15/11/2019

TECHNICAL FILE

PROJECT PRODUCT DESIGN

GROUP 4

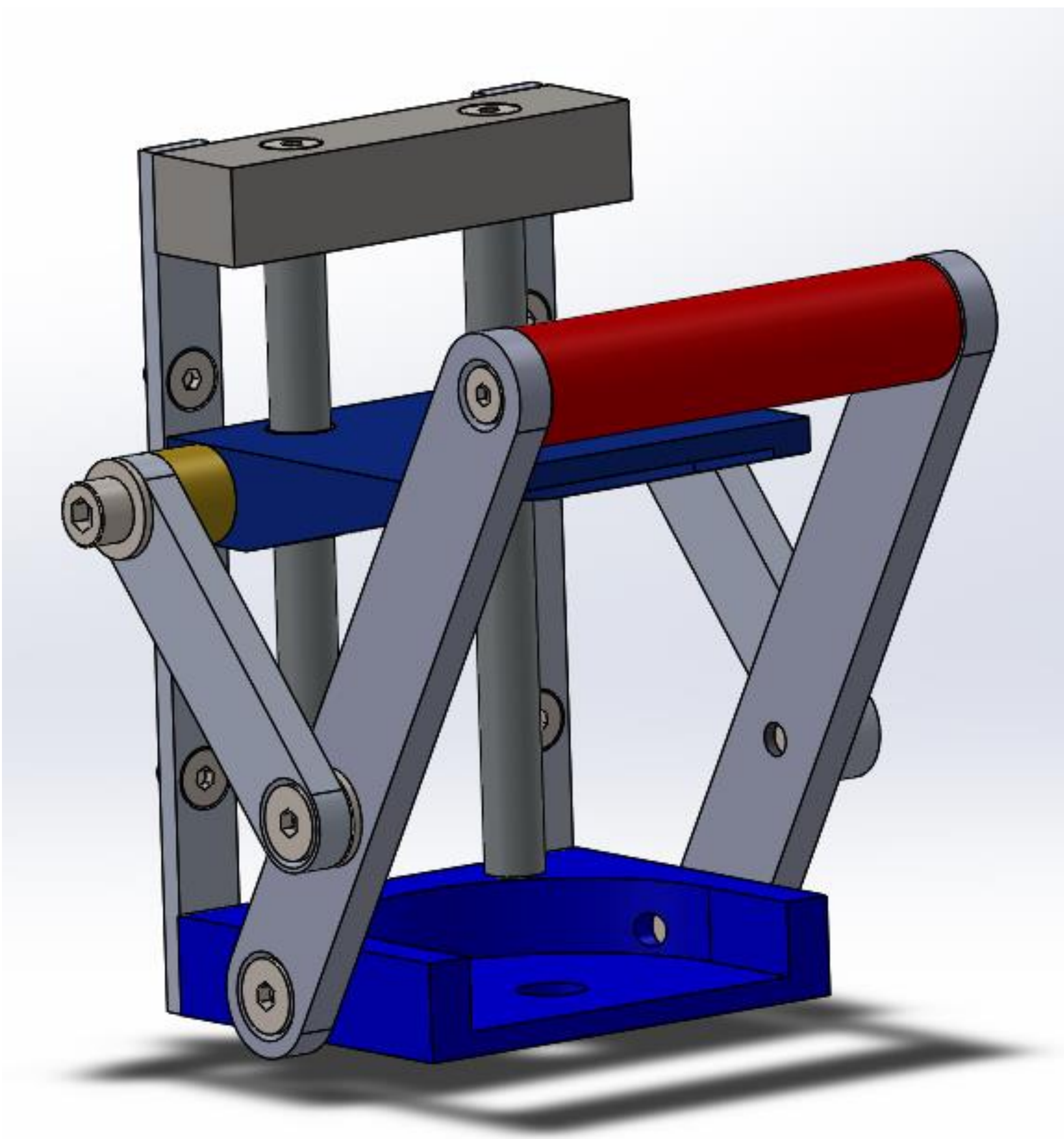


Table of contents

Introduction

The following report is a descriptive outline of the work conducted by Group 4 for the Project Product Design offered by the Department of Engineering of Hanze University of Applied Sciences for the BSc Mechanical Engineering. The contributing members of Group 4 for the Project Product Design are Dennis Houtsma, Donato S. Guarini, Silja Braune, Jeppe van den Brink, Tahsin M. Islam, Yves Hartman. This work has been possible thanks to the tutoring provide by our Professor and customer interface Mr. Grijpstra. The aim of this project is to answer the following question:

How can an existing can crusher be optimized to the wishes of the customer with the particular request of designing a product that would fit and could be operated in a space of 200x200x200 mm?

Throughout this paper we provide the reader with insight into the redesign process of the existing can crusher in a new optimized version. The team has adopted a systematic approach to decide on the best engineering design solution and has conducted a structural analysis of the old model to only then translate the concept ideas and the statics calculations in a final prototype assembly on Solidworks. The new version of the can crusher involves a different pull-bars system, with a shortened long pull-bar, a longer short pull-bar and different hinge positions. A quantitative overview of the manufacturing techniques and costs of the parts building up the can crusher is also provided.

Product

The can crusher is a machine designed to crush empty 330 ml aluminum cans while being securely mounted to the wall and operating in a volume of 200 x 200 x 200 mm. The can crusher consists of two press-plates, a handle and pull bar system, guiding slides and wall fixing strips. The upper plate can be moved downwards and upwards by pulling the handle up or down allowing for the crushing of the can. While the upper press-plate is guided by slides in the back, the lower-plate is fixed as a base for the apparatus. If there is uncertainty about a can’s material this can be checked using the built-in magnet: non-magnetic cans only can be crushed, aluminum being non-magnetic. This can crusher is designed to achieve approximately 80-85% compression of a can’s original height and it is guaranteed to last a minimum of three years if a maximum of 250 cans a day are crushed.

Systematic Engineering Design

Systematic design has been applied in order to optimize the old can crusher and redesigning it with the specific limitation of creating a can crusher that would fit and be operate in a cubic volume of defined by sides of 200 mm. Our approach consisted of an orientation, analyzing and decision stage with the outcome being a preliminary draft of the new concept which was later on perfected thanks to statics calculations.

Orientation stage- Data collection and Analysis

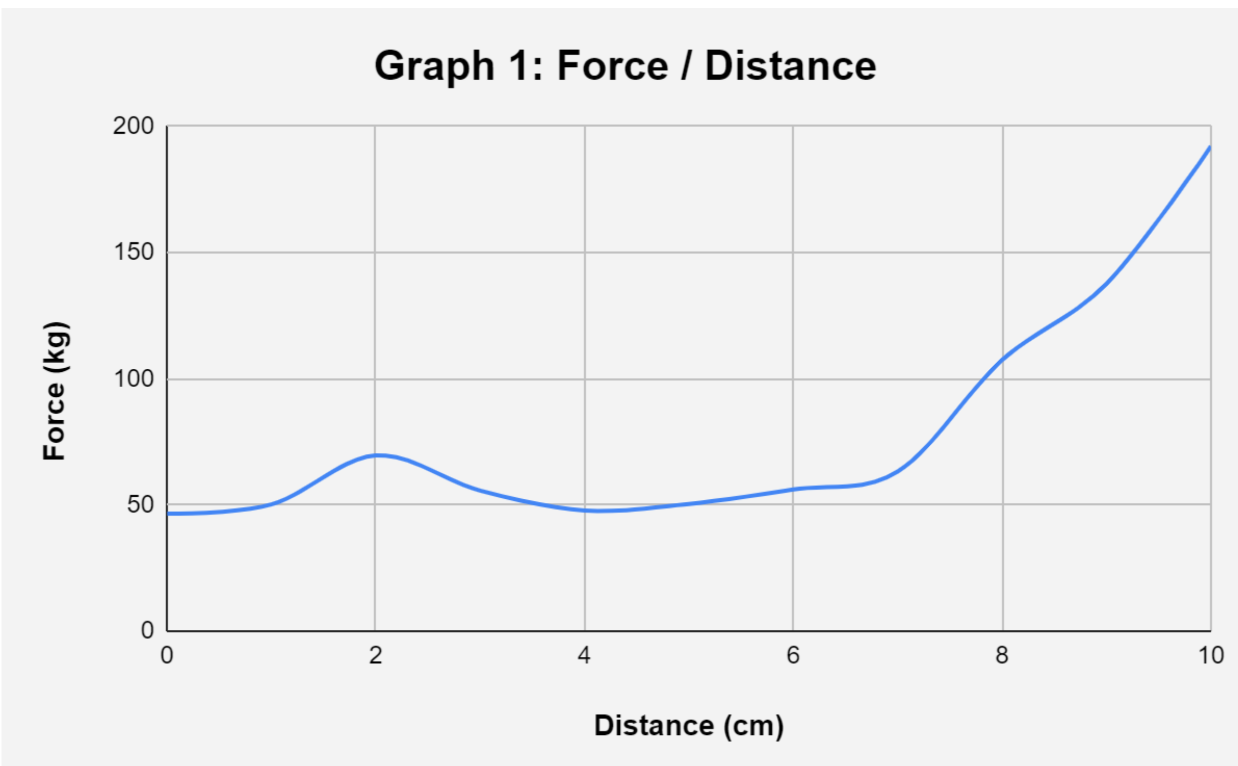
In order to design a can crusher different sets of data were needed to orient ourselves on the magnitude of the force to be applied for crushing the can and how this would be applied by the person operating the machine. Table 1 displays measurements and specifications pertaining with the cans allowed to be crushed by the machine.

Table 1: Can measurements and specifications	
Volume	330 mL
Height (h)	115 mm
Diameter (d)	66 mm
Distance between the top and bottom concavity	100 mm
Diameter of the top	54 mm
Material	Aluminum

Table 2 shows the Force measurements at different crushing distance of the can. All the data was collected in two separate laboratory sessions with the use of a hydraulic press, a scale to measure the applied force and a rule for distance measurements.

Table 2: Force / Distance											
	Distance (cm)										
	0	1	2	3	4	5	6	7	8	9	10
Force (kg)	50.5	52.7	67.5	48.5	50.3	47.7	53.3	54.5	93.5	148.3	203.5
	45.6	52.3	64.5	49.3	42.2	56.9	60.4	66.3	115.2	143.4	194.2
	47.9	45.9	73.1	57.3	45.5	43.4	53.3	60.5	112.4	137.2	207.5
	42.2	47.6	77.3	63.7	49.7	58.9	60.4	72.4	98.5	123.5	180.7
	46.3	52.5	65.8	59.5	51.2	45.1	53.3	62.5	117.7	135.8	174.4
Mean Force (kg)	46.5	50.2	69.64	55.66	47.78	50.4	56.14	63.24	107.46	137.64	192.1

Graph 1 is the represenation of the data in Table 2 and it illustrates a peak at a crushing distance of 2 cm and a stedily increasing trend from 7 till 10 cm.



Orientation stage - Requirement list

The following list of requirements has been signed by the customer and it lists all the specifics the final product should respect:

USER:

1) Expected sell price €15/piece (W) **[Variable]**;
2) 250 cans a day for 3 years (250000 cans) **[Variable]**;
3) 330 ml can (aluminum, h = 115mm, D = 66mm) **[Fixed]**;
4) Can crusher dimensions (cube of 200x200x200 mm, top-side open up to 1,5m) **[Fixed]**;
5) Can reduction of 80-85% **[Variable]**;
6) The can crusher is fixed to the wall **[Fixed]**;
7) The processing time is 3 cans/min **[Variable]**;
8) Low maintenance costs (half the can crusher's cost every 3 years) **[Variable]**.

MANUFACTURING:

1) Low manufacturing costs (⅓ of total sell price) **[Variable]**;
2) Magnet material check (W) **[Fixed]**.

GOVERNMENTAL / ENVIRONMENTAL:

1) Conforming to European standards **[Fixed]**;
2) Sustainable **[Fixed]**.

All variable requirements have been adopted in the Kesselring diagram in order to evaluate the best concept among the proposed ones.

Analyzing stage - Morphological chart

A morphological chart was developed in such a way to consider different can crusher designs, the product includes four different subfunctions:

- Force actuator
- Energy Transformer
- Containing system
- Guiding system

The force actuator sub function represents the element of the can crusher that allows a person to apply force to the system using his hand and arm and therefore applying its upper body weight. The possible working principles are a straight, folding, telescopic or twisting handle.

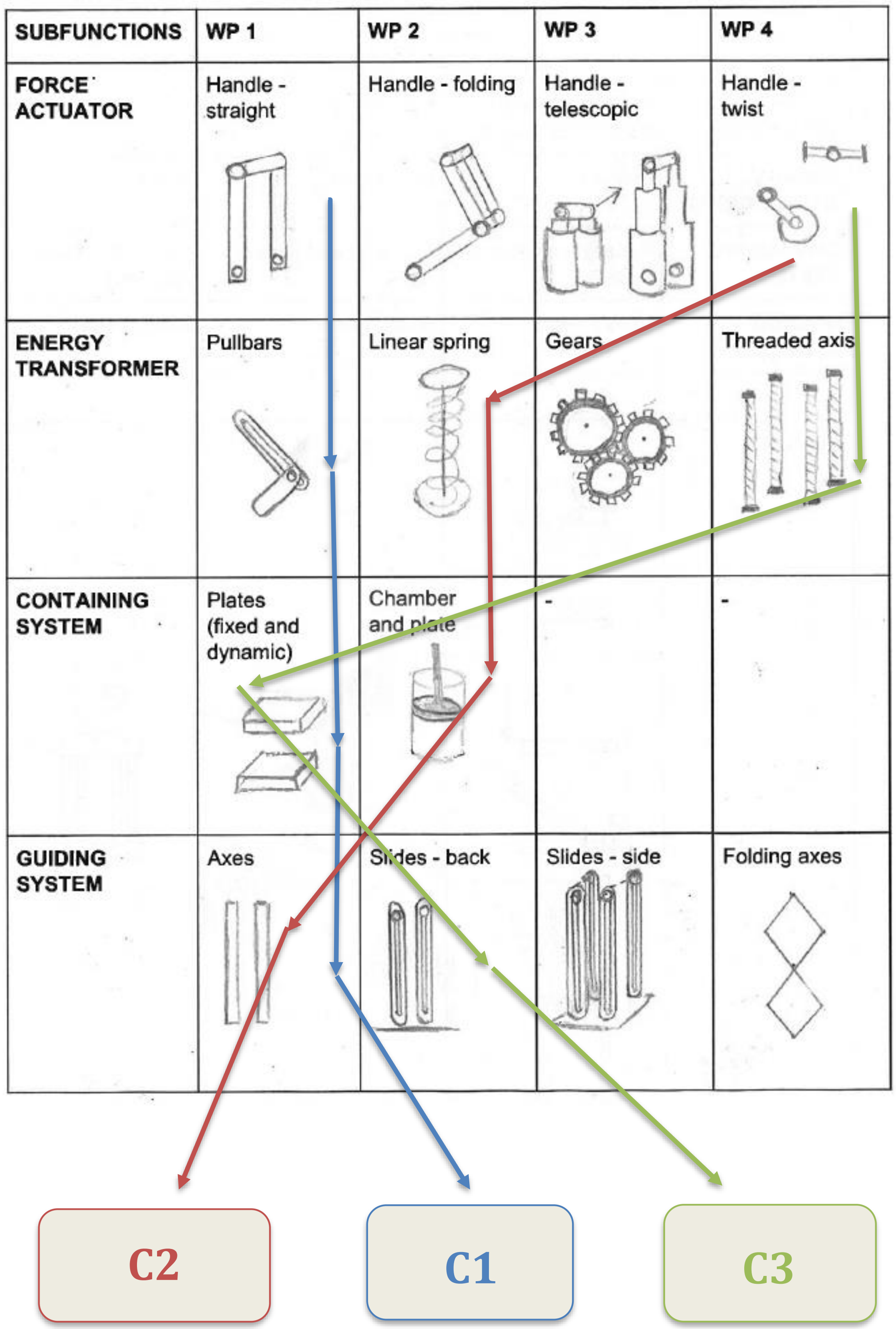
The energy transformer is the component of the concept which allows the energy inputted in the system from a person to be conveyed to the can and allow its crushing. The working principles include pull bars, a linear spring, gears and threaded axes.

The containing system is the part of the concept which confines the can while being crushed.
The possibilities illustrated in the morphological chart are limited to a double plate system where one plate stays fixed while the other one moves closer while crushing the can. The second working principle is a chamber and plate system.

The guiding system is the part which allows for the movement containing system and can therefore consists of axis, back or lateral slides and a folding set of axes.

The wall fixing has been agreed upon to function through metal strips being fixed at the wall through a set of screws

This chart includes four different Subfunctions illustrated through different Working Principles.



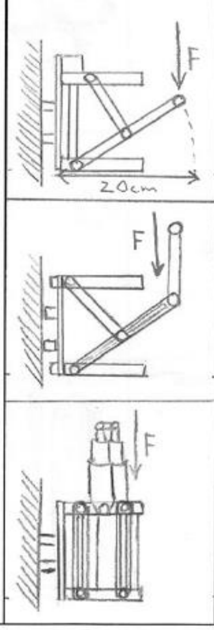
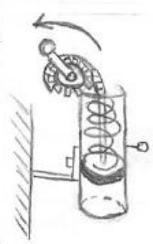
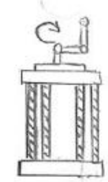
Analyzing stage - Concepts proposal

Three main broad concepts (C1, C2 and C3) have resulted from the Morphological Chart choices and they are reported below with their respective Subfunctions and possible designs.
Three main concept drafts have been created by uniting different working principles of different sub functions from the Morphological chart proposal.

Concept 1 stands as the most classical arrangement as it involves a handle with pull bars, plates and axes.

Concept 2 foresees the use of twisting handle to store energy into a linear spring which would then be released onto a plate as the can gets crushed into a chamber.

Concept 3 is the ensemble with gears turned by a twisting handle to allow for the upper plate to move down four threaded axis and crush the can.

	C1	C 2	C 3
FORCE ACTUATOR	Handle - straight / folding / telescopic	Handle - twist	Handle - twist
ENERGY TRANSFORMER	Pullbars	Linear spring	Gears
CONTAINING SYSTEM	Plates (fixed and dynamic)	Chamber and plate	Plates (fixed and dynamic)
GUIDING SYSTEM	Axes / Slides	Axes / Slides	Axes / Slides
DESIGNS			

Decision stage - Kesselring Diagram

The following table is the Kesselring diagram used in our systematic design to decide which concept between C1, C2 and C3 is the best solution for the new can crusher concept. The features against which the concepts were graded are listed in the left column under requirements. Those consist of the manufacturing price, reliability and durability of the apparatus (therefore the amount and rate of cans to be crushed, the potential can reduction of the system (fixed at 80-85%), wall fixation, processing time and maintenance costs. Grades were attributed from 1 to 4 respectively as sufficient, more than sufficient, good and very good.

REQUIREMENTS	**C1**	**C2**	**C3**
Manufacturing price (5€)	4	2	3
250 cans a day for 3 years (250000 cans)	4	2	3
Can reduction (80-85%)	3	2	2
Wall-fixed	4	4	3
Processing time (3 cans/min)	4	3	2
Maintenance costs (half the can crusher's cost every 3 years)	4	2	3
TOTAL (x/25)	23	15	16

Concept C1 scores the highest with 23/25 followed by C3 with 16/25 and C2 scoring 15/25.
The three concepts C1, C2 and C3 have been evaluated with respect to certain requirements which we would like to respect.

Decision stage - Concept conclusion

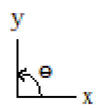
Upon agreement concept C1 was awarded the highest score by ranking higher in all sections of the Kesselring diagram. Concept C1 is **less expensive to manufacture**, **is more trustworthy** and can **potentially last longer**. Our concept decision would also ensure the **ideal can reduction** if supported by the right calculation, is **easy to fix to walls**, has a **short processing** time **and low maintenance costs**.

Through a systematic design approach our group has decided to redesign the can crusher readopting many of the old concept features and attempt to re-dimension it in a space of 200x200x200 mm. This implies shortening the length of the long pull bar in order to make it fit in the required dimensions. This has led to calculations needed for supporting such a decision.

Structural analysis

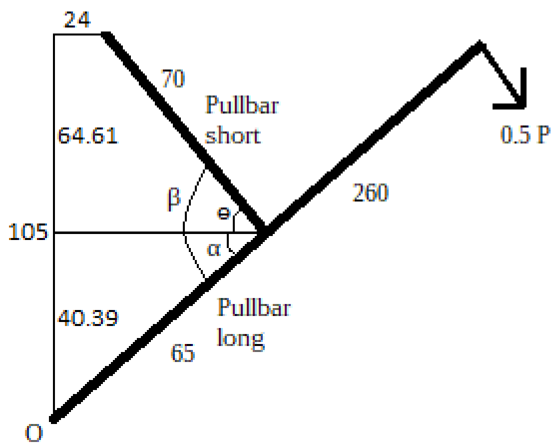
The following section treats the Physics and Mathematics behind the optimization of the old concept for the can crusher into the new one. In order to prove the functionality of the new concept we first have conducted an analysis of the old can crusher and only then applied our formulas to the new concept. In the following subchapters the reader may find Free Body Diagrams, and an analysis of the external loads and internal stresses using the method of sections. In particular we have conducted an analysis of the

All FBD's have this axis configuration and all lengths are in mm, unless otherwise noted.



Old Concept FBDs and Calculations

In order to calculate the stresses occurring in the parts of the can crusher, the most heavily loaded parts are analyzed at the moment that the can is about to buckle, since that is the minimum force the can crusher has to deliver.

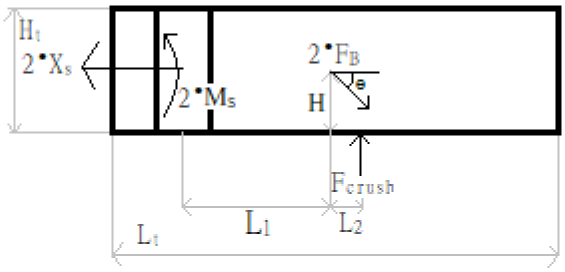


The hinges of both the short and the long pull bar are located 5 mm above the bottom of the press plates. The can is 115 mm long, so the distance between the hinges is 105 mm. The force that acts on the top of the long pull bar is half the force that needs to be delivered at the top of the long pull bar to crush the can, since there are two pull bars. Since the two pull bars and the horizontal and vertical distances between the two hinges is known, the angles $\beta, \theta$and α can be calculated. This gives the following results;

$$\beta = 105.79°, \theta \ = \ 67.37°, \alpha \ = \ 38.41°$$

From the literature (2) is known that the minimal force to crush an aluminum can is 210 pounds, which is 95.25 kg. This gives a minimal force, defined F_{crush} ,of 934.44 N.

Calculation loads and stresses in the upper press-plate



FBD Upper Pressplate

Table 3: Upper press-plate dimensions			
H_t	20 mm	L_t	79 mm
H	10 mm	L_1	24 mm
θ	67.37°	L_2	18.5 mm

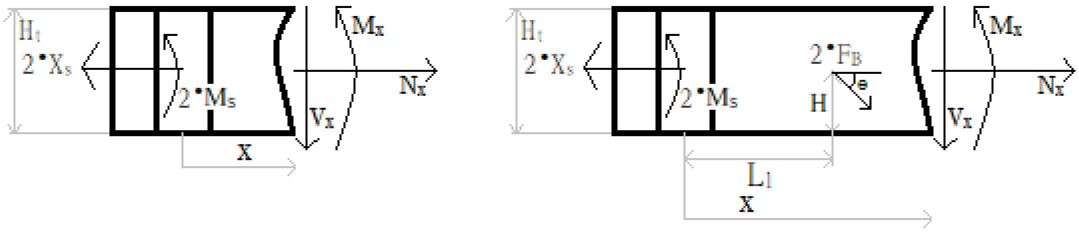
$\mathbf{\Sigma F_x} = -2 \cdot X_s + 2 \cdot \cos(\theta) \cdot F_B = 0$
$\mathbf{\Sigma F_y} = F_{crush} - 2 \cdot \sin(\theta) \cdot F_B = 0$
$\mathbf{\Sigma M_s} = 2 \cdot M_s + (L_1+L_2) \cdot F_{crush} - 2 \cdot L_1 \cdot \sin(\theta) \cdot F_B = 0$

$F_{crush} = 934.4$ N
$F_B = F_{crush} / 2 \cdot \sin(\theta) = 506.2$ N
$X_s = \cos(\theta) \cdot F_B = 194.7$ N

$M_s = -0.5 \cdot (L_1+L_2) \cdot F_{crush} + L_1 \cdot \sin(\theta) \cdot F_B = -8.643$ Nm

The upper press-plate experiences a bending moment in both the **x** and **z** axis.

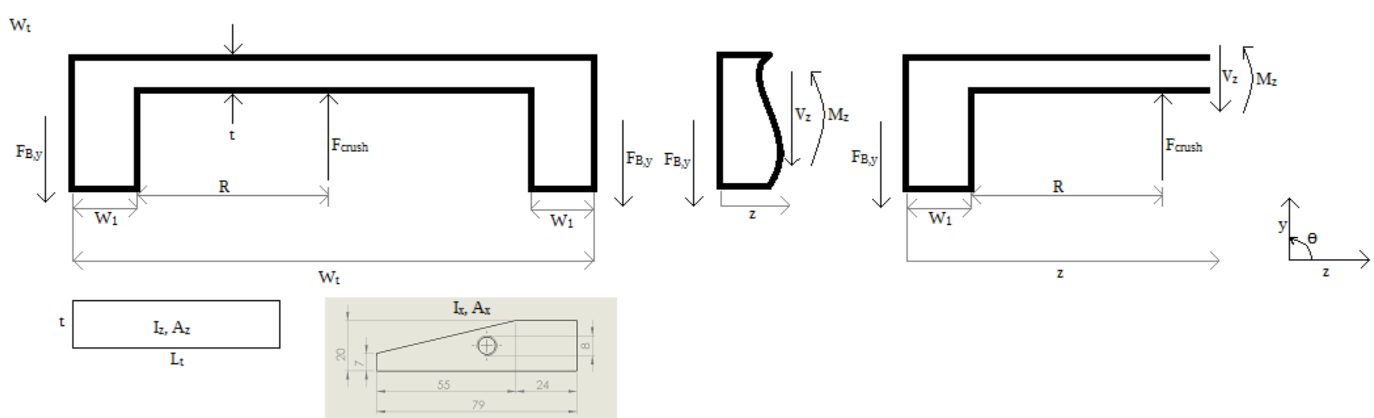
Calculation of internal loads x-y plane



$\Sigma \mathbf{F_x} = -2\cdot X_s+N_x=0$	$\Sigma \mathbf{F_x} = -2\cdot X_s+2\cdot\cos(\theta)\cdot F_B+ N_x= 0$
$\Sigma \mathbf{F_y} = -V_x=0$	$\Sigma \mathbf{F_y} = -2\cdot\sin(\theta)\cdot F_B-V_x = 0$
$\Sigma \mathbf{M_{@x}} = M_x+2\cdot M_s= 0$	$\Sigma \mathbf{M_{@x}} = M_x+2\cdot(x-L_1)\cdot\sin(\theta)\cdot F_B+2\cdot M_s= 0$
$N_x = 389.5$ N	$N_x = 0$ N
$V_x = 0$ N	$V_x = -934.4$ N
$M_x = 17.23$ Nm	$M_x = -934.4\cdot x+ 5.136$ Nm
$0<x<L_1$	$L_1<x<L_2$, (After L_2 the internal loads are 0)

From the diagrams from the internal loads follows that $N_{\mathbf{x},max} = 389.5$ N, $V_{\mathbf{x},max} = -934.4$ N, and they occur at $x = L_1$. $M_{\mathbf{x},max} = -34.57$ Nm and occurs at L_2.

Calculation of internal loads z-y plane



$W_1 = 9.5$ mm, $W_t = 99$ mm, $R = 40$ mm, $F_{By} = 467.2$ N, $t = 5$ mm

$\Sigma \mathbf{F_y} = -V_z-F_{By}=0$	$\Sigma \mathbf{F_y} = -V_z-F_{By}+F_{crush}=0$
$\Sigma \mathbf{M_{@z}} = M_z+z\cdot F_{By}= 0$	$\Sigma \mathbf{M_{@z}} = M_z+z\cdot F_{By}-(z-W_1-R)F_{crush}=0$
$V_z = -467.2$ N	$V_z = 467.2$ N
$M_z = -467.2\cdot z$ Nm	$M_z = 467.2\cdot z - 46.26$ Nm
$0<z<W_1+R$	$W_1+R<z<W_t$

From the diagrams from the internal loads follows that $V_{z,max}$ = 467.22 N and $M_{z,max}$ = -23.13 Nm, and they both occur at the center of the plate.

Table 4: Maximum internal loads upper press-plate						
	N_x	V_x	M_x	M_x	V_z	M_z
Maximum value	389.5 N	-934.4 N	-17.28 Nm (not the max value)	-34.57 Nm	467.2 N	-23.13 Nm
Occurring in	x = L_1	x = L_1	x = L_1	x = L_2	z = R+W_1	z = R+W_1
Area, Moment of Inertia (I_x,I_z)	$1.530 \cdot 10^{-3}$ m^2	$1.530 \cdot 10^{-3} m^2$	$3.626 \cdot 10^{-8}$ m^4	$3.626 \cdot 10^{-8}$ m^4	$3.950 \cdot 10^{-4}$ m^2	$8.229 \cdot 10^{-8}$ m^4

y_x = 10 mm, y_z = 2.5 mm , $\sigma_{b,x} = -\frac{y_x \cdot M_x}{I_x}$ (1), $\sigma_{b,z} = -\frac{y_z \cdot M_z}{I_z}$(2), $\sigma_{N,x} = \frac{N_x}{A_x}$(3), $\tau_x = \frac{3 \cdot V_x}{2 \cdot A_x}$(4),$\tau_z = \frac{3 \cdot V_z}{2 \cdot A_z}$(5), $\sigma_{b,N} = |\sigma_{b,x}| + |\sigma_{N,x}| + |\sigma_{b,z}| + |\sigma_{N,z}|$(6), $\tau = \tau_x + \tau_z$ (7)

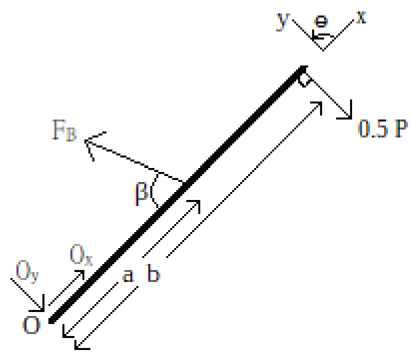
$\sigma_{max} = \sqrt{\sigma_{b,N}^2 + 3 \cdot \tau^2}$ (8)

The magnitudes of the stresses in point L_1 are;
$\sigma_{b,x}$= 4.76 MPa, $\sigma_{b,z}$= 0.703 MPa,$\sigma_{N,x}$= 0.255 MPa,τ_x= 0.916 MPa,τ_z=1.77 MPa

The magnitudes of the stresses in point L_2 are;
$\sigma_{b,x}$= 9.53 MPa,$\sigma_{b,z}$= 0.703 MPa,$\sigma_{N,x}$= 0 MPa,τ_x= 0.916 MPa,τ_z=1.77 MPa

When the stresses above are inserted in formula 6 and 7 it gives;
For L_1; $\sigma_{b,N}$ = 5.718 MPa and τ= 2.686 MPa
For L_2; $\sigma_{b,N}$ = 10.23 MPa and τ= 2.686 MPa
The total stresses in point L_2 are larger than at point L_1, so the maximum stress in point L_2 is calculated.
When $\sigma_{b,N}$ and $\tau$are inserted in formula 8, this results in σ_{max} = 11.24 MPa.The upper pressure plate is made of AISI1020, which has a yield strength (σ_y) of 351.6 MPa. The safety factor (N) used in the old design is calculated by $N = \sigma_y/\sigma_{max}$. So, N = 31.18.

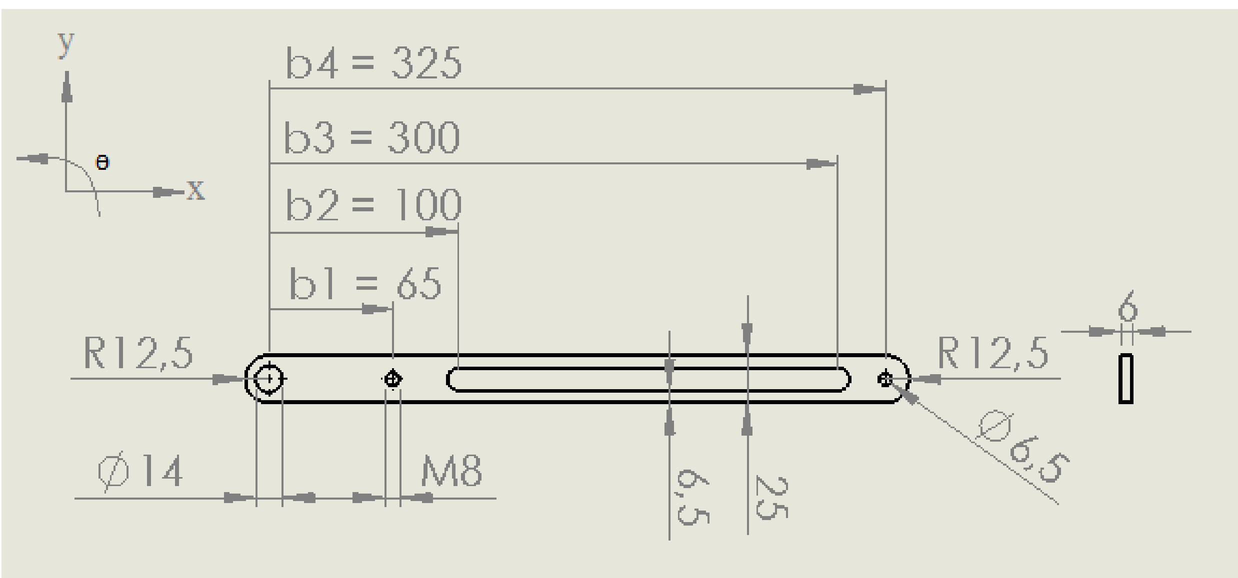
Calculation loads and stresses in the long pull-bar

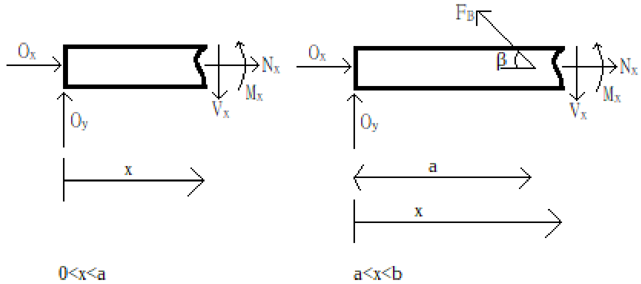


a = 65mm, b = 325mm
β = 105.79°

$\mathbf{\Sigma F_x} = O_x - \cos(\beta)\cdot F_B = 0$
$\mathbf{\Sigma F_y} = O_y + \sin(\beta)\cdot F_B - 0.5\cdot P = 0$
$\mathbf{\Sigma M_O} = a\cdot\sin(\beta)\cdot F_B - 0.5\cdot b\cdot P = 0$

$O_x = \cos(\beta)\cdot F_B = -137.73$ N
$P = 2\cdot a\cdot\sin(\beta)\cdot F_B / b$
$P = 194.8$ N
$O_y = 0.5\cdot P - \sin(\beta)\cdot F_B = -389.7$ N

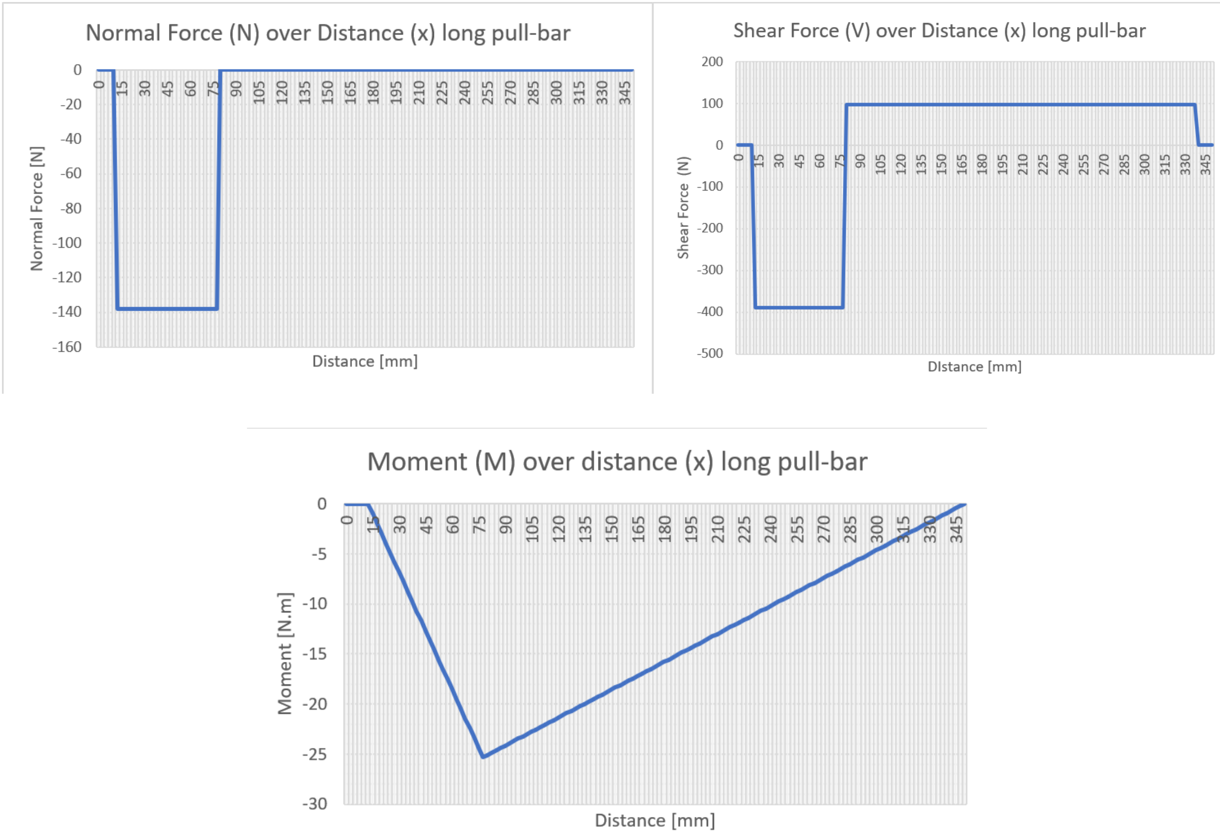




$\mathbf{\Sigma F_x} = O_x + N_x = 0$ $\mathbf{\Sigma F_y} = O_y - V_x = 0$ $\mathbf{\Sigma M_{@x}} = M_x - O_y \cdot x = 0$ $N_x = -O_x = -137.7$ N $V_x = O_y = -389.7$ N $M_x = -389.7 \cdot x$ Nm	$\mathbf{\Sigma F_x} = O_x - \cos(\beta) \cdot F_B + N_x = 0$ $\mathbf{\Sigma F_y} = O_y + \sin(\beta) \cdot F_B - V_x = 0$ $\mathbf{\Sigma M_{@x}} = M_x - O_y \cdot x - (x-a) \cdot \sin(\beta) \cdot F_B = 0$ $N_x = -O_x + \cos(\beta) \cdot F_B = 0$ N $V_x = O_y + \sin(\beta) \cdot F_B = 0.5 \cdot P = 97.42$ N $M_x = O_y \cdot x + (x-a) \cdot \sin(\beta) \cdot F_B$ $M_x = 0.5 \cdot P \cdot x - a \cdot \sin(\beta) \cdot F_B$ $M_X = 97.42 \cdot x - 31.66$ Nm

Table 5: Maximum internal loads long pull-bar

	N_x	V_x	M_x	V_x	M_x
Maximum value [N],[Nm]	-137.7	-389.7	-25.33	97.42	-21.92
Occurring in	b_1	b_1	b_1	b_2	b_2
Aera, Moment of Inertia (I_x)	$1.02 \cdot 10^{-4}$ m^2	$1.02 \cdot 10^{-4}$ m^2	$7.557 \cdot 10^{-9}$ m^4	$3.9 \cdot 10^{-5}$ m^2	$6.949 \cdot 10^{-9}$ m^4



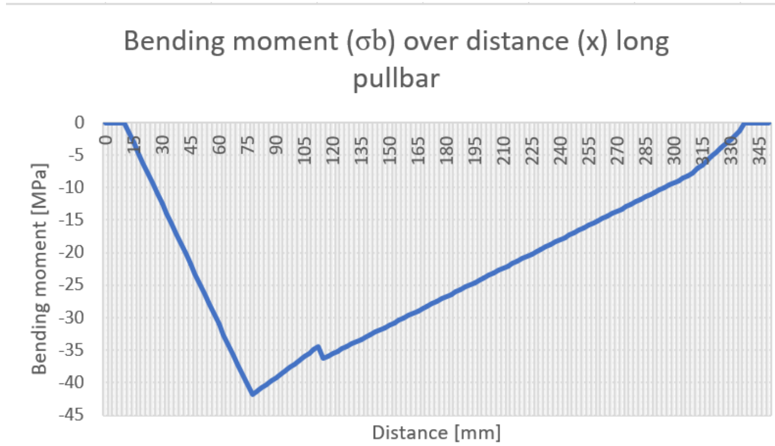
The internal loads diagrams of the long pull-bar. The x axis is shifted 12.5 mm to the left compared to the drawing of the long pull-bar above in order to let the x axis begin at zero.

y = 12.5 mm, $\sigma_b = -\frac{y \cdot M}{I}$ (1), $\sigma_N = \frac{N}{A}$ (2), $\tau = \frac{3 \cdot V}{2 \cdot A}$(3) $\sigma_{b,n} = |\sigma_b| + |\sigma_N|$(4)

$\sigma_{max} = \sqrt{{\sigma_{b,n}}^2 + 3 \cdot \tau^2}$ (5)

The magnitudes of the stresses in point b_1 are;
σ_b = 41.90 MPa, σ_N = 1.350 MPa, τ= 5.731MPa

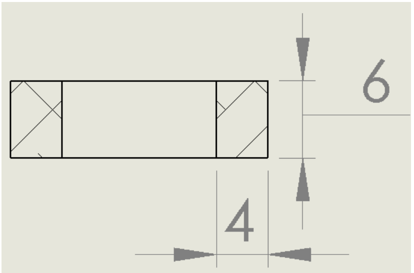
The magnitude of the stresses in point b_2 are;
σ_b = 34.43 MPa, τ=3.57 MPa



The graph of the internal bending moment is displayed above. Because the area moment of inertia of the long pull-bar is not constant along its length, the occurring stress is also checked at the point where the minimum moment of inertia is the smallest.

When σ_b and $\tau$are inserted in 5, this gives;
For $b_1 \rightarrow \sigma_{max}$ = 46.37 MPa
For $b_2 \rightarrow \sigma_{max}$ = 34.98 MPa
The stress between the first hinge and b_1 is the highest, which is visible in the graph and the calculations above. This stress is used to determine the safety factor. The long pull-bar is made of 1060 alloy, which has a yield strength (σ_y) of 27.5742 MPa. This is the material given in solidworks, but this material isn't strong enough. So, the alloy 1060-H12, with a yield strength of 85 MPa is used. The safety factor (N) used in the old design is calculated by $N = \sigma_y/\sigma_{max}$.
Therefore, N = 1.83.

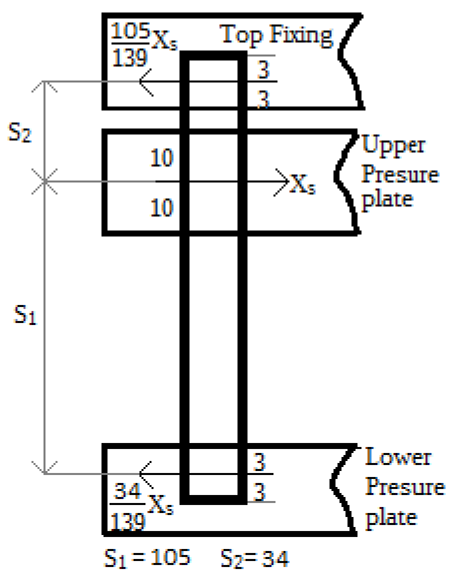
Calculation loads and stresses in the short pull bar



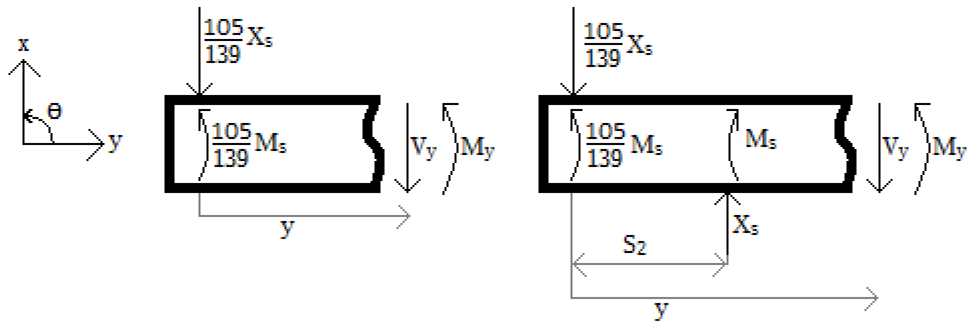
The cross section of the short pull bar. $A = 4.8 \cdot 10^{-5}\ m^2$

The short pull bar is connected to the rest of the can crusher by means of two hinges and the only forces working on it are the reaction forces created by the bolts in the hinges. This makes it a two-force member, which can only experience normal stress. The minimal area is shown in the image above. So, $A = 4.8 \cdot 10^{-5}\ m^2$ and $F_B = 506.2$ N. This results in $\sigma_N = 10.54$ MPa. The short pullbar consists out of the same material as the long pullbar, so N = 2.61.

Calculation loads and stresses in the sliders



The relation between the forces in the x direction is given in the picture above. The relation for the moments acting on the slider is the same.



ΣFx = $-(105/139)\cdot X_s - V_y = 0$ **ΣM@y**= $(105/139)\cdot M_s + y\cdot(105/139)\cdot X_s + M_y = 0$ $V_y = -147.1$ N $M_y = -147.1\cdot y + 6.527$ Nm $0<y<34$	**ΣFx** = $-(105/139)\cdot X_s + X_s - V_y = 0$ **ΣM@y**= $(105/139)\cdot M_s + y\cdot(105/139)\cdot X_s - (y-S_2)\cdot X_s - M_s + M_y = 0$ $V_y = 47.63$ N $M_y = 47.63\cdot y - 8.734$ Nm $34<y<139$

From the diagrams of the internal loads it follows that $M_{y,max}$= -7.115 Nm and $V_{y,max}$= -147.1 N. Both maximum values occur at $y=S_2$.

$\sigma_y = \frac{x\cdot \boldsymbol{M_y}}{I_y}$, $x=r_{slider}$= 6 mm

The cross section of the slider is circular, so:

$\tau = \frac{4\cdot V}{3\cdot A}$and $I_y=(\pi/4)\cdot r^4$

σ_b= 41.9 MPa, τ= 1.74

Inserting this in the von Mises formula gives; σ_{max}= 42 MPa

The material of the sliders is Chrome Stainless Steel, which has a yield strength of 172.339 MPa. This results in N=4.10.

The part with the lowest safety factor is the long pull-bars, and the part with the highest safety factor is the upper-press plate.

New concept calculations

The new concept is designed in such a way that the maximum force is delivered at the moment the handle is horizontal. Since the design closely resembles the old design, not all parts need to be analyzed. The most heavily loaded parts in the old design are the two pull-bars and slides, which have been analyzed for the old situation.
To check if the concept doesn't fail, the stresses are calculated at the moment the handle is horizontal.

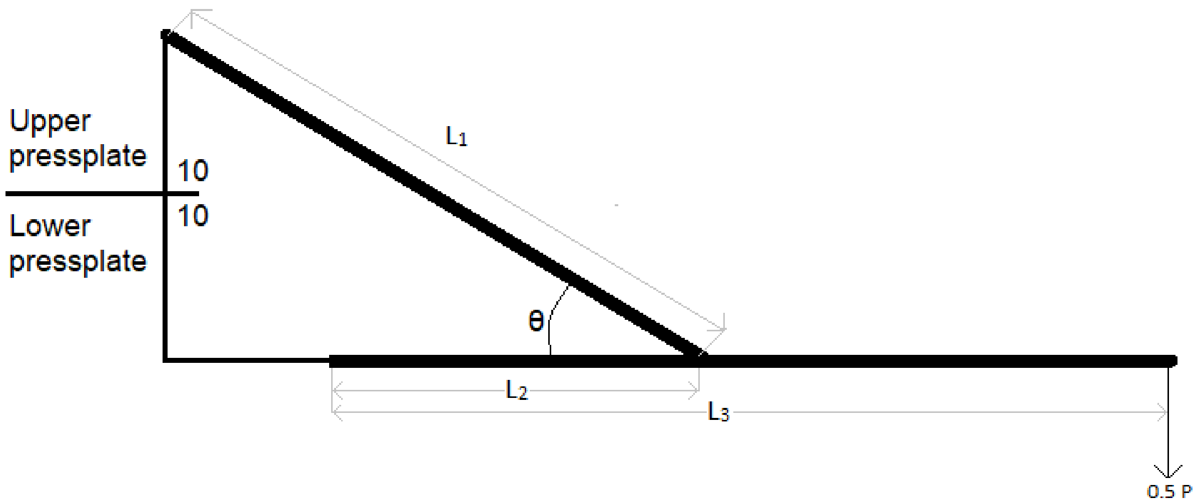
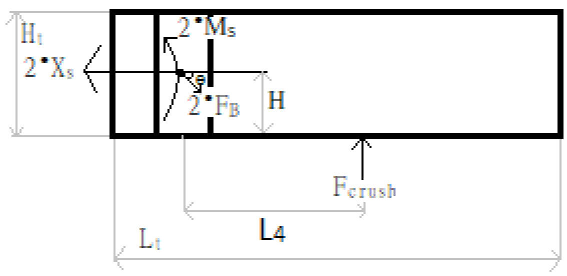


Table 6: Dimensions long pull-bar new concept					
L_1	76 mm	L_3	150 mm	0.5·P	165.2 N
L_2	45 mm	θ	sin (20/76)		

Calculation loads and stresses in the upper press-plate



FBD Upper Press-plate

Table 7: Upper press-plate dimensions			
H_t	20 mm	L_t	79 mm
H	10 mm	L_4	24 mm
θ	15.27°		

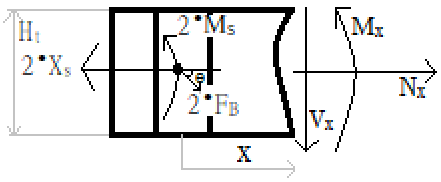
$\boldsymbol{\Sigma F_x} = -2 \cdot X_s + 2 \cdot \cos(\theta) \cdot F_B = 0$
$\boldsymbol{\Sigma F_y} = F_{crush} - 2 \cdot \sin(\theta) \cdot F_B = 0$
$\boldsymbol{\Sigma M_s} = 2 \cdot M_s + L_4 \cdot F_{crush} = 0$

$F_{crush} = 1766$ N
$F_B = Fcrush / 2 \cdot \sin(\theta) = 3355$ N
$X_s = \cos(\theta) \cdot F_B = 3237$ N

$M_s = -0.5 \cdot L_1 \cdot F_{crush} = -21.19$ Nm

The upper press-plate experiences a bending moment in both the **x** and **z** axis.

Calculation of internal loads x-y plane



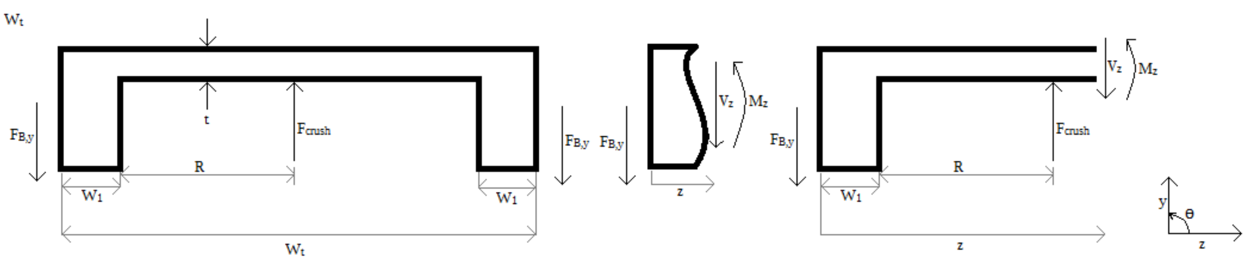
$\mathbf{\Sigma F_x}$ = $-2 \cdot X_s + \cos(\theta) \cdot F_B + N_x = 0$
$\mathbf{\Sigma F_y}$ = $-V_x - 2 \cdot \sin(\theta) \cdot F_B = 0$
$\mathbf{\Sigma M_{@x}}$ = $M_x + 2 \cdot M_s + 2 \cdot \sin(\theta) F_B \cdot x = 0$

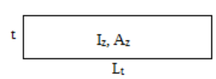
$N_x = -X_s + \cos(\theta) \cdot F_B = 0$
$V_x = -2 \cdot \sin(\theta) \cdot F_B = -1766$ N
$M_x = -2 \cdot \sin(\theta) F_B \cdot x - 2 \cdot M_s = -1766 \cdot x + 42.38$ Nm

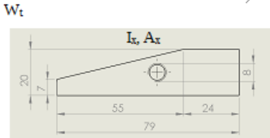
$0 < x < L_1$

From the diagrams from the internal loads follows that $V_{\mathbf{x},max}$ = -1766 N and $M_{\mathbf{x},max}$ = 42.38 Nm and they both occur at L_1.

Calculation of internal loads z-y plane







W_1 = 9.5 mm, W_t = 99 mm, R = 40 mm, F_{By} = 882.9 N, t = 5 mm

$\mathbf{\Sigma F_y}$ = $-V_z - F_{By} = 0$	$\mathbf{\Sigma F_y}$ = $-V_z - F_{By} + F_{crush} = 0$
$\mathbf{\Sigma M_{@z}}$ = $M_z + z \cdot F_{By} = 0$	$\mathbf{\Sigma M_{@z}}$ = $M_z + z \cdot F_{By} - (z - W_1 - R)\ Fcrush = 0$
V_z = -882.9 N	V_z = 889.9N
$M_z = -882.9 \cdot z$ Nm	$M_z = 882.9 \cdot z - 43.70$ Nm
$0 < z < W_1 + R$	$W_1 + R < z < W_t$

From the diagrams from the internal loads follows that $V_{\mathbf{z},max}$ = -882.9 N and $M_{\mathbf{z},max}$ = -43.70 Nm, and they both occur at the center of the plate.

Table 8: Maximum internal loads upper press-plate z-y plane				
	V_x	M_x	V_z	M_z
Maximum value	-1766 N	42.38	-882.9	-43.70
Occurring in	$x = L_1$	$x = L_1$	$z = R+W_1$	$z = R+W_1$
Area, Moment of Inertia (I_x,I_z)	$1.530 \cdot 10^{-3} m^2$	$3.626 \cdot 10^{-8}\ m^4$	$3.95 \cdot 10^{-4}\ m^2$	$8.229 \cdot 10^{-8}\ m^4$

y_x = 10 mm, y_z = 2.5 mm , $\sigma_{b,x} = -\frac{y_x \cdot M_x}{I_x}$ (1), $\sigma_{b,z} = -\frac{y_z \cdot M_z}{I_z}$(2), $\tau_x = \frac{3 \cdot V_x}{2 \cdot A_x}$(3),$\tau_z = \frac{3 \cdot V_z}{2 \cdot A_z}$(4), $\sigma_{b,N} = |\sigma_{b,x}| + |\sigma_{N,x}| + |\sigma_{b,z}| + |\sigma_{N,z}|$(5), $\tau = \tau_x + \tau_z$ (6)

$\sigma_{max} = \sqrt{\sigma_{b,N}{}^2 + 3 \cdot \tau^2}$ (7)

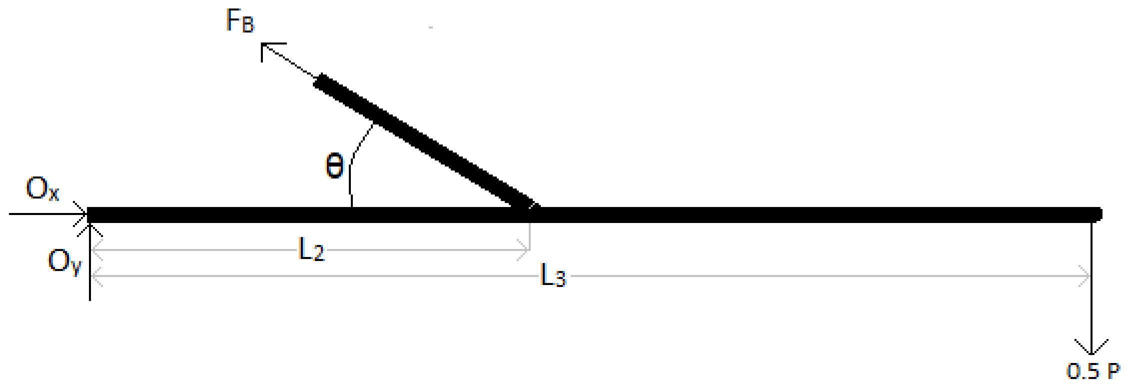
The magnitudes of the stresses in point L_1 are;
$\sigma_{b,x}$= 11.76 MPa, $\sigma_{b,z}$= 1.328 MPa,τ_x= 1.731 MPa,τ_z=3.353 MPa

When the stresses above are inserted in formula 5 and 6 it gives;
$\sigma_{b,N}$ = 13.09 MPa and τ= 5.084 MPa

When $\sigma_{b,N}$ and $\tau$are inserted in formula 7, this results in σ_{max} = 15.78 MPa.
The goal of the new design is to change as little in comparison with the old design as possible, while satisfying the new demands. In that way as much as possible components of the old design can be used in the new design.
The original upper pressure plate is made of AISI 1020, which has a yield strength (σ_y) of 351.6 MPa. The safety factor N = 17.5. The part with the lowest safety factor in the old design are the long pull-bars with N= 1.92, so the safety factor of the upper pressplate is acceptable.

The stresses in the lower pressure plate haven't been calculated. The reason for this being that the upper- and the lower press-plate both approximately experience amount of stress, and since the safety factor of the upper press-plate is already nine times higher than that of the part with the lowest safety factor, the new lower press-plate won't fail either.

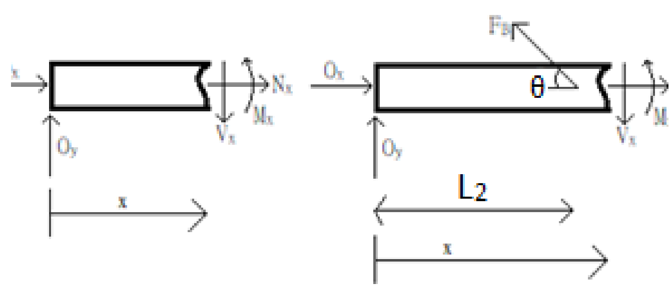
Calculation loads and stresses in the long pull-bar



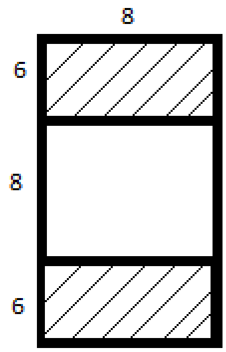
$\mathbf{\Sigma F_x}$ = $O_x - \cos(\theta) \cdot F_B = 0$
$\mathbf{\Sigma F_y}$ = $O_y + \sin(\theta) \cdot F_B - 0.5 \cdot P = 0$
$\mathbf{\Sigma M_O}$ = $L_2 \cdot \sin(\theta) \cdot F_B - 0.5 \cdot L_3 \cdot P = 0$

$O_x = \cos(\theta) \cdot F_B = 3237$ N
$P = 2 \cdot L_2 \cdot \sin(\theta) \cdot F_B / L_3$
$P = 529.7$ N
$O_y = 0.5 \cdot P - \sin(\theta) \cdot F_B = -586.6$ N

Calculation of the internal loads long pull-bar

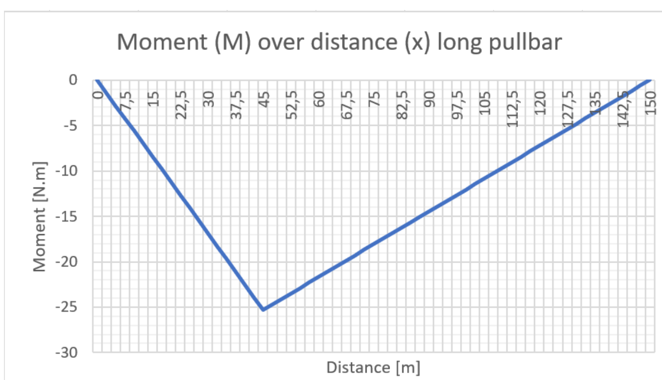


$\mathbf{\Sigma F_x}$ = $O_x + N_x = 0$ $\mathbf{\Sigma F_y}$ = $O_y - V_x = 0$ $\mathbf{\Sigma M_{@x}}$ = $M_x - O_y \cdot x = 0$ $N_x = -O_x = 3237$ N $V_x = O_y = -586.6$ N $M_x = -586.6 \cdot x$ Nm $0<x<L_2$	$\mathbf{\Sigma F_x}$ = $O_x - \cos(\theta) \cdot F_B + N_x = 0$ $\mathbf{\Sigma F_y}$ = $O_y + \sin(\theta) \cdot F_B - V_x = 0$ $\mathbf{\Sigma M_{@x}}$ = $M_x - O_y \cdot x - (x-L_2) \cdot \sin(\theta) \cdot F_B = 0$ $N_x = -O_x + \cos(\theta) \cdot F_B = 0$ N $V_x = Oy + \sin(\theta) \cdot F_B = 0.5 \cdot P = 264.9$ N $M_x = O_y \cdot x + (x-L_2) \cdot \sin(\theta) \cdot F_B$ $M_x = 0.5 \cdot P \cdot x - L_2 \cdot \sin(\theta) \cdot F_B$ $M_X = 264.9 \cdot x - 39.73$ Nm $L_2>x>L_3$



The cross section of the long pull-bar at the points O and L_2. This is used to calculate the area and the moment of inertia around the x - axis.

Table 9: Maximum internal forces long pull-bar			
	N_x	V_x	M_x
Maximum value [N],[Nm]	-137.7	-389.7	-25.33
Occurring in	b_1	b_1	b_1
Aera, Moment of Inertia (I_x)	$9.5 \cdot 10^{-5}$ m^2	$9.5 \cdot 10^{-5}$ m^2	$4.992 \cdot 10^{-9}$ m^4



y = 10 mm, $\sigma_b = -\frac{y \cdot M}{I}$ (1), $\sigma_N = \frac{N}{A}$ (2), $\tau = \frac{3 \cdot V}{2 \cdot A}$(3) $\sigma_{b,n} = |\sigma_b| + |\sigma_N|$(4)

$\sigma_{max} = \sqrt{{\sigma_{b,n}}^2 + 3 \cdot \tau^2}$ (5)

The magnitudes of the stresses at point L_2 are;
σ_b = 50.74 MPa, σ_N = 1.449 MPa, τ= 6.153MPa

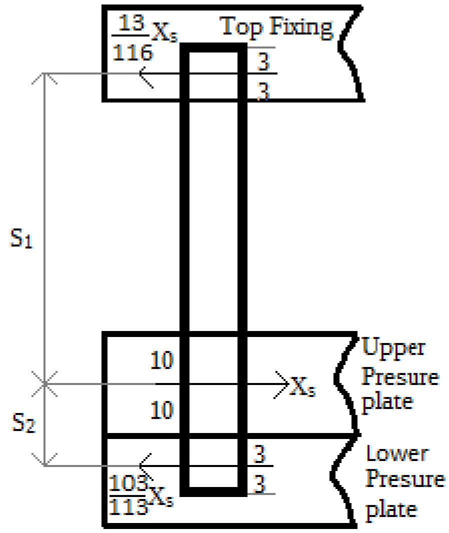
When σ_b and $\tau$are inserted in 5, this gives;
σ_{max} = 53.32 MPa

The original long pull-bar is made of 1060-H12 alloy, which has a yield strength (σ_y) of 85 MPa. This results in N = 1.6 for the new long pull-bar. This is a lower safety factor than used in the old design, but still high enough for practical use, it is still acceptable.

Calculation loads and stresses in the short pull bar

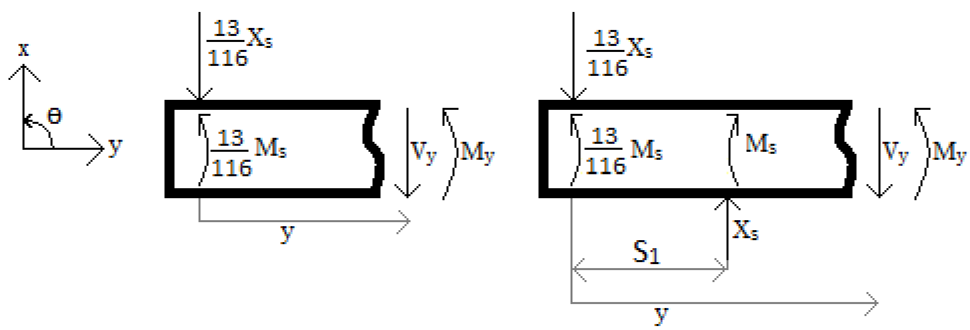
The short pull-bar is connected to the rest of the can crusher by means of two hinges and the only forces working on it are the reaction forces created by the bolts in the hinges. This makes it a two-force member, which can only experience normal stress. The minimal area is located at the bolts, has exactly the same size as the cross section of the new long pull-bar, given above. So, A = $9.5 \cdot 10^{-5}$ m^2 and F_B = 3355 N. This results in σ_N= 32.3 MPa. The material of the new short pull-bar is the same as that of the old short pull-bar, so N = 2.6. This is higher than the old safety factor of 1.92 for the old pullbars, so it is acceptable.

Calculation loads and stresses in the sliders



S_1 = 103 mm, S_2 = 13 mm

The relation between the forces in the x direction is given in the picture above. The relation and direction for the moments acting on the slider is the same as the forces in the x direction.



X_s = 3237 N, M_s= -21.19 Nm

$\Sigma F_x = -(13/116) \cdot X_s - V_y = 0$ $\Sigma M_{@y} = (13/116) \cdot M_s + y \cdot (13/116) \cdot X_s + M_y = 0$ V_y = -362.8 N M_y= -362.8·y -2.375 Nm 0<y<103	$\Sigma F_x = -(13/116) \cdot X_s + X_s - V_y = 0$ $\Sigma M_{@y} = (13/116) \cdot M_s + y \cdot (13/116) \cdot X_s - (y - S_1) \cdot X_s - M_s + M_y = 0$ $M_y = (103/116) \cdot M_s + y \cdot (103/116) \cdot X_s - S_1 \cdot X_s$ V_y= 2874 N M_y = 2874·y-314.6 Nm 103<y<113

From the diagrams of the internal loads it follows that $M_{y,max}$= -39.74 Nm and $V_{y,max}$= -2874 N. Both maximum values occur at y=S_1.

$\sigma_y = \frac{x \cdot \boldsymbol{M_y}}{I_y}$, x=$r_{slider}$= 6 mm, the cross section of the slider is circular, so, $\tau = \frac{4 \cdot V}{3 \cdot A}$ and I_y=(π/4) ·r^4. This results in σ_b= 234.3 MPa and τ= 33.88 MPa.

Inserting this in the von Mises formula gives; σ_{max}= 241.5 MPa. The original material of the sliders is Chrome Stainless Steel and has a yield strength of 172.339 MPa. Given the occurring stress the sliders experience, they would fail. To prevent that two things can be done; replace the material of the sliders for one with a higher yield strength, or make the radius of the sliders larger. The first of the two options is chosen, to prevent having to change the bearings, the top-fixing, the upper pressure plate and the lower pressure plate.

The new sliders are made of a steel type called alloy 1040, which has a yield strength of 490 MPa. This results in N=2.0. This safety factor is higher than is used for the long pull-bars in the old design, so this is acceptable.

Calculation bolts

The last part that need to be checked are the bolts. In order to see if the bolts do not fail, the most heavily loaded bolt is analyzed. That bolt is the M8 countersunk bolt connecting the lower press-plate to the long pull-bar. The formula for computing the shear stress in the bolt is: V=FQIb.
Where: Q [m3] = first moment of inertia
b [m] = thickness of material
F [N] = the force applied, in theis case Ox and Oy

From the cross section of the bolt, the values for Q and I are taken as Q = 153.83 mm^3 and I = 536.83 mm^4. The thickness varies over the length of the bolt, so the lowest possible value of 6.5 mm is used. This gives y= 25.85 MPa and x= 142.6 MPa, so the total shear stress experienced by the bolt is 168.4 MPa.

M8 bolts can be made out of different materials, and the A4 austenitic stainless steel is chosen. This bolt has a yield strength of 600 MPa, so the maximum allowable shear stress is; max= y3 = 346.4 MPa. This results in a safety factor of 2.05, which is higher than that of the long pullbar, and thus allowed. The bolts can be made out of other versions of steel, but they have a lower yield strength, and would fail. Only the shear stress is analyzed, since the bolt is relatively short compared to its length.

Manufacturing

The entire cost of manufacturing our product depends very much on the amount of can crushers that will be manufactured. We've calculated the costs for three situations:

- Manufacturing less than 10 can crushers, in which case all the parts will be machined by hand. This option has the highest material cost, takes the most time per product to produce and is more prone to have issues do to chance of human errors.

- Manufacturing more than 100 can crushers, in which case most parts will be made with CNC-techniques and some parts by hand. With this option, it's already possible to buy the materials at lower price as we order a fairly large amount. It's also less prone to human errors as most of it will go automatically. However, in this case a human error would normally have more impact as it affects many more repetitions.

- Manufacturing more than 1000 can crushers, in which a number of parts will be ordered (nearly) in their desired shape. This will be done by injection molding. Creating the rest of the parts and the finishing actions required on the parts created through injection molding will be done with CNC techniques. This option will save a lot of time as it allows us to skip a lot of machining steps and will be the most environmentally friendly option, as we end up with a much smaller amount of scrap metal.

We have made separated the manufacturing side into two subdivisions: Manufacturing techniques and manufacturing costs, as both of those will be important to different types of professionals. In both subdivisions we will evaluate the three aforementioned options more thoroughly.

compare it to the second as they are the most similar and require all the same machining steps.

The first option means to machine every part by hand. For a single can crusher, the needed 'starting dimensions' per part are (all in mm):

Blocks:

- Top fixing: 100x25x20=50000mm^3
- Upper press-plate: 99x80x20=158400mm^3
- Lower press-plate: 100x80x20=160000mm^3
- Long pull-bar: 160x10x8 (x2) =25600mm^3
- Short pull-bar: 86x10x8 (x2) =13760mm^3
- Fix strip: 173x15x5 (x2) =25950mm^3

Tubes:

- Slider: diameter 12, length 145 (x2) = 32798mm^3
- Handle: diameter 18, length 104=26464mm^3
- Bearing: diameter 20, length 21 (x2) =13194mm^3

Hollow tubes

- Handle cover (inside diameter 20, outside diameter 24, length 104) = 14375mm^3

All parts will be made of plain carbon steel, except for the sliders which will be made of aluminum 1060 h12.

The total volume of all carbon steel parts will be: 50000 + 158400 + 160000 + 25600 + 13760 + 25950 + 26464 + 13194 + 14375 = 502119 mm^3

Steel weighs about 7700kg/m^3, so 7700x10^-9 x 502119 = 3,86 kg of carbon steel per can crusher

Aluminum weighs about 2699kg/m^3, so 2699x10^-9 x 32798 = 0,0885 kg of aluminum per can crusher

Next, we'll evaluate how many steps of machining each part needs to reach its final shape.

Top fixing: 12 steps

1. Cut with depth 15mm, diameter M6 (x2)
2. Thread in cut (x2)
3. Through cut, diameter M6 (x2)
4. Cut with depth 6mm, diameter 12 mm (x2)
5. Thread in cut (step 3) (x2)
6. Cut countersink (x2)

Upper press-plate: 9 steps

1. Cut with depth 24,5mm, diameter M8 (x2)
2. Thread in cut (x2)
3. Through cut, diameter 14mm(x3)
4. Cut with depth 13mm, diameter 40mm
5. Cut inclined plane

Lower press-plate: 18 steps

1. Cut with depth 15mm, diameter M8 (x2)
2. Thread in cut (x2)
3. Cut with depth 18,5mm, diameter M6 (x2)
4. Thread in cut (x2)
5. Through cut, diameter M6 (x2)
6. Cut countersink (x2)
7. Cut with depth 6mm, diameter 12mm (x2)
8. Thread in cut (step 5) (x2)
9. Through cut, diameter 12mm
10. Cut with depth 13mm, diameter 40mm

Long pull-bar: 6 steps (x2)

1. Cut a half circle at each end (x2)
2. Through cut with diameter 18mm
3. Through cut with diameter 14,5mm
4. Through cut with diameter M8
5. Thread in cut

Short pull-bar: 5 steps (x2)

1. Cut half circle at each end (x2)
2. Through cut with diameter 12mm
3. Through cut with diameter 8mm
4. Cut countersink

Fix strip: 4 steps (x2)

1. Through cut, diameter M6 (x2)
2. Cut countersink (x2)

Slider: 4 steps (x2)

1. Cut with depth 14mm, diameter M6 (x2)
2. Thread in cut, depth 12mm (x2)

Handle: 6 steps

1. Cut with depth 15mm, diameter M6 (x2)
2. Thread in cut (x2)
3. Chamfer (x2)

Bearing: 2 steps (x2)

1. Cut 8mm off diameter, depth 8mm
2. Through cut with diameter 6,5mm

Handle-cover: 4 steps

1. Chamfer outside edge (x2)
2. Chamfer inside edge (x2)

This results in 12 + 9 + 18 + 6x2 + 5x2 + 4x2 + 4x2 + 6 + 2x2 + 4 = 91 steps required to make all the parts in our model. Using the rule of thumb 1 step = 1 minute, it would take 91 minutes to hand-machine one can-crusher (assuming you have all the needed metal in its ‘starting dimensions’ already.

With the second option, the time needed per step on average could be much lower. This depends greatly on the type of machine, how well/quickly it’s programmed and the exact amount of can crushers to be produced. The more repetitions, the less time you lose on steps needed in between the cutting process (e.g. programming the CNC machine). Also, the material cost would become significantly lower as you can buy the metals in bulk. For buying in bulk, you need three types of metal shapes:

- Metal strips/blocks. Used for the top fixing, upper- and lower press-plate (all 20mm thick), the long- and short pull-bars (all 8mm thick) and the fix strips (5mm thick)

- Metal tubes. Used for the sliders (diameter of 12mm), the handle (diameter of 18mm) and the bearing (diameter of 20mm)

- Hollow metal tubes. Used for the handle cover (inside-outside diameter of 20mm-24mm)

When producing larger amounts, we have to add steps for the process of cutting parts into their starting dimensions. For the metal strips/blocks this will be two extra steps per piece (cut off in length and width), for the (hollow) metal tubes it will be one extra step per piece (cut off in length). This adds another 24 steps. 24+91=115 steps. Since each step will be completed much faster however, these 115 steps will likely end up taking about 60 minutes.

With the third option, many of these steps can be eliminated. Only the threads would have to be added to an injection molded block. Since some parts don't need many steps, we will continue to CNC these. The more complicated will be ordered to be injection molded in large amounts (1000+). These parts would be made through injection molding:

- Upper press-plate -> this will leave it with 7 instead of 9 steps left
- Lower press-plate -> this will leave it with 6 instead of 18 steps left
- Top fixing -> this will leave it with 4 instead of 12 steps left

The rest of the parts will be ordered in bulk like in the second option, adding together all steps leaves us with:

- 7 + 6 + 4 = 17 steps to finish the injection molded parts
- 6x2 + 5x2 + 4x2 + 4x2 + 6 + 2x2 + 4 = 52 steps to finish the other parts in their 'starting dimensions'
- 10 steps to cut the other parts to their 'starting dimensions'

____+

- A total of 79 steps. Once again, as we repeat the same steps more often, the needed time per step on average will become lower so these 79 steps will take about 35 minutes to finish.

Manufacturing costs

The manufacturing costs consists of:

The amount of time needed to create all the parts, multiplied by the hourly rate charged for this.

- 1st option: 90 minutes x hourly rate between 20-30 euros = 30-45 euros per product
- 2nd option: 60 minutes x hourly rate between 30-50 euros = 30-50 euros per product
- 3rd option: 35 minutes x hourly rate between 30-50 euros = 17,50-29 euros per product

The weight in kg of the metal needed to create all the parts, multiplied by the cost per kg of such metals.

- 3,86 kg of carbon steel x 0,50 euros per kg = 1,93 euros per product
- 0,0885 kg of aluminum 1060 h12 x 2 euros per kg = 0,17 euros per product

____+

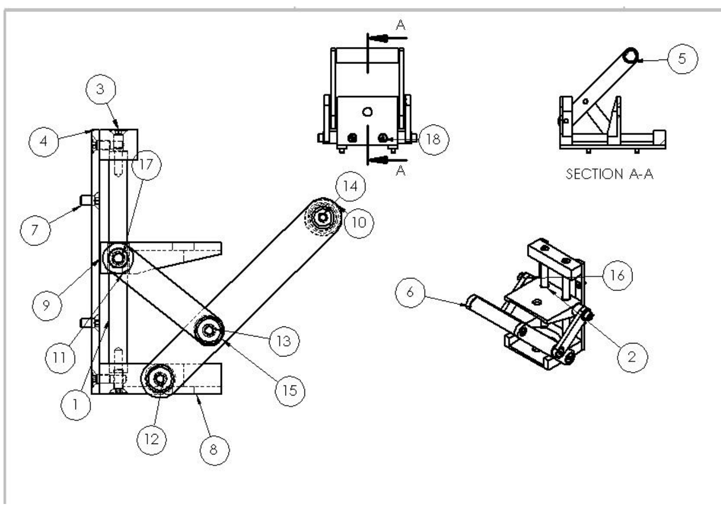
2,10 euros per product

The price of all additional parts (bolts etc.) that will be bought. This will be 22 parts at approximately 2 cents per piece = 0,44 per product.

Concept drawings

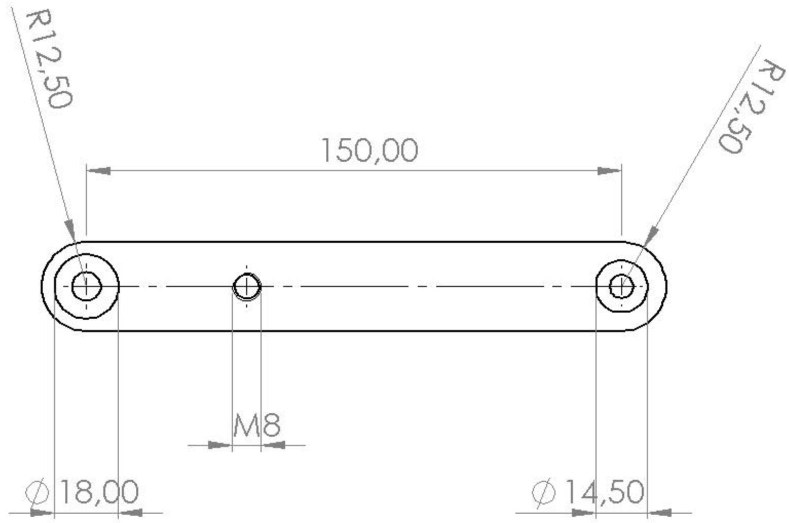
The drawings of the new concept have been sketched multiple times to ensure a correctly working model to use in order to derive the right calculations. Subsequently each group member redesigned at least one part of the model and a new assembly was created using the adapted parts. In particular the long pull-bar, the short pull-bar, the upper press-plate, the lower press-plate, the slides, the top fixing and the wall fixing strips have all undergone a series of changes. An assembly drawing and all parts drawings are provided below with the exception of Toolbox components.

Assembly drawing

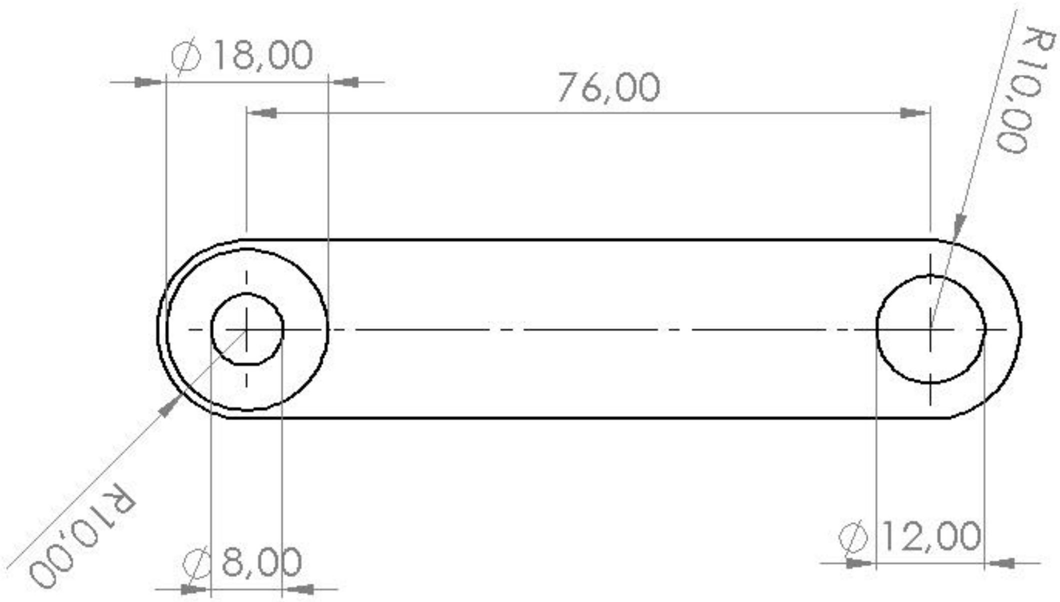


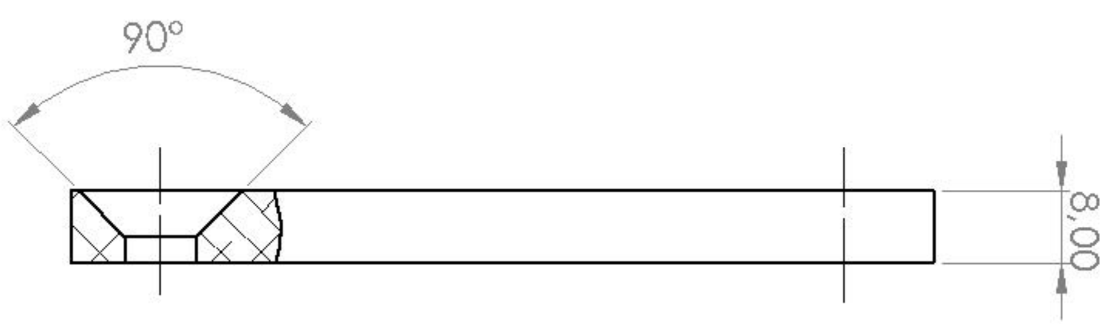
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	slider		2
2	Bearing PAP1220		2
3	top_part		1
4	Fix-strip		2
5	Handle		1
6	Handvathuls		1
7	DIN 7991 - M6 x 12 --- 5.7C		10
8	lowerpressplatenewconcept		1
9	upper-pressplate project		1
10	Pullbar-long new model		2
11	ISO 10669-8.8-N		5
12	ISO 10642 - M8 x 20 - 20N		2
13	ISO 10642 - M8 x 16 - 16N		2
14	ISO 10642 - M6 x 30 - 30N		2
15	Pullbar-short NEW MODEL		2
16	Afstandsbus_bottom		2
17	ISO 4762 M8 x 30 - 30N		2
18	ISO 10642 - M6 x 16 - 16N		2

Long pull-bar

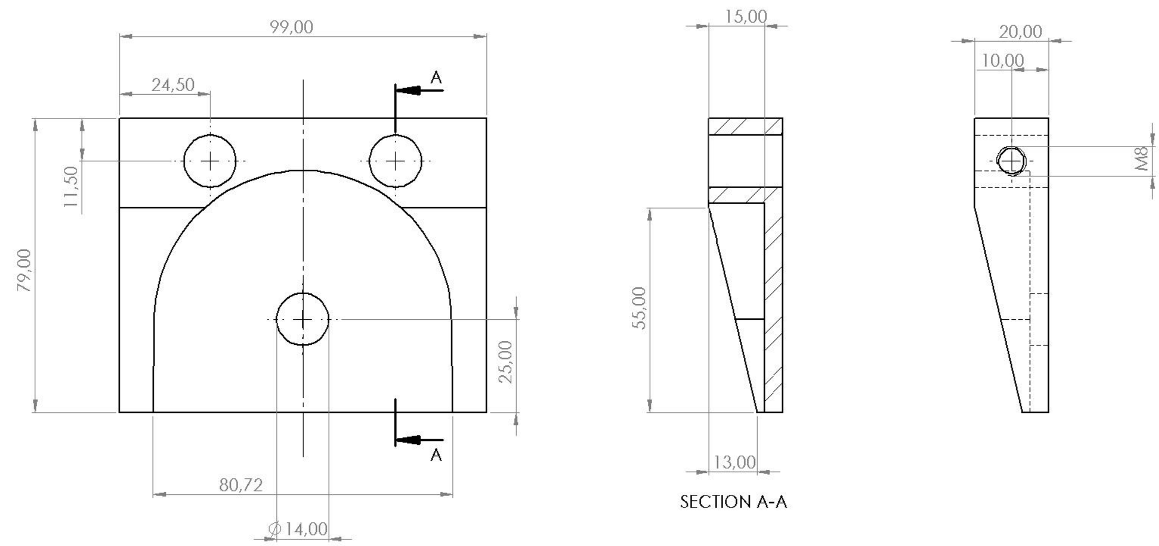


Short pull-bar

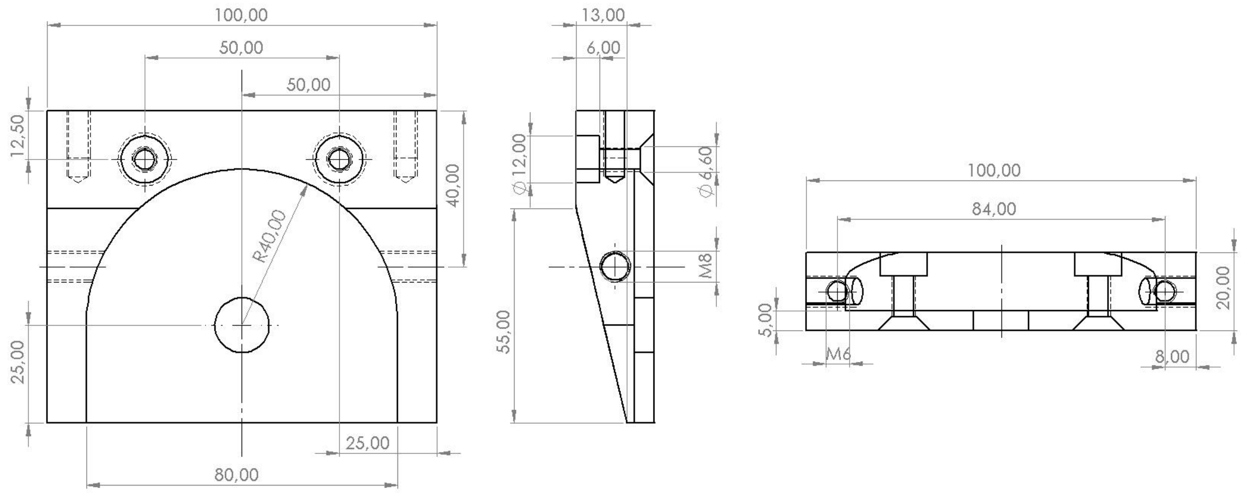




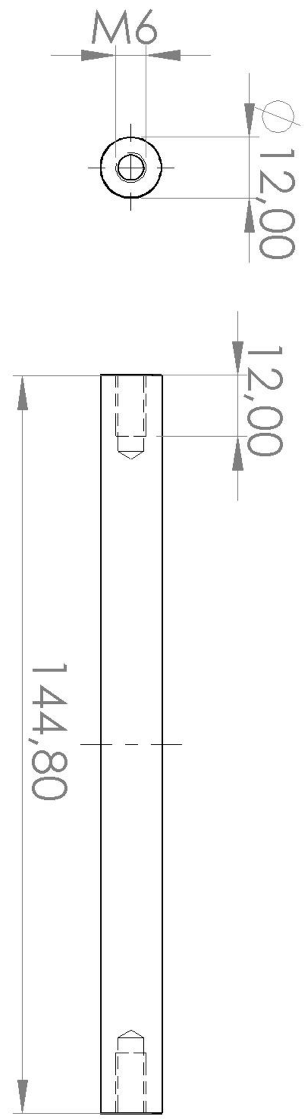
Upper press-plate



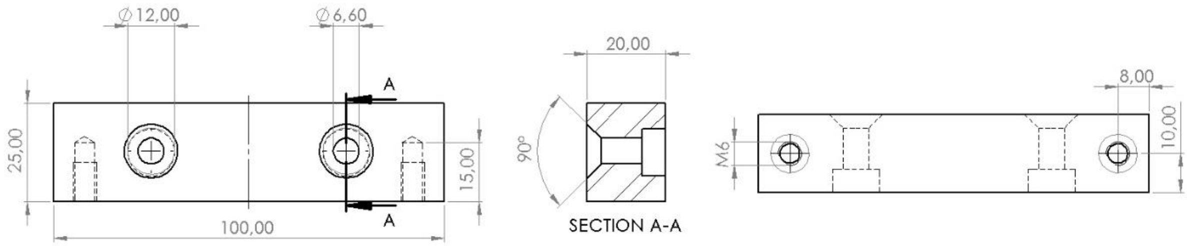
Lower press-plate



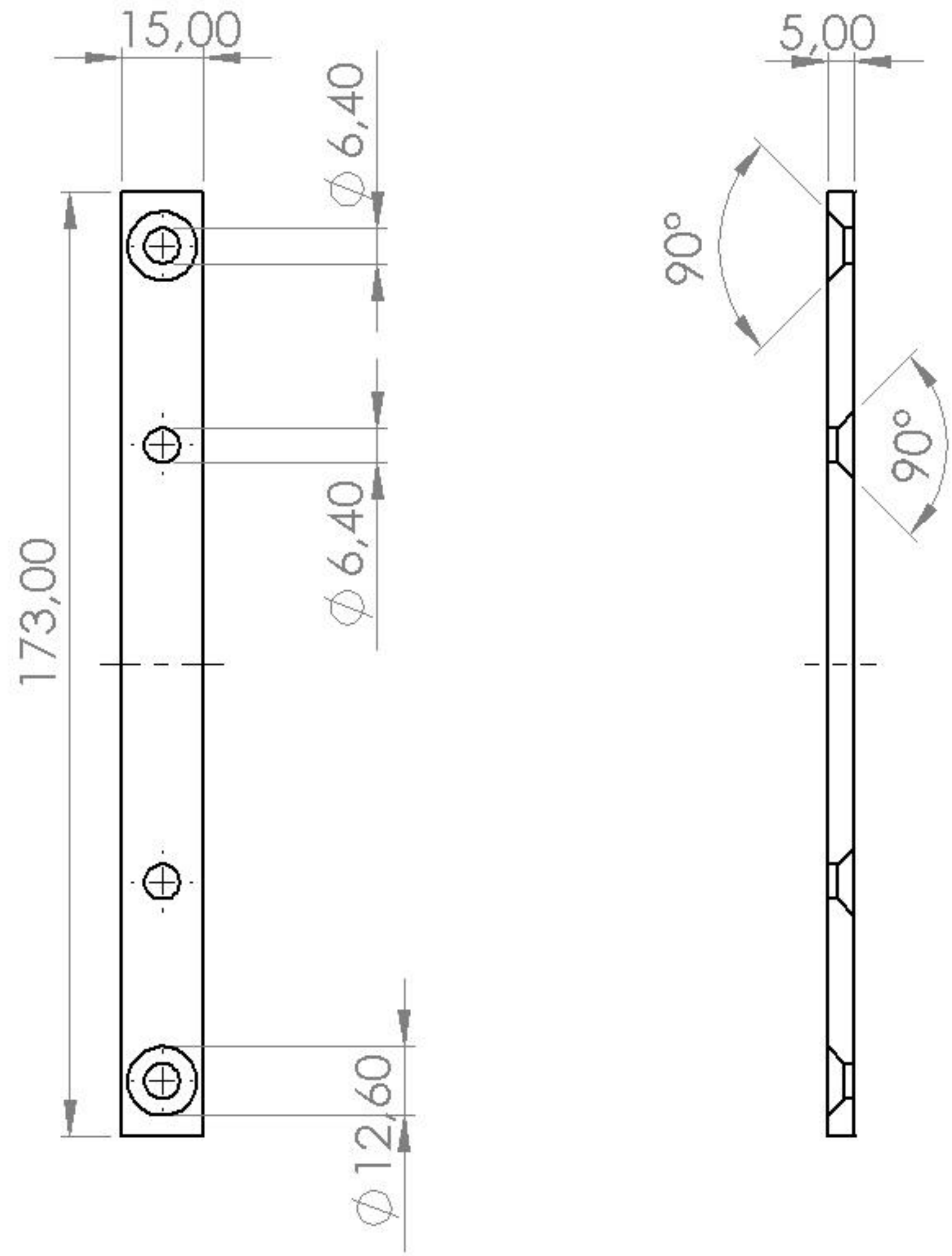
Slider



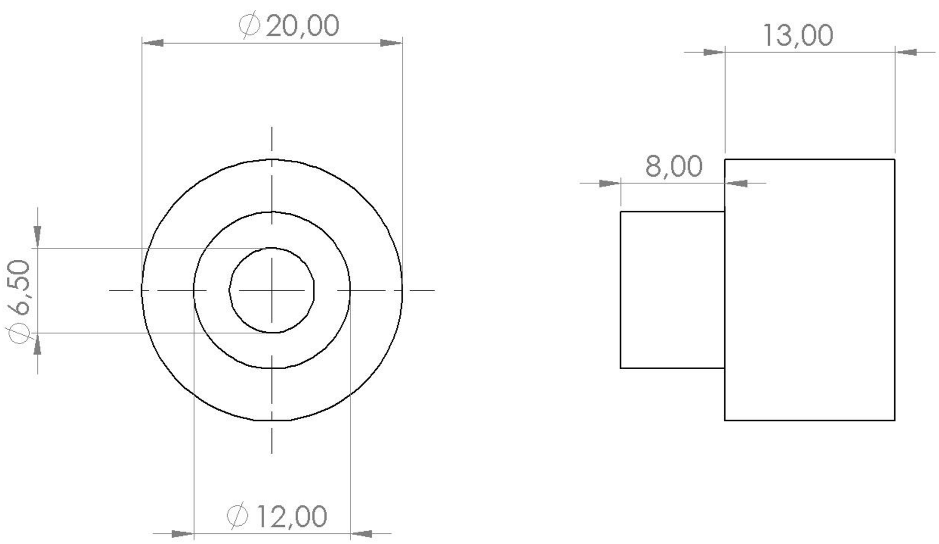
Top fix



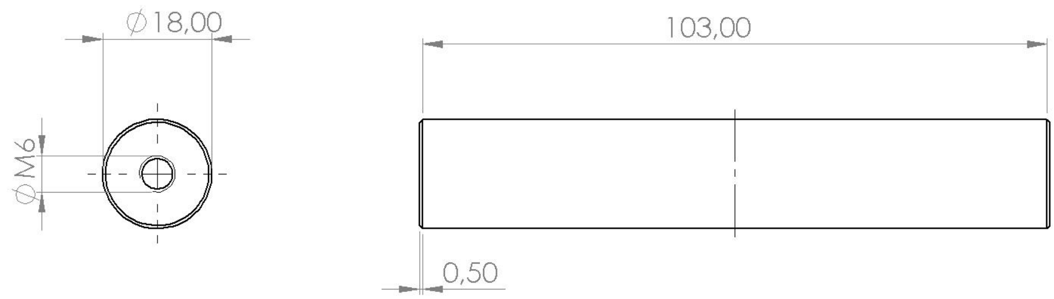
Fix strip



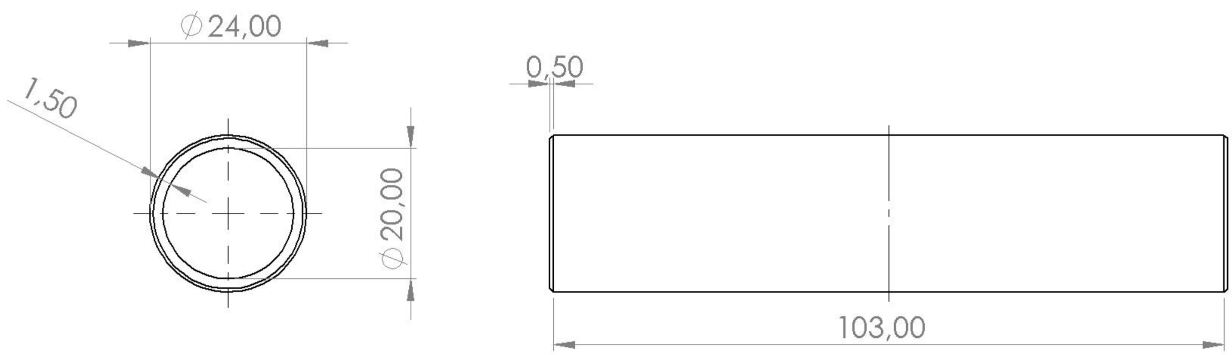
Bearing



Handle



Handle cover



Instructions

Before use the can crusher must be securely mounted to the wall by inserting screws through the designated holes in the back-fixing strips. Only empty, non-magnetic 330 ml aluminum cans are to be crushed, if there is any uncertainty about a can's material you may use the built-in magnet to check its properties. The operator may proceed by placing the can on the lower plate by hand and pushing the handle down until the upper press-plate touches the lower press-plate, at this point 85% compression of the can has occurred. Next, the handle has to be moved back up to its original position and the crushed can may finally be removed by hand. At this point the can crusher is ready to crush another can with a processing time of three cans a minute. Maintenance and other modifications are only being conducted by an expert.

Safety Measures

The can crusher should be cleaned regularly.
When operating the can crusher, wear protective gear such as safety glasses and gloves.
During the crushing procedure no human body parts are supposed to be touching or be inside the machine apart from the handlebar.
Only trained and certified personnel are permitted to operate this machine.
Children under the age of 12 are prohibited to operate this machine.
We are not liable for damage, injury or death caused by inappropriate use.

References

- Statics & Mechanics of Materials: SI Edition, 4th edition by Russel C.Hibbeler, ISBN-13: 9789814526043
- Grit, R., Project Management, Noordhoff Uitgevers, fourth edition, 2015, ISBN 978-90-01-85054-8
- Manual of Engineering Drawing, 4th edition DE, Simmons CH, Phelps N, Maguire, ISBN 978-0-0809-6652-6
- Pahl G, Beitz W, Feldhusen, J, Grote KH, Engineering Design - A systematic approach, 3rd edition, Springer, ISBN 978-1-84628-318-5
- Industrial production the manufacture of mechanical products, 1st edition, HJJ Kals, Cs. Buiting-Csikós, KA Moulijn, C.A. van Luttervelt, A.H. Streppel, J.M. Punching, ISBN: 9789024407309
- Patent US4290354A by Benjamin A. Stevens https://patents.google.com/patent/US4290354A/en

Appendix

Data Internal stresses (N, V, M, σb) long pull-bar in old concept

b	N	V	M	σx,bend	b	N	V	M	σx,bend
0	0	0	0	0	175	0	97,4	-16,267	-27,506
2,5	0	0	0	0	177,5	0	97,4	-16,0346	-27
5	0	0	0	0	180	0	97,4	-15,8022	-26,7765
7,5	0	0	0	0	182,5	0	97,4	-15,5698	-26
10	0	0	0	0	185	0	97,4	-15,3374	-26,047
12,5	-138	-390	0	-1,552222222	187,5	0	97,4	-15,105	-26
15	-138	-390	-0,97423	-3,104444444	190	0	97,4	-14,8727	-25,3175
17,5	-138	-390	-1,94846	-4,656666666	192,5	0	97,4	-14,6403	-25
20	-138	-390	-2,92269	-6,208888888	195	0	97,4	-14,4079	-24,588
22,5	-138	-390	-3,89692	-7,76111111	197,5	0	97,4	-14,1755	-24

25	-138	-390	-4,87115	-9,313333332	200	0	97,4	-13,9431	-23,8585
27,5	-138	-390	-5,84538	-10,86555555	202,5	0	97,4	-13,7107	-23
30	-138	-390	-6,81962	-12,41777778	205	0	97,4	-13,4783	-23,129
32,5	-138	-390	-7,79385	-13,97	207,5	0	97,4	-13,246	-23
35	-138	-390	-8,76808	-15,52222222	210	0	97,4	-13,0136	-22,3995
37,5	-138	-390	-9,74231	-17,07444444	212,5	0	97,4	-12,7812	-22
40	-138	-390	-10,7165	-18,62666666	215	0	97,4	-12,5488	-21,67
42,5	-138	-390	-11,6908	-20,17888889	217,5	0	97,4	-12,3164	-21
45	-138	-390	-12,665	-21,73111111	220	0	97,4	-12,084	-20,9405
47,5	-138	-390	-13,6392	-23,28333333	222,5	0	97,4	-11,8517	-21
50	-138	-390	-14,6135	-24,83555555	225	0	97,4	-11,6193	-20,211
52,5	-138	-390	-15,5877	-26,38777777	227,5	0	97,4	-11,3869	-20

55	-138	-390	-16,5619	-27,94	230	0	97,4	-11,1545	-19,4815
57,5	-138	-390	-17,5362	-29,49222222	232,5	0	97,4	-10,9221	-19
60	-138	-390	-18,5104	-31,04444444	235	0	97,4	-10,6897	-18,752
62,5	-138	-390	-19,4846	-32,59666666	237,5	0	97,4	-10,4573	-18
65	-138	-390	-20,4588	-34,14888888	240	0	97,4	-10,225	-18,0225
67,5	-138	-390	-21,4331	-35,70111111	242,5	0	97,4	-9,99257	-18
70	-138	-390	-22,4073	-37,25333333	245	0	97,4	-9,76018	-17,293
72,5	-138	-390	-23,3815	-38,80555555	247,5	0	97,4	-9,5278	-17
75	-138	-390	-24,3558	-40,35777777	250	0	97,4	-9,29541	-16,5635
77,5	-138	-390	-25,33	-41,9	252,5	0	97,4	-9,06303	-16
80	0	97,4	-25,0976	-41,36642857	255	0	97,4	-8,83064	-15,834
82,5	0	97,4	-24,8652	-40,83285714	257,5	0	97,4	-8,59826	-15

85	0	97,4	-24,6328	-40,29928571	260	0	97,4	-8,36587	-15,1045
87,5	0	97,4	-24,4005	-39,76571428	262,5	0	97,4	-8,13349	-15
90	0	97,4	-24,1681	-39,23214285	265	0	97,4	-7,9011	-14,375
92,5	0	97,4	-23,9357	-38,69857142	267,5	0	97,4	-7,66872	-14
95	0	97,4	-23,7033	-38,16499999	270	0	97,4	-7,43633	-13,6455
97,5	0	97,4	-23,4709	-37,63142856	272,5	0	97,4	-7,20394	-13
100	0	97,4	-23,2385	-37,09785713	275	0	97,4	-6,97156	-12,916
102,5	0	97,4	-23,0061	-36,5642857	277,5	0	97,4	-6,73917	-13
105	0	97,4	-22,7738	-36,03071427	280	0	97,4	-6,50679	-12,1865
107,5	0	97,4	-22,5414	-35,49714284	282,5	0	97,4	-6,2744	-12
110	0	97,4	-22,309	-34,96357141	285	0	97,4	-6,04202	-11,457
112,5	0	97,4	-22,0766	-34,43	287,5	0	97,4	-5,80963	-11

115	0	97,4	-21,8442	-36,26	290	0	97,4	-5,57725	-10,7275
117,5	0	97,4	-21,6118	-36	292,5	0	97,4	-5,34486	-10
120	0	97,4	-21,3794	-35,5305	295	0	97,4	-5,11248	-9,998
122,5	0	97,4	-21,1471	-35	297,5	0	97,4	-4,88009	-10
125	0	97,4	-20,9147	-34,801	300	0	97,4	-4,64771	-9,2685
127,5	0	97,4	-20,6823	-34	302,5	0	97,4	-4,41532	-9
130	0	97,4	-20,4499	-34,0715	305	0	97,4	-4,18294	-8,539
132,5	0	97,4	-20,2175	-34	307,5	0	97,4	-3,95055	-8
135	0	97,4	-19,9851	-33,342	310	0	97,4	-3,71816	-7,8095
137,5	0	97,4	-19,7528	-33	312,5	0	97,4	-3,48578	-7
140	0	97,4	-19,5204	-32,6125	315	0	97,4	-3,25339	-6,51
142,5	0	97,4	-19,288	-32	317,5	0	97,4	-3,02101	-6

145	0	97,4	-19,0556	-31,883	320	0	97,4	-2,78862	-5,208
147,5	0	97,4	-18,8232	-32	322,5	0	97,4	-2,55624	-5
150	0	97,4	-18,5908	-31,1535	325	0	97,4	-2,32385	-3,906
152,5	0	97,4	-18,3584	-31	327,5	0	97,4	-2,09147	-3
155	0	97,4	-18,1261	-30,424	330	0	97,4	-1,85908	-2,604
157,5	0	97,4	-17,8937	-30	332,5	0	97,4	-1,6267	-2
160	0	97,4	-17,6613	-29,6945	335	0	97,4	-1,39431	-1,302
162,5	0	97,4	-17,4289	-29	337,5	0	97,4	-1,16193	0
165	0	97,4	-17,1965	-28,965	340	0	0	-0,92954	0
167,5	0	97,4	-16,9641	-29	342,5	0	0	-0,69716	0
170	0	97,4	-16,7317	-28,2355	345	0	0	-0,46477	0
172,5	0	97,4	-16,4994	-28	347,5	0	0	-0,23239	0

					350	0	0	0	0

Data Internal stresses (N, V, M, σb) long pull-bar in new concept

b (m)	M (N.m)	b (m)	M (N.m)
0	0	75	-18,0857
2,5	-1,40667	77,5	-17,4829
5	-2,81333	80	-16,88
7,5	-4,22	82,5	-16,2771
10	-5,62667	85	-15,6743
12,5	-7,03333	87,5	-15,0714
15	-8,44	90	-14,4686
17,5	-9,84667	92,5	-13,8657
20	-11,2533	95	-13,2629
22,5	-12,66	97,5	-12,66
25	-14,0667	100	-12,0571
27,5	-15,4733	102,5	-11,4543
30	-16,88	105	-10,8514
32,5	-18,2867	107,5	-10,2486
35	-19,6933	110	-9,64571
37,5	-21,1	112,5	-9,04286
40	-22,5067	115	-8,44
42,5	-23,9133	117,5	-7,83714
45	-25,32	120	-7,23429
47,5	-24,7171	122,5	-6,63143
50	-24,1143	125	-6,02857
52,5	-23,5114	127,5	-5,42571

55	-22,9086	130	-4,82286
57,5	-22,3057	132,5	-4,22
60	-21,7029	135	-3,61714
62,5	-21,1	137,5	-3,01429
65	-20,4971	140	-2,41143
67,5	-19,8943	142,5	-1,80857
70	-19,2914	145	-1,20571
72,5	-18,6886	147,5	-0,60286
		150	0

European Conformity Regulations

DIRECTIVE 2006/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 17 May 2006 on machinery, and amending Directive 95/16/EC.