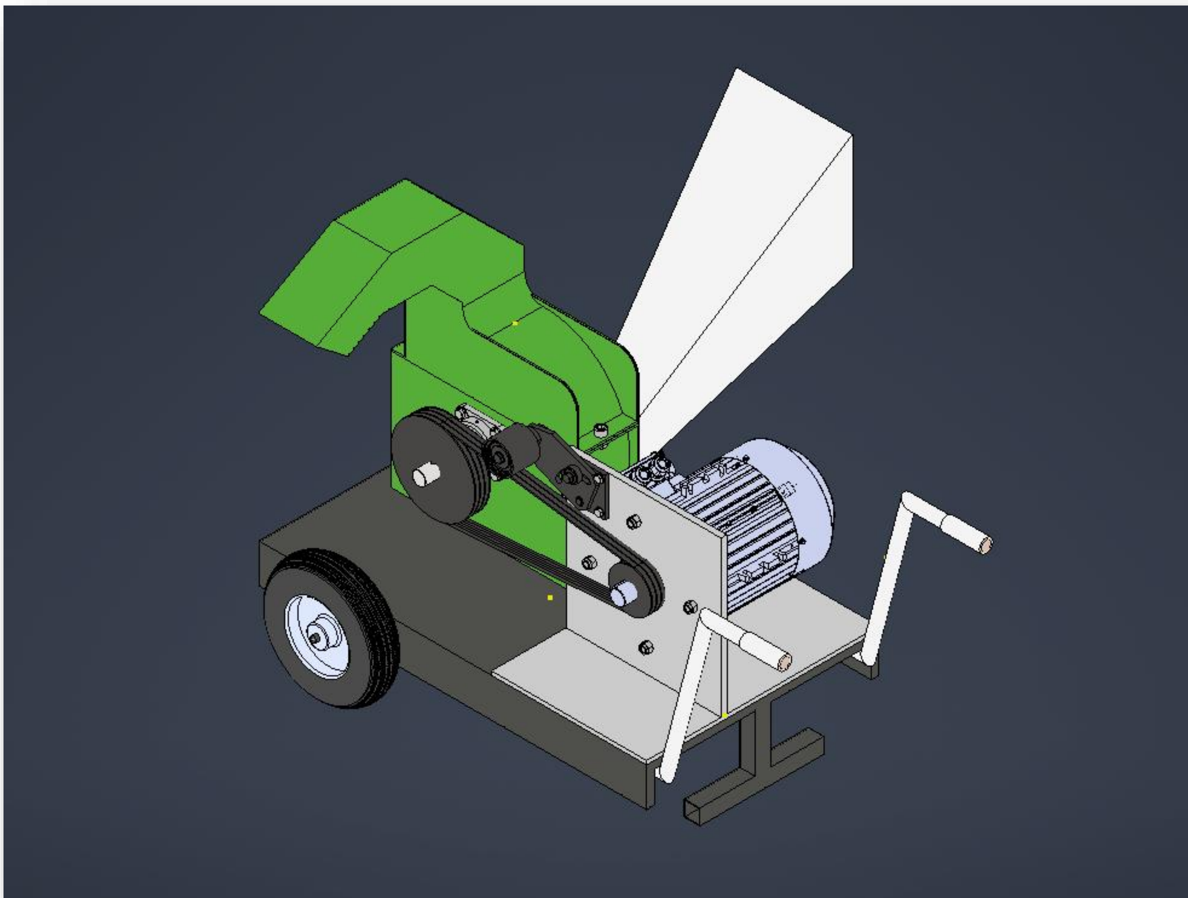
Design of a 7.5 kW Mobile Woodchipper



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CONTENTS

1. INTRODUCTION & PROJECT SCOPE

The objective of this project was to design, calculate, and document a complete, safe, and mobile woodchipper. The machine is designed for the "prosumer" market, bridging the gap between small garden shredders and commercial forestry equipment.

Core Specifications:

- **Power Source:** 7.5 kW Electric Motor.
- **Target Capacity:** Processing branches up to **50 mm** in diameter.
- **Mobility:** Mobile platform on wheels for easy transport.

2. MARKET RESEARCH & DESIGN PHILOSOPHY

2.1 CUTTER MECHANISM SELECTION

Three distinct cutter mechanisms commonly available were analyzed based on the easiness in production and price constraints. The decision was made to utilize a **Disc Cutter** design.

Table 1 Cutter types and differences

Cutter Type	Mechanism Description	Pros	Cons
Hammer Mill	Swinging metal flails smash wood through a screen.	Handles contaminated wood (nails/sand) well.	Extremely loud; produces shredded mulch rather than clean chips; high power consumption.
Drum Chipper	Cylindrical drum with knives mounted on the outer surface.	Very high throughput; consistent chip size.	Complex to balance; difficult to manufacture; dangerous if the drum unbalances.
Disc (Wheel) Chipper	**Selected Design.** Knives mounted on a heavy steel flywheel face.	**Easiest to model and manufacture**; high inertia (flywheel effect); produces small, uniform chips.	Requires a specific feed angle (usually 45° or 90°).

Justification: The **Disc Cutter** was selected because it offers the best balance of manufacturing simplicity and performance. It naturally acts as a flywheel, storing energy to cut through knots without stalling the motor, and produces the smallest, most uniform chip size desired for the output.

2.2 DRIVETRAIN PHILOSOPHY: TORQUE VS. SPEED

The “High speed/low torque” technique that is commonly available in budget conscious options in market was rejected. Instead, a **Moderate-Speed/High-Torque** system using a belt reduction was introduced.

- **The Logic:** Power (P) is the product of Torque (T) and Angular Velocity (ω). By reducing the speed by half (2:1 ratio), available torque at the cutter shaft was doubled.
- **Result:** This allows the 7.5 kW motor to chip 50mm branches without stalling, which would otherwise require a much larger engine.

3. ENGINEERING CALCULATIONS

The drivetrain was calculated following the **Optibelt Technical Manual** standards. [1]

3.1 DESIGN POWER CALCULATION

To account for shock loads and heavy-duty operation (>16 hours/day), a Service Factor (c_2) was applied .

- **Motor Power (P):** 7.5 kW
- **Service Factor (c_2):** 1.6
- **Design Power (P_b):** $P * c_2 = 7.5kW * 1.6 = 12kW$

3.2 BELT AND PULLEY CALCULATIONS (SPZ PROFILE)

Based on the Design Power (12 kW) and Motor Speed (2920 RPM), the **SPZ Wedge Belt** profile was selected from the Optibelt nomogram. [1]

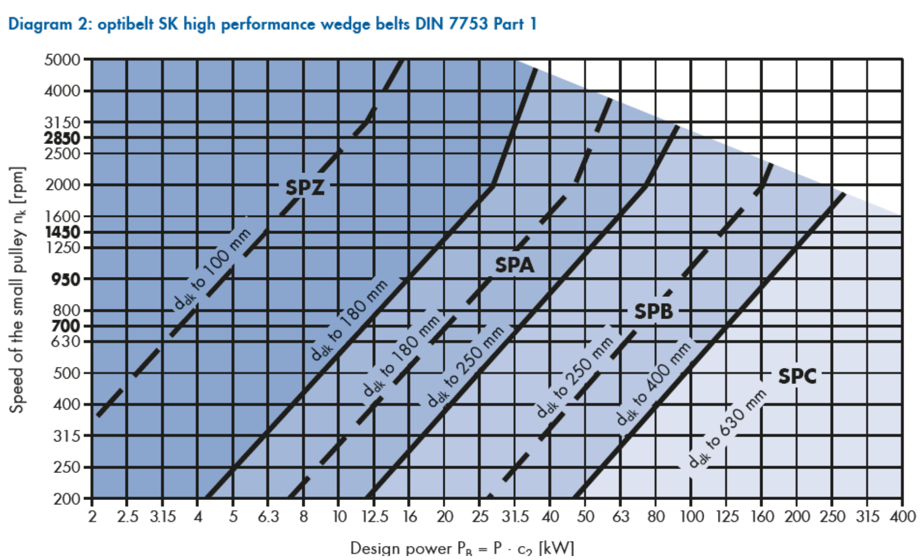


Figure 1 Screenshot of Optibelt nomogram

- **Transmission Ratio ($\boldsymbol{i}$):**

$$i = \frac{n_1}{n_2} = \frac{2920}{1460} = 2.0$$

- **Selected Pulleys:**
  - Motor Pulley (d_{dk}): **106 mm** (from the nomogram as it should be slightly greater than 100mm and a standard value)
  - Cutter Pulley (d_{dg}): **212 mm**

- **Drive center distance ($\boldsymbol{a}$):**
  Recommended; $\left[0.7 * \left(d_{dg} + d_{dk}\right)\right] < a < \left[2 * \left(d_{dk} + d_{dg}\right)\right] = 222.6 < a < 636$
  Therefore, center distance was selected as 500 mm.

- **Datum length of the V-belt ($\boldsymbol{L_{dth}}$):**

$$L_{dth} \approx 2 * a + 1.57\left(d_{dg} + d_{dk}\right) + \frac{\left(d_{dg} - d_{dk}\right)^2}{4 * a} = 2 * (500) + 1.57(318) + \frac{106^2}{4 * 500} = 1504.8\,mm$$

  Therefore, as the standard value (L_{dSt}) 1500 mm long V-belt was selected.

- **Center distance ($\boldsymbol{a_{nom}}$):**

  As $L_{dSt} < L_{dth}$; $a_{nom} \approx a - \frac{L_{dth} - L_{dSt}}{2} = 497.6\,mm$

- **Arc of contact ($\boldsymbol{\beta}$) and correctional factor ($\boldsymbol{c_1}$):**

  Using the table in the Optibelt catalog, approximations were made. [1]

$$\frac{d_{dg} - d_{dk}}{a_{nom}} = \frac{212 - 106}{497.6} = 0.21 \approx 0.20$$

$\frac{d_{dg} - d_{dk}}{a_{nom}}$	$\beta \approx$	c_1
0	180°	1.00
0.05	177°	1.00
0.10	174°	1.00
0.15	171°	1.00
0.20	168°	0.99

Figure 2 Arc of contact and correctional factor table

Therefore, $\beta = 168^{o}$ and $c_1 = 0.99$.

- **Number of belts:**

$$z = \frac{P * c_2}{P_N * c_1 * c_3} = \frac{7.5 * 1.6}{4.8 * 0.99 * 0.99} = 2.55$$

Thus, it was decided to go with 3 SPZ 1500 mm belts.

(here, P_N was decided based on the Optibelt catalog) [1]

Pulleys	v [m/s]	n_k [min^{-1}]	Datum diameter of small pulley d_{dk} [mm] 90	100	112	118	125	132	140	150	160	180	200	224	250	280	315	Additional power [kW] per belt for speed ratio i 1.01 to 1.05	1.06 to 1.26	1.27 to 1.57	> 1.57
		700	1.17	1.55	1.99	2.21	2.47	2.72	3.01	3.37	3.73	4.44	5.14	5.97	6.85	7.86	9.01	0.02	0.15	0.21	0.26
		950	1.49	1.98	2.57	2.86	3.20	3.53	3.91	4.39	4.86	5.78	6.70	7.78	8.92	10.21	11.68	0.03	0.20	0.29	0.36
		1450	2.04	2.76	3.62	4.04	4.53	5.02	5.57	6.25	6.92	8.24	9.52	11.02	12.58	14.30	16.18	0.05	0.31	0.44	0.54
		2850	3.14	4.40	5.88	6.60	7.43	8.23	9.13	10.21	11.25	13.21	14.97	16.81	18.43	19.78	20.57	0.09	0.61	0.87	1.07
		100	0.23	0.30	0.37	0.40	0.45	0.49	0.54	0.60	0.65	0.77	0.89	1.03	1.18	1.35	1.55	0.00	0.02	0.03	0.04
		200	0.42	0.54	0.68	0.75	0.83	0.91	1.00	1.11	1.22	1.45	1.67	1.94	2.22	2.55	2.92	0.01	0.04	0.06	0.07
		300	0.59	0.76	0.96	1.07	1.18	1.30	1.43	1.60	1.76	2.09	2.41	2.80	3.21	3.68	4.23	0.01	0.06	0.09	0.11
		400	0.75	0.97	1.24	1.37	1.52	1.67	1.85	2.06	2.28	2.70	3.12	3.63	4.16	4.78	5.49	0.01	0.09	0.12	0.15
		500	0.90	1.17	1.50	1.66	1.85	2.03	2.25	2.51	2.77	3.30	3.81	4.43	5.09	5.84	6.70	0.02	0.11	0.15	0.19
		600	1.04	1.36	1.75	1.94	2.16	2.38	2.63	2.95	3.26	3.87	4.48	5.21	5.98	6.86	7.88	0.02	0.13	0.18	0.22
		700	1.17	1.55	1.99	2.21	2.47	2.72	3.01	3.37	3.73	4.44	5.14	5.97	6.85	7.86	9.01	0.02	0.15	0.21	0.26
		800	1.30	1.72	2.23	2.47	2.76	3.05	3.38	3.78	4.19	4.99	5.77	6.71	7.70	8.82	10.11	0.03	0.17	0.24	0.30
		900	1.43	1.90	2.45	2.73	3.05	3.37	3.74	4.19	4.64	5.52	6.39	7.43	8.52	9.76	11.17	0.03	0.19	0.27	0.34
		1000	1.55	2.06	2.68	2.98	3.34	3.69	4.09	4.58	5.07	6.04	7.00	8.12	9.32	10.66	12.18	0.03	0.22	0.31	0.37
	5	1100	1.66	2.23	2.90	3.23	3.61	4.00	4.43	4.97	5.50	6.55	7.59	8.80	10.09	11.53	13.15	0.04	0.24	0.34	0.41
		1200	1.77	2.38	3.11	3.47	3.88	4.30	4.76	5.34	5.92	7.05	8.16	9.46	10.84	12.37	14.08	0.04	0.26	0.37	0.45
		1300	1.88	2.54	3.31	3.70	4.15	4.59	5.09	5.71	6.33	7.54	8.72	10.10	11.55	13.17	14.96	0.04	0.28	0.40	0.49
		1400	1.99	2.69	3.52	3.93	4.40	4.87	5.41	6.07	6.72	8.01	9.26	10.72	12.25	13.93	15.79	0.05	0.30	0.43	0.52
		1500	2.09	2.83	3.71	4.15	4.65	5.15	5.72	6.42	7.11	8.47	9.79	11.32	12.91	14.66	16.56	0.05	0.32	0.46	0.56
		1600	2.19	2.97	3.91	4.37	4.90	5.43	6.02	6.76	7.49	8.91	10.29	11.89	13.54	15.34	17.29	0.05	0.34	0.49	0.60

Figure 3 Table for finding power per belt (P_N)

- **Static tension per belt :**

$$T \approx \frac{500 * (2.04 - c_1) * P_B}{c_1 * z * v} + k * v^2 = 149.3\ N$$

(k was selected from the Optibelt catalog; $k = 0.07$) [1]

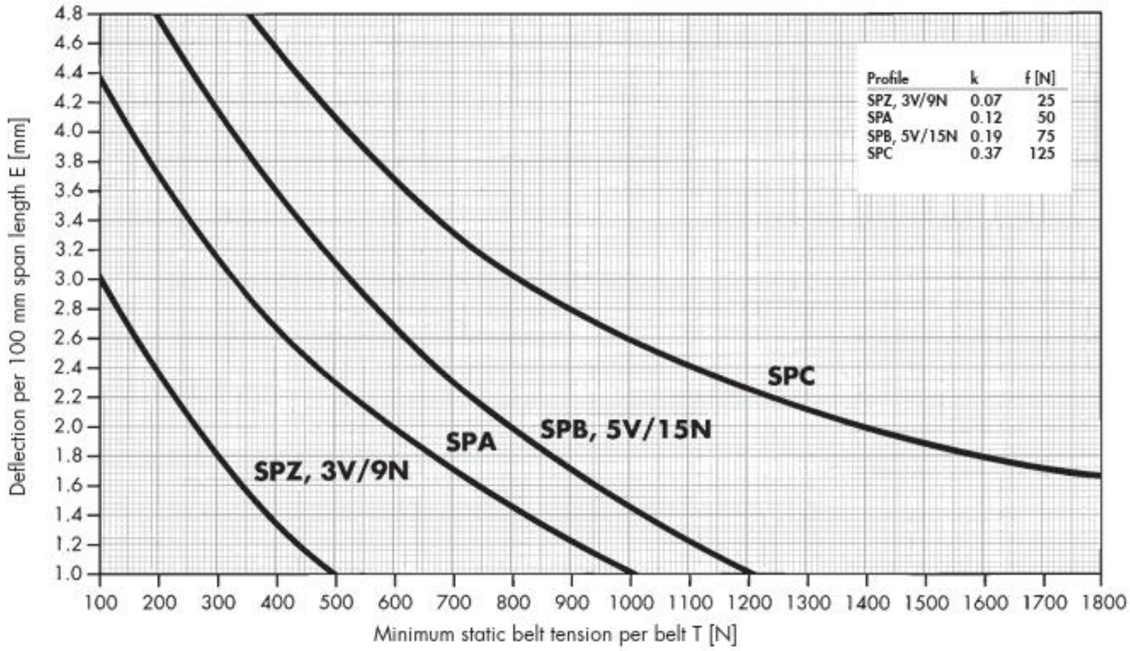


Figure 4 Belt tension characteristics for optibelt SK high performance wedge belts

- **Static shaft load:**

$$S_a = 2 * T * sin\frac{\beta}{2} * 3 = 890.89\ N$$

Initial installation load;

$$S_a = 1.3 * 890.89 = 1158.157\ N$$

3.3 VERIFICATION CHECKS

- Belt Speed (v): Must be < 42m/s.

$$v = \frac{d_{dk} * n_k}{19100} = 16.2 m/s \text{ (Passed)}$$

- Flex Frequency (f_b): Must be <100Hz.

$$f_b = \frac{2 * 1000 * v}{L\_dSt} = \frac{2 * 1000 * 16.2}{1500} = 21.6 Hz \text{ (Passed)}$$

- Number of Belts (z):

Calculated as 2.57, rounded up to 3 Belts (SPZ 1500) for redundancy.

3.4 CUTTER TIP SPEED

To ensure effective chip ejection, the tip speed must exceed 25 m/s.

- **Disc Diameter:** 400 mm
- **Speed:** 1460 RPM
- **Tip Speed (V_c): 30.58 m/s** (Passed).

3.5 SHAFT DESIGN (STATIC ANALYSIS)

The main shaft is subjected to both bending (from belt tension) and torsion (from cutting).

- **Max Bending Force (S_{max}):** 1158 N.

$$M_b = S_{max} * a = 1158 * 0.06 \approx 69.5\ Nm$$

(a = overhang that carries the pulley which is subjected to bending)

- **Torsional Moment (M_t):** 49.2 Nm.

$$M_t = \frac{P}{2 * \pi * rps} = \frac{7500}{2 * \pi * \frac{1460}{60}} = 49.2\ Nm$$

- **Material:** C45 Steel (Yield Strength ≈ 340 MPa).
- **Safety Factor (n):** 6.0 (Selected for high shock/impact).

$$\tau_{allow} = \frac{340}{6} = 56.67\ Mpa$$

$$K_p = \frac{M_t}{\tau} = \frac{49.2 * 1000}{56.67} = 868.18\ mm^3$$

$$K_p = \frac{\pi * D^3}{16}$$

$$D = \sqrt[3]{\frac{16 * K_p}{\pi}} = 16.41\ mm \text{ (according to torsional moment)}$$

But here as the bending moment also plays a key role, diameter was calculated with equivalent torque.

$$\tau_e = \sqrt{M_b^2 + M_t^2} = \sqrt{69.5^2 + 49.2^2} \approx 85.15\ Nm$$

$$D_e = \sqrt[3]{\frac{16 * \tau_e}{\pi * \tau_{allow}}} = \sqrt[3]{\frac{16 * 85150}{\pi * 56.67}} \approx 20\ mm$$

- **Result:** A **35 mm diameter** shaft was selected, which exceeds the calculated minimum of 20 mm, ensuring high stiffness.

4. MECHANICAL DESIGN & MATERIAL SELECTION

4.1 CUTTER DISC

- **Material: AISI 4140 Steel**.
- **Justification:** This alloy offers high toughness and fatigue resistance. The 400mm diameter provides significant rotational inertia (flywheel effect), smoothing out the cutting action.

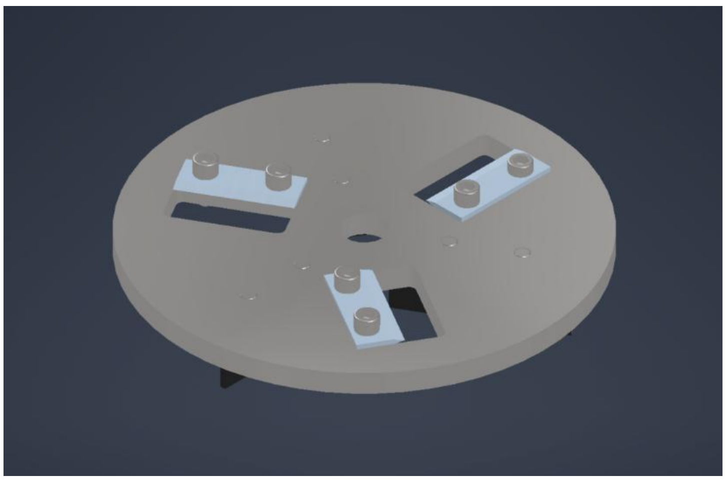


Figure 5 Cutter wheel assembly – view 1

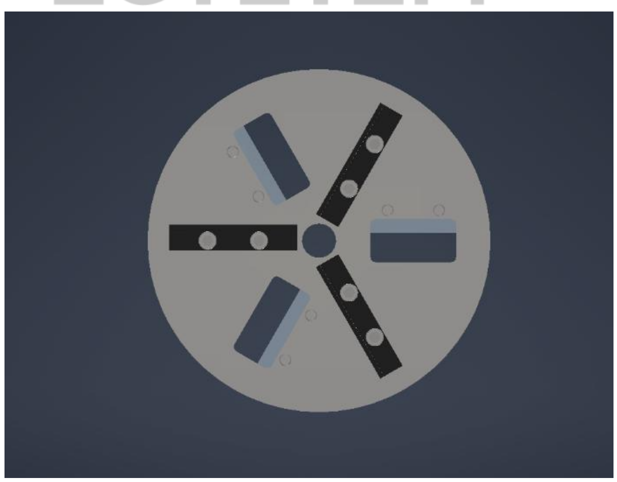


Figure 6 Cutter wheel assembly - view 2

4.2 MAIN SHAFT

- **Material: C45 Carbon Steel**.
- **Justification:** An industry-standard structural steel that balances strength with excellent machinability for keyways and bearing seats.

Figure 7 Main shaft

4.3 STRUCTURAL FRAME

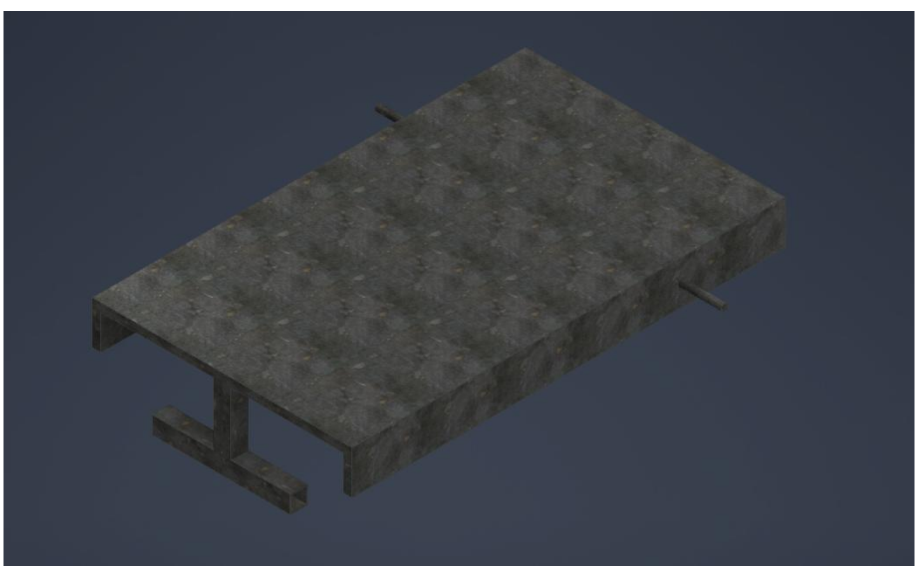


Figure 8 Main body

- **Chassis Material: ASTM A36 Steel**.
- **Justification:** Highly weldable and cost-effective structural steel, ideal for the base frame which must endure vibration.

- **Feeder: Aluminum 6061-T6**. Selected to reduce the overall weight of the machine tipping point.

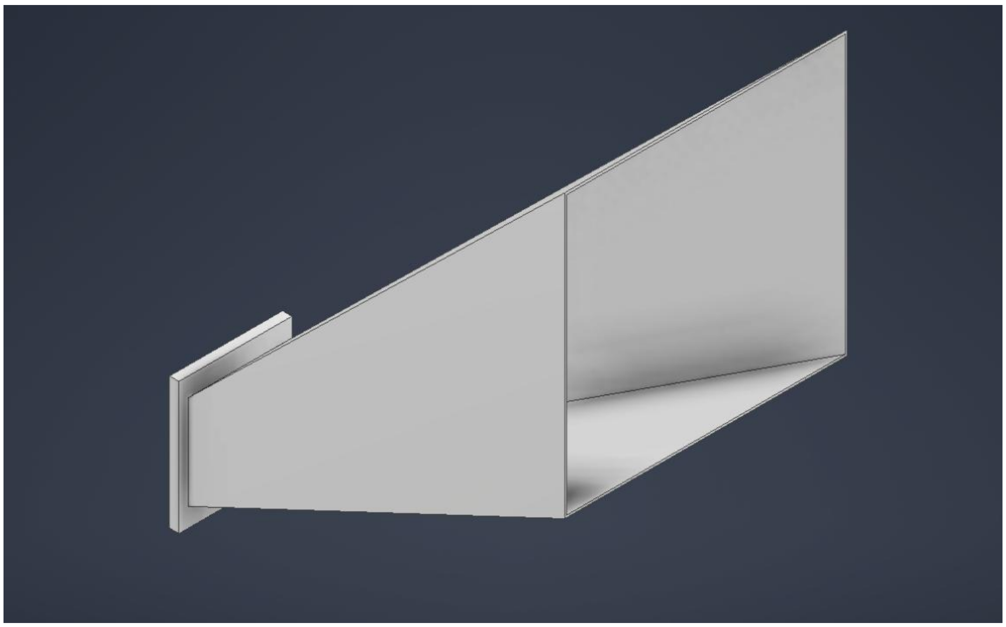


Figure 9 Feeder of woodchipper

4.4 BELT TENSIONING SYSTEM

Unlike automatic spring tensioners which can resonate (bounce) under chipping shock loads, we implemented a **Manual Slotted Bracket** design.

- **Mechanism:** A rotating arm with a locking arc slot.
- **Source:** The basic geometry for this pivoting idler was adapted from a GrabCAD model and modified to fit our specific geometry. [7]
- **Advantage:** Once locked with the **M11 Nyloc nut**, the system is static and rigid, preventing belt slip during heavy cuts.

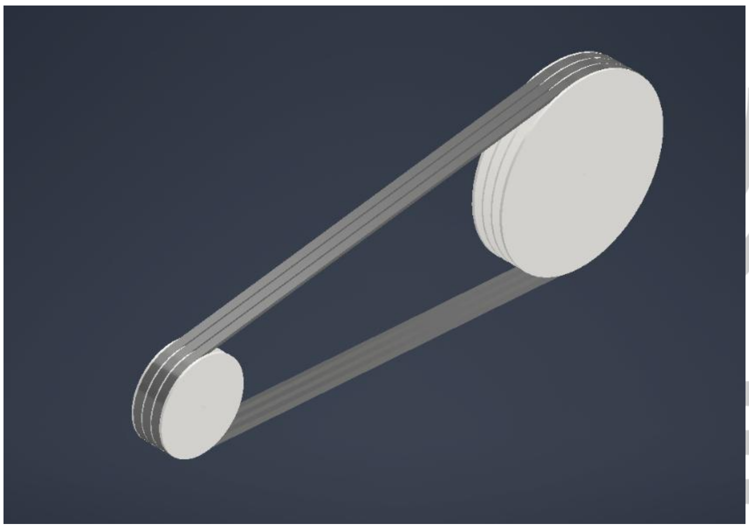


Figure 11 V-belts with pulleys

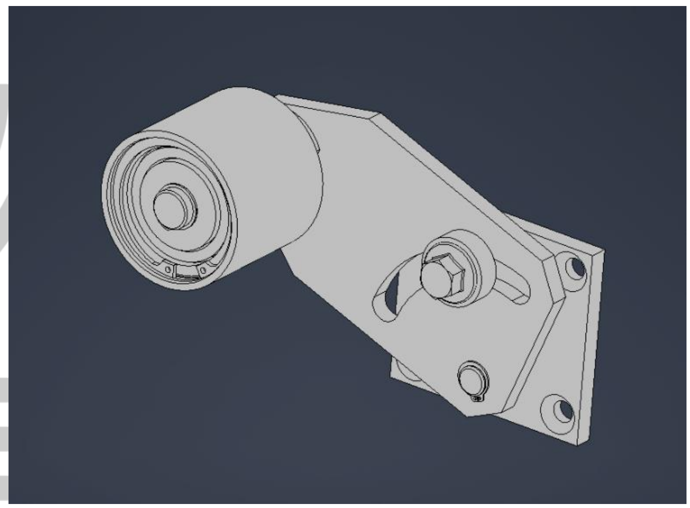


Figure 10 Belt tensioner

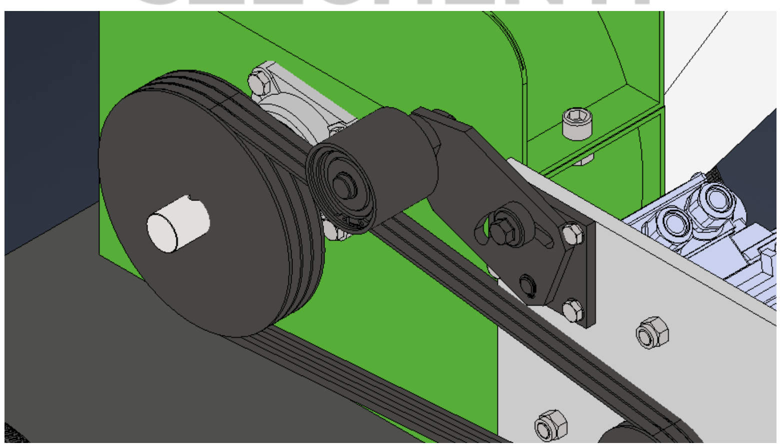


Figure 12 Belt tensioner in action

5. COMPONENT SOURCING & STANDARD PARTS

To ensure manufacturability and maintenance, ISO standard parts were used where possible.

- **Electric Motor:**
    - **Source: SEVA-TEC Website** (Catalog Model: MX3-132S2-2). [2]
    - **Spec:** 7.5 kW, 2920 RPM, IE3 Efficiency, B5 Flange Mount.

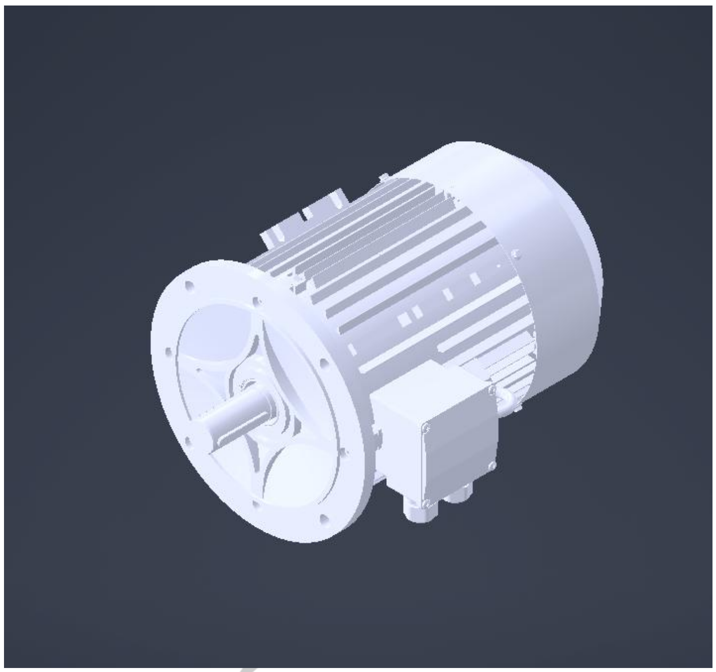


Figure 13 Electric motor

- **Bearings:**

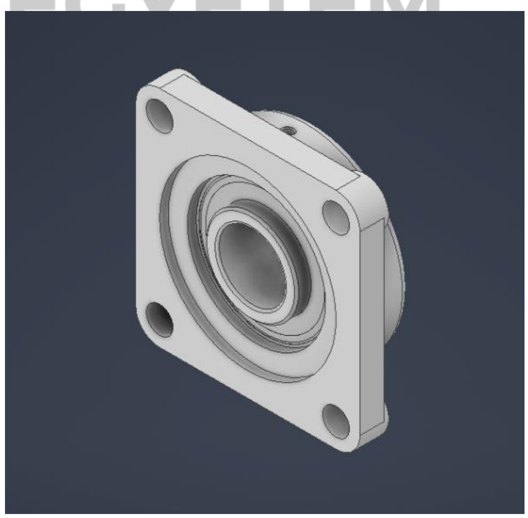


Figure 14 Bearing housing

- **Type: UCF 207 Flange Units** (ISO 3228). [4]
- **Justification:** These 4-bolt units feature self-aligning inserts, which accommodate slight misalignments in the welded frame.

- **Wheels & Tensioner Model:**
  - **Source: GrabCAD Community Library**. [7]
  - Note: 3D models were downloaded to speed up the CAD assembly process and verified against our sizing constraints.

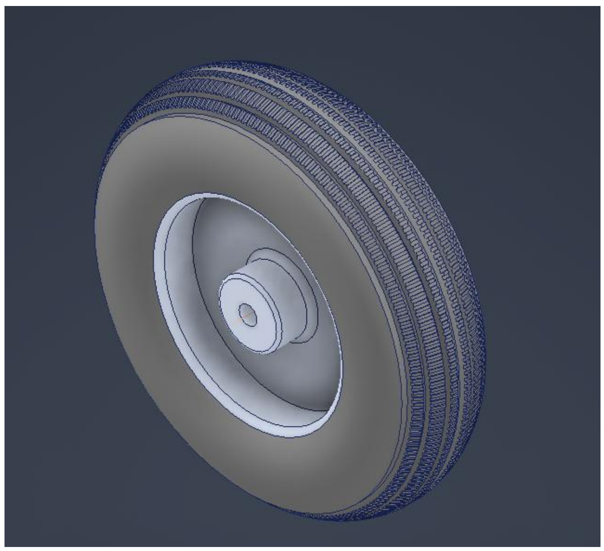


Figure 15 Wheel

- **Fasteners:**
  - High-tensile (Class 10.9) Fine Pitch bolts were selected for the motor (M15x1.5) and tensioner (M11x1.0) to resist vibrational loosening.

6. TECHNICAL DRAWINGS

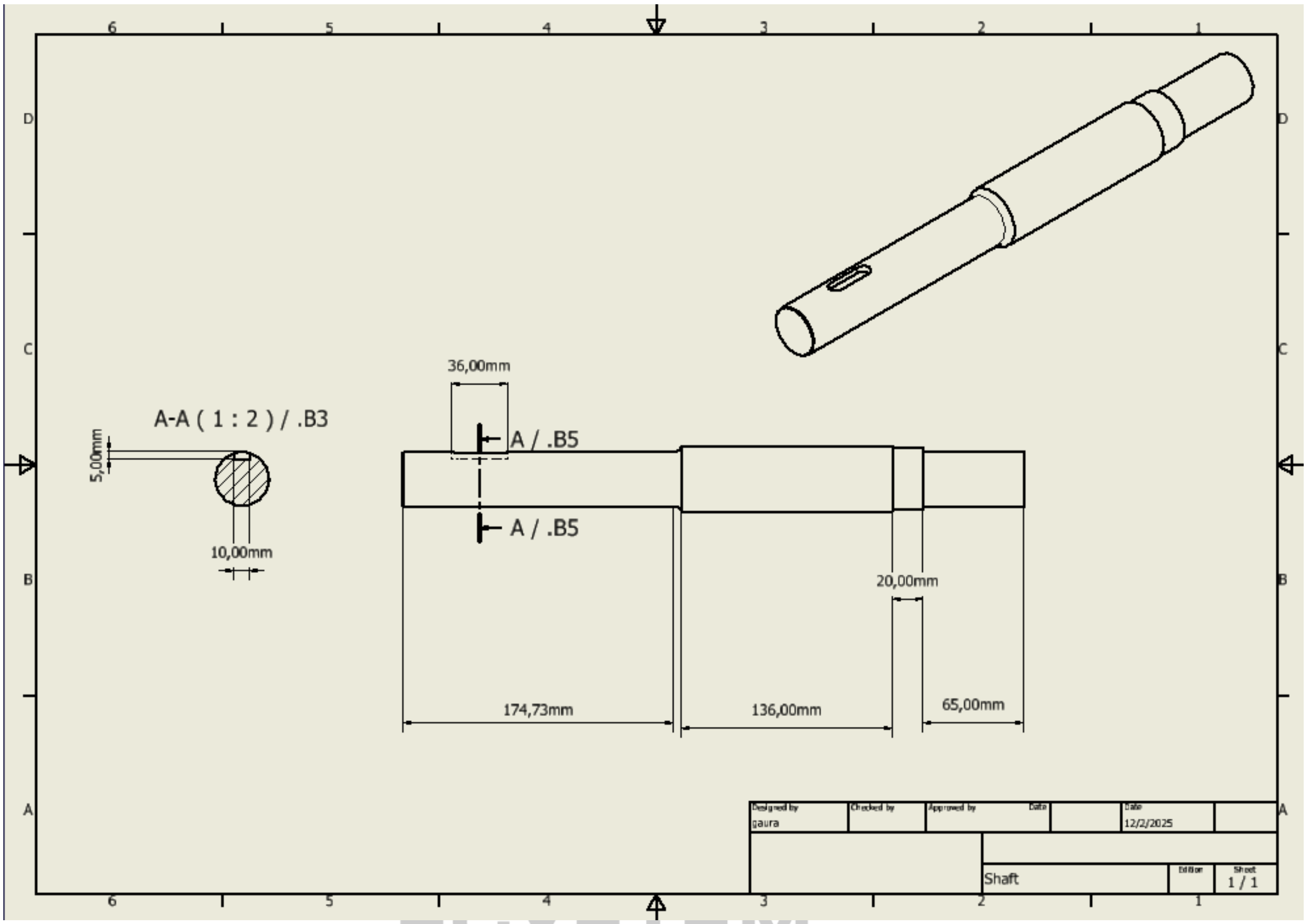
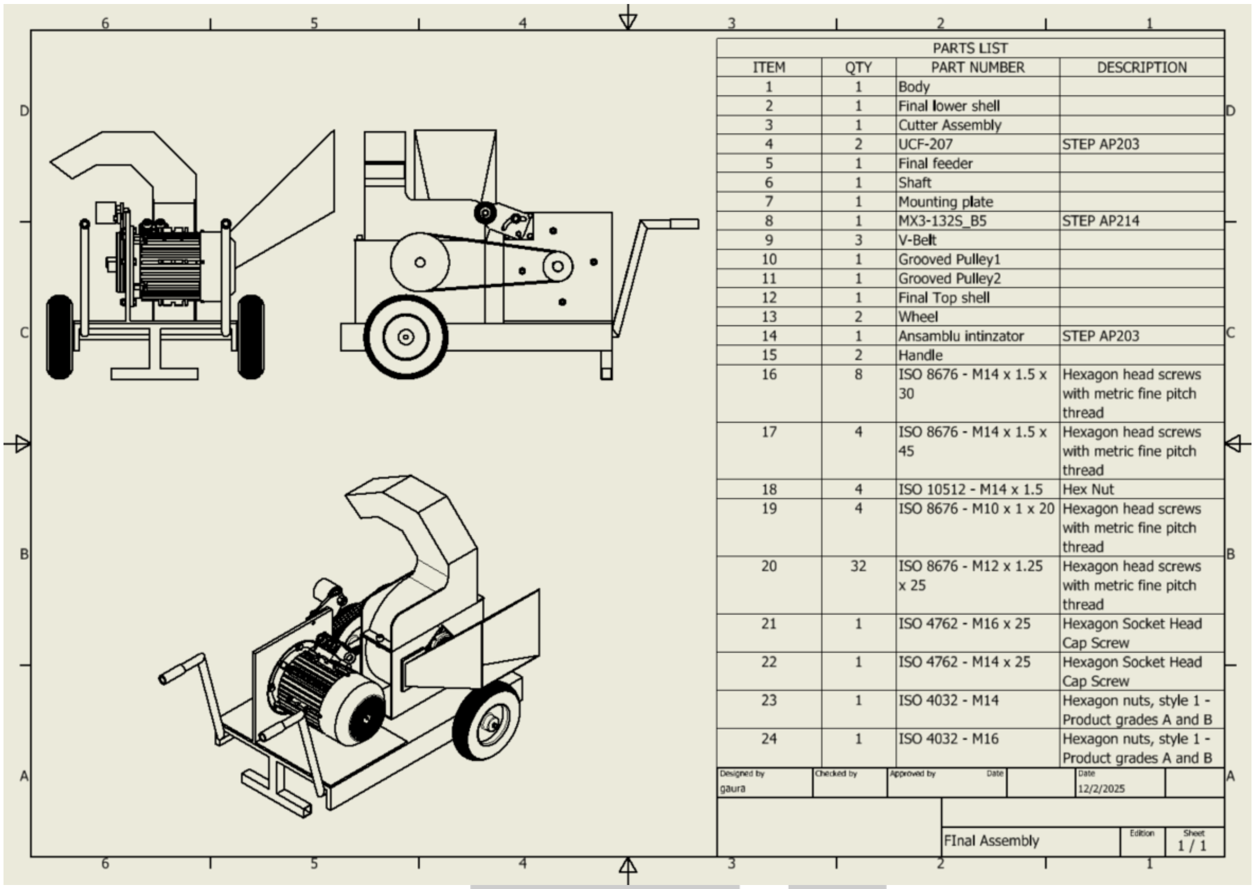


Figure 16 Shaft technical drawing



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Body	
2	1	Final lower shell	
3	1	Cutter Assembly	
4	2	UCF-207	STEP AP203
5	1	Final feeder	
6	1	Shaft	
7	1	Mounting plate	
8	1	MX3-132S_B5	STEP AP214
9	3	V-Belt	
10	1	Grooved Pulley1	
11	1	Grooved Pulley2	
12	1	Final Top shell	
13	2	Wheel	
14	1	Ansamblu intinzator	STEP AP203
15	2	Handle	
16	8	ISO 8676 - M14 x 1.5 x 30	Hexagon head screws with metric fine pitch thread
17	4	ISO 8676 - M14 x 1.5 x 45	Hexagon head screws with metric fine pitch thread
18	4	ISO 10512 - M14 x 1.5	Hex Nut
19	4	ISO 8676 - M10 x 1 x 20	Hexagon head screws with metric fine pitch thread
20	32	ISO 8676 - M12 x 1.25 x 25	Hexagon head screws with metric fine pitch thread
21	1	ISO 4762 - M16 x 25	Hexagon Socket Head Cap Screw
22	1	ISO 4762 - M14 x 25	Hexagon Socket Head Cap Screw
23	1	ISO 4032 - M14	Hexagon nuts, style 1 - Product grades A and B
24	1	ISO 4032 - M16	Hexagon nuts, style 1 - Product grades A and B

Figure 17 Assembly drawing and the Bill of material

7. CONCLUSION

The final design successfully meets all project requirements. By utilizing a **2:1 belt reduction**, the machine leverages the 7.5 kW motor to deliver high torque capable of processing 50mm hard wood. The use of a heavy **AISI 4140 flywheel** and a rigid **manual tensioner** ensure the system remains stable under shock loads. All safety factors, specifically the shaft safety factor of 6.0, guarantee a long service life.

8. REFERENCES

[1] **Optibelt Technical Manual:** V-Belt Calculation & Power Ratings.

[2] **SEVA-TEC GmbH:** Technical Datasheet for MX3-132S2-2 Electric Motor.

[3] **ISO 4184**: Classical and Narrow V-Belts.
[4] **ISO 3228**: Rolling Bearings (Flange Units).
[5] **ISO 10512**: Prevailing Torque Type Nuts (Nyloc).

[6] **Reczulski, M. (2015):** Analysis of Chip Ejection Velocities in Woodchippers.

[7] **GrabCAD Community:** 3D Models for Standard Wheels and Tensioner geometry.

[8] **Project PowerPoint 1:** "Woodchipper Design - Conceptualization."

[9] **Project PowerPoint 2:** "Machine Elements 2 - Calculations & Final Design."