Semi-Autogenous Grinding (SAG) Mill Cone Replacement Device

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1. Project Background

SAG Mills use a cone to feed recirculated ore back into the mill for additional grinding. The cones wear out with use and require replacement. The current process of changing SAG mill cones is dangerous to personnel and equipment.

The project goal is to enhance the safety of replacing the cone in SAG mill. The improvement aims to address the challenges posed by the current difficult and unsafe process, primarily due to equipment limitations and clearance issues in the mill feed-end. The designed tool aims to integrate directly into the currently used equipment. (i.e. a telehandler)

The team, in conjunction with subject matter experts, developed a CAD design influenced by FEA analysis.

Fig 1: Example picture of current cone replacement process

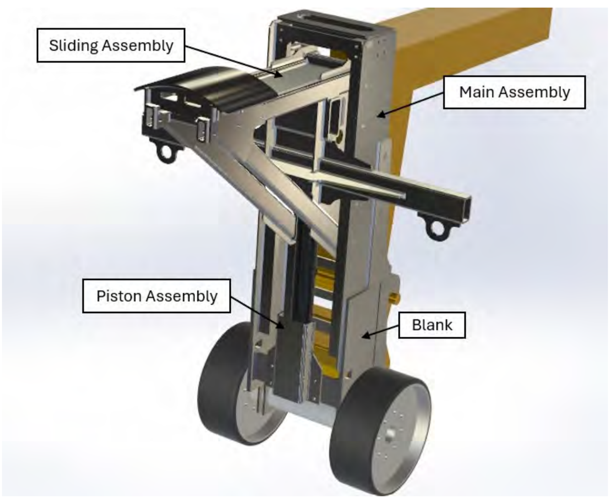


Fig 2: CAD model of device

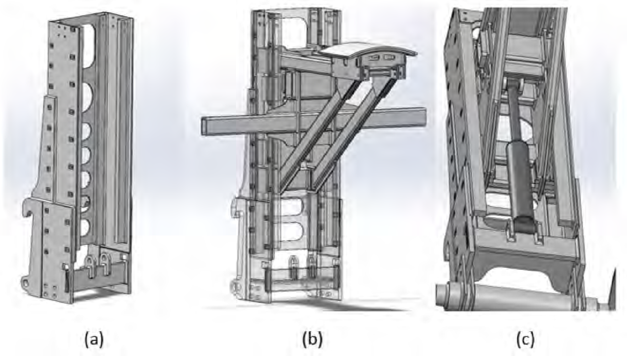


Fig 3: Standalone CAD models of Main assembly, sliding assembly and piston assembly

2. Device Design

The **Main Assembly** provides the main structural strength of the device. It integrates directly into the blank provided by Wheeler and contains the rails along which the Sliding Assembly travels.

The **Sliding Assembly** serves as the main load force-transferring device. The nose extends into the cone and aims to support the cone directly underneath the cone's center of mass. The Assembly makes use of Delrin friction blocks to ease the movement of the entire Assembly. The sliding assembly uses low-friction HDPE blocks (i.e. Delrin) to reduce friction and allow easy sliding. The sliding assembly includes horizontal stabilizer arms and a chain mount passthrough. These features are intended to ease the process of rotating the cone to line up the bolt holes of the SAG mill with the bolt holes of the cone.

The **Piston Assembly** provides the pushing force required to hold the cone at the end of the telehandler boom. The hydraulic piston was selected to provide 33,000 lb of pushing force at the 3307 psi provided by the auxiliary hydraulic line of the telehandler. The piston assembly is attached to the main assembly and sliding assembly via welded eyelet sockets.

The **Wheel Assembly** serves to allow the device to roll across the rough environment of the SAG Mill. The axle is a hollow cylinder that integrates directly with a wheel spindle/hub assembly. The axle is attached to the bottom of the main assembly via brackets. Wheeler has agreed to take on the wheel/hub/spindle selection and integration.

*** Rio Tinto has accepted this device shortcoming. Any safety improvement to the process is considered a worthwhile improvement.**

3. Design Requirements

Requirement #	Requirement Description	Units	Goal Value	Result
1	Device supports the cone weight	lbs	>= 11,000	Device can support 33,000 lbs without yielding
2	Device is smaller than the diameter of the mill entrance to fit into the mill.	inches	< 102.375	Device height is 98.125" when including 27" wheels.
3	Device can travel the distance between the cone install location and the mill entrance	feet	25	Device has wheels to allow rolling.
4	Minimum height to lift the cone from the ground to fit into the cone install site.	inches	> 20	Hydraulic piston used has a stroke length of 20 inches.
5	Device does not cause telehandler to exceed weight capacity	lbs	<= 2407	Device exceeds weight restriction. Final device weight is ~2650 lbs.*
6	All critical lifting components follow a safety factor (SF)	sf	>= 3	All load cases tested met a SF of 3.
7	Device has a means to secure the cone to the device during transport.	N/A	N/A	Device has a chain passthrough to allow chain connections to cone.
8	Device achieves infinite fatigue life for standard loading conditions.	cycles	> 1,000,000	Fatigue Life Analysis proved that the device will achieve desired fatigue life at SF of 1.

4. Device Iterations

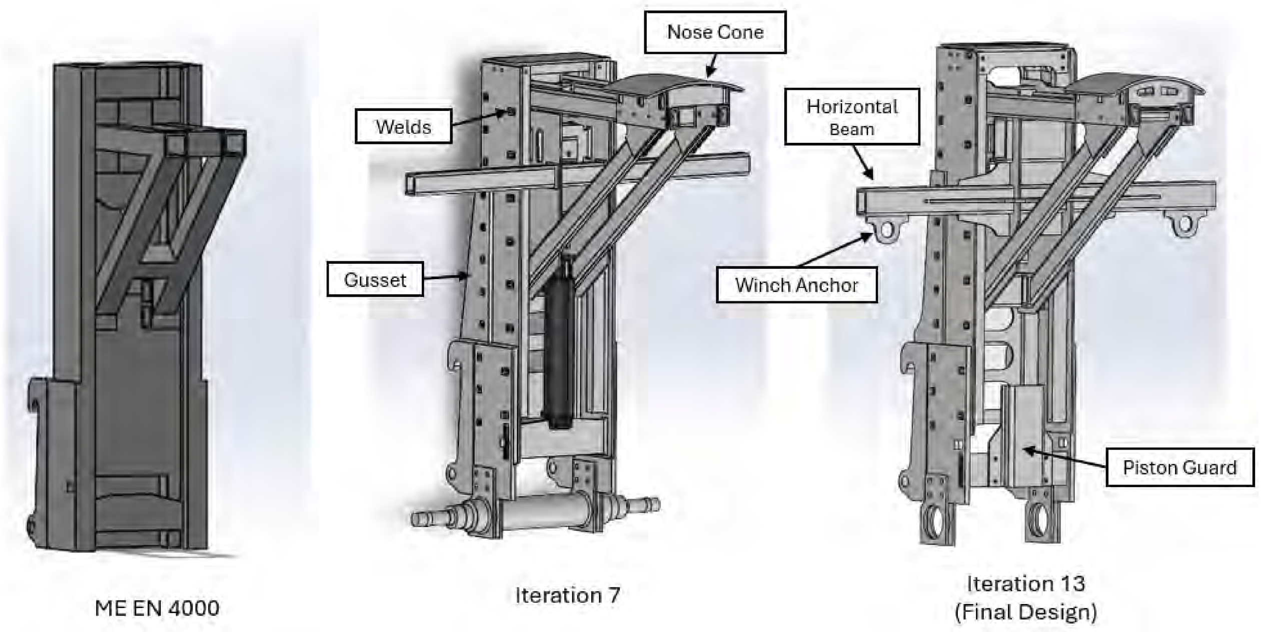


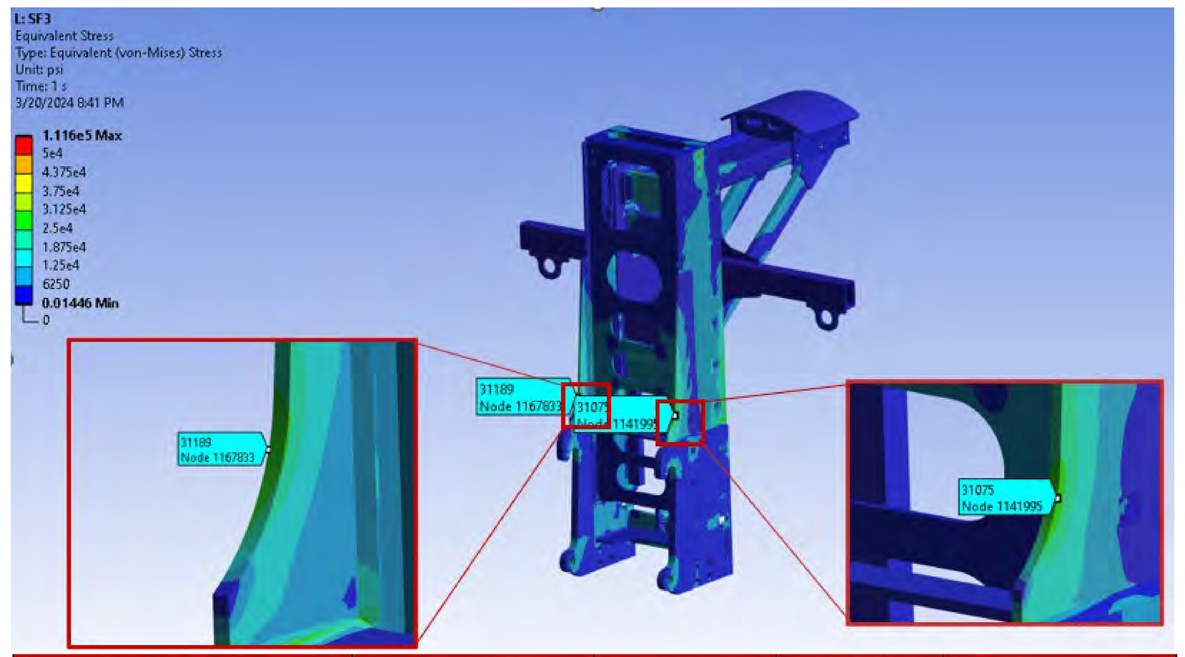
Fig 4: Design Iterations. These pictures show the major design changes developed over the course of the semester.

The primary design changes:

- Reinforce the structure via gussets
- Design welds and bolts
- Change the plate thickness
- Additional needs (e.g. nose cone, winch anchor points, chain pass through)

Based on the work of last semester, the team pivoted to a 'forklift' style design, using fixed axle and pushing a sliding portion upward via a hydraulic piston to provide a lifting force for the cone.

5. Main Load Case



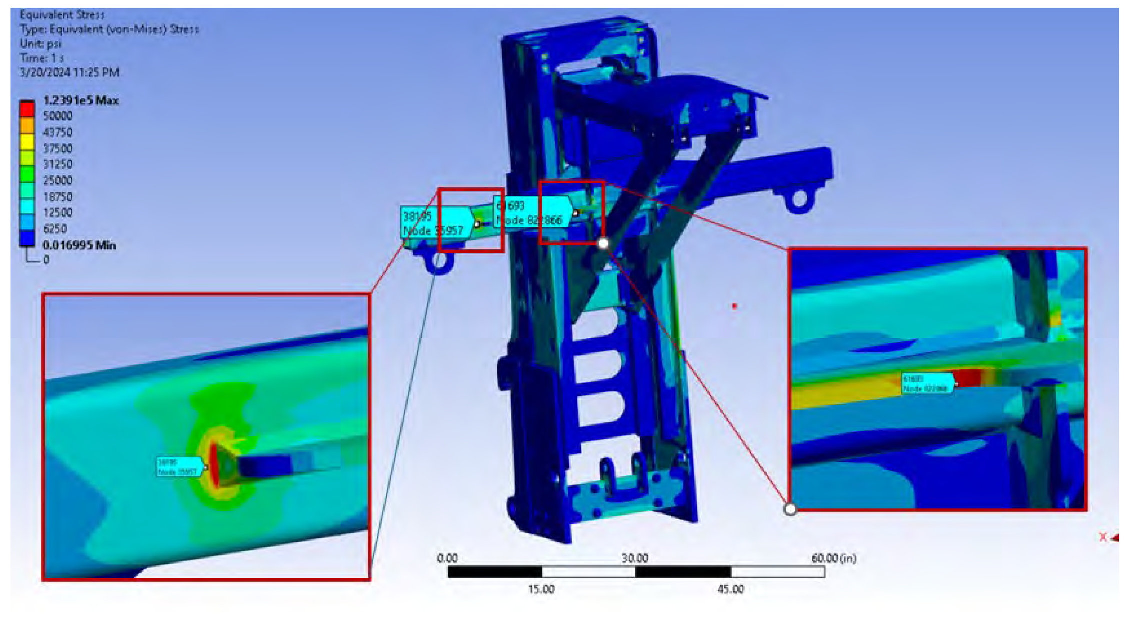
Load Case	Location	Stress (psi)	Goal (psi)*	Acceptance
SF3	Edge (1167833)	31,189	50,000	MET
SF3	Edge (1141995)	31,075	50,000	MET

Figure 5: Picture of FEA results for the main load case. The included table shows the location, and magnitude of the maximum stress in the model.

The main load case is meant to demonstrate the device's ability to hold the cone alone. This included figure is the result for a device holding a 33,000 lb load, which is a safety factor of 3. The device does not yield for this load case.

The close-up views depict the reinforced gusset on the backside. This gusset underwent several size iterations during the design process due to its critical structural role.

6. Rotation Load Case

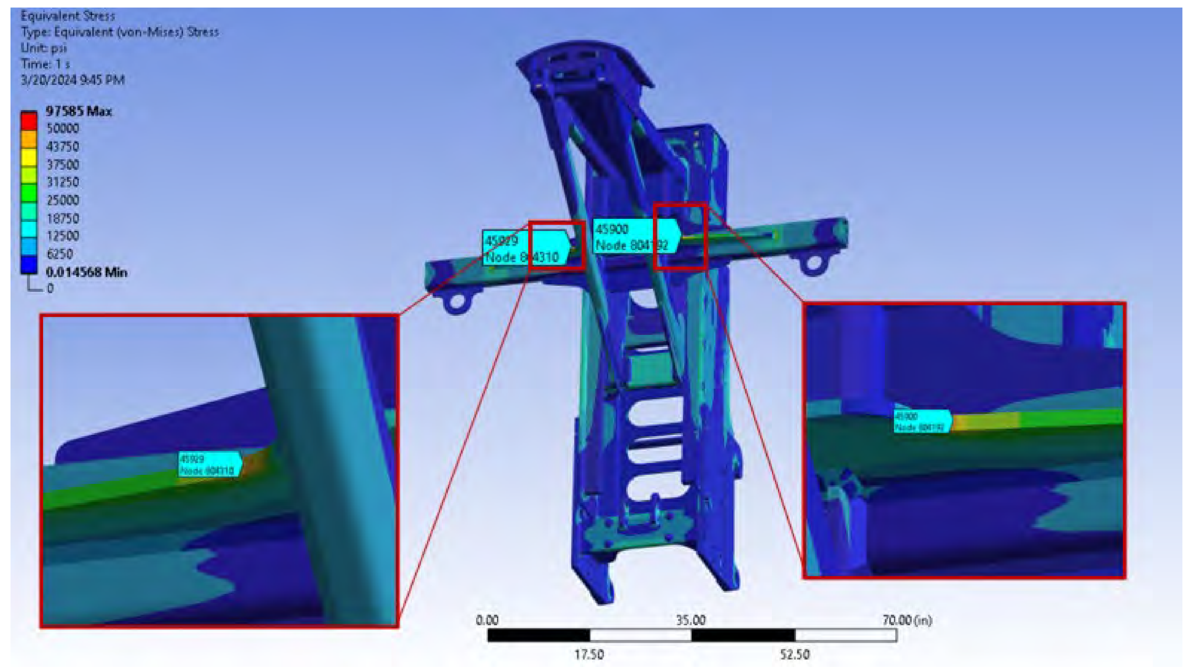


Load Case	Location	Stress (psi)	Goal (psi)*	Acceptance
SF3 Twist Chain w/ 3000 lb load	Edge (822866)	61,693	50,000	MET (Localized Yielding, No Through Section Yielding)
SF3 Twist Chain w/ 3000 lb load	Weld (35957)	38,195	50,00	MET

Figure 6: Picture of FEA results for the rotation load case. The included table shows the location, and magnitude of the maximum stress in the model.

During cone install, the craftsmen need to rotate the cone to line up the bolt holes of the cone with the bolt holes of the mill. The rotation load case is meant to demonstrate the device's ability to resist the forces applied during this procedure.
Craftsmen typically burn holes into the cone and to attach chains. The eyelets on the end of the horizontal stabilizers facilitate this process.
The figure shows the close ups of highest stress on the horizontal stabilizers. The model shows yielding, but it is surface yielding and considered safe.

7. Wall Pull Load Case



Load Case	Location	Stress (psi)	Goal (psi)*	Acceptance
SF3 Wall Pull Load Case	Edge (245774)	48,082	50,000	MET

Figure 7: Picture of FEA results for the wall pull load case. The included table shows the location, and magnitude of the maximum stress in the model.

During cone removal, the craftsmen need to pull on the cone if it has become stuck. The wall pull load case is meant to demonstrate the device's ability to resist the forces applied during this procedure. Again, Craftsmen burn holes in the cone to attach chains.

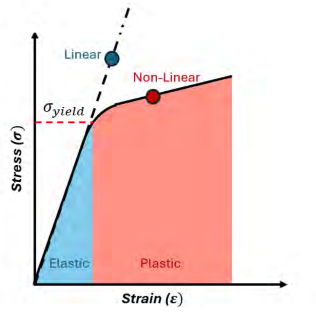
The figure shows the close ups of highest stress on the horizontal stabilizers. The device does not yield under this load case.

8. Fatigue Life

Fatigue life calculations are essential for predicting the durability and reliability of the device under repeated loading conditions, ensuring its safety and longevity throughout its intended lifespan. By accurately assessing fatigue life, the team designed and optimized components to withstand cyclic stresses and prevent unexpected failures.

The team performed the following to calculate fatigue life:

- Use Neuber and Ramberg-Osgood equations to account for non-linear FEA.
- Strain life methods can be used when the loading is a combination of elastic and plastic. It is based on observations in critical locations (e.g., notch).
- Use Smith, Watson, and Topper stress correction to account for the effect of non-zero mean stresses.



Neuber's Equation

$$\Delta\sigma\Delta\varepsilon = \frac{(k_f \cdot \Delta S)^2}{E}$$

- k_f - Fatigue notch factor
- S – Linear curve elastic stress
- E – Modulus of Elasticity
- $\Delta\varepsilon$ – Cyclic stress/strain curve strain
- $\Delta\sigma$ – Cyclic stress/strain curve stress

Smith, Watson, and Topper Method

$$\sigma_{max}\varepsilon_a = \sigma_{max}\frac{\Delta\varepsilon}{2} = \frac{(\sigma')^2}{E}(2N_f)^{2b} + \varepsilon_f' \cdot \sigma_f' (2N_f)^{b+c}$$

- $2N_f$ - Fatigue life in reversals
- b – Fatigue Strength Exponent → Basquin's Equation to describe high-cycle low strain
- ε_f' - Fatigue Ductility Coefficient
- c – Fatigue Ductility Exponent → Coffin-Manson Equation to describe low-cycle high strain
- $\frac{\Delta\varepsilon}{2}$ - Strain amplitude
- σ_f' - Fatigue Strength Coefficient
- E - Modulus of Elasticity

9. Next Steps

- Device design was delivered to Wheeler for fabrication on 3-29-2024. (OpsCon, FEA results, and a bill of materials)
- Wheeler responsible for selecting and integrating wheels and axle into the device.
- Team will communicate with Wheeler to ensure design integrity during fabrication
- Rio Tinto to perform a field test of the device before use in operating environment. High stress points reported to Rio Tinto for observation during field test.

Special Thanks: Carter Oman, Rio Tinto Craftsmen, Team at West Valley Wheeler, Andy Gill

Figure 8: Picture of 3D printed device holding a 3D printed cone at a 16:1 scale, attached to 16:1 scaled CAT toy.