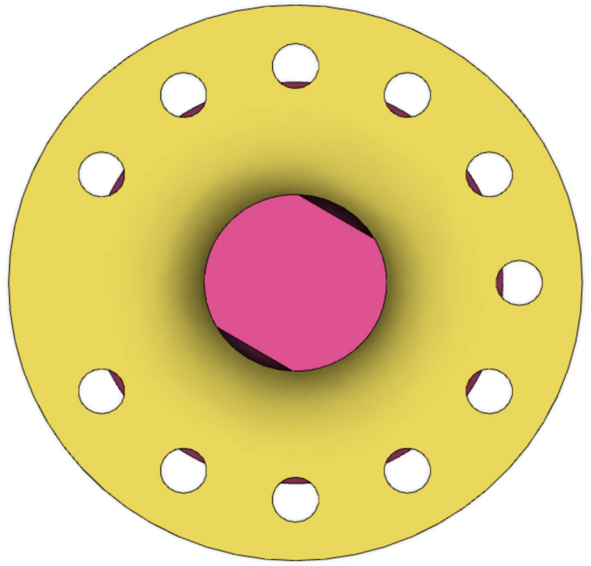
Shredder shaft



Coupling cross section



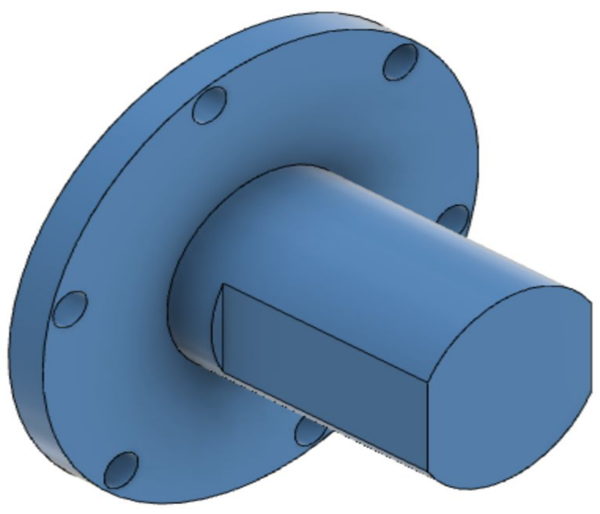
Custom coupling with round bore



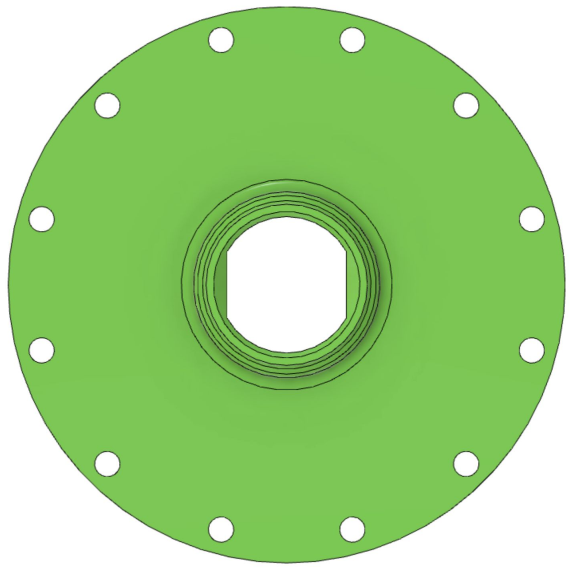
Custom coupling with keyed shredder shaft (pink)

Mitigations on shredder coupling:

- Incorporate an abutment face to match the shaft as shown.
- A clearance fit should be used to account for installation and thermal expansion considerations.
- Increase flange diameter to secure to outer flange of slew gear.
- Consider adding a torque limiting clutch to accommodate any torque spikes during operation.

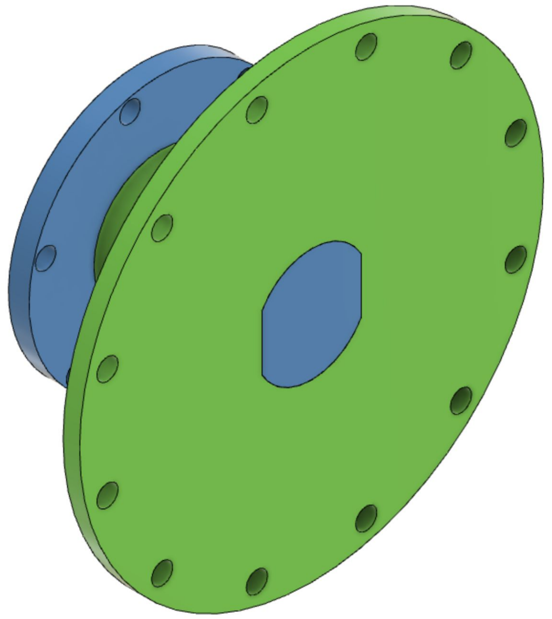


Shredder shaft

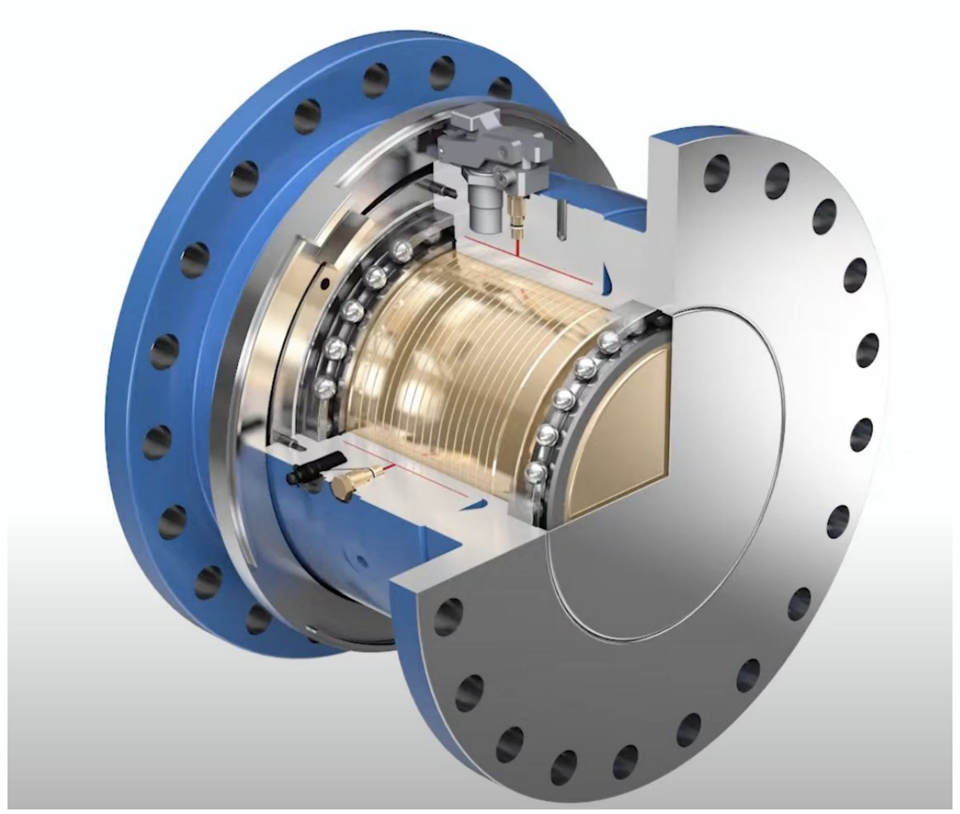


New coupling

(Resized & keyed)



New coupling mated to shredder shaft



Torque Limiting Clutch

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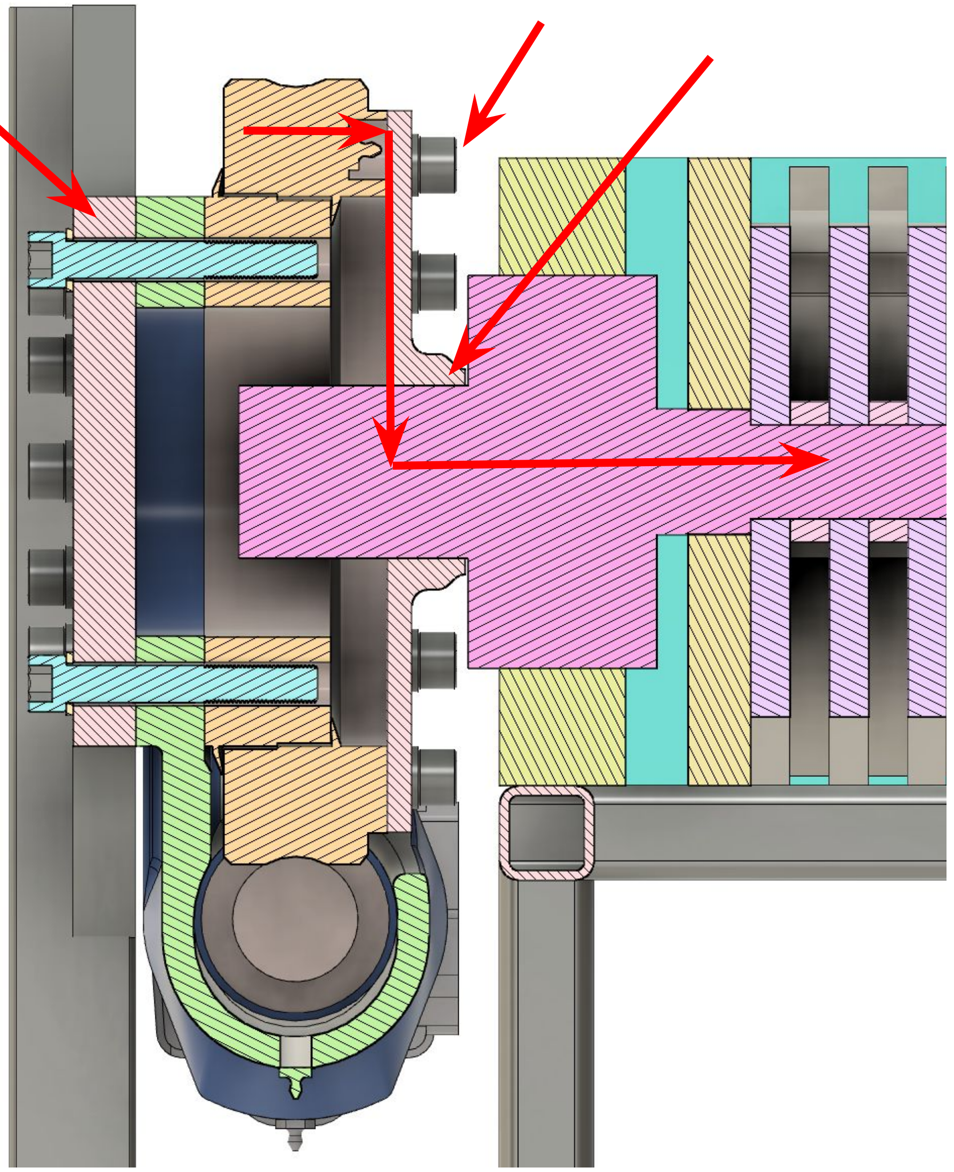
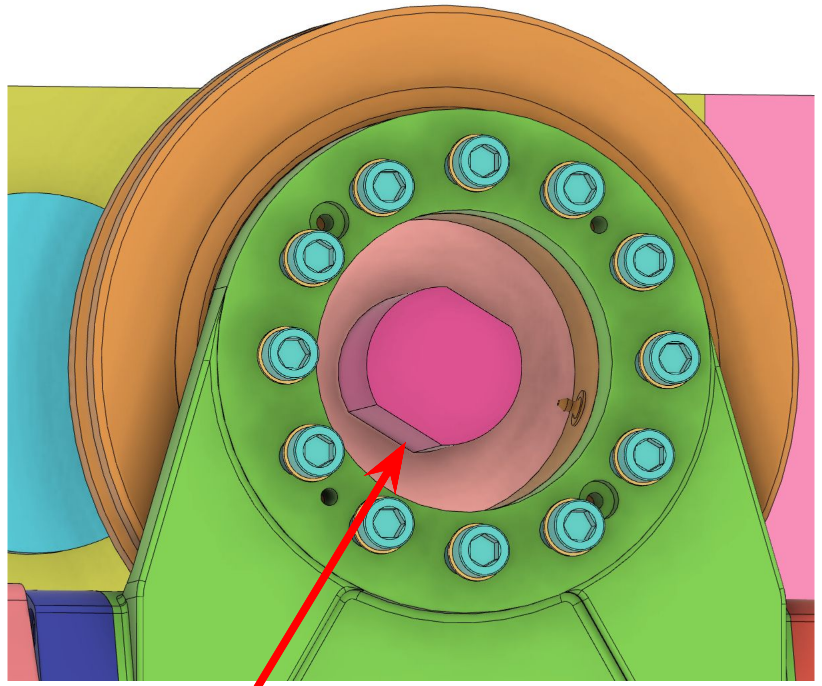
1. The slewing assembly is mounted to the new shredder coupling which is then pushed onto the shredder shaft.
2. A custom mounting plate provides the fixing points for the slewing assembly. Bolts are inserted from the rear to mount the assembly to the rear.
3. The Plate is then bolted to the frame.

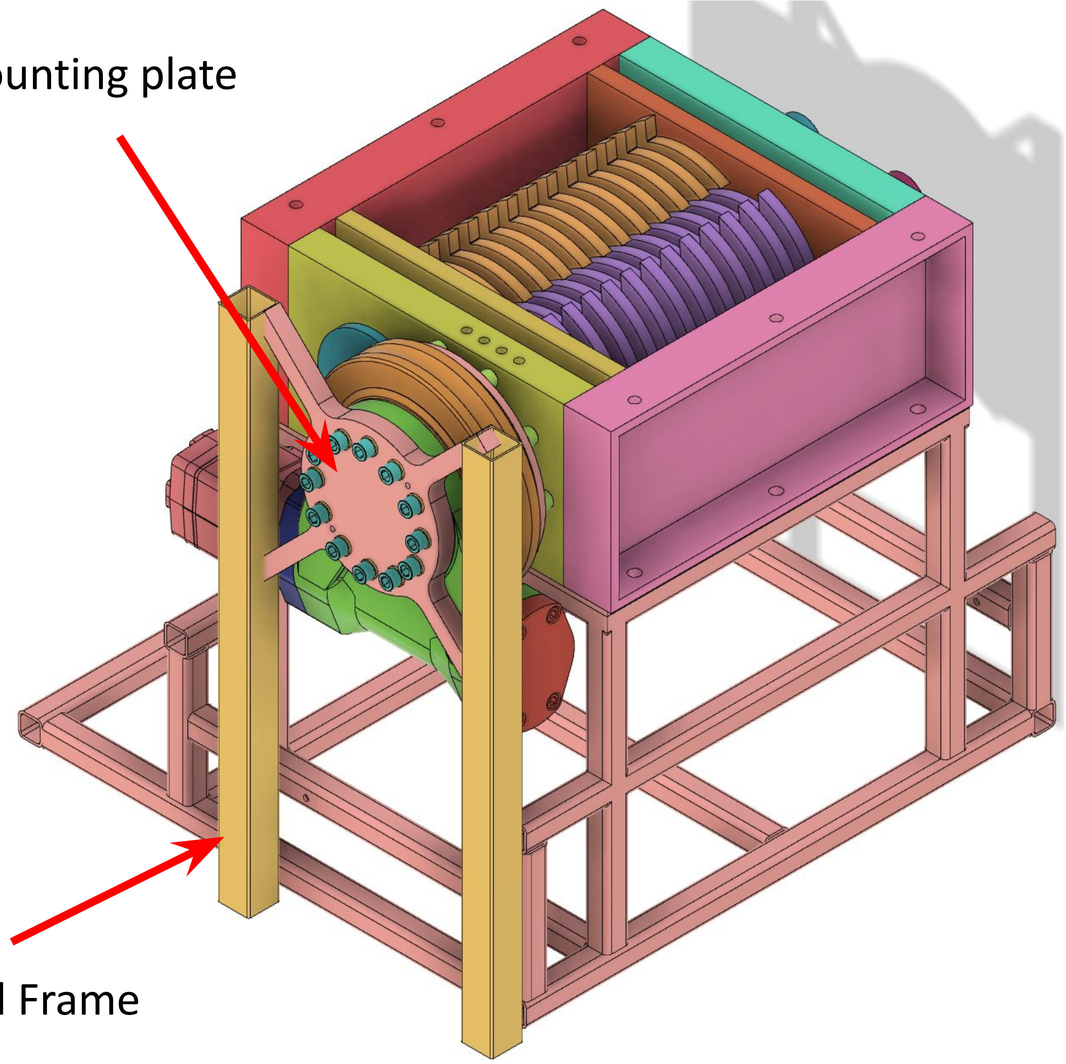
Custom mounting plate

New Shredder Coupling mounting points



Custom mounting plate





Shaft Abutment Face

Bolted Frame

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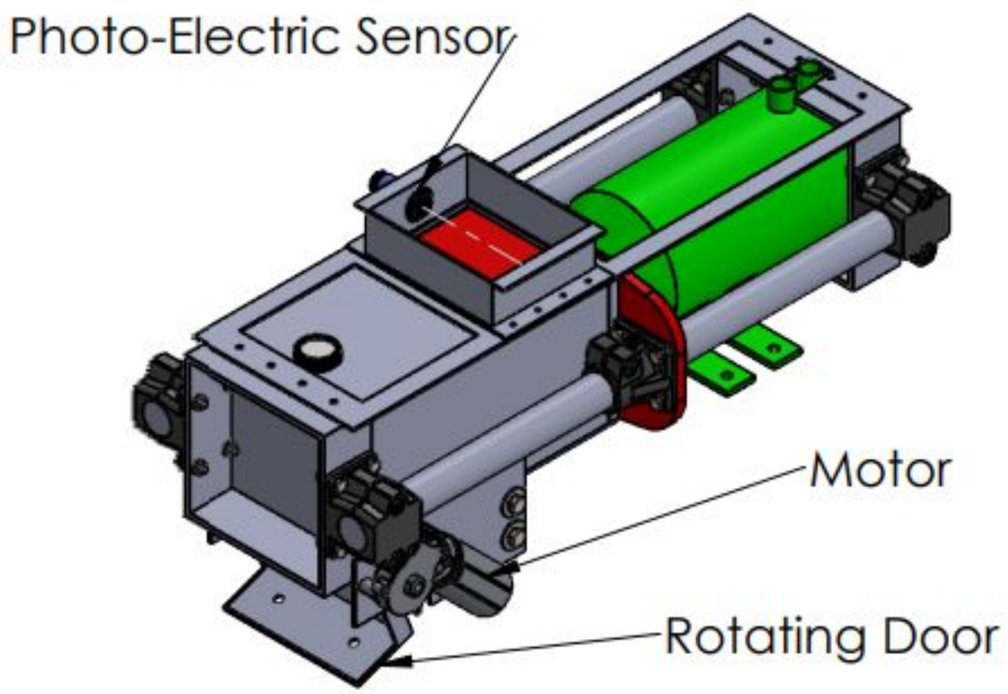
The Compactor Assembly is made up of:

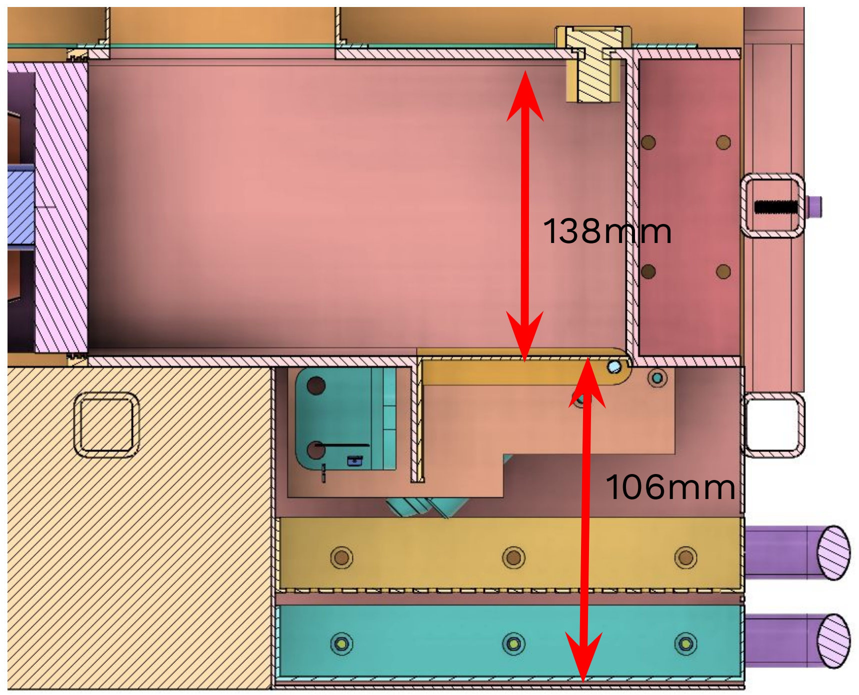
- Waste compression chamber structure
- Minimum fill sensor
- Hydraulic cylinder
- Ram
- Guide rods
- Guide rod bushing and connectors
- Rotating trap door
- Trap door motor
- Trap door locking solenoid

There are no specific performance related concerns with compression capability.

Risks/Gaps:

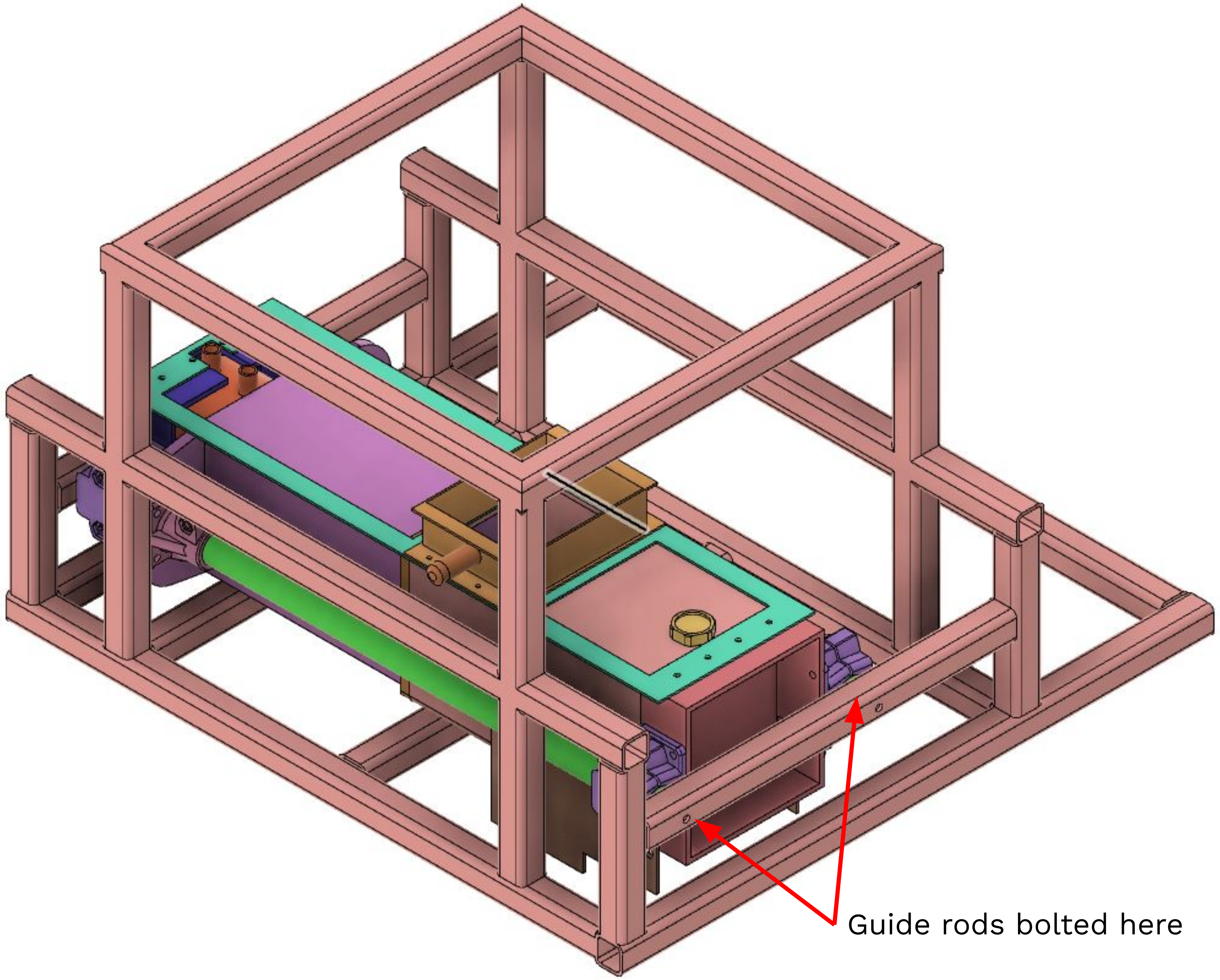
- Strength of compactor structure to withstand distortion under its own power
- Will photo-electric sensor trigger prematurely as shredded waste passes through chamber
- Briquette may get stuck in chamber even after trap door opens
- Debris may get caught between moving parts causing jam
- Briquette height can be larger than tray height by 32mm therefore briquette will not fully exit the chamber and trap door may not be able to shut.
- The system does not know when trap door is open or if briquette is already present
- The user may have to empty drawer after every compaction





Mitigations:

- Increase guide rod diameters and bolt ends to box section chassis.
- Longitudinal box section provides tensile stiffness to resist deformation caused by 20kN Ram
- Consider mechanism to actively push briquettes out of chamber post compression from above or below.
- Increase size of briquette drawer (involves increasing overall product height)
- Drain fluid to sump instead of drawer to make more room for briquettes
- Add sensor to determine if briquette is present and if trap door or removal drawer is open
- Add sensor for minimum fill sensor and detect debris over time to indicate chamber if full
- Add maximum fill sensor on hopper as an error trap.
- Test assembly to see how briquettes of differing materials behave.



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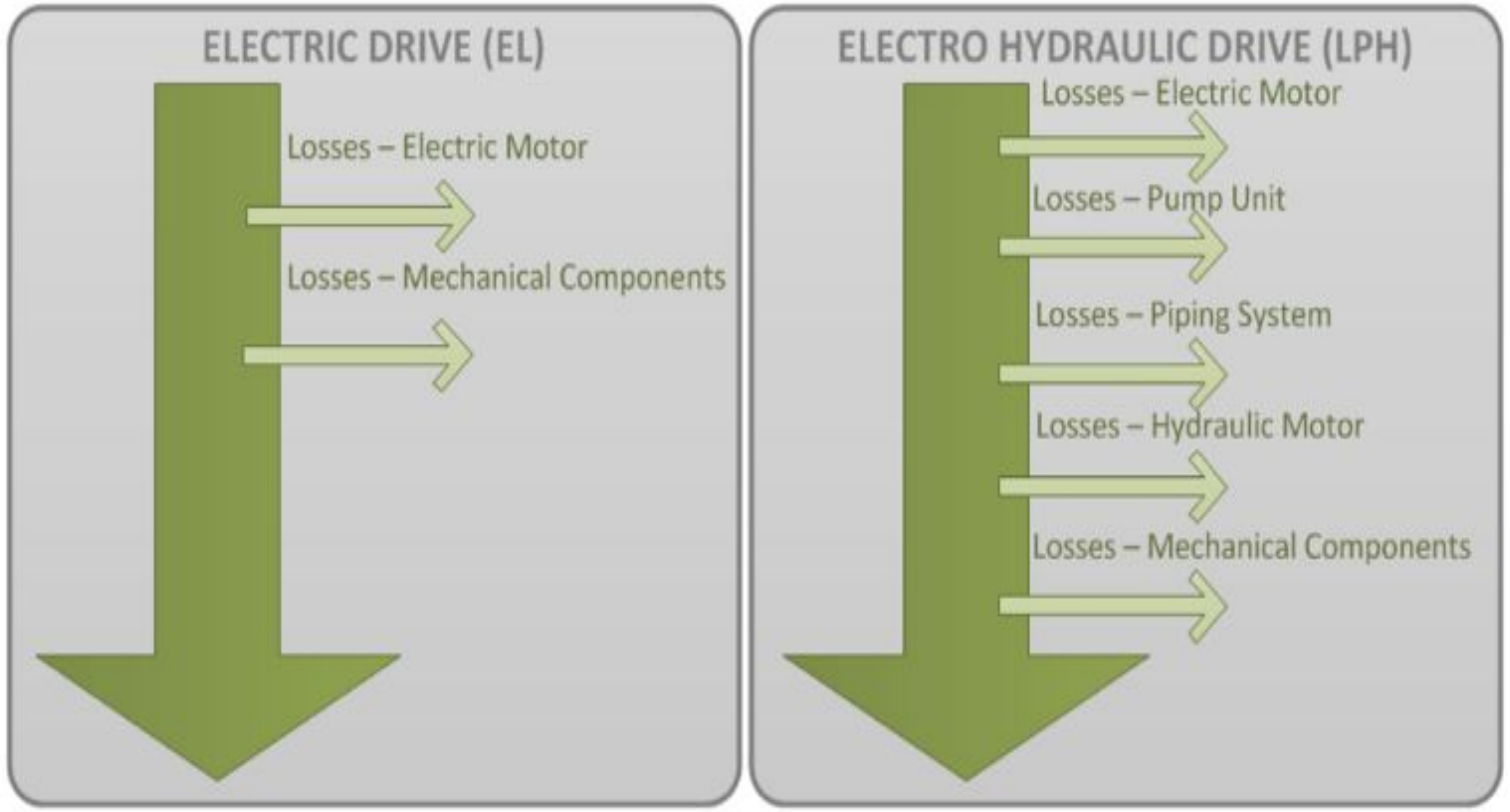
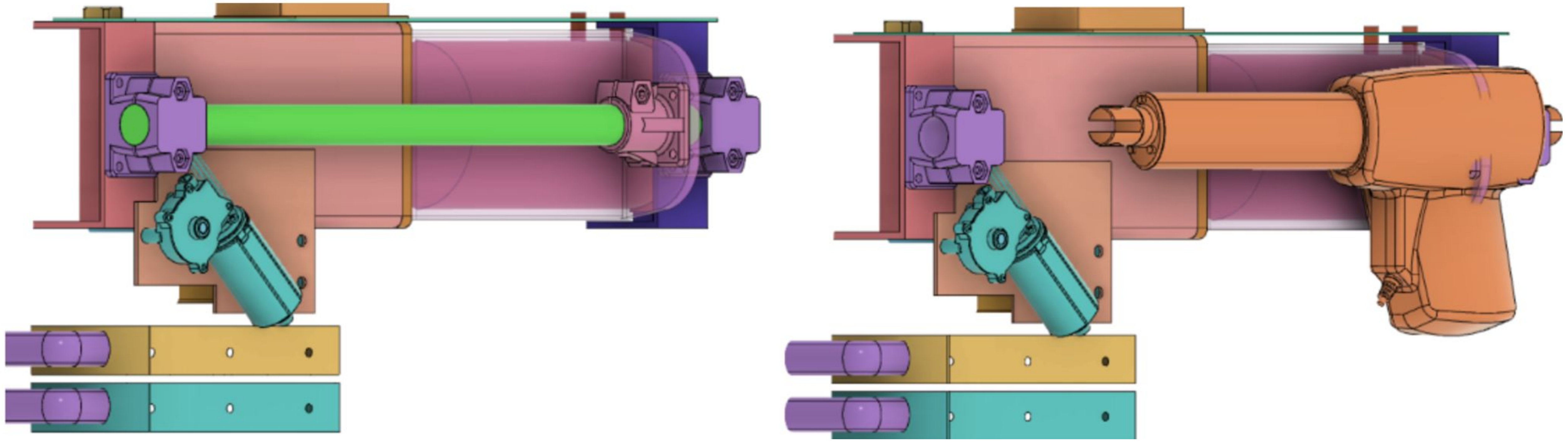
Due to some of the risks associated with hydraulic systems, the client may wish to consider prototyping an electrically driven alternative based on the following:

- Electrically operated components transfer electrical energy directly into mechanical energy and so have a better efficiency compared to hydraulic systems. Savings in efficiency of between 30% to 40%.
- Weight and volume: The electric drive has less volume and weight due to the absence of a pump, oil tank, piping, valves and connectors.
- Maintenance: Electric systems have reduced maintenance due to the presence of fewer moving parts or parts subject to deterioration due to dirt.
- Safety: Oil leakages can occur at connections and couplings and may risk accidents to staff.
- Noise: hydraulic equipment is noisier than the electric system because of its pumps, which are characterized by their high level of noise.
- Reference Paper: A REVIEW OF THE DRIVE OPTIONS FOR OFFSHORE ANCHOR HANDLING WINCHES



Conceptually an electrically powered system could comprise of:

- Primary Shredding: A 3 phase electric motor and speed reducer direct drive is recommended to replace the hydraulic drive solution.
- Secondary compaction: Electric linear actuators are recommended to replace the hydraulic ram. 2 off 10kN Dual TiMotion TA12 linear actuators can be used to replace the single 20kN hydraulic ram requiring a 24V power supply. Tie's into 24 volt power bus



CHASSIS

The chassis for the ZLX machine is yet to be defined. A stiff and strong structure will be required to support the significant weight of the components such as the shredder and slewing gear. It will also have to withstand compactor focus without distorting.

For initial low volumes of production we suggest employing a welded 30mm steel box section as shown in the images.

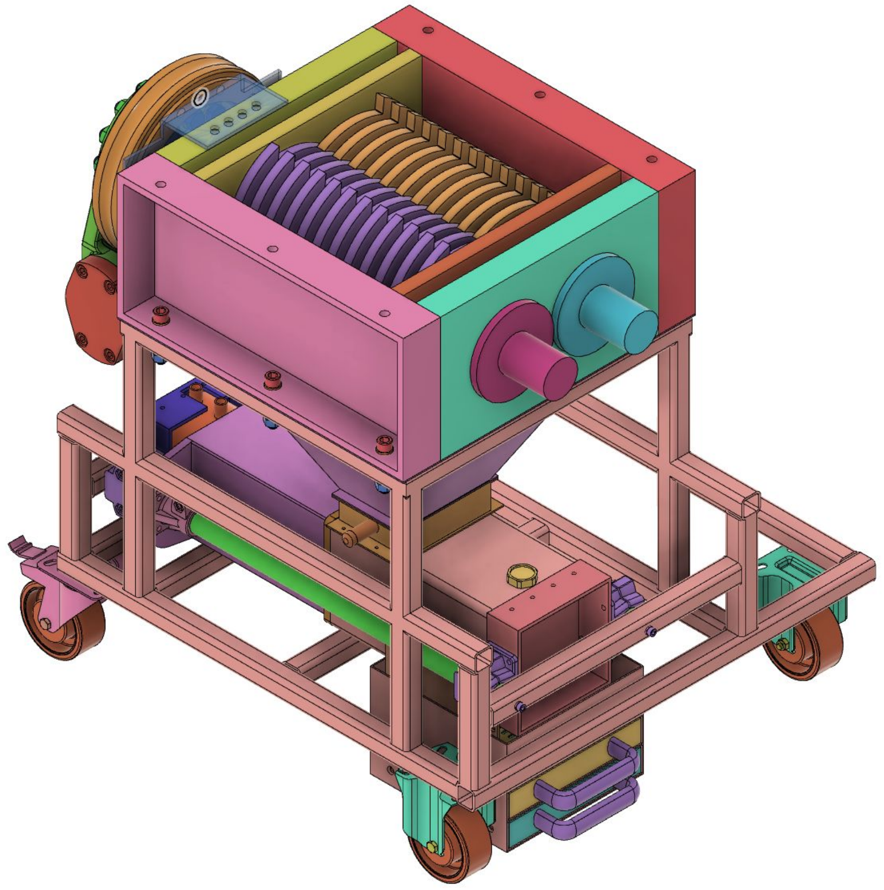
However further stress work would be required to verify beam sizing against loads

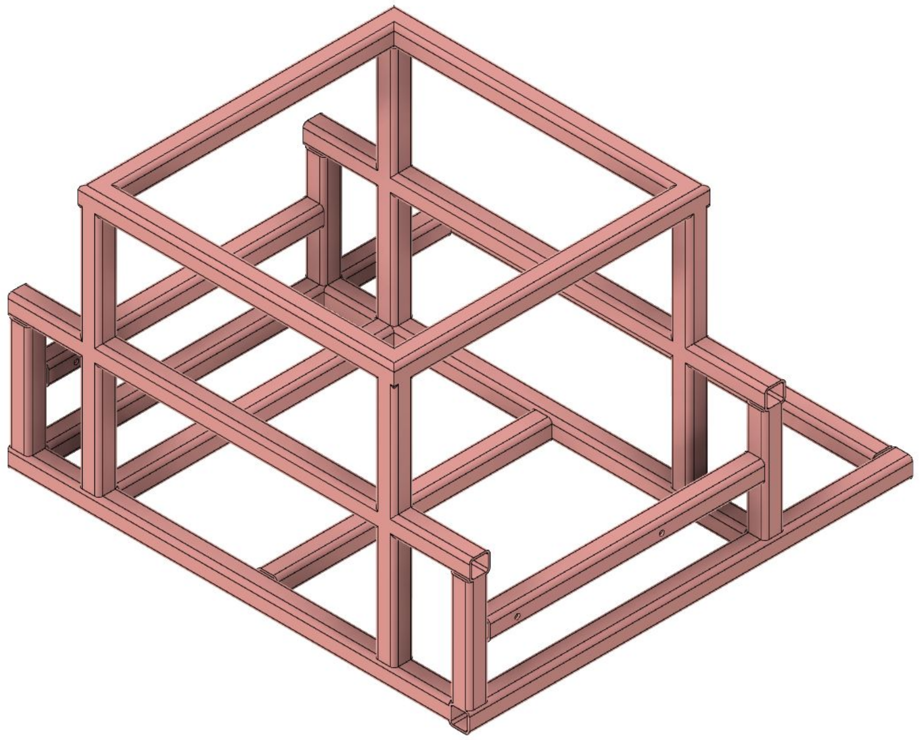
Reinforcement or lifting points may need to be considered for installing the machine on premises. The castors drawn may not be able to cope with loads of over 500kg.

For prototyping, alternative options to welded box section could possibly be considered to allow flexibility in the arrangement of the functional test rigs. This could be:

- Steel box section and plates screwed together with rivet nuts and bolts
- 40x40 aluminium extrusion and custom aluminium plates bolted together
- The fasteners would need to be checked frequently due to the high forces and vibration.

Stress analysis would be required





WEIGHT

A provisional weight estimate is given in the table opposite for discussion purposes. The total weight of 663kg is significantly higher than the 150kg target mentioned in the kick off meeting.

Risk: The mass this machine may be difficult to transport and maybe more suited to permanent installation at semi industrial environment.

Component	Mass (kg)
Shredder	160
shredder coupling	5
slewing gear	35
Chassis	26
Hydraulic power unit and piping	300
Reservoir oil	40
compactor assembly	25
hopper	7
feeder hopper	5
Outer enclosure	60
total	663

SIZE

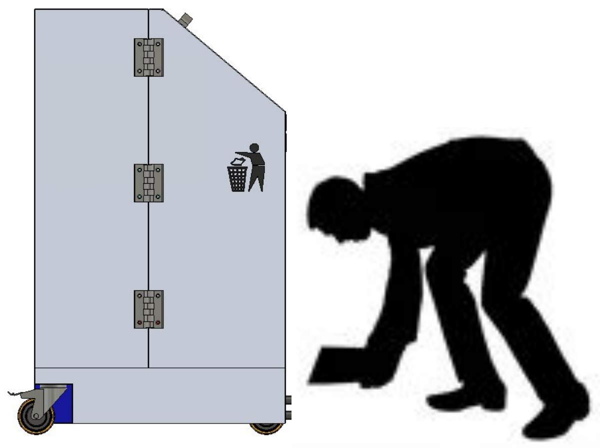
The concept cad looks like a reasonable size. It is likely that some extra depth will be needed in front and behind the shredder assembly to allow for clearances. Hydraulic tubing, bend radius and connection points to the HPU may require extra space to the side of the main stack but can be evaluated after receiving initial samples.

ENCLOSURE

IP67 was mentioned at the kickoff meeting but on review IP rating of IP54 or IP55 should be suitable for this environment. The hatch and joins in the enclosure may need sealing or modified angles to encourage runoff.

INTERFACES

It may be desirable to elevate the collection point for the briquettes to encourage people to remove them. This may pose a challenge to change from the current arrangement but may become important during user testing. It is envisaged that a button similar to that on pillar drills could be employed. THis would give standby, on/off and emergency off functions in one button



SUMMARY

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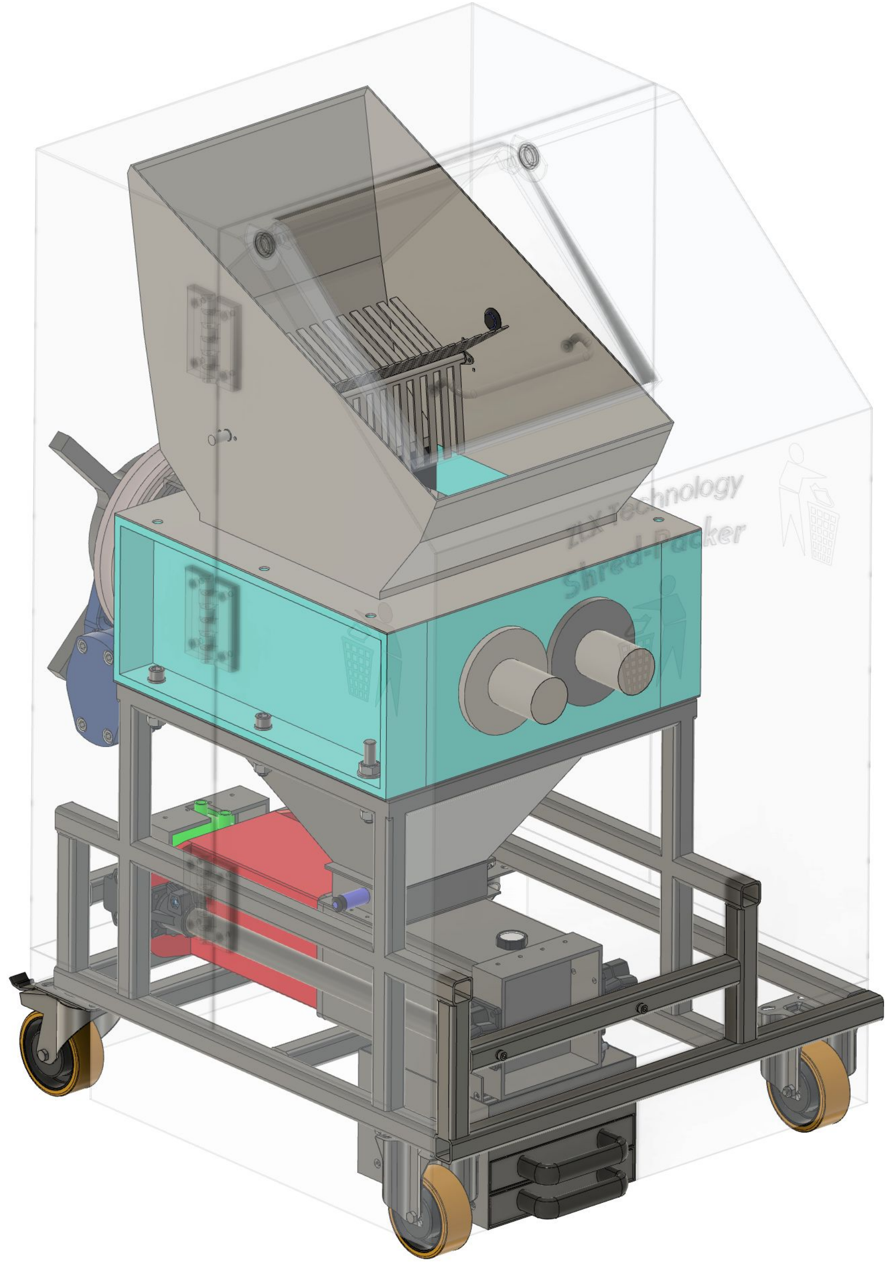
ZLX have identified the key elements required to provide a functional product that can provide great benefit to the user. Filament have identified following issues that may impact performance, function and safety:

Issue	Issue Description	Proposed Actions/Mitigations
1	Shredder will operate at lower speed and lower power than specified in the requirements/datasheet	Speak to the supplier Test shredder Choose alternative to slew gear Higher power hydraulic motor Consider electrically driven alt
2	System weight is in excess of 660kg	Design machine with lifting points Intend for specific site/environment Consider electrically driven alt Reduced spec of shredder Purchase heavy gear lifting system for prototyping
3	Hatch - user safety	Add interlock Concept phase on door openings and trial basic prototypes Test how dangerous system is (i.e test shredding all materials with guard in place)
4	Slew gear is attached incorrectly	Redesign coupling between slew gear based on recommendation Consider alternative gearbox type
5	Briquette drawer not large enough	Remove fluid drawer and use a drain to another location. Increase height of briquette drawer Test compactor with pre shredded materials to troubleshoot



RECOMMENDATIONS ON NEXT STEPS

Due to the risks highlighted in summary we would recommend the following next steps:

Fabrication of Alpha functional prototype:

- Open prototype without enclosure
- Hydraulic system not constrained by footprint of product
- Chassis to hold main stack and test functional elements (feeder, shredder, hopper, Ram)
- Basic protective cage with acrylic sheeting to trap projectile splinters from feeder.
- Feeder hatch interlock
- Raspberry PI or arduino controller with options to add new sensors and buttons
- Adjustable chassis
- Heavy lifting gear
- Leave out trap door and briquette drawer

Design activities for functional prototype:

- Consider electric vs hydraulic
- Consider planetary vs slew gear
- Choose controller, design logic and test
- Detail design of adjustable chassis
- Detail design of hopper and feeder with safety cover

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