Wisco Stirling Engine Redesign

Team J

ME 449 Redesign & Prototype Fabrication

Semester Project Presentation

5 May 2022

Introduction

- Main design criteria:
  - Aesthetics
  - Build quality
  - Speed

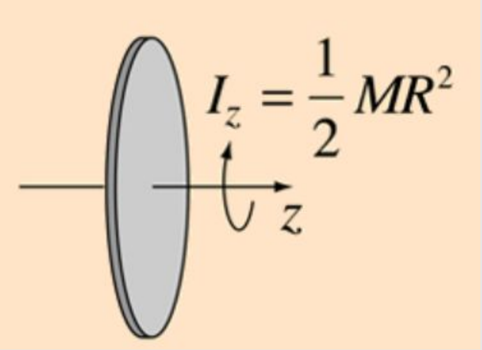
- Re-design criteria:
  - Reducing frictional contact and fluid losses
  - Minimize conduction between plates
  - Smoothen motion
  - Identify customer’s design preferences

Before

After

Reducing Flywheel Mass

- Inertia: tendency of an object to resist changes in its velocity, Newton's first law



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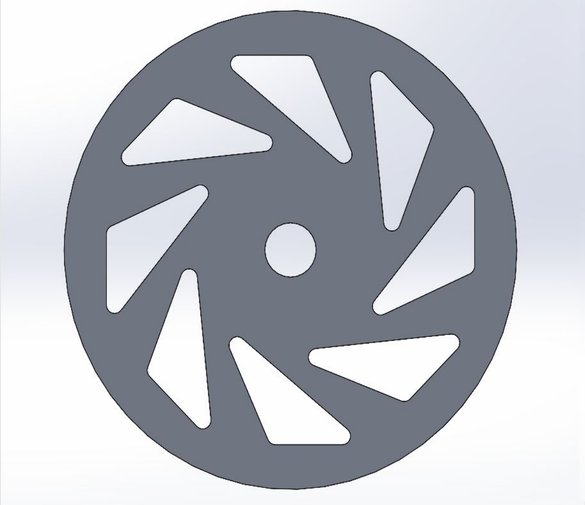


Mass = 0.31 [g]
Moment of Inertia = 1.26 [lb-in]

Mass = 0.27 [g]
Moment of Inertia = 1.31 [lb-in]

- Lower mass results in higher acceleration
  - Reaching max speed faster
  - Less reliant on kick start

Minimizing Heat Loss Between Plates

- Heat transferred between plates reduces temperature difference
- Bolts halved from 12 to 6
- Thermal conductivity:
  - Stainless steel: ~14 [W/mK]
  - Nylon Plastic: ~.25 [W/mK]

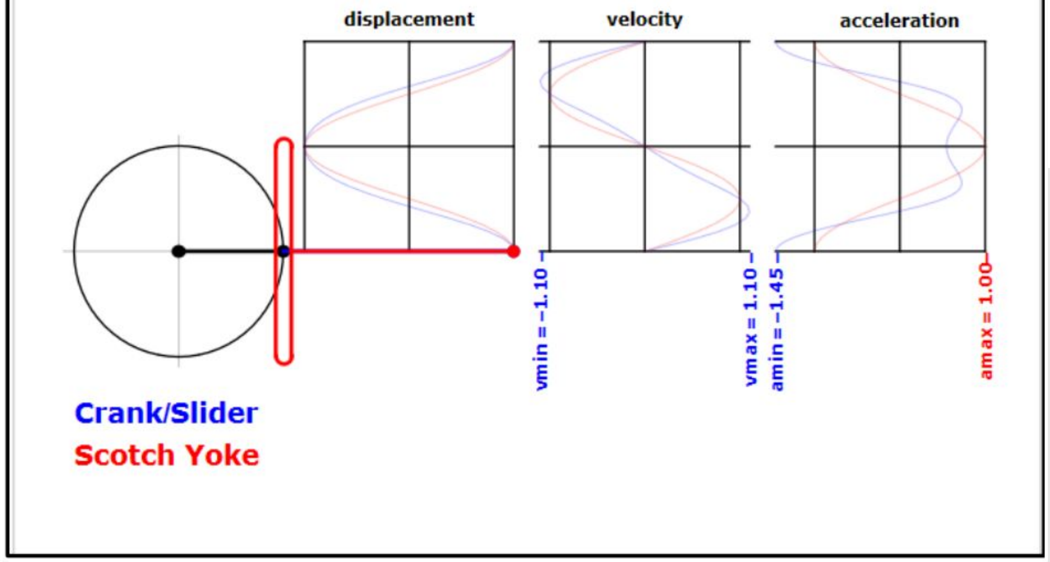
$$\dot{q}_{bolts} = N_{bolts} * k_{bolt} * A_c * \frac{1}{L} * (T_{RT} - T_{cold})$$

$\dot{q}_{stainless}$ = 0.851 [W]

$\dot{q}_{plastic}$ = 0.007598 [W]

- 99.1% reduction in conductive heat transfer through bolts

Smoothening the Engine’

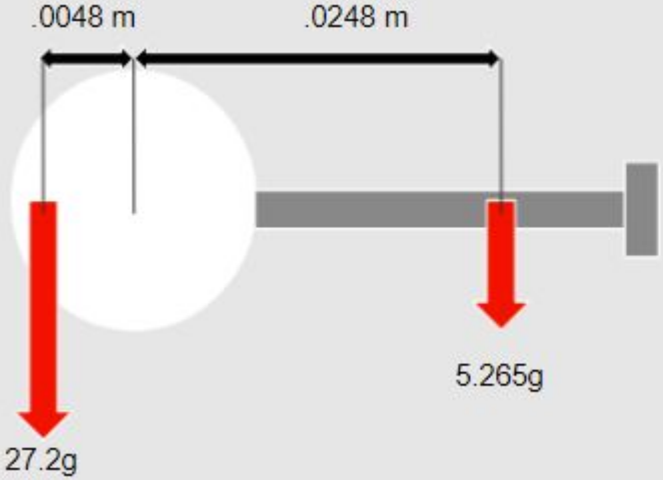


- Ideal engine should:
  - Minimize acceleration
  - Isolate motions to reduce friction
  - Follow sinusoidal motion

$$P_{loss,friction} = F_{friction} * V = \mu * N * V_t$$

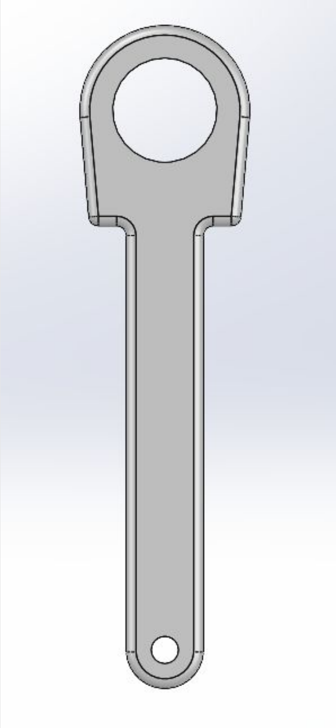
$$P_{loss,viscous} = F_{friction} * V = \mu * \pi * D * L * V_t^2$$

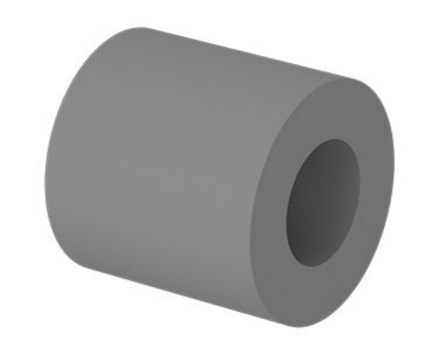
- Counterbalances
  - Eliminate speed variations
  - Moment on each side of shaft equal
  - Originally had motion W 3D print (4.7g)
  - Interfered with linkages



Reducing Frictional Losses at Link Contacts

- Issues with bent links:
  - Horizontal forces introduced
  - Inconsistent assembly
- 3D printed link:
  - Slightly lower weight (10% infill)
  - More rigid
  - Better fit, machinability
- Bearings and shoulder bolts:
  - Dynamic coefficient of friction = 0.1
  - Originally (steel on steel) = .42





Fluid Losses in Power Piston Cylinder

$$\Delta h_{A,B,contract} = \frac{V_1^2}{2 \cdot g} \cdot \left[f_1 \cdot \frac{l_s}{D_o} + K_{lam,contract} \right] + \frac{V_2^2}{2 \cdot g} \cdot f_2 \cdot \frac{l_i}{D_i}$$ *head loss of contraction (downward stroke of piston)*

$$\Delta h_{A,B,contract} = \frac{\Delta P_{contract}}{\rho_{air} \cdot g}$$ *pressure drop through contraction*

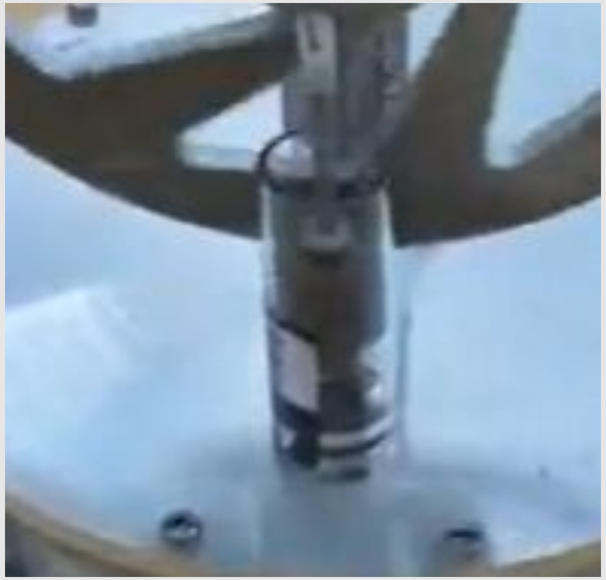
$$\Delta h_{A,B} = \frac{V_1^2}{2 \cdot g} \cdot f_1 \cdot \left[\frac{l_s + l_i}{D_o} \right]$$ *head loss through redesigned cylinder base*

$$\Delta h_{A,B} = \frac{\Delta P_{tube,down}}{\rho_{air} \cdot g}$$ *pressure drop on downward stroke*

	Original	Redesign
Downward Stroke	ΔP_contraction = 0.02489 Pa	ΔP_downward = 0.005177 Pa
Upward Stroke	ΔP_expansion = 0.02505 Pa	ΔP_upward = 0.005177 Pa

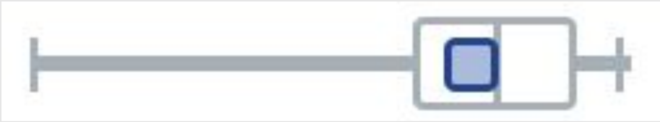
Pressure loss is 4.81 times less in redesigned part.

No measured increase in engine speed after testing.



Improving Aesthetics and Build Quality

- Baseline scores were below average:

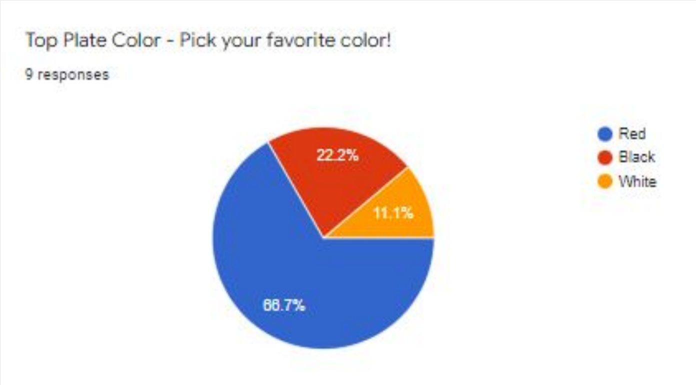


Aesthetics score: 7.37
Average: 7.91

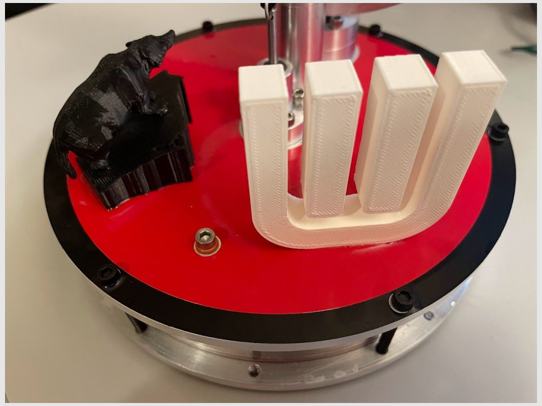
Build Quality score: 7.93
Average: 8.11

- Survey
  - Audience for survey: attendees of graduation party
  - Top Plate Color
  - Metal Finish
  - Popular Wisconsin Icons

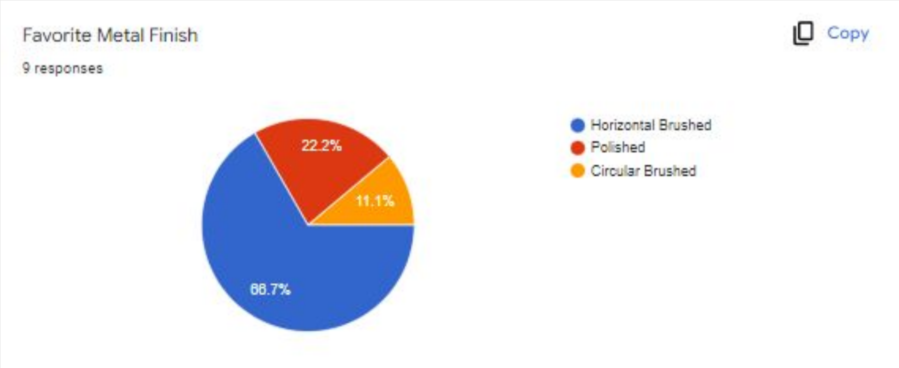
Survey Results



Final Aesthetics Score: 9.89
Average: 9.55



Final Build Quality Score: 9.64
Average: 9.56



Testing Plan and Results

- Metronome app
- Test after each design change
- Eliminate changes that slow engine

Design Change	**RPM**
Baseline Build	77
Cylinder Base	77 (no definitive change)
Flywheel	Not measured, expected ~ 70-80
Counter Balance	87
Linkages with shoulder bolts and sleeve bearings	155
Testing Day (sitting in sunlight)	212

Summary

- Design improvements achieved:
  - Nearly highest class points for aesthetics and build quality
  - Roughly 175% improvement in engine speed
  - Jeff Rappe's favorite engine
- Lessons Learned:
  - Importance of tolerancing and accuracy
  - Theoretical improvements don't always work
- Acknowledgements
  - Team Lab Pro Staff (Jeff, Jay, Eric, and Mike)
  - Prof. Pfefferkorn and Hemant
  - Team Lab Student Staff
  - Makerspace Staff

References

[1] "Moment of Inertia, Thin Disk". Hyperphysics.gsu.edu. [Online] http://hyperphysics.phy-astr.gsu.edu/hbase/tdisc.html. Accessed on May 3rd 2022.

Back-up Slides

Not required but often nice to have to help answer questions

Fluid Losses in Power Piston Cylinder

V_1 = Velocity of air through glass cylinder
V_2 = Velocity of air through original cylinder base
l_s = stroke length
l_i = length of cylinder base
D_o = Diameter of glass cylinder
D_i = Diameter of original cylinder base
f_1 = friction factor in glass cylinder
f_2 = friction factor through constriction of cylinder base
$K_{lam,contract}$ = loss coefficient of flow moving through constriction
g = gravitational constant
$\triangle h_{A,B}$ = head loss from top to bottom of cylinder
p_{air} = density of air
$\triangle P$ = pressure loss

$$\Delta h_{A,B,contract} = \frac{V_1^2}{2 \cdot g} \cdot \left[f_1 \cdot \frac{l_s}{D_o} + K_{lam,contract} \right] + \frac{V_2^2}{2 \cdot g} \cdot f_2 \cdot \frac{l_i}{D_i}$$ *head loss of contraction (downward stroke of piston)*

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