Power Transmission Design

Mini Trash Compactor

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Project Summary:

Municipal solid waste management (MSWM) is an increasingly important issue with growing populations and changes in lifestyles leading to much greater amounts of waste produced per capita. Appropriate waste management has far-reaching impacts, spanning from effects on public health, economies, and climate change. Shortages of landfill space, difficulties in collecting large volumes of trash in developing areas, and greenhouse gas emissions from more frequent waste transportation are all motivations for devising a more accessible method of reducing the volume of solid waste through creation of household trash compactors. Many trash compact compactors are either too large, expansive, or high in energy consumption for household use. As a result, there is a need for a more compact, affordable and manageable device, which can be integrated into small spaces. This small compactor can serve small apartments, dorms, or offices where full sized solutions are not feasible.

After further exploration, our team developed the Mini Trash Compactor, a motorized device designed to compact household waste while being easily affordable and efficient. The device utilizes an electric motor connected to a belt system, driving dual lead screws. These screws control the vertical motion of the ram, creating a crushing force when moving down the frame to the bottom of the waste bin, ultimately crushing any items in the process. Once the compaction process is complete, the user can open the drawer and remove the bin to access the compacted items. This mechanism ensures effective and consistent compaction without relying on bulky hydraulic or pneumatic systems typically found in the preexisting models.

Design Specifications

Combating the pre existing models, our product must meet design specifications in order to be useful for the consumers. Thus, each design component has their own specifications and the product itself has an overall criteria to meet. The overall device specifications include:

- Dimensions approximately 14” W X 16” D X 20” H

- Total weight of the product should be about up to 25 lb to ensure portability
- Power to be standard 120 AC input from wall socket
- Should last 1000 cycles per year for 5 years, totaling 5000 cycles
- Components must withstand loads required to crush a full bin of aluminum cans and paper

Individual Component Specifications include the following

- Ram is constructed of ANSI 330 Stainless Steel
- Lead screws constructed of AISI 1018 Steel
- Chain is ANSI 25

In order to actually build the product, the most important component to meet specifications would be the frame. The frame specifications contains:

- Should be able to withstand a vertical load of 200N applied to the top of the frame
- Protect the mechanism from external forces and possible wear and tear/damage
- Object should remain stationary during cycle
- Never change the orientation of the product
- Constructed of 6061 Aluminum T-slot extrusions

Drawings, Illustrations and Models

Included below are models of our device with component and dimension call outs. The compactor consists of a t-slot frame connected by t-slot brackets. The lead screws connect to the top and bottom frame members via end supports that have t-slot nuts. A flange nut attaches each side of the ram to the lead screw. On each set screw between the flange nut and the upper end support is a sprocket that will hold the chain that is driven by a motor to rotate the screws and move the ram vertically.

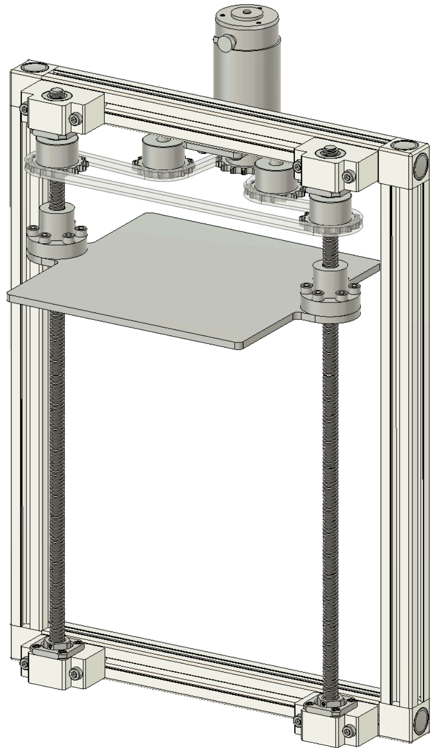

Figure 1 - CAD model of our trash compactor without exterior housing and bin

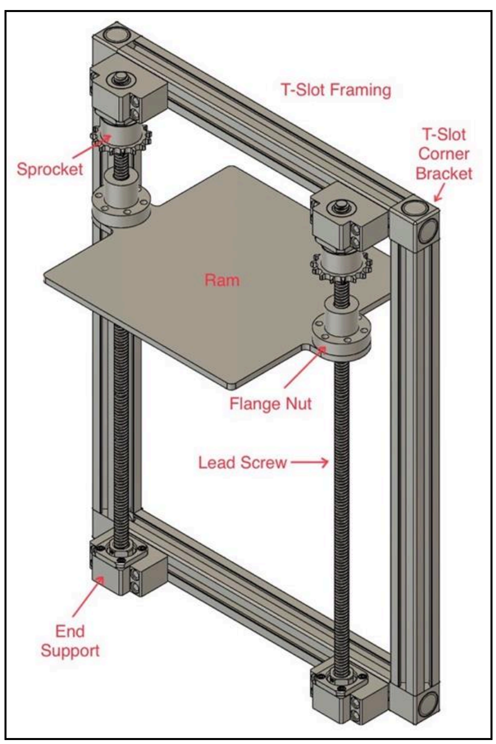

Figure 2 - Labeled Trash Compactor Assembly

Material Properties				
Steel AISI 1018 Lead Screw	330 Stainless Steel Ram	6061 Aluminum T-Slot Framing	304 Stainless Steel #12-24 Socket Cap Screw	Delrin Flange Nut
S_y = 572 MPa S_{ut}' = 696 MPa E = 207 GPa	S_y = 276 MPa S_{ut}' = 568 MPa E = 200 GPA	S_y = 275 MPa S_{ut}' = 310 MPa E = 68.9 GPa	S_y = 30 ksi S_{ut}' = 75 ksi E = 28000 ksi S_p = 120 ksi	S_y = 9.137 ksi S_{ut}' = 5.903 ksi E = 420.609 ksi

Power Screw Analysis

For power screw analysis, we identified screw characteristics and used these values to find the required torque to raise and lower the ram, the speed of the power screws, thread efficiency, and power requirement. Note there are two identical power screw setups in our design, therefore we only analyzed one. Screw characteristics and detailed calculations for each subsection in this analysis can be found in Appendix B.

Torque Required

To analyze the torque required to move the screw we assessed the different loads experienced by the power screw during lowering of the ram to crush an object and raising of the ram to reveal the compacted waste. During ram lowering, the maximum torque will occur during the initial crushing stage, therefore the load for this calculation is the weight of the ram plus the load required to crush the object. These forces will be split evenly between the two power screws. When the ram is being raised, the only load will be the weight of the ram.

$$Torque\ to\ raise\ ram\ =\ T_r = \frac{Wd_m}{2} \cdot \frac{f\pi d_m + L\cos\alpha_n}{\pi d_m \cos\alpha_n - fL} + \frac{Wf_c d_c}{2} = 50.87\ N \cdot mm$$

$$Torque\ to\ lower\ ram\ and\ exert\ 100N\ crushing\ load\ =\ T_L = \frac{Wd_m}{2} \cdot \frac{f\pi d_m - L\cos\alpha_n}{\pi d_m \cos\alpha_n + fL} + \frac{Wf_c d_c}{2} = 421.30\ N \cdot mm$$

Speed

$$speed = \frac{v}{L} = 240.7\ rpm = 4\ revolutions\ per\ second$$

Thread Efficiency

Power screws are known to be less efficient than other power transmissions methods. Our calculations support this case.

$$Raising\ thread\ efficiency = e_r = \frac{WL}{2\pi T_r} \cdot 100 = 9.91\%$$

$$Lowering\ thread\ efficiency = e_L = \frac{WL}{2\pi T_L} \cdot 100 = 12.53\%$$

Power

The major conclusion drawn from our power calculations is the minimum power output of the motor that drives the power screws. It will take approximately 11 watts to lower the ram and compact an object that requires 200N of crushing force, thus our motor will need to supply 11 watts of power or more.

$$Power\ to\ raise = P_r = \frac{T_r 2\pi n}{60 \cdot 1000} = 1.28\ Watts$$

$$Power\ to\ lower = P_L = \frac{T_L 2\pi n}{60 \cdot 1000} = 10.63\ Watts$$

Motor and Chain Analysis

The chain drive system transfers power from the driver to the dual lead screws that drive the compacting ram. The power transmission requirements were based off the required power to run the lead screws as defined in the previous section. Refer to Appendix C for a detailed explanation on calculations

Power Requirements

From the power screw analysis, the chain must transmit power to two lead screws operating at 240.6 rpm with a maximum torque of $421.30\ N \cdot mm$. Therefore the total torque requirement is:

$$T_{total} = 2(421.30\,N \cdot mm) = 842.6\,N \cdot mm = 7.457\,lbf \cdot in$$

Using the relationship between this torque and angular velocity from the rpm requirement, the nominal power output can be defined as

$$H_{nom} = 7.457\,lbf \cdot in \cdot \frac{1ft}{12\,in} \cdot \frac{240.7\,rev}{1\,min} \cdot \frac{2\pi}{1\,rev} \cdot \frac{1\,hp}{33000\frac{ft-lbf}{min}} = 0.0285\,hp$$

To account for real-world operating conditions, service factors and design factors must be applied. A service factor $K_s = 1.3$ was selected for moderate shock loading which consider impact forces during compaction cycles during the trash compactor's operation. A design factor of $n_d = 1.5$ provides additional safety margin for uncertainties in loading and manufacturing tolerances. By taking these factors into account, the design power requirement biomes

$$H_d = H_{nom} \cdot K_s \cdot n_d = 0.0555\,hp$$

Chain Selection and Capacity

An ANSI25 roller chain was selected based on the space constraints of the mini trash compactor and that it was the lightest option of its ANSI Chain options. From Table 17-19 in Shigley's, the ANSI chain specifications include a pitch of 0.25 inches and an average weight of 0.09 lbf/ft. A 17-tooth sprocket was chosen because industry standards recommend a driving sprocket of at least 17 teeth, and a lower tooth-count minimizes chordal speed variation. Chordal speed variation results in more noise and increased wear, and is inversely proportional to tooth count, therefore a 17-teeth sprocket worked in our favor.

From Table 17-20, interpolating between 200 and 300 rpm for Type A lubrication (manual/drip lubrication), the tabulated horsepower capacity was determined to be

$$H_{tab} = 0.1885\ hp$$

Since a 17-tooth sprocket it used, the tooth correction factor from Table 17-22 is $K_1 = 1$. Since a single-strand chain is used, $K_2 = 1$ as seen in Table 17-23. Therefore using Equation 17-37, the allowable power is

$$H_a = H_{tab} \cdot K_1 \cdot K_2 = 0.1885\ hp$$

Safety Factor

The power capacity safety factor ensures that there is a margin for reliable operation and is calculated by

$$n_p = \frac{H_a}{H_d} = 3.412 \;\; >> 1$$

Since the safety factor exceeds one, it confirms that the chosen ANSI 25 chain has sufficient capacity for this application. It can be concluded that H_d represents the power that needs to be supplied by the motor/driver to allow the chain to operate properly.

Power

In other words, the motor should be capable of supplying at least 0.0555 hp or approximately 42 Watts of power. This power already takes into account the power required by the power screws, so should be used in determining a suitable motor.

The capacities calculated were based off Shigley's tables which assume a chain that is able to operate at 15000 hours at full load. By utilizing the data from these tables, we can ensure that we meet our design specification which stated that this device can operate for over 5000 cycles.

Appendices

Appendix A: Team Contribution

Below is a table with the individual contributions of team members to the Power Transmission Design Report. All members contributed to report writing.

Member	**Responsibilities**
Alvin Reji	Chain and motor analysis and respective report and appendix sections
Marlena Eichelroth	Power screw analysis and respective report and appendix sections
Nathaniel Boutin	Initial Free Body Diagrams; CAD modelling; FEA analysis
Salim Hamzaoui	Chain Analysis Research; Document Editing
Sandra Chai	FEA analysis; Document Write-Up
Suyash Gundecha	Chain and motor analysis, Power screw analysis and respective report and appendix sections

Appendix B: Power Screw Analysis Detailed Explanation

Screw Characteristics

$d = 12\,mm$

$p = 3\,mm$

Single thread

$L = p = 3\,mm$

$d_r = d - 1.226869p = 8.319393$

$d_m = d - 0.649519p = 10.051443$

$\lambda = \tan^{-1}\left(\frac{L}{\pi d_m}\right) = 5.427^\circ$

$\alpha = 30^\circ$

$\alpha_n = \tan^{-1}(\tan(\alpha)\cos(\lambda)) = 29.889^\circ$

Torque Required to Raise and Lower Load

$W = 100\,N$

$f = 0.2$

$f_c = 0.17$

$d_c = 36.98\,mm$

330 SS Ram

- density $\rho = 8.0\,g/cm^3 = 8000\,kg/m^3$
- ram volume (from solidwork): $V = 0.000269\,m^3$
- mass of Ram: $m = \rho V = (8000)(0.000269) = 2.152\,kg$
- Ram load on 1 lead screw: $F = (mg)/2 = \frac{(2.152)(9.81)}{2} = 10.56\,N$

$$T_r = \left(\frac{W d_m}{2}\right)\left(\frac{f\pi d_m + L\cos\alpha_n}{\pi d_m \cos\alpha_n - fL}\right) + \frac{W f_c d_c}{2}$$

$$= \left(\frac{10.56 \cdot 10.051443}{2}\right)\left(\frac{0.2\pi(10.051443) + 3\cos 29.889}{\pi(10.051443)\cos 29.889 - 0.2(3)}\right) + \left(\frac{10.56 \cdot 0.17 \cdot 36.98}{2}\right) = 50.87\,N\cdot mm$$

$$T_L = \left(\frac{W d_m}{2}\right)\left(\frac{f\pi d_m - L\cos\alpha_n}{\pi d_m \cos\alpha_n + fL}\right) + \frac{W f_c d_c}{2} \quad \text{where } W = 100N + 10.56N$$

$$\left(\frac{110.56 \cdot 10.051443}{2}\right)\left(\frac{0.2\pi(10.051443) - 3\cos 29.889}{\pi(10.051443)\cos 29.889 + 0.2(3)}\right) + \left(\frac{110.56 \cdot 0.17 \cdot 36.98}{2}\right) = 421.30\,N\cdot mm$$

Speed

$$L_s = 361 \text{ mm}$$

$$v = \frac{L_s}{30} \cdot 60 = 722$$

$$n = \frac{v}{L} = 240.667 \text{ rpm}$$

Thread Efficiency

$$e_r = \frac{WL}{2\pi T_r} = \frac{(10.56)(3)}{2\pi(50.87)} \times 100 = 9.91\%$$

$$e_L = \frac{WL}{2\pi T_L} = \frac{(110.56)(3)}{2\pi(421.30)} \times 100 = 12.53\%$$

Power

$$P_r = \frac{T_r 2\pi n}{60 \cdot 1000} = \frac{(50.87)(2\pi)(240.667)}{(60)(1000)} = 1.28 \text{ W}$$

$$P_L = \frac{T_L 2\pi n}{60 \cdot 1000} = \frac{(421.30)(2\pi)(240.667)}{(60)(1000)} = 10.63 \text{ W}$$

Appendix C: Motor and Chain Analysis Detailed Explanation

Torque to Power Calculation

Total Torque (2 Powerscrews)

$$T = 2(421.30\,N\cdot mm)\cdot\frac{1\,m}{1000\,mm}\cdot\frac{8.85\,lbf\text{-}in}{1\,Nm} = 7.457\ lbf\text{-}in$$

$$H_{nom} = 7.457\,lbf\text{-}in\cdot\frac{1\,ft}{12\,in}\cdot\frac{240.6\,rev}{min}\cdot\frac{2\pi\,rad}{1\,rev}\cdot\frac{1\,hp}{33000\,\frac{ft\text{-}lbf}{min}} = 0.0285\ hp$$

Design Power Calculation

Service Factor: $K_s = 1.3$

↳ moderate shock

Design Factor: $n_d = 1.5$

Transmission Power: $H_d = H_{nom}K_s n_d = (0.0285)(1.3)(1.5) = 0.0555\ hp$

Allowable Power Calculation

$K_1 = 1$ [17 teeth]

$K_2 = 1$ [1 strand]

Interpolation

slope: $\frac{0.23-0.16}{300-200} = 0.007$

$0.16 + 0.007(240.66-200) = 0.1885$

$H_{tab} \approx 0.1885\ hp$ [Table 17-20]

Allowable Power [Eq 17-37]: $H_a = K_1 K_2 H_{tab} = (1)(1)(0.1885) = 0.1885\ hp$

Power Safety Factor

Power Safety Factor : $n_p = \frac{H_a}{H_d} = \frac{0.1895}{0.0555} = 3.412 > 1$ $\therefore$ safe

$\therefore$ Power supplied by motor $= H_d = 0.0555 \text{ hp} \cdot \frac{745.7 \text{ W}}{1 \text{hp}} = 41.404 \text{ W}$