BOISE STATE UNIVERSITY

Engineering Innovation Studio
Hydraulic Retrofitted Tube Bender

Faith W.

Matt L.

Austin E.

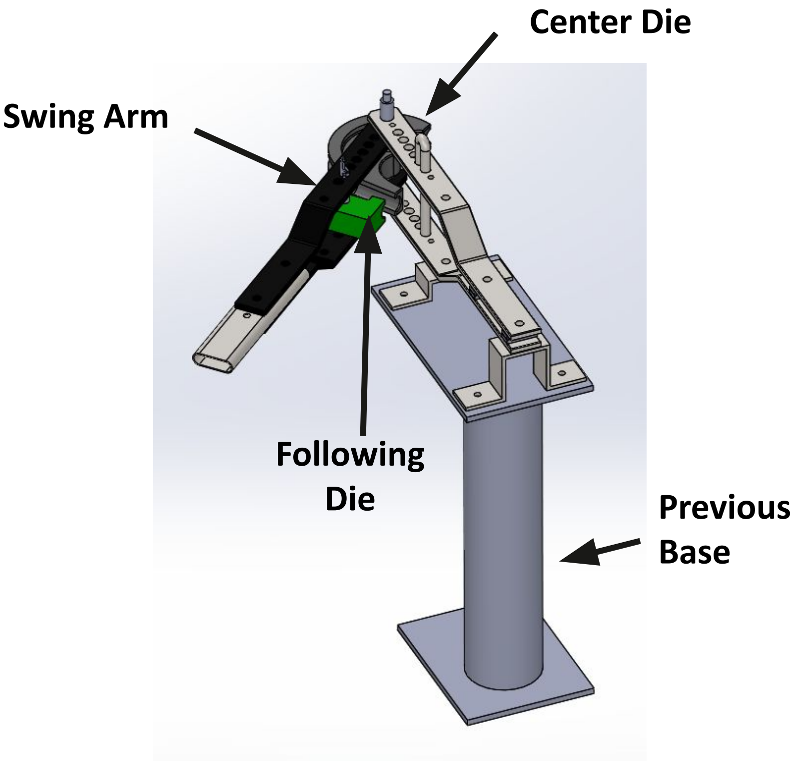
Ernest S.

Problem Statement

Retrofit the Engineering Innovation Studio's (EIS) current tube bender to eliminate the need for manual force input, while increasing mobility.

Background

- Requires a few people to move, has virtually no mobility
- Needs to be bolted to the floor
- Largest & strongest pipe requires multiple people and a 12’ “cheater” bar to bend
  - Requires ~15 ft radius of space to operate



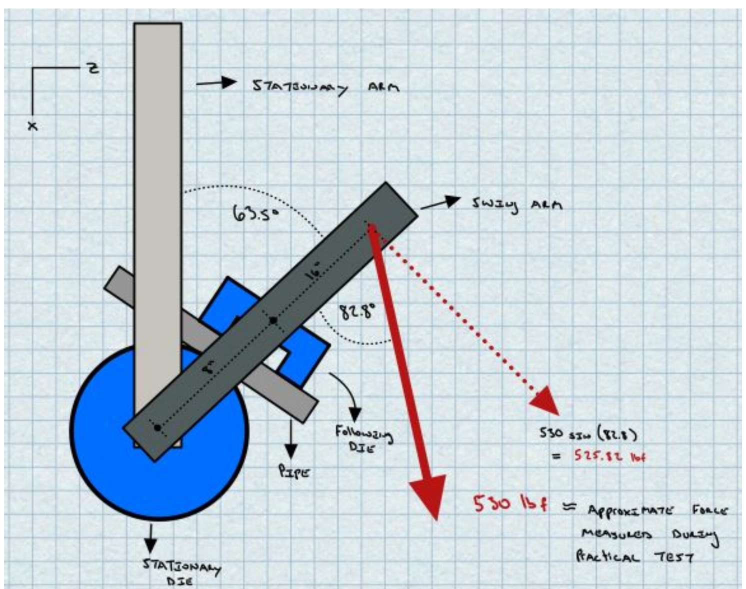
Specifications

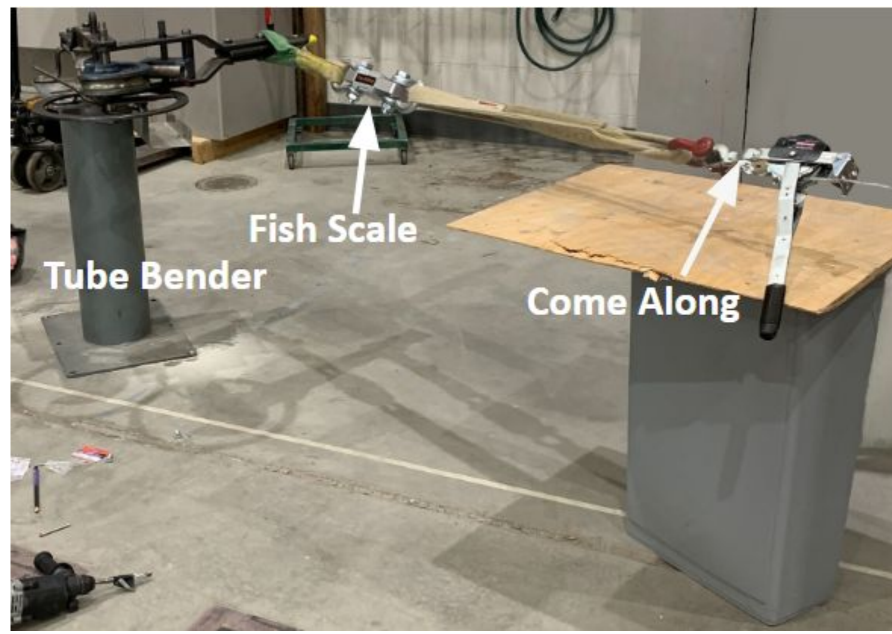
- Meets Federal & OSHA regulations
- Retains functionality of current setup
- Minimum force required: **4,855 lbf**
- One EIS approved individual can move bender
- Hydraulic component must be able to plug into **120V** outlets
- Flexible budget goal of **$1000**
- Aesthetically pleasing

References: [11][5]

Analysis

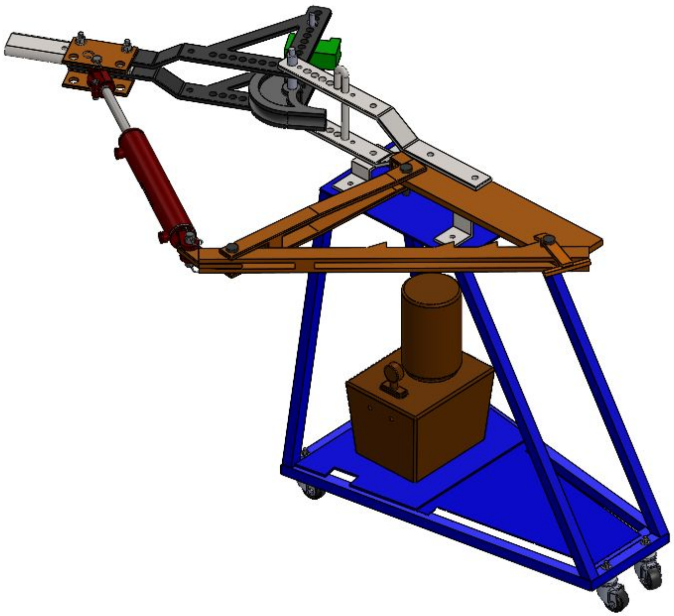
- Theoretical Force: 2,621 lbf
- Practical Force: 4,855 lbf
- Bore size = Minimum 2.03” at 1500 psi





Initial Design

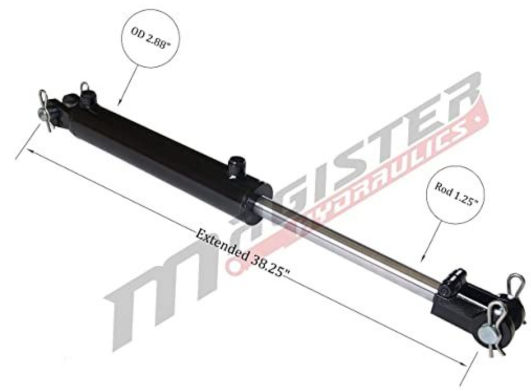
Bends tubes and pipes of various size to desired angles using a hydraulic cylinder and ratchet arm mechanism, including the following components:



- Hydraulic power pack (brown)
- Hydraulic cylinder (red)
- Ratchet system (orange)
- Mobile base (blue)

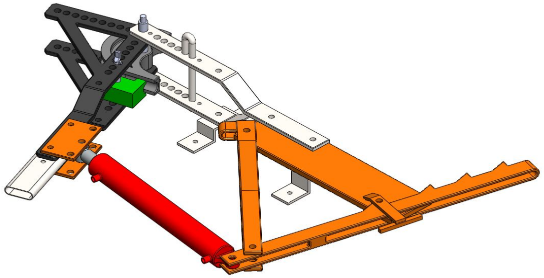
Design Components [Hydraulics]

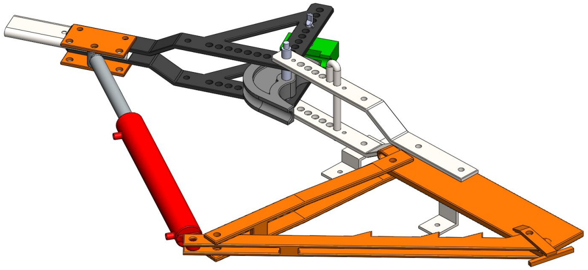
Power pack supplies hydraulic pressure to the cylinder for operation



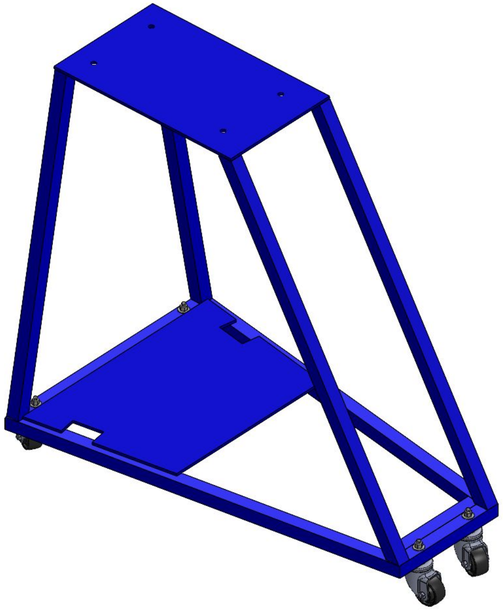
Double Acting Hydraulic Cylinder provides the force necessary to bend tubing

Design Components [Ratchet & Frame]





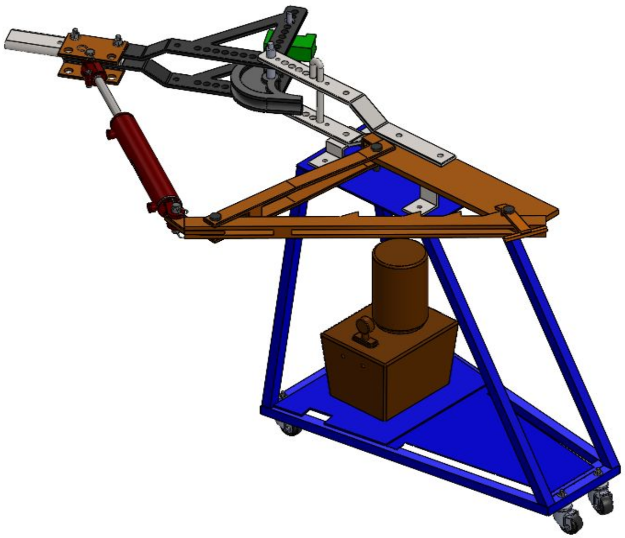
Ratchet mechanism increases bending angle capabilities

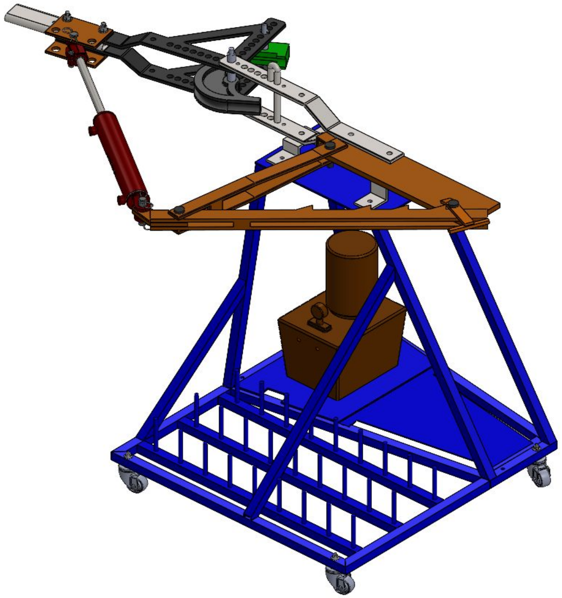


Custom fabricated base with caster wheels and die storage

Stability Concern

- Tipping to the side became an issue due to weight of ratchet system and hydraulic cylinder
- Resolved by widening base which allowed for die storage





Final Design

Stability Test

Procedure:

- Rotated swing arm through full range of motion while supporting 70 lbs of weight
  - Weight was determined by moment calculations
- Brackets were placed as a precaution

Criteria: Passes test if all casters remain in contact with the floor

Result: All casters remained on the ground for all 5 trials —> design passed!

Functionality Tests

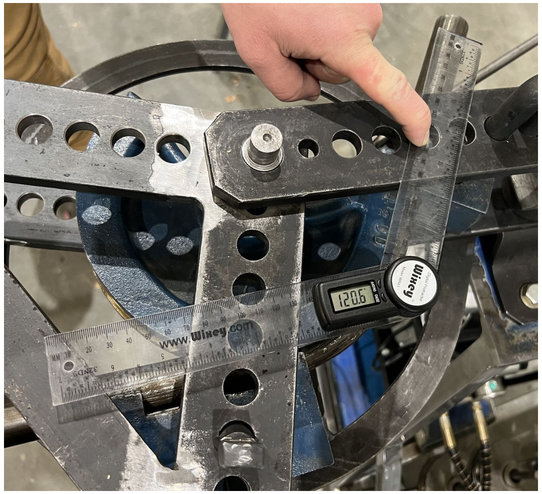
Procedure:

- Tested tube bender using 1 ¼” DOM Steel Tubing with ⅛” wall thickness
- Created successive bends of 60°, 120°, and 180°, measuring with an angle gauge

Criteria: Passes test if each bend angle is successfully reached

Results: Tubing was successfully bent to each angle

*Total time for bending was 8 minutes



Bill of Materials & Budget

Ratchet Design + Custom Base

Flat A36 Steel:	$146.29
Power Pack:	$1007.95
Hydraulic Cylinder:	$186.07
AW - 10 hydraulic oil:	$114.52
*Outsourced Laser Cutting:	$100.00
Hardware:	$30.50
Paint:	$32.40
DOM Test Tube:	$65.71
Total:	**$1,683.44**
Hossfeld Price Comparison:	$3000.00+

[4][6][7][2][3][1][10][12]

Conclusions & Recommendations

Conclusions

- Retrofit met all **essential** specifications
- Non-essential specifications not fully met:
  - One individual can easily operate tube bender alone
  - Operation time is between 2-3 minutes

Recommendations

- It is recommended that a foothold be placed somewhere on the frame to help operator pull on ratchet system
- Operators should read *Standard Operating Procedure* and be fully familiar with bender before utilizing

THANK YOU TO…

Griff A. | Sponsor

Aaron S., PhD | Mentor & Professor

Mechanical & Biomedical Engineering Department | BSU

References

[1] “1.0 In ID - 1.25 in OD .125 in Wall Dom.” *Ballistic Fabrication*, https://www.ballisticfabrication.com/products/1-0-id-1-25-od-125-wall-dom?variant=25411035911.

[2] “6805-08-06: #8 SAE/Orb Male X 3/8’ NPTF Female 90°.” *DiscountHydraulicHose.com*, https://www.discounthydraulichose.com/6805-08-06-8-saeorb-male-x-38-nptf-female-90.html.

[3] “AW 46 Premium Anti-Wear Hydraulic Oil Fluid - 5 Gallon Pail (18L - 4.75 Gal).” *Walmart.com*, https://www.walmart.com/ip/AW-46-Premium-Anti-wear-Hydraulic-Oil-Fluid-5-Gallon-Pail-18L-4-75-GAL/591535174?irgwc=1&sourceid=imp_15oS22QrixyIR5E2d%3A2cd0vRUkGSSRwWwTW7To0&veh=aff&wmlspartner=imp_27795&clickid=15oS22QrixyIR5E2d%3A2cd0vRUkGSSRwWwTW7To0&sharedid=3045&affiliates_ad_id=612734&campaign_id=9383.

[4] *DB 2.5X14 Orb Hydraulic Cylinder - Amazon.com*. https://www.amazon.com/DB-2-5X14-ORB-Hydraulic-Cylinder/dp/B00V8Z6SNO.

[5] “ECFR :: 46 CFR 28.880 -- hydraulic equipment.” [Online]. Available: https://www.ecfr.gov/current/title-46/chapter-I/subchapter-C/part-28/subpart-G/section-28.880. [Accessed: 28-Mar-2022].

[6] “Hot Rolled Steel: Bar, Rod, Sheet: Boise Steel Supply.” *Hot Rolled Steel: Bar, Rod, Sheet | Boise Steel Supply*, https://rockymtnsteelboise.com/hot-rolled-steel.html.

[7] “HP0003 - Electric Hydraulic Pump Power Pack Unit 2 Stage Double Acting 110V 10K Psi 488 Cubic in Capacity.” *TEMCo Industrial*, https://temcoindustrial.com/HP0003-Electric-Hydraulic-Pump-Power-Pack-Unit-2-Stage-Double-Acting-110v-10k-psi-488-Cubic-in-Capacity.

[8] “Hydraulics.” HOSSFELD UNIVERSAL® BENDERS, www.hossfeldbender.com/hydraulics.html.

[9] Jay, and Jason. “Eastwood Hydraulic Tubing Bender.” Auto Body Repair Tools Shop - Auto Body Supplies - Classic Car Restoration, 26 June 2021, www.eastwood.com/eastwood-hydraulic-tubing-bender.html?gclid=Cj0KCQiApL2QBhC8ARIsAGMm-KEgbUHutgSo5BPAKmMggZDx7uKybaFPHABMLa_zNlYCWJ8A4plAFYIaAs8lEALw_wcB&wickedid=555900045758&wickedsource=google&wv=3.1.

[10]“Solejazz Workbench Caster Kit 880 Lbs Capacity 3’ Heavy Duty Retractable Workbench Caster All Steel Construction Urethane Wheels, Bonus Install Template, Pack of 4.” - *Amazon.com*, https://tinyurl.com/2xrhzs5u.

[11] “*United States Department of Labor*. 1910.212 - General requirements for all machines. | Occupational Safety and Health Administration. (n.d.). Retrieved March 28, 2022, from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.212.

[12] “Hydraulics.” HOSSFELD UNIVERSAL® BENDERS. Retrieved December 11th, 2022 from www.hossfeldbender.com/hydraulics.html.

BOM

Part	Name	Description	Material	Specifications	Manufacturer	Unit Price	Quantity	Total Price	Link
1	Magister Hydraulic Double Acting Cylinder	Hydraulic Cylinder (3500 psi) With Clevis End	Steel	2.5" bore diameter, 14" stroke	Farm and Ranch Depot [35]	$186.07	1	$186.07	https://farmandranchdepot.com/2-5-bore-x-14-stroke-clevis-hydraulic-cylinder
2	HP0003 - Electric Hydraulic Pump Power Pack Unit 2 Stage Double Acting	AC Power Pack	Multiple	2.11 gallons	TEMCo Industrial [33]	$1,007.95	1	$1,007.95	https://temcoindustrial.com/HP0003-Electric-Hydraulic-Pump-Power-Pack-Unit-2-Stage-Double-Acting-110v-10k-psi-488-Cubic-in-Capacity
3	Ratchet Base Plate and Cylinder Mounting Bracket	Plate that holds ratchet and piece that extends hydraulic cylinder	HR A36 Steel	3/4" x 6" x 36"	Rocky Mountain [32]	$58.60	1	$58.60	https://rockymtnsteelboise.com/hot-rolled-steel.html
4	Ratchet	Ratchet arm with triangle pieces	HR A36 Steel	1/2" x 3.5"x 84"	Rocky Mountain [32]	$49.11	1	$49.11	https://rockymtnsteelboise.com/hot-rolled-steel.html
5	Ratchet Spacers	Small pieces of metal in between ratchet arms	HR A36 Steel	1/2" x 3/4" x 2"	EIS Inventory	n/a	2	n/a	n/a
6	Ratchet Butt Spacer	Small piece of metal at the end of the ratchet arm	HR A36 Steel	1/2" x 3/4" x 2"	EIS Inventory	n/a	1	n/a	n/a
7	Laser cut ratchet arm	Outsourced laser cut ratchet arm piece	Mild Steel	½" thick	YMC Inc	$70.00	1	$70.00	http://ymcinc.com/metal-fabrication/

BOM Continued…

8	Cylinder Mount Bracket	Outsourced laser cut metal for cylinder mounting bracket	Mild Steel	¾" thick	YMC Inc	$30.00	1	$30.00	http://ymcinc.com/metal-fabrication/
9	Ratchet Support Arm	Piece of metal that extends in the middle of the system and connects to ratchet arm	HR A36 Steel	1/2" x 2" x 60"	Rocky Mountain [32]	$19.69	1	$19.69	https://rockymtnsteelboise.com/hot-rolled-steel.html
10	Ratchet Support Arm Spacer	Spacer between ratchet support arm plates	Steel	1/2" x 1.75" x 2"	EIS Inventory	n/a	1	n/a	n/a
11	Ratchet Support Arm End Cap	Metal at the end of the ratchet support arm	Steel	1/2" x 1.75" x 4.75"	EIS Inventory	n/a	1	n/a	n/a
12	L-shape Arm	Metal arm in the shape of an L where pins go through and set the die	Steel	1/2" x 2.5" x 24"	Rocky Mountain [32]	$9.81	2	$9.81	https://rockymtnsteelboise.com/hot-rolled-steel.html
13	Diagonal Support	Diagonal piece of metal that is set between L-shaped arms	Steel	1/2" x 1.5" x 36"	Rocky Mountain [32]	$9.08	1	$9.08	https://rockymtnsteelboise.com/hot-rolled-steel.html
14	Swing Arm Mounting Plate	Plates of metal that sandwich the swing arm	Steel	3/8" x 4.5" x 7"	EIS Inventory	n/a	2	n/a	n/a
15	Thin Mounting Plate Spacer	Thin sheet of metal that is between mounting plate and swing arm	Steel	1/4" x 2" x 7"	EIS Inventory	n/a	2	n/a	n/a
16	Large Ratchet Pin	Pins that secure main ratchet pieces	Steel	OD = 3/4" Length = 3.5"	EIS Inventory	n/a	3	n/a	n/a

BOM Continued…

17	Cylinder Mounting Pin	Pin that holds mounting plates and hydraulic cylinder together	Steel	OD = 1" Length = 4.5"	EIS Inventory	n/a	1	n/a	n/a
18	T-Retainer	Metal piece that retains ratchet arm	Steel	Top: 3/8" x 1.25" x 6.75" Side: 1/2" x 1/2" x 5.25"	EIS Inventory	n/a	1	n/a	n/a
19	Bender Mounting Plate	Large plate of metal that is the base for the ratchet system	Steel	1/4" x 12" x 19.5"	EIS Inventory	n/a	1	n/a	n/a
20	Front Frame Riser	Riser of custom frame that is more upright	Steel	1.25" x 1.25" square tubing, 1/16" thickness, 33" length	EIS Inventory	n/a	2	n/a	n/a
21	Back Frame Riser	Riser of custom frame that has more intense angle	Steel	1.25" x 1.25" square tubing, 1/16th thickness, 37" length	EIS Inventory	n/a	2	n/a	n/a
22	Frame Base Side	Angled side piece of custom frame	Steel	1.25" x 1.25" square tubing, 1/16th thickness, 38.5" length	EIS Inventory	n/a	2	n/a	n/a
23	Frame Base Front	Front piece for base of custom frame	Steel	1.25" x 1.25" square tubing, 1/16th thickness, 24" length	EIS Inventory	n/a	1	n/a	n/a

BOM Continued…

24	Frame Base Back	Small back piece for base of custom frame	Steel	1.25" x 1.25" square tubing, 1/16th thickness, 12" length	EIS Inventory	n/a	1	n/a	n/a
25	Power Pack Shelf	Metal shelf that power pack sits on	Steel	1/4" x 12" x 22"	EIS Inventory	n/a	1	n/a	n/a
26	Bracket	Brackets for bolting to ground	Steel	3/8" x 2" x 14.5"	EIS Inventory	n/a	3	n/a	n/a
27	Zinc Yellow-Chromate Plated Hex Head Screw	Hardware for casters		3/8" - 24 thread, 2.5" long	Fastenal [31]	$6.78	1 pack	$6.78	https://www.fastenal.com/product/details/0118842
28	Grade 5 Zinc Finish NE Steel Nylon Insert Lock Nut	Hardware for casters	Steel	3/8"- 24 thread	Fastenal [31]	$2.50	1 pack	$2.50	https://www.fastenal.com/product/details/0169791
29	Grade 8 Steel Washer	Hardware for casters	Steel	3/8" screw size, 1" OD	Fastenal [31]	$2.16	1 pack	$2.16	https://www.fastenal.com/product/details/1133859
30	Grade 9 Steel Washer	Mounting plate hardware	Steel	9/16" screw size, 1.186" OD	Fastenal [31]	$1.05	2	$2.10	https://www.fastenal.com/product/details/923083419
31	Medium-Strength Steel Hex Nut	Mounting plate hardware	Steel	9/16" - 18 thread size	Fastenal [31]	$0.51	2	$1.02	https://www.fastenal.com/product/details/36362
32	Medium-Strength Grade 5 Steel Hex Head Screw	Mounting plate hardware	Steel	9/16" - 18 thread size, 4.5" long	Fastenal [31]	$3.08	2	$6.16	https://www.fastenal.com/product/details/17273
33	Casters	Casters for mobility	Multiple	4.5" Diameter	EIS Scrap	-	4	-	-
34	Hydarulic Fitting	fitting to connect hydraulic cylinder and power pack	Steel	6805-08-06 | #8 SAE/ORB Male x 3/8" NPTF	Discount Hydraulic Hose [36]	$4.89	2	$9.78	https://www.discounthydraulichose.com/6805-08-06-8-saeorb-male-x-38-nptf-femal

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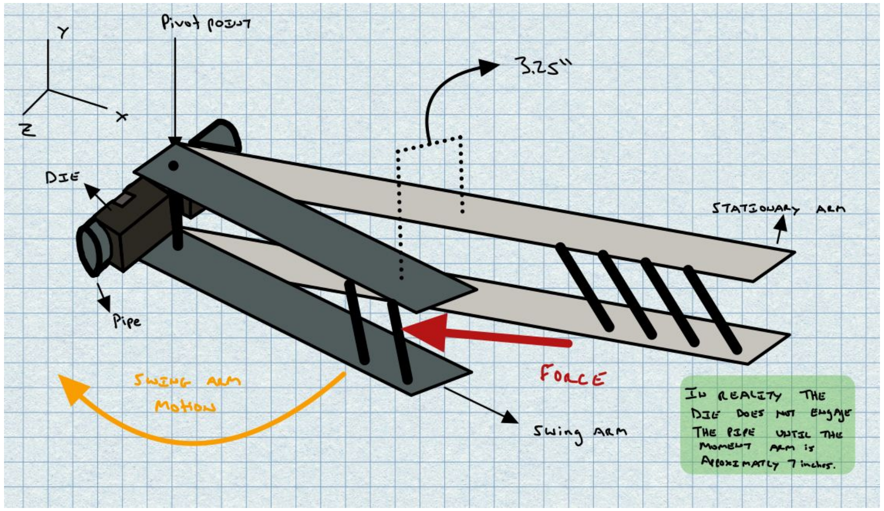
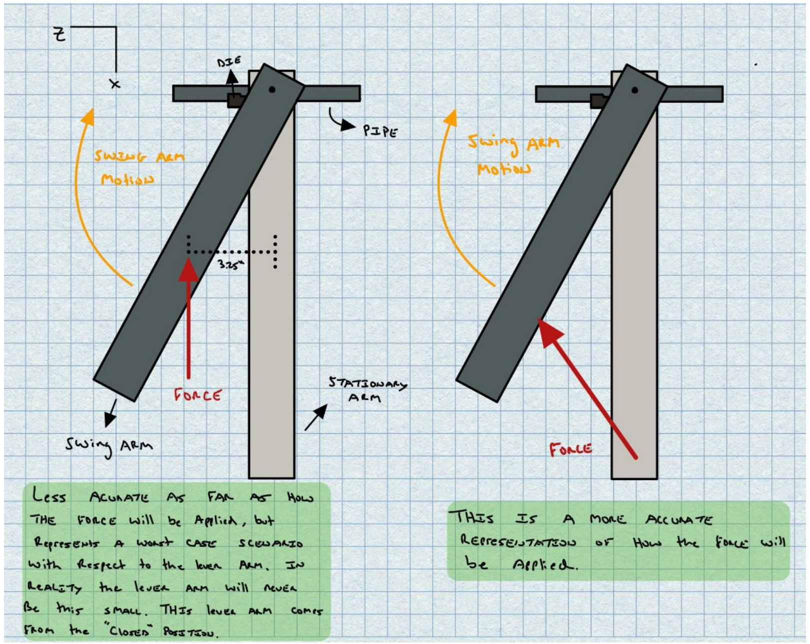
				Female 90°					e-90.html
35	Hydraulic Oil	AW 10 Hydraulic Oil	Oil	5 gallon bucket	Gran-del Petroleum [37]	$114.52	1	$114.52	https://www.grandeloil.net/products
36	Spray Paint	Rust-Oleum Painter's Touch 2X Spray Paint	Gloss	12 ounces	Home Depot	$6.48	5	$32.40	https://www.homedepot.com/p/Rust-Oleum-Painter-s-Touch-2X-12-oz-Gloss-Black-General-Purpose-Spray-Paint-334026/307244831
37	DOM tubing for testing	Strongest DOM drawn tubing compatible with tube bender dies	SAE 1026 cold drawn steel	6' of 1.25" OD with 0.125" wall thickness	Rocky Mountain [38]	$65.71	1	$65.71	https://rockymtnsteelboise.com/hot-rolled-steel.html

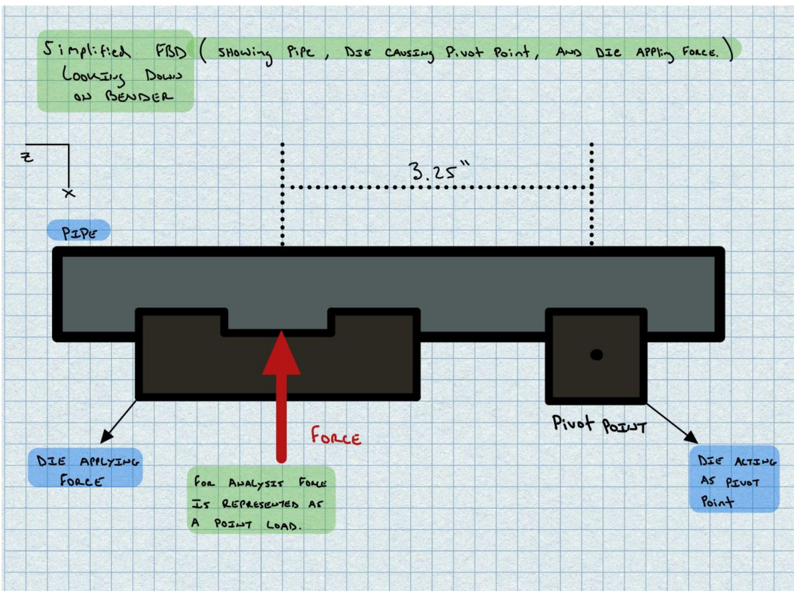
Budgets for Different Design Variations

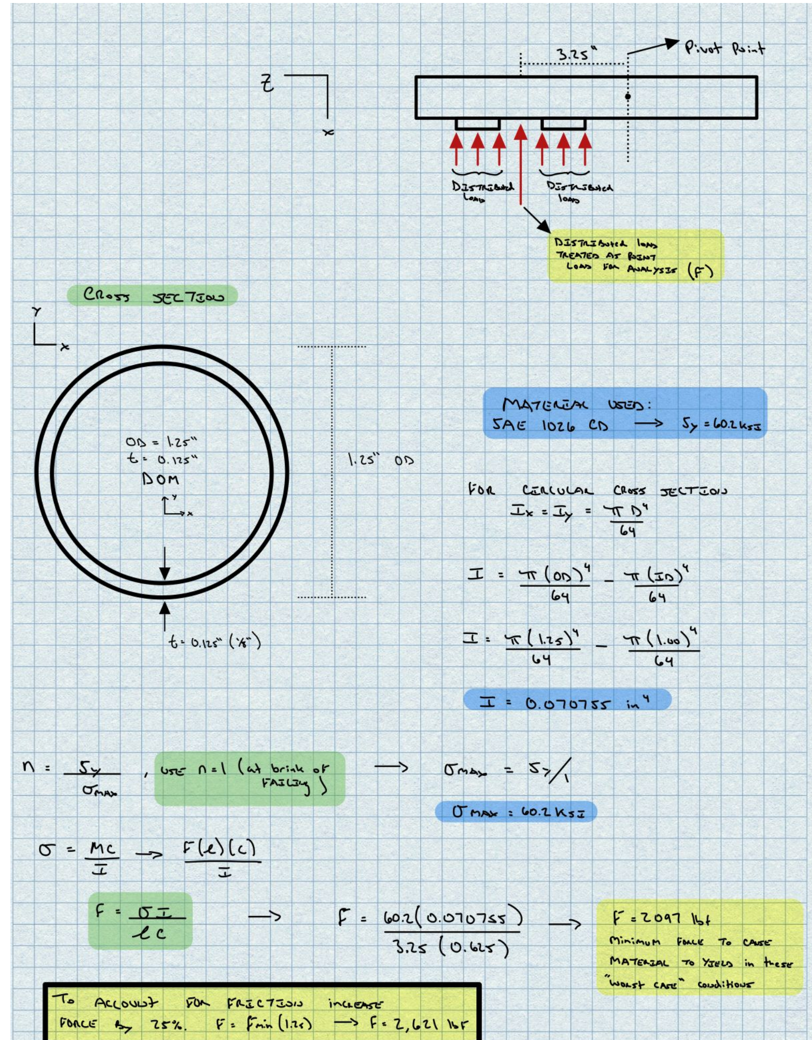
Design Description	Components Included	Total Price
Final Design	All components (includes testing materials)	$1,683.44

Theoretical Analysis

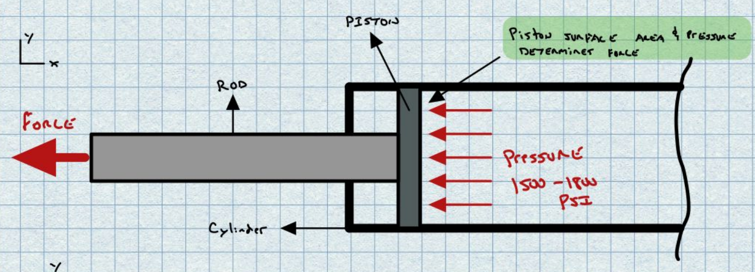


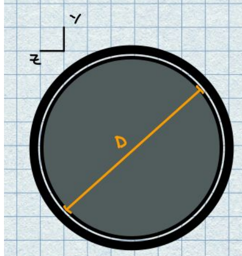



Simplified FBD Looking Down on Bender
(Showing Pipe, Die causing Pivot Point, And Die Appling Force.)
z
x
3.25"
Pipe
Force
Pivot Point
Die Applying Force
For Analysis Force Is Represented As A Point Load.
Die Acting As Pivot Point


3.25"
Pivot Point
z
x
Distributed Load
Distributed Load
Distributed load treated as point load for analysis (F)
Cross Section
y
x
OD = 1.25"
t = 0.125"
DOM
1.25" OD
t = 0.125" (1/8")
Material used:
SAE 1026 CD → Sy = 60.2 ksi
For circular cross section
Ix = Iy = π D^4 / 64
I = π (OD)^4 / 64 − π (ID)^4 / 64
I = π (1.25)^4 / 64 − π (1.00)^4 / 64
I = 0.070755 in^4
n = Sy / σmax , use n = 1 (at brink of failing) → σmax = Sy/1
σmax = 60.2 ksi
σ = Mc / I → F(ℓ)(c) / I
F = σ I / ℓ c → F = 60.2(0.070755) / 3.25 (0.625) →
F = 2097 lbf
Minimum force to cause material to yield in these "worst case" conditions
To account for friction increase force by 25%. F = Fmin (1.25) → F = 2,621 lbf

Cylinder / Piston Sizing





- Given system runs on low pressure of 1500 psi and high pressure of 1800 psi
- Force needed, plus 25% to account for friction equals 2,621 lbf

Solve for diameter of piston using max / min system pressure

$$P = F/A \rightarrow A = F/P \rightarrow \frac{\pi D^2}{4} = F/P \rightarrow D = \left(\frac{4F}{P\pi}\right)^{1/2}$$

Using 1500 PSI

$$D = \left[\frac{4(2{,}621)}{1500\,\pi}\right]^{1/2}$$

$D = 1.49"$

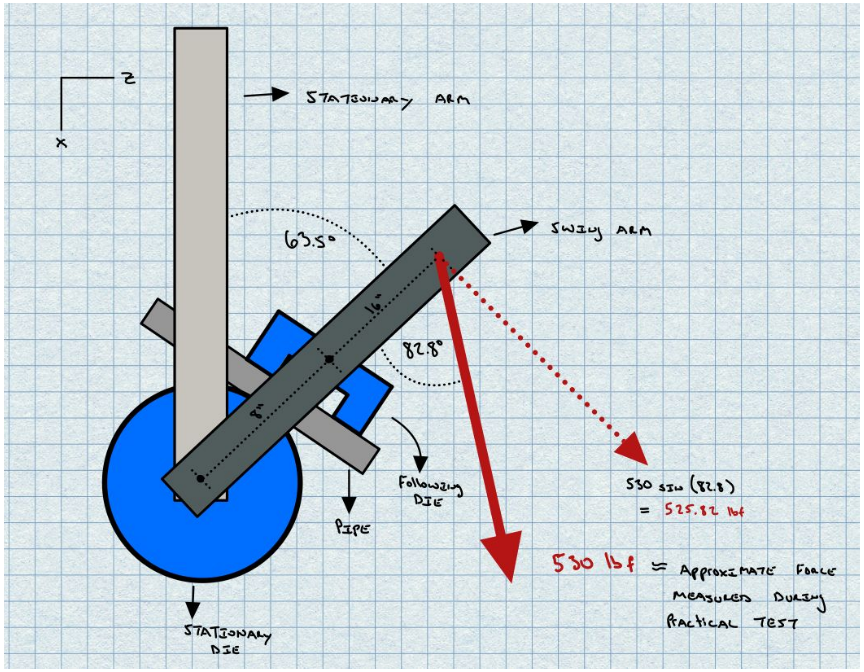
Using 1800 PSI

$$D = \left[\frac{4(2{,}621)}{1800\,\pi}\right]^{1/2}$$

$D = 1.36"$

Depending on system pressure diameter of piston must be a minimum of 1.49" (1500 PSI) or 1.36" (1800 PSI)

Practical Analysis



MOMENT CALCULATION:

M = FORCE * MOMENT ARM

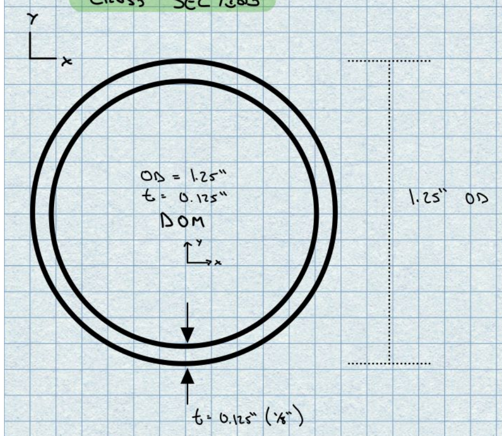
$M = \overset{\text{FORCE}}{(525.82)}(24") = 12{,}619.7 \text{ lb}\cdot\text{in}$

BENDING STRESS CALCULATIONS:

$\sigma = \frac{Mc}{I} \longrightarrow \frac{12619.7\,(0.625)}{0.070755} \longrightarrow \sigma = 111.47 \text{ ksi}$

THE FORCE AND MOMENT ARM CREATE 111.5 ksi OF STRESS. VIRTUALLY DOUBLE THE REQUIRED AMOUNT TO CAUSE YIELD OF DOM MATERIAL.

Cross Section



Recalculation of Force using σ_{Bend} = 111.5 ksi

For circular cross section

$$I_x = I_y = \frac{\pi D^4}{64}$$

$$I = \frac{\pi (OD)^4}{64} - \frac{\pi (ID)^4}{64}$$

$$I = \frac{\pi (1.25)^4}{64} - \frac{\pi (1.00)^4}{64}$$

$$I = 0.070755 \text{ in}^4$$

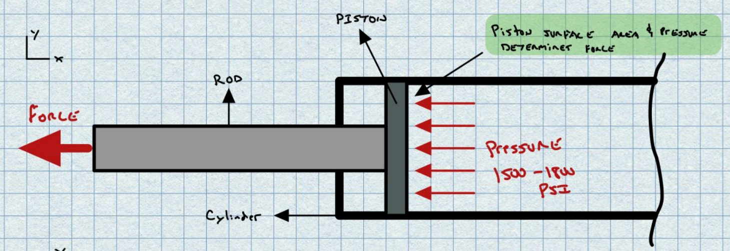
$$\sigma = \frac{Mc}{I} \rightarrow \frac{F(\ell)(c)}{I}$$

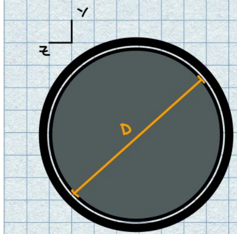
$$F = \frac{\sigma I}{\ell c} \rightarrow F = \frac{111.5(0.070755)}{3.25(0.625)} \rightarrow$$

F = 3,884 lbf
Minimum force to cause material to yield based on practical test results

To account for friction increase force by 25%. $F = F_{min}(1.25) \rightarrow F = 4{,}855$ lbf

Cylinder / Piston Sizing Based on Practical Test Results





- Given system runs on low pressure of 1500 psi and high pressure of 1800 psi
- Force needed, plus 25% to account for friction equals 4,855 lbf

Solve for diameter of piston using max / min system pressure

$$P = F/A \rightarrow A = F/P \rightarrow \frac{\pi D^2}{4} = F/P \rightarrow D = \left(\frac{4F}{P\pi}\right)^{1/2}$$

Using 1500 PSI

$$D = \left[\frac{4(4{,}855)}{1500\pi}\right]^{1/2}$$

D = 2.03"

Using 1800 PSI

$$D = \left[\frac{4(4{,}855)}{1800\pi}\right]^{1/2}$$

D = 1.85"

Depending on system pressure diameter of piston must be a minimum of 2.03" (1500 psi) or 1.85" (1800 psi)

2.5" diameter @ 1500 PSI

$$P = F/A \longrightarrow F = PA \longrightarrow F = P\left(\frac{\pi D^2}{4}\right)$$

$$F = 1500\left[\frac{\pi (2.5)^2}{4}\right] \longrightarrow \boxed{F = 7{,}363.11 \text{ lbf}}$$

Factor of Safety

$$n = \frac{\text{Actual}}{\text{"Theoretical"}} \longrightarrow \frac{7{,}363.11}{4{,}855}$$

$$\boxed{n = 1.52}$$

Weight Calculations

WEIGHT CALCULATIONS:

DENSITY OF CARBON STEEL (A36) = 0.284 lb/in^3

Weight = Volume × Density

Volume of RATCHET system

1/2" × 2.5" × 10' = 150 in^3
3/4" × 6" × 2' = 108 in^3
3/8" × 4" × 8.5' = 153 in^3
Total = 411 in^3

WEIGHT = 411 × 0.284
WEIGHT = 116.72 lbs

Volume of Custom Frame
1/8" × 1 1/4" × 4 sides × 30' = 225 in^3

WEIGHT = 225 × 0.284
WEIGHT = 63.9 lbs

WEIGHT OF VARIOUS COMPONENTS

Power Pack = 65 lbs
Piston = 25 lbs
Hydraulic oil (2 gal) = 14.4 lb
Current Bender Components ≅ 50 lbs (SolidWorks)

TOTAL WEIGHT = 116.72 + 63.9 + 65 + 25 + 14.4 + 50

TOTAL WEIGHT = 335 lbs

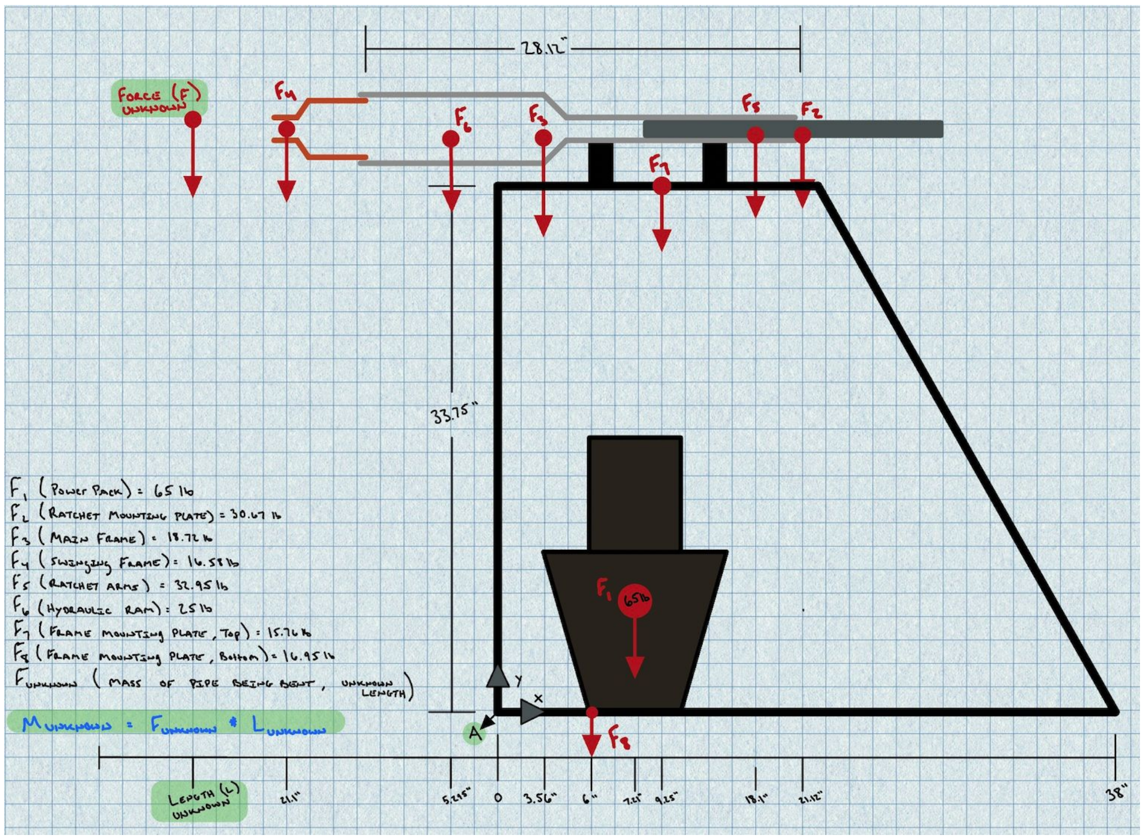
WEIGHT TO BE USED IN TESTING:

FACTOR OF SAFETY = 1.5

TEST WEIGHT = Total WEIGHT × FACTOR OF SAFETY
= 335 × 1.5

TEST WEIGHT = 502.54 lbs

Forward Tipping Analysis



$M_{unknown} = F_{unknown} * L_{unknown}$

$\Sigma M_A \circlearrowleft +$

$0 = -F_1(7.21") - F_2(21.12) - F_3(3.56") + F_4(21.1") - F_5(18.1") + F_6(5.295")$
$\quad - F_7(9.25") - F_8(6") + M_{unknown}$

$\rightarrow 0 = -65(7.21) - 30.67(21.12) - 18.72(3.56) + 16.58(21.1) - 32.95(18.1) + 25(5.295)$
$\quad - 15.76(9.25) - 16.95(6) + M_{unknown}$

$\rightarrow \quad 0 = -2244.38 \text{ lb}\cdot\text{in} + M_{unknown}$

$M_{unknown} = 2244.38 \text{ lb}\cdot\text{in}$

USING STEEL DOM PIPING (1.25" OD w/ 1/8" WALL THICKNESS)

DENSITY = 0.284 lb/in^3

CROSS SECTIONAL AREA = 0.4418 in^2

Volume = AREA · Length(x)

Weight = DENSITY · Volume

↳ $(0.284\ lb/in^3)(0.4418\ in^2 \cdot x\ in)$

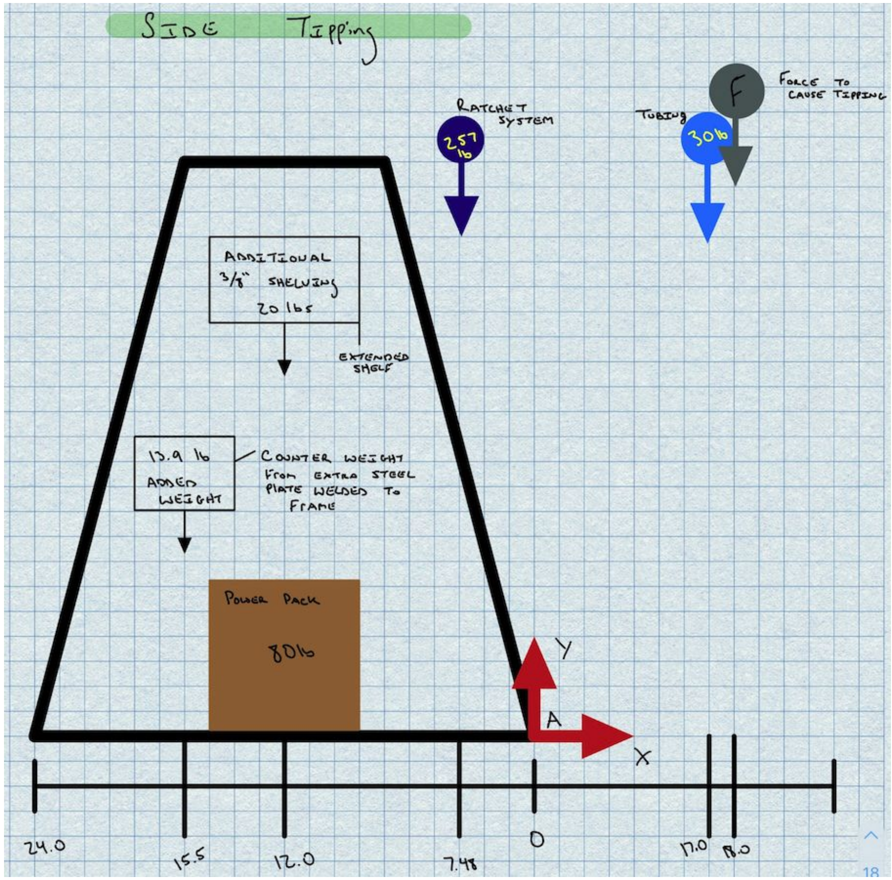
CENTER OF MASS = $\frac{\text{Length}(x)}{2}$

$M_{\text{UNKNOWN}} = (0.284)(0.4418x)(x/2) = 2244.38\ lb\cdot in$

$x = 189.14" \longrightarrow 15.76ft$

SAFE FROM TIPPING WITH PIPE LENGTH OF ≅ 15ft OR LESS

Side Tipping Analysis



AS IS

$$M_A^{+\circlearrowright} = 0, \quad 0 = 80(12) + 257(7.48) - 30(17) - F(18)$$

$$F = \frac{80(12) + 257(7.48) - 30(17)}{18}$$

$F = 131.798$ lb TO CAUSE TIP AS IS

With ADDED SHELVING & COUNTER WIEGHT

STEEL DENSITY = 0.2818 lb/in^3

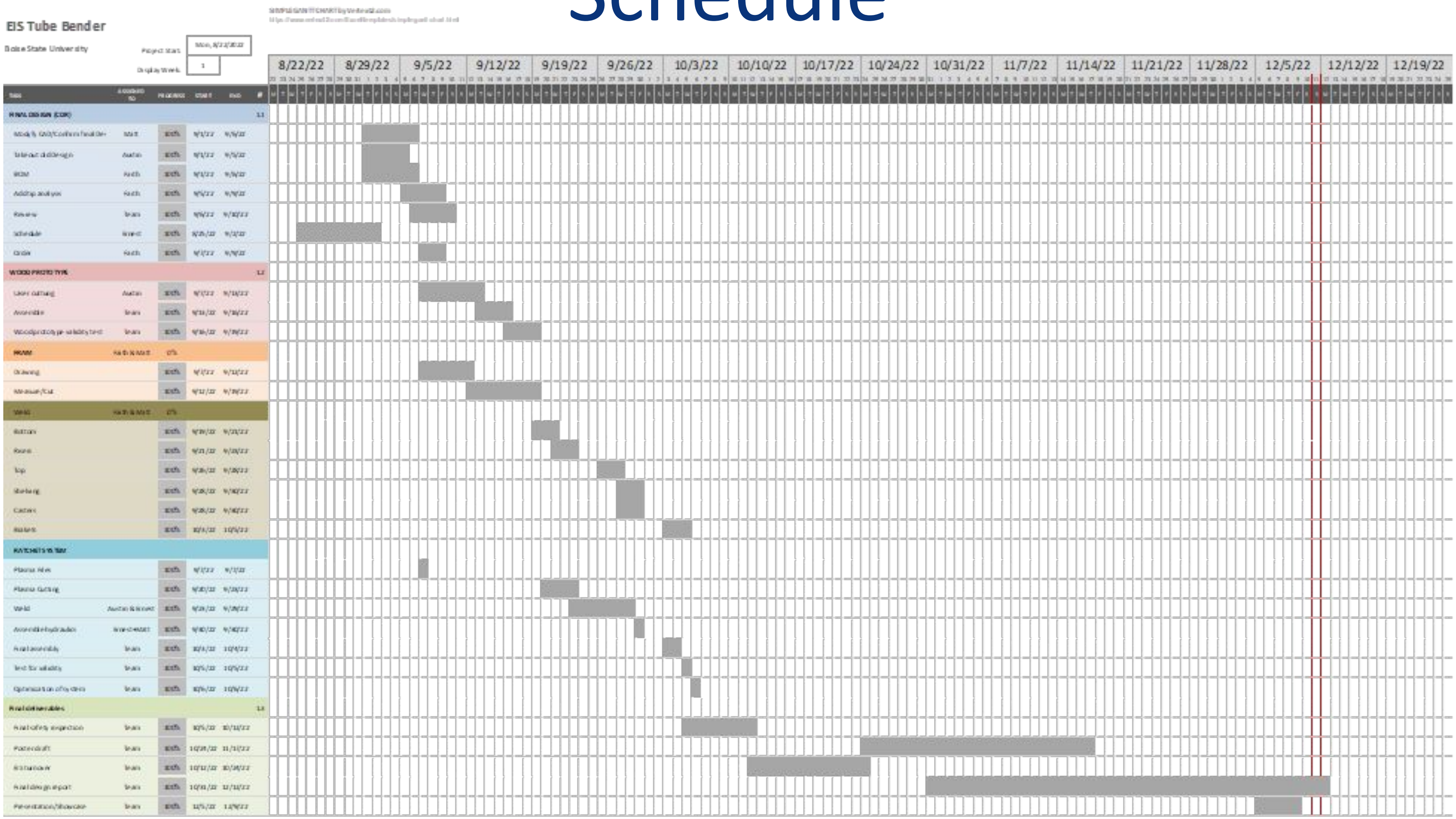
COUNTER WIEGHT = 13.9 lbf (USING 3.5" × 28" × 0.5" PLATE STEEL)
ADDITIONAL SHELVING = 20 lbf (USING 3/8" PLATE COVER REST OF BOTTOM FRAME)

$$M_A^{+\circlearrowright} = 0, \quad 0 = 80(12) + 257(7.48) + 13.9(15.5) + 20(12) - 30(17) - F(18)$$

$$F = \frac{80(12) + 257(7.48) + 13.9(15.5) + 20(12) - 30(17)}{18}$$

$F = 157.1$ lbf TO CAUSE TIP
→ ADDED COUNTER WEIGHT DOES NOT ALTER TIPPING FOR MUCH

Schedule


EIS Tube Bender
Boise State University
8/22/22
8/29/22
9/5/22
9/12/22
9/19/22
9/26/22
10/3/22
10/10/22
10/17/22
10/24/22
10/31/22
11/7/22
11/14/22
11/21/22
11/28/22
12/5/22
12/12/22
12/19/22

Stability Testing Plan

Testing Plan A

Table 1: Testing plan for Tube Bender tipping

Objective	To analyze the tube bender for any tipping through full range of motion. • Specifications C and D
Assumptions	• The tube bender will be operated in the EIS i.e., no extreme conditions. • The tube bender will only be used as intended. • Calculations for tipping are reasonable for predicting tipping.
Hazards and PPE	Hazards • The tube bender may fall on someone if procedure is not followed correctly • Pinch points on the tube bender (specifically the ratcheting mechanism). • Clothes can become caught in the mechanism if the operator isn't careful. PPE • Pants • Steel-toe shoes • Safety glasses • Long hair tied back • No loose clothing
Tools required	• Clamps • Rope, strap, or chain • Weights (70 lbs will be needed to replicate a worst case scenario) • Floor mounting brackets for tube bender • Base extensions in case of tipping
Test Setup, Required Environment	• Fully assembled tube bender in an open area within the EIS. • Power pack filled to spec (3 gallons) with hydraulic fluid. • Open area for testing • Leg extensions available for support if required.
Procedure (Execution and Data Collection)	1. Loosely secure frame to the ground using brackets. Brackets should be tight enough to catch the bender if tipping occurs, but loose enough to visually detect tipping if it begins to occur. 2. Hang a rope, strap or chain from the swing arm just inside of the outermost bolt and clamp on either side to prevent the strap from traversing the swing arm. 3. Attach 70 lbs of weight to rope and allow weight to hang approximately 2 inches from the ground. 4. Perform multiple tests with the weight fixed to the swing arm of the tube bender through full range of motion. Start with the swing arm at one end with weight attached and slowly move through full range of motion as shown in Figure 1. 5. Stop the test and add leg extensions if tipping is observed throughout the test. 6. Perform Steps 1-5 five more times for a total of 5 tests.
Data Analysis & Conclusion	A good passing grade is given if all the caster wheels remain on the ground without using the leg extensions. An okay passing grade will be given if the caster wheels remain on the ground only with using the leg extensions. A failure is if the machine tips even with the leg extensions.

Figure 1: Use rope to hang weight approximately 2 inches from the ground. The ground will catch weight if tipping begins to occur.

Figure 2: Begin with the swing arm at position shown and move through the full range of motion with weight attached.

Table 2: Testing plan A Data Collection Sheet

Trial #	Data Collected (Pass/Fail)
1	
2	
3	
4	
5	

(Data analysis /calculation recording area)

Tester Signature: ________________________________

Date of Test: ____________________________________

Stability Testing Plan Data

Table 2: Testing plan A Data Collection Sheet

Trial #	Data Collected (Pass/Fail)
1	Pass
2	Pass
3	Pass
4	Pass
5	Pass

Functionality Testing Plan

Testing Plan B

Table 2: Testing plan for Tube Bender with testing tube

Objective	To ensure the bender is capable of bending tubing that is up to the strength specifications of 1.25 inch DOM with a 0.125 inch wall thickness. This will be done through a full 180 degrees. • Specifications F, G, K, L, M
Assumptions	• Tube bender will be fully assembled. • The tube bender will be operated inside the EIS. • Standard temperature and pressure. • No external forces applied.
Hazards and PPE	Hazards • Pinch points on the tube bender (specifically, the ratcheting mechanism) • Clothes could become caught in the mechanism if the operator isn't careful • Possibility of tube being swung into nearby persons • Risk of electrical shock PPE • Pants • Closed toed shoes • Safety glasses • Long hair tied back • No loose clothing
Tools required	• Minimum of 3 ft of test tube (DOM 1.25" OD w/ 0.125" wall thickness) • Screwdriver set • Wrenches
Test Setup, Required Environment	• The powerpack will be energized through any 120V outlet in the EIS • Fully assembled tube bender in an open area within the EIS • Power pack filled to spec (3 gallons) with hydraulic fluid. • Open area for testing large enough to accommodate test tube length • Leg extensions available for support if required
Procedure (Execution and Data Collection)	1. Start by clearing the area of all bystanders and material. 2. Fully retract the ratchet mechanism. 3. Place test tubing into the tube bender. 4. With the powerpack plugged into the receptacle, energize by turning the power switch to the on position. 5. Begin moving the cylinder with the controller. When bending begins, start a timer. 6. Test that the bender can achieve multiple angles. The angles that should be tested are 60, 120, and 180 degrees. These angles will be measured on a single piece of test tubing in sequential order. Utilize a combination of the ratchet system and die position to accomplish this. 7. Pause the timer when each 60 and 120 degrees angles are completed. 8. Measure each angle with an angle gauge to confirm if bending was successful. 9. Restart timer after measuring with angle gauge - continue bend to 180 degrees. 10. Stop timer once 180 degree bend is achieved 11. Measure with angle gauge to confirm 180 degree bend.
Data Analysis & Conclusion	If the tube bender makes a full 180 degree range of motion within 2 to 3 minutes without breakdown or other errors, then it is concluded that the machine passes testing. It will also be marked in the data collection sheet if the smaller angles are successful. Success for the smaller angles will mean that the smaller angles are completed without breakdown or other errors.

Table 4: Testing Plan B Data Collection Sheet

Trial #	Data Collected
1 (60°)	
2 (120°)	
3 (180°)	

(Data analysis /calculation recording area)

Tester Signature: ______________________________

Date of Test: ______________________________

Functionality Testing Plan Data

Table 4: Testing Plan B Data Collection Sheet

Trial #	Data Collected (time in minutes)
1 (60°)	1:11.14
2 (120°)	3:20.28
3 (180°)	8:35.15

S.O.P.

College of Engineering Shop Procedure

HYDRAULIC TUBE BENDER			
Dept: Multi-department	**Laboratory: Student Machine Shop**		**Rm: HML High Bay**
Authored by:	Austin Eggers, Matt Lester, Ernest Slater, Faith Wilder Date: 12/09/2022		
Reviewed and Approved by:	____________________	Date: ________	
Filename:	Hydraulic tube bender 09-Dec-22	**Revision:** 1	

Procedure Type	☒ Process/Protocol
Brief Overview & Scope	This procedure provides general instructions on how to use the hydraulic tube bender. The bender is used to bend straight piping and tubing of various shapes and sizes to a desired angle up to 180°. For general tube bending, the respective material is placed between three size corresponding dies. The hydraulic cylinder is then actuated until the desired angle is achieved. This document describes typical operations only; consult a shop supervisor if you need to perform an operation not described here. Maintenance and setup of the tool are beyond the scope of this document due to the skill required and diversity of tools and processes associated with these operations.
Potential Hazards	• Crush or other injury to fingers or hand when placed between ratchet system or ratchet support arm. • Crush or other injury to fingers or hand when placed between swing arms. • Crush or other injury to fingers or hand when placed between bending dies and tubing. • Crush or other injury to feet when handling tubing material and bending dies. • Injury due to explosive failure if pressure exceeds hydraulic cylinder rating of 3500 psi. • Injury due to system tipping when bending tubing that is greater than 15' in length.
Engr. Controls	none
PPE	Safety glasses, gloves, non-slip, close-toed shoes
Add'l Equipment, Tools:	none
Mat'ls, Supplies:	Lubrication grease
Add'l Training Requirements	• All mandatory shop training modules • Hands-on training for this tool
Special Requirements:	

HYDRAULIC TUBE BENDER

Handling & Facilities	n/a
Spill & Incident	As described by the Innovation Studio Safety Rules, any incidents that cause damages to operator or machine must be reported to a Studio supervisor.
Decontamination/ Waste Disposal	All studio consumables to be disposed of per Innovation Waste Materials Disposal SOP.
Sources/ References	https://www.youtube.com/watch?v=GcYF8FePgq0 ← video of a Hossfeld Hydraulic Tube Bender being operated, which is very similar to this tube bender.

HYDRAULIC TUBE BENDER

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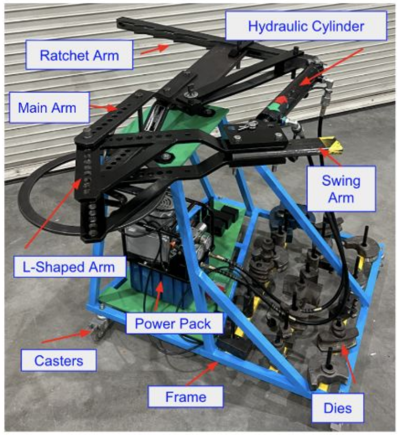
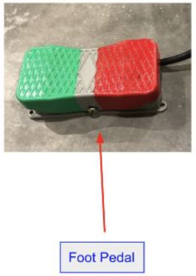
S.O.P.

HYDRAULIC TUBE BENDER

TOOL COMPONENTS





GENERAL TOOL SAFETY RULES

a. Safety glasses are required to use this tool.
b. Before using, tie back long hair and tuck under shirt, roll up long sleeves, and remove loose clothing.
c. WARNING: Do not exceed a pressure of 3500 psi. This is the **MAX** pressure the hydraulic cylinder is rated for. The hydraulic power pack is rated up to 10,000 psi. If the pressure gauge reads above 3500 psi contact the shop supervisor immediately.
d. WARNING: Take care to keep fingers away from all pinch points. Common pinch point locations involve the ratchet system, support arm, and swing arms. Failure to keep fingers and other body parts away from these areas may result in injury or loss of finger or body part.
e. Maintain a safe working area free of people or other obstruction of 5' on sides and 10' in front and 10' behind machine.
f. Wear slip-resistant shoes to maintain a secure footing and balance.
g. Material limitations:
   - Max thickness: 0.125"
   - Max. width: 1.25"
   - Acceptable materials: metal tubing and metal piping.
   - Unacceptable materials: ceramics and plastics. **If you are unsure if your material can be used with the bender, ask a shop supervisor.**

If you have any questions about this tool or its use, stop what you are doing and ask a shop supervisor.

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HYDRAULIC TUBE BENDER

COMMON TASKS

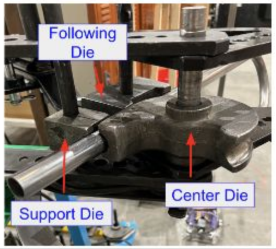
1. Selecting and Setting Up the Correct Dies

In order to bend tubing successfully, the correct size dies and placement must be used.

a. Start by measuring and taking note of the outer diameter of the tube to be bent.
b. Find the round center die labeled with the same outer diameter as tube and confirm that tube fits flush in the die.
c. Find the support (smaller) and following (larger) dies (both rectangular and unmarked) with the same diameter of the tube and confirm that the tube fits flush in both dies.
d. Once the correct dies are selected, start by pinning the center die at the intersection of the main arm and swingarm with the text facing upwards.
e. Place the support die a couple of pins outwards on the main arm (to be adjusted later).
f. Place the following die a couple of pins outwards on the straight part of the L-shaped swingarm (to be adjusted later).
g. Ensure that the ratchet system and hydraulic cylinder are completely retracted and lace the tube in between the dies. The support and following dies must now be adjusted to *fit as tightly as possible.*
h. Start by shifting the support die inward until it clamps the tube between itself and the center die. *Note: This may require some force to get as tight as possible.*
i. Do the same for the following die. The tube is now ready to be bent. *Note: In order to reduce friction and produce a smoother bend, consider lubricating the contact points of the dies as well as the tube.*

*Due to the discreet pin holes and dies, the ratchet system/cylinder may have to be actuated/moved in either direction to get the correct fitment.


Fully Retracted Tube Bender

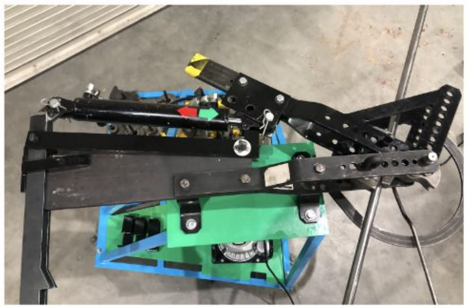


2. Bending Tube

a. Regardless of tubing being bent, the ratchet should start as close to the main arm as possible. This will shift the hydraulic cylinder into a position that is nearly parallel with the main arm.
b. Plug the power pack into a 120V outlet. Note, the power pack has no true on and off switch. Once plugged in, pressing the pedal will actuate the hydraulic cylinder.

S.O.P.

HYDRAULIC TUBE BENDER



General starting position

c. Ensure that yourself and any bystanders are clear of the bender and actuate the foot pedal (green side of foot pedal) to extend the hydraulic cylinder. Continue extending the hydraulic cylinder until the cylinder has reached its maximum extension and then **STOP**. Note - Pressure will continue to build if the hydraulic cylinder has reached its maximum extension or retraction point and the pedal is continued to be pressed.

d. After the hydraulic cylinder has reached its maximum extension, hold the swing arm in its current position and retract the hydraulic cylinder (red side of foot pedal). This will pull the ratchet system forward. Continue to pull the ratchet system forward until the hydraulic cylinder is either closed or next triangle notch cannot be reached.

e. Repeat steps C and D until the desired angle is reached or until the hydraulic cylinder has been extended while using the last triangle notch.

f. If the desired angle has not been reached by the time the last notch has been used, the following die will need to be moved to the L-shaped swing arm.

g. To move the following die to the L-shaped swing arm, retract the hydraulic cylinder until you are able to pull the pin on the following die. This is best done with two people as the tubing will need support during the repositioning of the following die.

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HYDRAULIC TUBE BENDER

h. Once the following die is free, reposition it on the L-shaped swing arm so that it secures the tubing as tightly as possible. This may require some actuation of the hydraulic cylinder.

i. Once the following die is in the desired position, shift the ratchet arm back to the first notch without actuating the hydraulic cylinder. This will allow you to "reset" the system while the tubing is held securely in place.

Following die placement after repositioning

j. Repeat steps C and D until the desired angle is reached.

3. **Cleanup and storage**

This machine requires cleanup after each use.

a. Retract the cylinder and ratchet mechanism. This will be the storage configuration.

b. Unplug the power cord from the wall outlet - it's important to de-energized the powerpack prior to removing the finished product and cleaning to avoid accidental activation.

c. Degrease the dies and the finished product. This should be done to prevent dripping and can be accomplished with a mild solvent and a rag.

d. Put the dies back in their respective location in the die storage.

e. Put the foot pedal neatly on the bottom shelf. *This will prevent a tripping hazard.*

f. Unlock the casters and move the tube bender back to its designated storage area. This is an EIS manager approved storage area. If you're unsure where that is, ask a shop supervisor.