Examining upgrade options when rotary kiln tires are mounted on the kiln shell with no filler bars

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Abstract

Rotary kilns are some of the largest pieces of processing equipment in the world that are utilized in many industries globally to refine raw materials into useful products. Within the pulp and paper industry, rotary kilns have been utilized since the advent of the Kraft recovery process. The rotary kiln has remained largely unchanged in its conceptual design. Yet there have been significant design improvements and upgrades throughout the past century.

Upgrades to the rotary kiln are necessary to increase capacity, reduce energy, and meet industry demands. A unique cost cutting feature that was introduced to rotary kilns in the late 1970s and early 1980s was mounting the tire directly on the kiln shell. This took the place of the traditional method of mounting plates between the inside diameter of the tire and the outside diameter of the kiln shell, these were called filler bars.

After decades of operation the rotary kilns that have the tire mounted directly to the kiln shell are requiring larger repairs and upgrades to continue operation. This paper will examine the design differences, required maintenance, and upgrade and replacement options for rotary kilns with tires mounted directly on the shell.

Part 1 Introduction

When the life of the kiln component is nearing or at the end of its life, it is imperative to examine the different options available for replacement and align the goals of the equipment owner with the upgrade and replacement that is required. The focus of this paper will be the unique feature of lime recovery kilns being supplied without filler bars. The reasons for the removal, the many different types of filler bars, and the upgrade options that exist for component replacement will be examined. Since many options for replacement and upgrading exist, a discussion between the plant personnel and equipment vendor should be completed in order to figure out the best path forward. When all the facts and known and the risk is evaluated, and solution can be supplied to ensure the long term success of the plant.

Part 2 Why filler bars were removed on pulp and paper kilns

In the late 1970s, competition in North America for rotary kiln supply was dominated by two companies Allis-Chalmers and Fuller (GATX Fuller Corp/ Traylor). They were the leading suppliers for rotary kilns in most industry segments. Two competitors FLSmidth & Kennedy Van Saun had a smaller foothold within North America in more specific markets like cement (FLSmidth) and coke & lime (Kennedy Van Saun). A fifth company, Ahlstrom Machinery Corporation, was looking to expand outside of Europe and into the thriving pulp and paper market in North America. The competition between these companies lead to price cuts on equipment and design changes to reduce real costs on a project.

The major changes to the rotary kiln in this timeframe were; removal of the uphill thrust roller, reduction in the tire plate length, longer kiln diameter to length ratios to reduce number of piers, copying existing kiln supply instead of design for duty/ purpose, and finally the removal of the filler bars. In the 1960s, FLSmidth installed the first rotary kiln without filler bars in the North American pulp and paper market. Mounting the tire directly onto the kiln shell introduced the following cost cutting measures:

1 – The filler bar assembly was removed, which includes the filler bars, the retaining blocks, shims, shim blocks, and side keepers for each support pier. Most rotary kilns were supplied three or four support piers in the 1970s and 1980s. Multiply cost savings of one filler bar assembly by the number of piers on the rotary kiln.

2 – The size of the tire could be reduced. The inside diameter and outside diameter could be reduced by the thickness of the filler bars x 2 (2 filler bars in the outside diameter of the kiln shell) which will save approximately 2% weight of the supply of the tire. Multiply cost savings of one tire by the number of piers on the rotary kiln.

3 – To reduce supply costs, engineering would replicate a similar sized kiln instead of designing a new custom size kiln. Sometimes the savings in engineering was more cost effective than supplying a slightly oversized kiln or kiln part. Therefore, some of the components could be oversized for their duty including carrying rollers and tires.

Reducing the cost of a kiln by a filler bar assembly, 2% on the tire weight at each pier, and replicating an existing kiln, may not appear to be a significant cost when considering the entire supply of the rotary kiln assembly. However, in the fight to win rotary kiln contracts in the 1980s and 1990s, a contract could be won or lost by a few thousand dollars between suppliers. Purchasing would forgo any advantages a kiln had with the inclusion of filler bars and typically bought the machinery on price alone.

As this was a new design feature in the world of rotary kiln supply in North America, no one could fully understand the long-term maintenance implications of the design change, which consisted of removing of the filler bar system and mounting the tire directly on the kiln shell. After nearly 40 years in operation for some of these kilns, the design and maintenance challenges are now known.

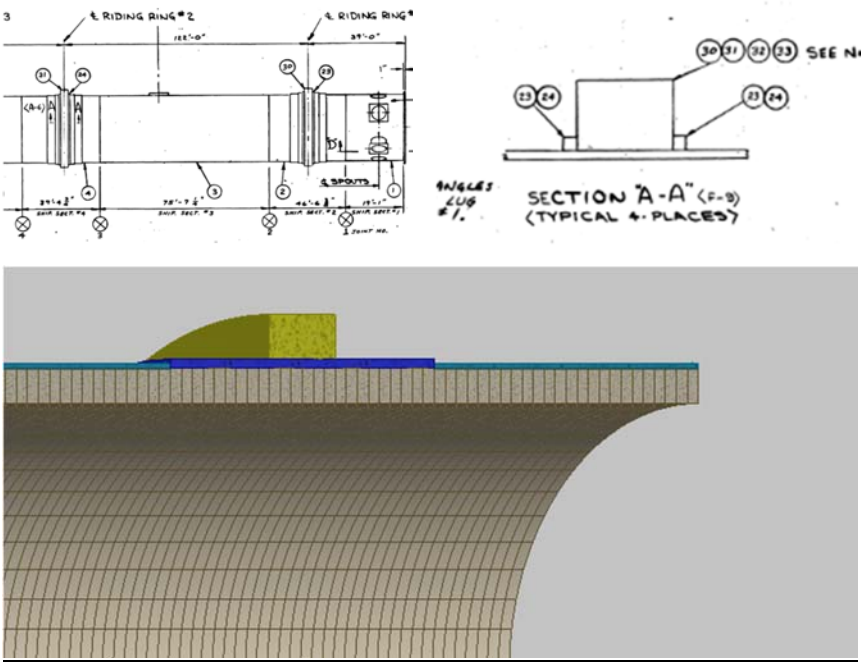


Figure 1 - Shell without filler bars – 1990 designed kiln. This figure shows the tire mounted directly onto the kiln shell.

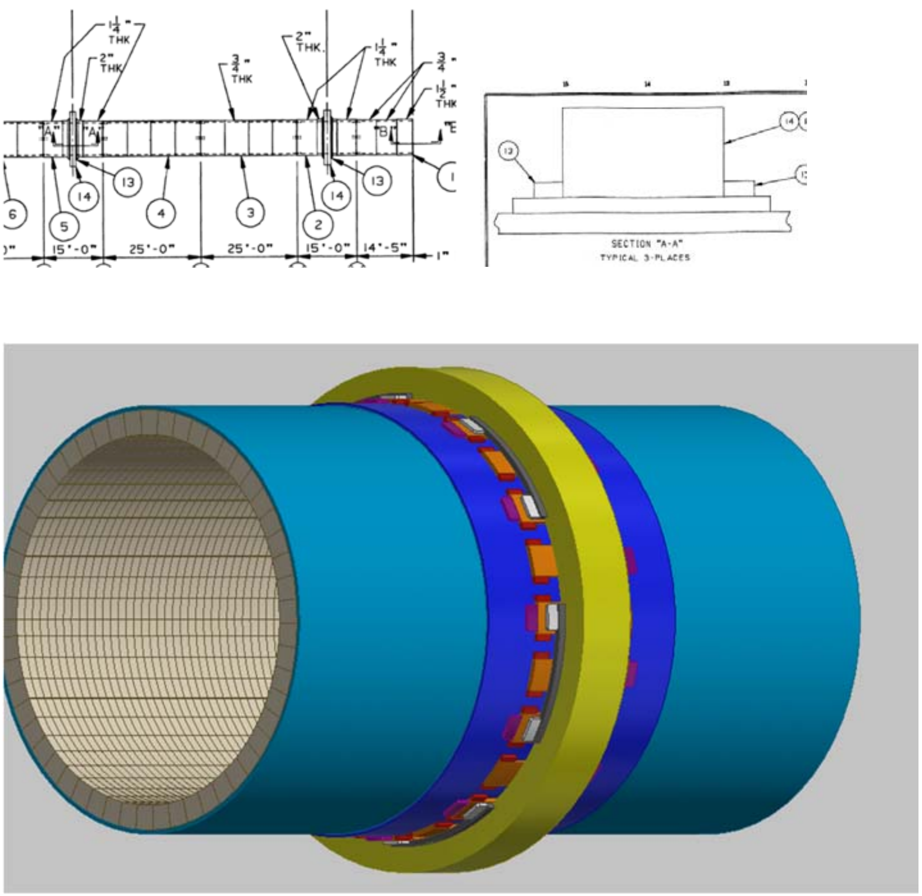
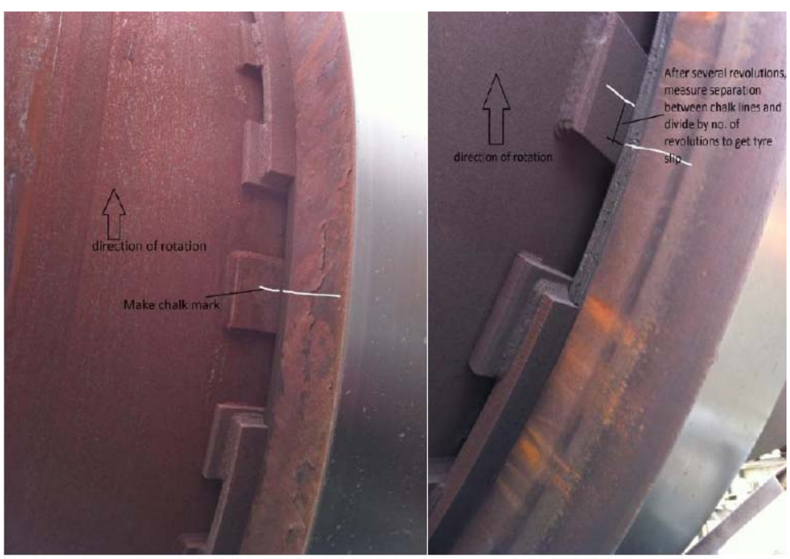


Figure 2 - Shell with filler bars – 1982 designed kiln – this figure shows the typical mounting of the tire on the filler bar assembly.

Part 2.1 Why filler bars are recommended on rotary kilns

Thermal expansion of the kiln shell and tire occurs during start-up and operation of the rotary kiln. The thermal expansion of the kiln shell is greater than that of the tire due to the kiln shell having a higher operating temperature than the tire. If the kiln shell in the bore of the tire and the tire bore were the same diameter, there would be no space for the kiln shell to expand. The kiln shell would be become constricted in the tire. Kiln shell that is uphill and downhill of the tire would expand and permanent deformation of the shell and loss of brick would result. The common term for this situation is coke bottling. Rotary kiln designers allow for expansion of the kiln shell at the bore of the tire to reduce the risk of coke bottling. The space between the bore of the tire and the outside diameter of the filler bar is called the diametrical clearance. Rotary kiln designers also need to control too much diametrical clearance between the tire bore and kiln shell/ filler bars. Too much diametrical clearance will lead to high ovality on the kiln shell and result in brick crushing, brick loss, and shell cracking. There is a need to control the diametrical clearance between a lower tolerance level and upper tolerance level to reduce risk of damaged to the kiln components in operation.

Diametrical clearance is measured at top dead center of the rotary kiln, which is difficult to do. It is much easier to measure diametrical clearance by measuring the creep at each pier. Creep is measured by marking the side face of the tire and a fixed component on the kiln shell like a retainer, or the shell itself. The temperature of the shell and side face of the tire are also measured. Temperature readings of these components will allow the end user to know the thermal differential between the two components. This information is required for knowing the true condition of the rotary kiln creep/ diametrical clearance at each pier. To find diametrical clearance, the creep number is divided by Pi. As stated above, too much creep (aka diametrical clearance) and the ovality of the tire plate will become excessive. Which results in refractory issues and shell cracking. Too little creep, and coke bottling of the kiln shell will result.



<u>Figure 3</u> – Shows marking kiln components for creep (on left) & result after completing a rotation (on right).

Ovality is defined simply as non-permanent elastic deformation of the kiln shell, or shell flex. Shell plate ovality can be influenced by an increase or decrease of the diametrical clearance between the tire bore and kiln shell/ filler bar. As previously stated, a high amount of creep at the pier will result in brick crushing, brick failure, and shell cracking. Please note that tire ovality is not included in this discussion, but it should be noted that tire ovality is calculated on the design of the tire (width and thickness). The tire ovality will transfer directly into the shell plate. Thus, shell ovality can never be less than tire ovality. Shell ovality will always be the same or greater as the tire ovality.

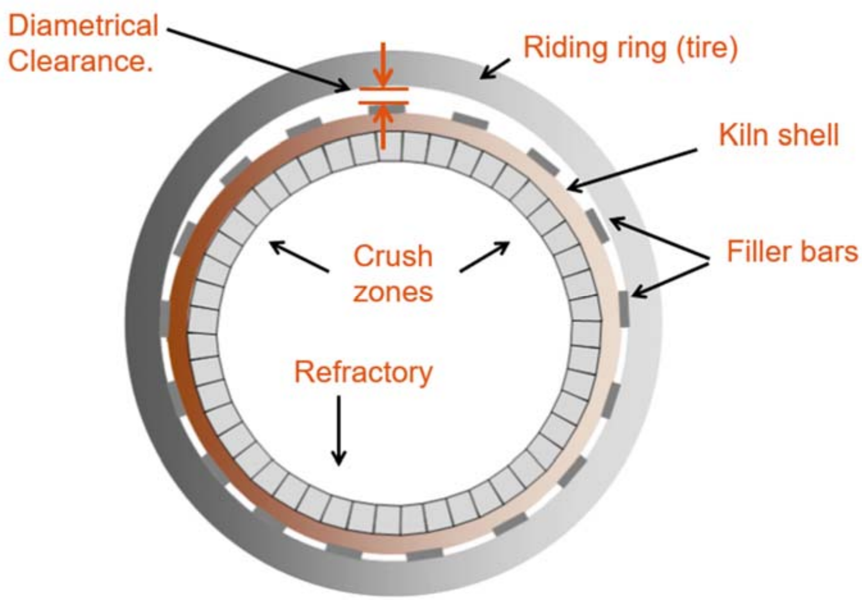


Figure 4 – Diagram showing the rotary kiln components at the pier and the terms used to describe each component.

With filler bars present on the rotary kiln, the adjustment of the diametrical clearance is possible. When the tire is mounted directly onto the shell, the diametrical clearance is not adjustable. If the diametrical clearance is not adjustable, the equipment owner can only monitor the condition over time. There is no other option for repair other than major component replacement to fix high or low diametrical clearance. When the rotary kiln has filler bars, correction of the condition can be completed when wear or degradation occurs to the rotary kiln components.

Part 3 Types of filler bar assemblies, their role in rotary kiln maintenance and advantages over tires mounted on kiln shells

The typical filler bar system has gone through several design changes from the first rotary kilns supplied in the early 1900s through today. These designs started with riveted and bolted filler bars and evolved into a semi-floating design where one end of the filler bar is welded, and the opposite end has side keepers to allow for expansion of the filler bar plate. The newest filler bar design incorporates a full floating filler bar where the filler bar is retained by keepers and is not welded to the kiln shell.

Most suppliers have moved away from older designs due to the welds breaking, and the filler bar could not easily be shimmed or replaced. The bolted and riveted design offers similar challenges but adds complexity. In that, to remove the bolts or rivets, the refractory from inside the kiln must be removed to perform a filler bar replacement or add shims. This is a time consuming and a costly repair versus repairing the semi-floating and fully floating designs.

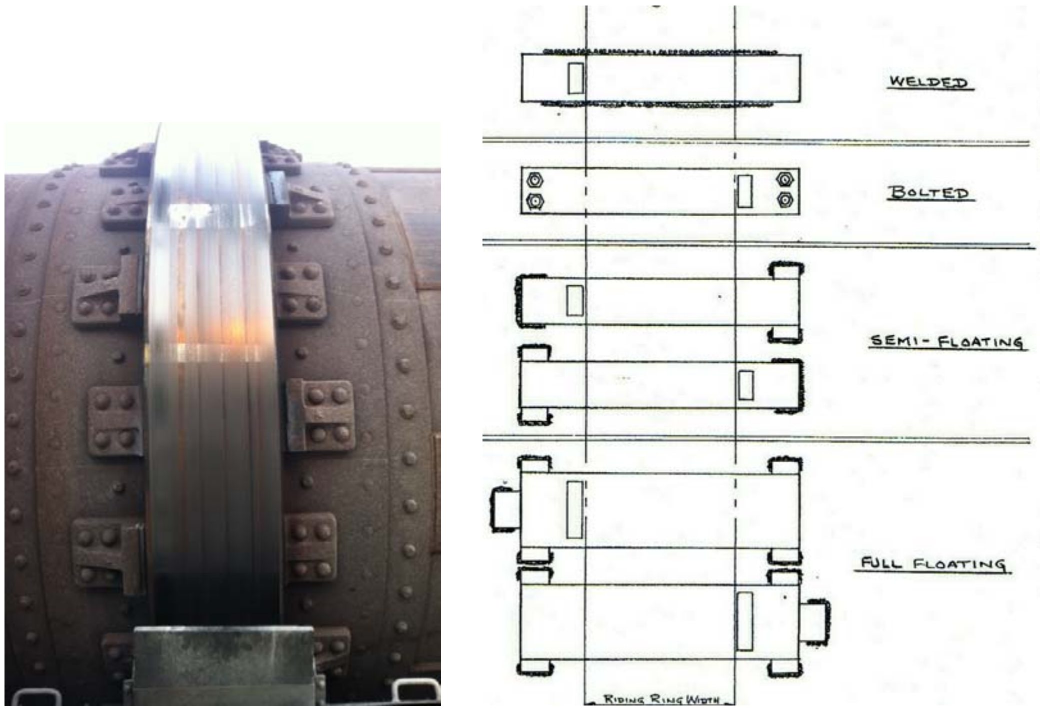


Figure 5 - Left: Riveted design. Right: Evolution of filler bars.

The semi-floating design was upgraded to a full floating design to allow for better expansion and contraction of the filler bars. It also allows for easier shimming of the filler bar once the creep becomes excessive. The semi-floating design can be upgraded to a full floating design with addition of side blocks, and a proper tire retainer.

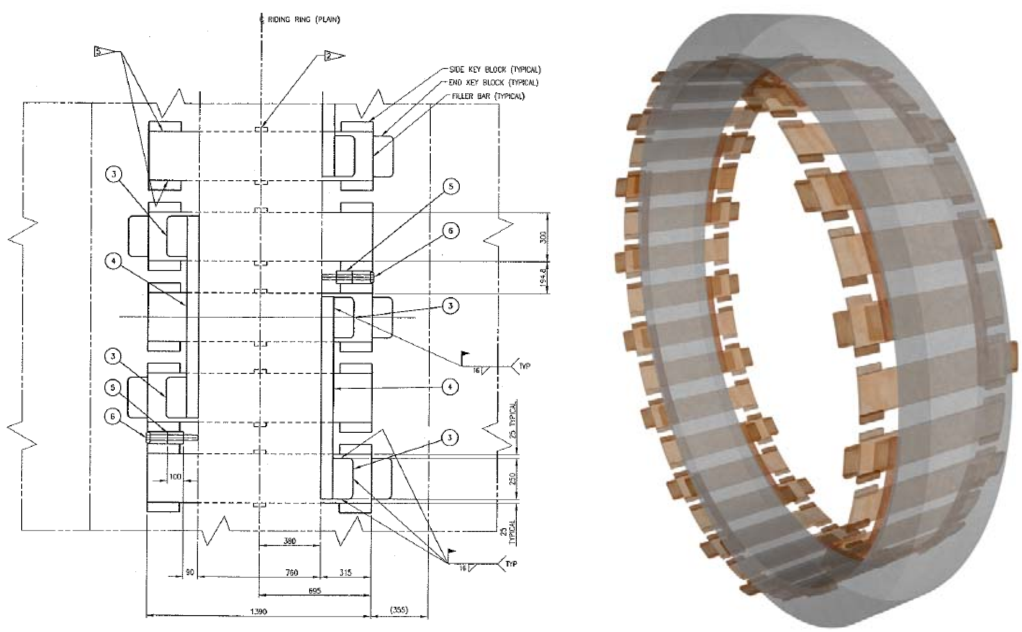


Figure 6 – Full floating filler bar design for rotary kilns

Part 3.1 Shimming capabilities

The filler bar assembly arrangement has a key design feature that allows for more flexible over the tire mounted directly on the kiln shell. The flexibility is derived from the ability to replace and/ or shim the filler bars when worn.

When the tire is mounted directly onto the shell, there is no adjustment that can be made to the diametrical clearance once delivered and installed at the site. The diametrical clearance is fixed, and the creep cannot be adjusted. With the system being fixed, the owner of the equipment can simply monitor, and eventually replace or upgrade when the components wear out.

Shimming the filler bars can prolong the life of the refractory, kiln shell, filler bar system, and tire. Through filler bar shimming and filler bar replacement capabilities the following advantages exist:

- Refractory exposure to high crushing forces due to high ovality will be reduced.
- The kiln shell will have reduced exposure to high ovality readings, which causes shell cracking.
- The filler bar system wear will be reduced by controlling diametrical clearance.
- The tire side face wear will be reduced. Sliding friction can be reduced by controlling diametrical clearance.

Part 3.2 Lubrication

Lubricating the bore of the tire and side face of the tire is recommended. Anywhere there is metal on metal contact, proper lubrication methods will reduce the friction between the metal components. Thus, improving wear life. With the filler bar design, it is quite simple to lubricate the bore of the tire by applying a solid bar or spray at the bottom areas of the kiln shell in the 6 o'clock position.

With the tire mounted directly on the shell, only a spray lubricant should be used since there is no space for the bar to melt and distribute properly on the shell's outer diameter or tire bore. A bar would be crushed and most of the lubrication will not be contained in the tire bore. A spray should be utilized to avoid this issue.

Applying lubrication at top dead center is a challenge. Either a permanent ladder and cross walk needs to be installed over the kiln or a man basket must be used. Both offer advantages and disadvantages, and neither are as safe as applying lubrication on the pier top at a safe distance from the rotating shell.

Part 3.3 Comparing yearly and long-term maintenance for rotary kilns with and without filler bars

Current industry standards recommend that all rotary kilns (especially aging rotary kilns) receive a full kiln evaluation every 1-3 years to determine rate of wear, component integrity, and alignment of all components. The information will allow the end user to properly plan repair activities on the rotary kiln. A rotary kiln evaluation normally includes an alignment, shell ovality, shell profile/ shell runout, tire axial runout, gear axial and radial runout, roller shaft deflection, base/ roller slope, and full visual inspection of the kiln assembly. Creep should be monitored on a weekly basis by plant personnel, along with shell temperature uphill and downhill of the tire and the tire side face. Following the OEM daily, monthly, and yearly checks (which can be found in the manual supplied with equipment) is also recommended.

There are too many variables to predict when the long-term maintenance will be required. There are also many opinions on when replacement, upgrades, and fixes to rotary kilns. The recommendations expressed in this paper are based on the experience of the author and the many kiln inspections, kiln evaluations, and repairs that have been conducted by the author and the OEM for which the author works. General guidelines can be described and quantified. Major repairs and upgrades are a discussion and each OEM, repair company, and equipment owner will have different opinions, experiences, and suggestions. But general guidelines can be followed and are generally accepted.

Part 3.3.1 Shimming

Filler bar assemblies will require shims installed once the creep becomes too great. The generally accepted practice is that creep greater than 1 inch should be addressed at the next shutdown via shimming. This activity typically takes place 5-10 years after installation. However, there are many cases of rotary kilns running 40 years with the original filler bars that do not require shimming.

Tire mounted directly on the shell – since it is not possible to adjust creep this activity is not completed. The end user should monitor the creep on a weekly basis and ovality on a 1-2 yearly cycle to track rate of degradation.

Part 3.3.2 Tire retainer replacement

Both systems will require tire retainer repairs and or replacement after the kiln is in operation for many years. There is no evidence to suggest filler bar assembly or tire mounted directly on the shell will last longer than the other. Properly aligned kilns with proper thrust loads and skews on carrying rollers will last longer than misaligned and unbalanced kilns. The replacement is completely dependent on a proper design and kiln maintenance carried out on the components. Typically, a complete replacement is required every 10-15 years.

Part 3.3.3 Filler bar replacement

The filler bars will need replacement at some point in the rotary kiln life. This may take place a couple of years after start-up due to a problem with the kiln shell or may only be required when the kiln shell also needs replaced. But typically, filler bars will need to be replaced every 15-25 years on a lime recovery kiln. The most common reason filler bars need replaced is that the outside diameter is worn, the bar is broken, or bending of the bar has occurred, causing damage to the filler bar system. Most repair companies and OEMs will recommend that filler bars should be replaced the next time creep is excessive after the first set of shims is installed (due to filler bar OD wear).

Tires mounted directly on the kiln shell do not have filler bars and thus cannot be replaced. Diametrical clearance can only be fixed with a new shell and or new tire.

Part 3.3.4 Kiln shell replacement

Kiln shell replacement is not easily predicted and may require replacement after initial start-up due to kiln operational issues causing a hot spot and coke bottling, 50 years after operation, or anytime in between for various reasons. In any case, after 30 to 40 years of good operation and maintenance, if the kiln shell at each pier has not been replaced, it will most likely start showing indications that replacement will be required in the near future. These indications include: high ovality and refractory crushing, kiln shell cracking (longitudinal and circumferential), excessive shaft deflection due to a shell crank (dog leg) in the kiln, and shell thinning.

Even with the design advantages that the filler bar system has, it does not necessarily prevent the kiln shell from being replaced any sooner or later than a tire mounted directly on the kiln shell. Replacement goes hand in hand with operation and maintenance of the equipment. Timely and effective kiln maintenance and operation will increase the probability of the parts lasting longer. There are numerous examples of lime recovery kilns that were installed in the early 1980’s with no filler bar system that show little sign that a shell section replacement is required soon. There are also rotary kilns with the tire mounted directly on the shell that showed signs of replacement soon after start-up. The difference between these kilns is typically the manufacturing tolerances and specifications, quality of installation of the components, operation of the rotary kiln, and maintenance that is performed during the life of the assembly.

Part 4 Upgrade options

When replacement of a shell section on a rotary kiln becomes necessary, there are many options that need to be considered, especially when the tire is mounted directly onto the kiln shell. When replacing a rotary kiln tire section that currently has a filler bar assembly, the end user will most likely replace the current design as is or upgrade the filler bar arrangement if the design is out-dated. At times, the client will opt to keep the existing tire and only replace the kiln shell and filler bars. This is a practical option when the tire is in good mechanical condition and filler bars are present to control the diametrical clearance. Before reuse of a tire, the full risk for reuse should be evaluated and determined if the equipment owner can take such risk with the project. If the tire fails shortly after installation of a new shell and filler bar section, then the work will need to be redone and the rework will be greater due to the addition of the new tire.

When the tire is mounted directly onto the kiln shell there are several upgrade options the equipment owner can select. The equipment owner should align their long-term goals with a proper upgrade. This is to ensure that money is spent effectively and not wasted.

For example, if the long-term goal of the plant is to replace their existing rotary kiln with a larger rotary kiln to increase capacity, and the long-term goal will be realized in approximately 10 years. Should the equipment owner consider a 50 year solution to the kiln? The 50 year solution should be considered, but a cheaper option may exist that achieves the goal of 10 more years of production with less cost.

Part 4.1 Options for replacing kiln shells with no filler bars and replacing the current design.

The typical reason to replace a kiln shell tire section arise from refractory issues, or extreme shell plate cracking. When cracking and refractory issues are noticed, a mechanical assessment should be completed by a kiln OEM or repair company to determine the severity of the issue by taking several measurements. After the results are known and it is determined that high ovality does exist at the problem area, most recommendations are to simply replace the shell and do an upgrade – as soon as possible. The issue with this recommendation is the cost. Most equipment owners do not have this unplanned cost in their budgets. And the fix is not cheap.

However, there is a way to help stabilize the ovality and hopefully prolong the need for replacement when the issue is known. Adding segmented stiffeners to the shell plate immediately adjacent to the tire will help preserve the current ovality and help steady brick issues in the near term until a shell section replacement can be budgeted. It should be noted that adding stiffeners cannot guarantee refractory issues will be relinquished. For the low cost of supply and install versus a shell section, it might be worth the risk to the equipment owner. All risk should be evaluated before any options are purchased.

Please note that on the drive pier, the stiffeners will need to be positioned further away from the tire due to the thrust roller interference. The stiffeners will have less affect at this pier due to the interference.

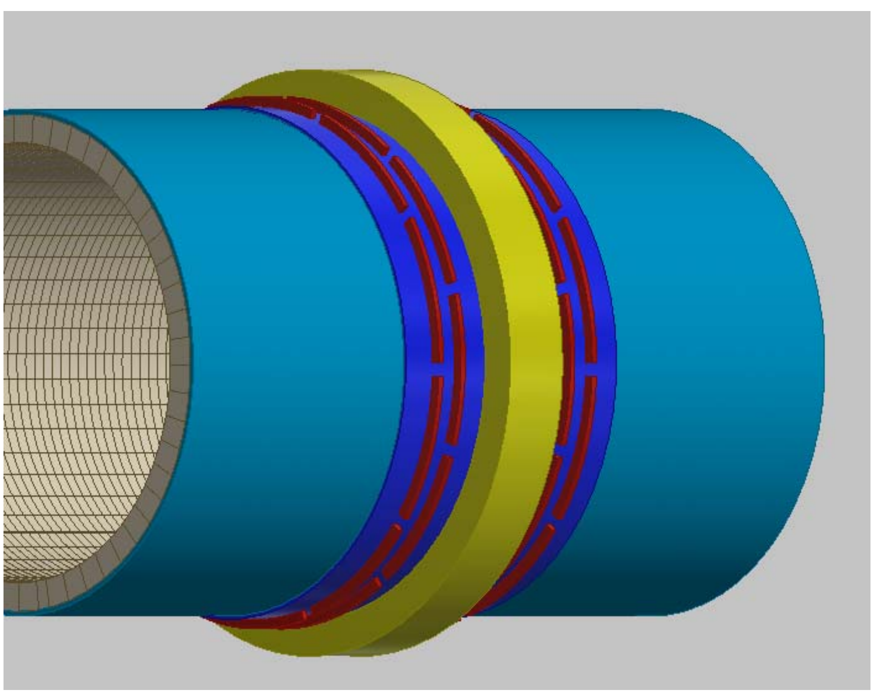


Figure 7 – Segmented stiffeners added to the kiln shell tire plate for concept purposes.

Once the decision is made to replace the shell and or tire, there are two options available when no filler bars are present, and the equipment owner wants to replace the equipment as is. Option one; the equipment owner can replace the kiln shell and reuse the tire. Option two; the equipment owner can replace the kiln shell and install a new tire.

Option One

Replacing the kiln shell and reuse of the tire is risky in that the condition of the tire bore is not truly known. The bore of the tire wears in operation and usually it is minor. Yet there will be some amount of wear. Also, the bore of the tire could be damaged in the form of galling. The only way to know the condition of the tire bore is when the tire is removed from the kiln shell and inspected. The other key aspect to understand is the remaining usable life of the tire. The outside diameter of the tire wears more significantly than the bore due to contact with the support rollers. The amount of usable life left should be understood before making the decision to reuse the existing tire. Calculating the proper diametrical clearance can be complicated in this situation. If the equipment owner is looking for a long-term solution; this option would be ill advised for that reason alone. If the diametrical clearance is miscalculated the entire project may be in jeopardy. Mechanical issues like kiln necking/ coke bottling or excessive creep and ovality may result from reusing the existing tire. When reusing the existing tire, the shell and tire must be removed from the pier, and the tire separated from the kiln shell before the existing tire is inspected and slid onto the new shell section. This adds time for installation versus option two described next.

Figure 8 - Tire mounted directly on kiln shell – damage to tire inside diameter when removing from the kiln shell

Option Two

Replacing the kiln shell and tire is more expensive, but the higher supply cost may be offset by shorter installation timeframe than option one. When a new tire and shell are supplied, the two parts can be assembled before the rotary kiln is shutdown or during the preparations for removal of the existing kiln shell section. The existing shell section can be removed and the new shell section with new tire can immediately be installed. This can easily save 12-24 hours over option one. This option should also reduce the amount of crane time that is required on the project.

When evaluating these two options the equipment owner should determine what the long-term goals are before a decision is made. If a temporary quick fix is needed, option one might be a consideration that warrants the risk. If a long-term solution is needed, then option two is likely the best option.

Part 4.2 Considerations to be discussed before adding filler bars to the system

Before any decisions are made on how to install the filler bars on the kiln shell when the current design does not incorporate filler bars, a load study should be performed on the rotary kiln. The load study will evaluate the tire and roller sizing and determine if the originally supplied tire and roller dimensions are adequate for the current rotary kiln process.

The goal of the load study is to evaluate the rotary kiln components and keep the vertical distance of the kiln center to the carrying roller center the same for proper kiln alignment. The load study will present the end user with the following conclusions.

1 – Whether the rollers and or tires are the correct size.

2 – Whether the rollers and or tires are oversized.

3 – Whether the rollers and or tires are undersized.

Once the load study is completed, the proper solution for adding filler bars can begin.

If the conclusion of the load study suggests an increase in the roller outside diameter or tire outside diameter, compensation for rotary kiln elevation is required. The rotary kiln centreline at the pier receiving filler bars will be high if elevation is not corrected on the other piers. This will result in overloading at the pier receiving filler bars, causing severe kiln maintenance issues – appendix 4. Elevation compensation is accomplished by dropping the rotary kiln elevation at the pier where the tire diameter is increasing, and possibly raising the kiln elevation at other piers. This is performed by adjusting the carrying rollers inward and outward as needed to correct the kiln centreline. If the distance required to move the carrying roller outward is greater than the adjusting screw travel, then two more options for compensation exist – the overall kiln centreline must be raised, or the base frame elevation must be lowered to accommodate the correct rotary kiln centreline.

Refer to Appendices 1 and 2 for tire and roller position changes when increasing the tire outside diameter and the effect of the kiln, roller shaft angle along with determining when a base frame needs to be removed, and elevation dropped to accommodate a larger tire.

Part 4.3 Changing kiln elevation when increasing tire diameters to add filler bars

Increasing the tire diameters to install filler bars on the kiln shell assembly will raise the kiln elevation and will require adjustment of the piers to keep the kiln in proper alignment. There are 3 ways to correct rotary kiln elevation.

1 – Push the carry rollers outward from the kiln center line to maintain elevation at the pier receiving filler bars. Most rotary kilns will have three to six inches of adjustment to allow for the rollers to move outwards.

2 – Raise the overall kiln elevation. If there is not enough adjusting lug travel in item 1 to allow for the kiln shell center line to placed in the correct elevation, then consideration should be given to raise the elevation on the remaining piers by pushing the carrying rollers inwards toward the kiln center line. Refer to Appendix 5 for other kiln components that require review when raising the kiln centreline.

3 – Lower the elevation of the base frame. If the current base frame requires replacement, this is a good option. If the base frame is in mechanically good condition, then this should be the last option to consider after items one and two.

A full mechanical evaluation of the kiln must be completed to understand how much vertical travel the kiln can safely achieve due to the interference items mentioned noted in appendix 5.

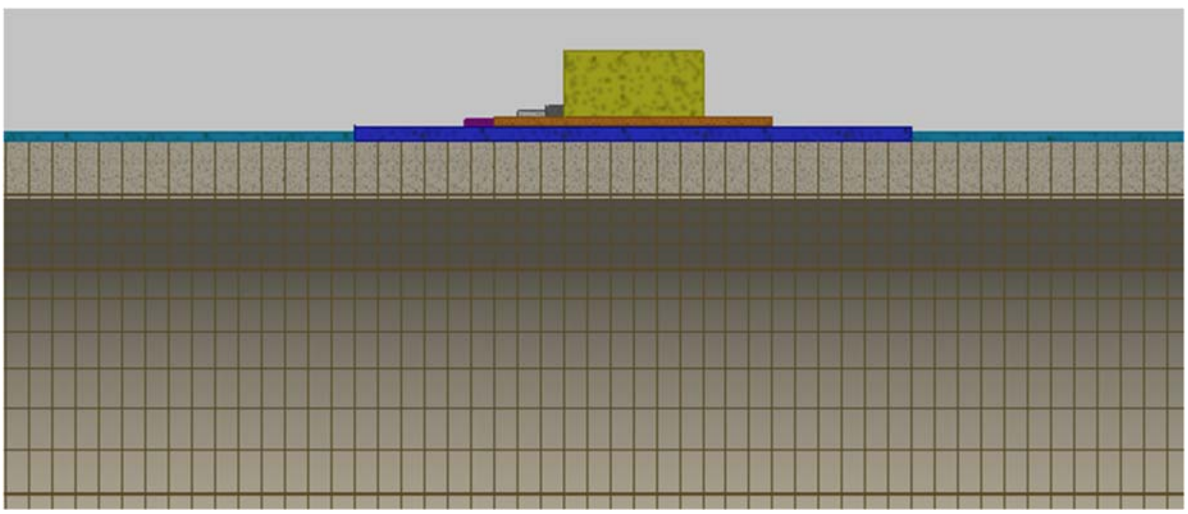


Figure 9 - Increasing tire diameters to install filler bars.

Part 4.4 A new way to install filler bars on the kiln shell

The options mentioned in the previous section are the traditional methods for adding filler bars to a rotary kiln when the tire is mounted onto the kiln shell. However, another solution exists. It would allow the addition of filler bars while reducing the parts supply and installation costs to the end user.

As a substitute to increasing the diameter of the tire to accommodate the new filler system, reduction of the kiln shell diameter under the tire could be accomplished. Reducing the outside and inside diameters and maintaining the current tire plate thickness will allow the filler bar to be installed, and it will also keep the same geometry for the kiln center lines. Thus, negating any reason to push carrying rollers outwards or lowering base frame elevations.

From a mechanical perspective, there is no reason reducing the diameter of the kiln shell cannot be done. This may even allow the existing tire to be re-used if the tire is in good mechanical condition. Note that all risks present when re-using components must be accounted for and understood. The downside to this approach is that a step on the inside diameter of the kiln shell will be present. This may hinder brick installation, which is the most important component for a rotary kiln to operate properly. Cutting of the brick, different brick radius, and more installation time for brick may all be required in this method.

See Appendix 4.

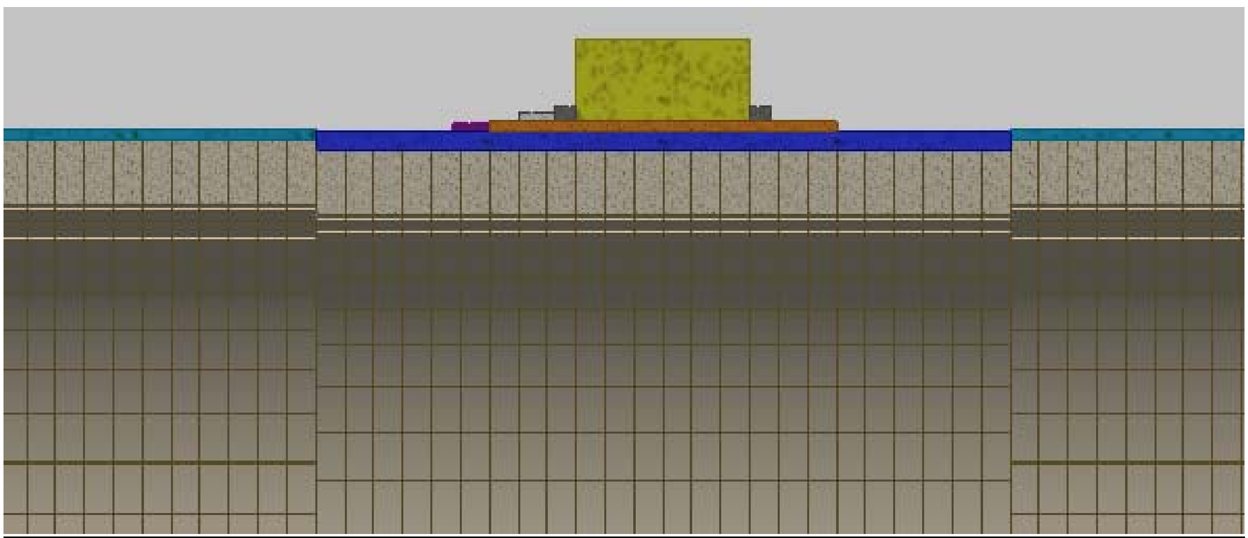


Figure 10 - Decreased tire plate diameters to insert filler bars

Part 4.5 Relative cost for the options presented

Not only is component integrity and function of the parts important, but the cost of supply, install, and to maintain is also of great importance to the equipment owner. The various options for installation of filler bars can be quantified. Thus, allowing for an informed decision that aligns with the long-term goals of the pulp mill to be achieved.

Part 4.5.1 Low to high supply costs (approximate for a 13’ diameter kiln, larger diameter kilns will see an increase in costs due to the tire size)

1 – Segmented stiffeners – low cost for supply and install – About 20% the cost of a shell section replacement. – This is not a permanent fix and should be treated as temporary to allow time for budgeting of a proper solution.

2 – New kiln shell with no filler bars, reuse tire – greatest risk, lowest cost for supply

3 - New kiln shell with smaller diameters, supply filler bars, reuse tire ~ 50% more expensive than item 2.

3 – New kiln shell & tire with no filler bars ~100% more expensive than item 2

4 – New kiln shell (with smaller inside diameter), tire, filler bars ~ 150% more expensive than item 2

5 – New kiln shell, tire, filler bars, base frame ~ 200% more expensive than item 2

Part 4.5.2 Summary installation costs (approximate for a 13' diameter kiln, larger kilns will see an increase in costs due to larger cranes, and more hours to perform installation)

1 – New kiln shell & tire, no filler bars – lowest installation cost

2 – New kiln shell, reuse tire, no filler bars – 10% higher installation cost than item 1 – to remove existing tire from shell add installation time & crane time.

3 – New kiln shell (smaller inside diameter), tire, and filler bars –10-20% higher installation cost than item 1– aligning joint and welding properly from inside and extra brick work.

4 – New kiln shell (smaller inside diameter), filler bars, and reuse tire – 20-30% higher installation cost than item 1 – remove old tire from shell to reuse, aligning joint and welding properly from inside and extra brick work.

5 – New kiln shell, tire, filler bars, and base – 75-100% higher installation cost – Project duration is approximately 3-4 days longer to replace the base frame. Crane costs to perform the base framework. If completed in tandem with refractory; additional costs for setting falsework and lifting kiln, extra time required to remove rollers assemblies and base frame from around kiln shell and tire, could require 2 cranes versus 1.

4.5.3 Production costs

The first 4 options can be completed in relatively the same time frame. Option 4 may require an extra 24 hours for installation.

Option 5 could cost up to 4 days or more of production. If the kiln shell replacement is the critical path for the mill to restart this translates to 4 days of makeup lime purchases for the white liquor plant.

If the rotary kiln is not the critical path, then production costs can most certainly be reduced or eliminated.

Note - Poor fresh lime can cause downstream process issues resulting in poor performance.

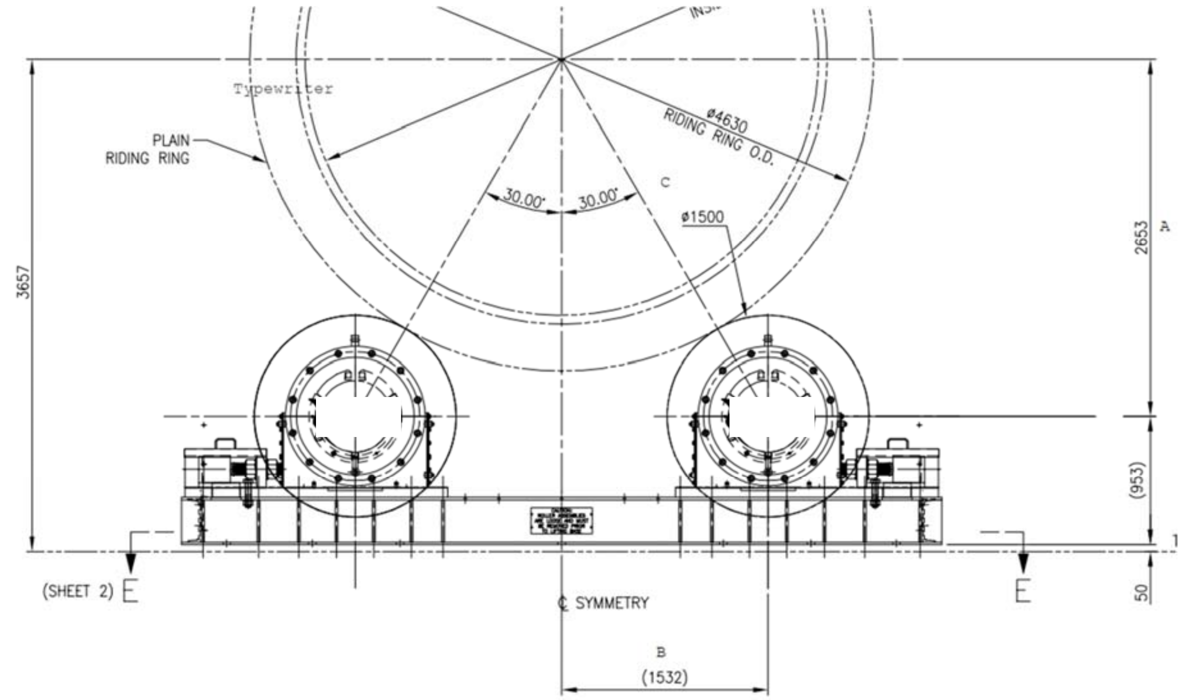
Part 5 Conclusion

It is imperative that the equipment owner decides what option is optimal for the project. As previously mentioned, aligning with long-term goals with the pulp mill is essential when selecting replacement options and upgrades. Consider for example, does the project warrant a 100, 200, or even 300% increase in price over another option that may be suitable for the pulp mill's needs? The answer completely depends on the goals of the equipment owner.

To fully understand the long term costs of upgrading or replacing large components on the rotary kiln, multiply the project cost by the number of piers. Most kilns of this era have 3-4 piers. All will require a shell section and tire replacement at some point in the future.

Whatever decision is made, ensure that all the facts of the project are known through mechanical evaluation and load study. Relying on a visual inspection only or a similar kiln project being completed are important facts that should be understood but more information should be gathered since each plant has a unique process and equipment with different goals.

Appendix 1



Typical Carrying Roller & Tire Assembly/ Arrangement.

When increasing the tire outside diameter, the kiln elevation must be kept per the original design. This requires carrying rollers to move outward to hold the vertical distance. For this example, the following formula is used to determine how much roller movement is required when increasing the outside diameter of the tire.

25 mm filler bars are used in this example, thus requiring a diameter increase of 50mm of the tire.

Tire OD original is 4630 mm – New Tire OD is 4680.

Vertical distance from centreline of kiln to centreline of roller = 2653 mm (A)

Horizontal distance from centreline of kiln to centreline of roller = 1532 mm (B)

Angle from kiln center to roller center = 30 deg (Ka)

(Tire OD + Roller OD) / 2 = C

Cos-1 (A / C) = new angle (Ka)

Sin (Ka) * C = new B

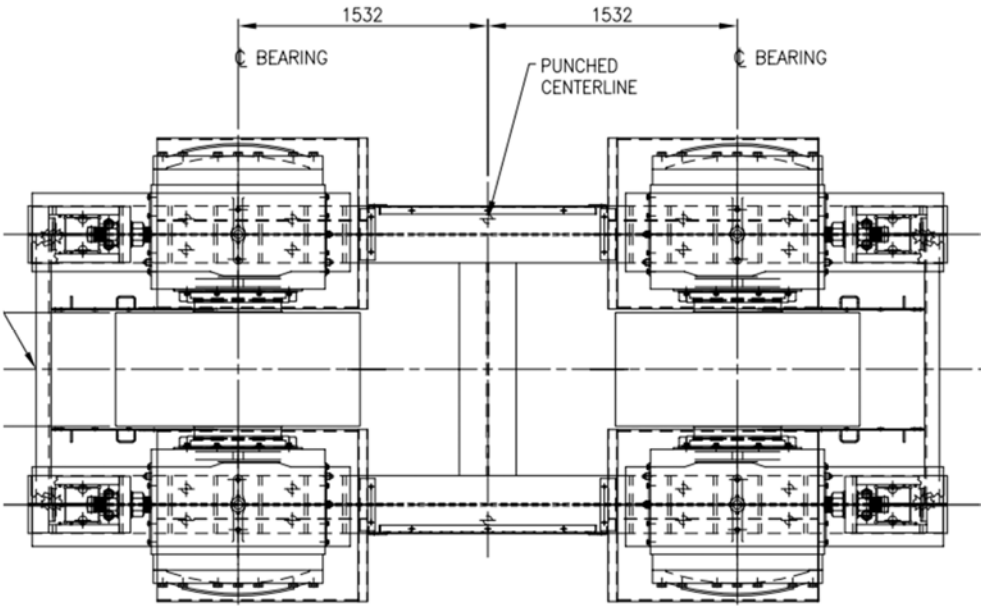
(4680+1500)/2 = 3090 mm

Cos-1 (2653/3090) = 30.84 degrees

Sin (30.84) * 3090 = 1584 mm

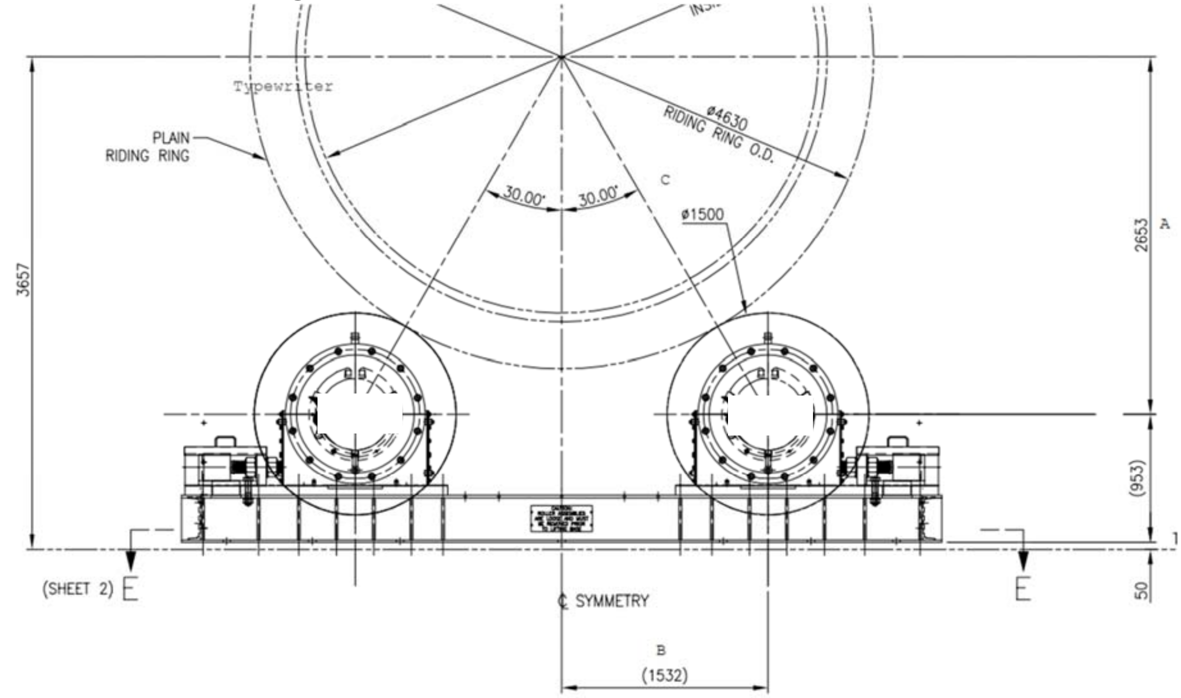
This results in 1584 mm, which is 52 mm larger than the original dimension. Therefore, requiring the carrying rollers to move outwards by 52 mm total.

Appendix 2 – Adjusting Lugs



Carrying roller stations typically have 150-200 mm of travel total, and about 75-100 mm in each direction for adjusting the kiln overtime. Typically, these housings are moved inward when alignments are performed and roller and tire diameters wear to compensate for the losses. All calculations for new positions of carrying rollers must be made with the original carrying roller diameters in mind. Sizing the new tire and determining if the base frame elevation can only be properly evaluated with the correct size carrying roller in place.

Appendix 3 – Raising Kiln Elevation



25 mm filler bars are used in this example, thus requiring a diameter increase of 50mm of the tire.

Tire OD original is 4630 mm – New Tire OD is 4680 mm.

Vertical distance from centreline of kiln to centreline of roller = 2653 mm (A)

Horizontal distance from centreline of kiln to centreline of roller = 1532 mm (B)

Angle from kiln center to roller center = 30 deg (Ka)

(Tire OD + Roller OD) / 2 = C

Sin-1 (B / C) = new angle (Ka)

Cos (Ka) * C = new A

(4680+1500)/2 = 3090 mm

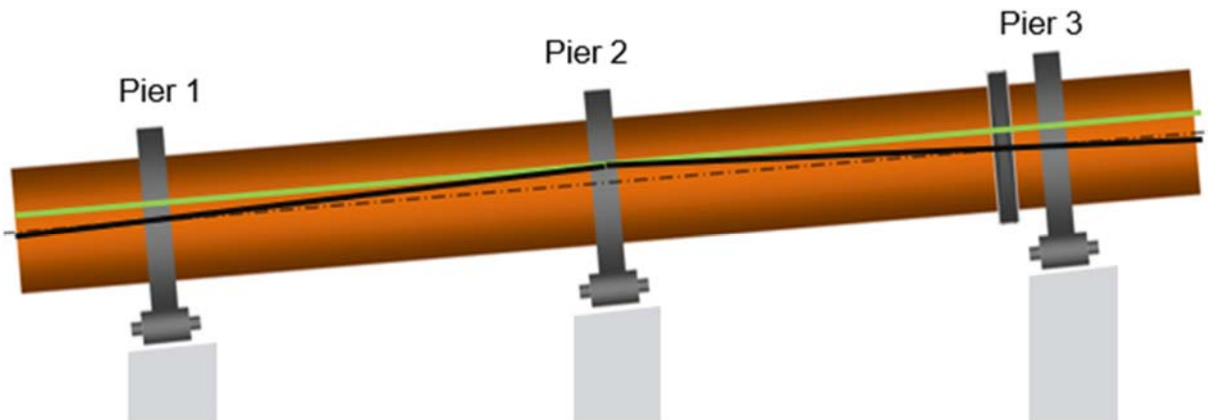
Sin-1 (1532/3090) = 29.72 degrees

Cos (29.72) * 3090 = 2683 mm

This results in 2683 mm, which is 30 mm larger than the original dimension. This requires the kiln height to be raised 30 mm on the remaining piers to keep the kiln in vertical alignment. C = (4630 + 1500/ 2) since original size components are being used at the other piers.

$A^2 + B^2 = C^2$ ($2683^2 + B^2 = 3065^2$) B = 1481 mm. B is 51 mm smaller and would require each carrying roller to be pushed inward by 51 mm on the piers that are not receiving filler bars to maintain kiln vertical alignment.

Appendix 4

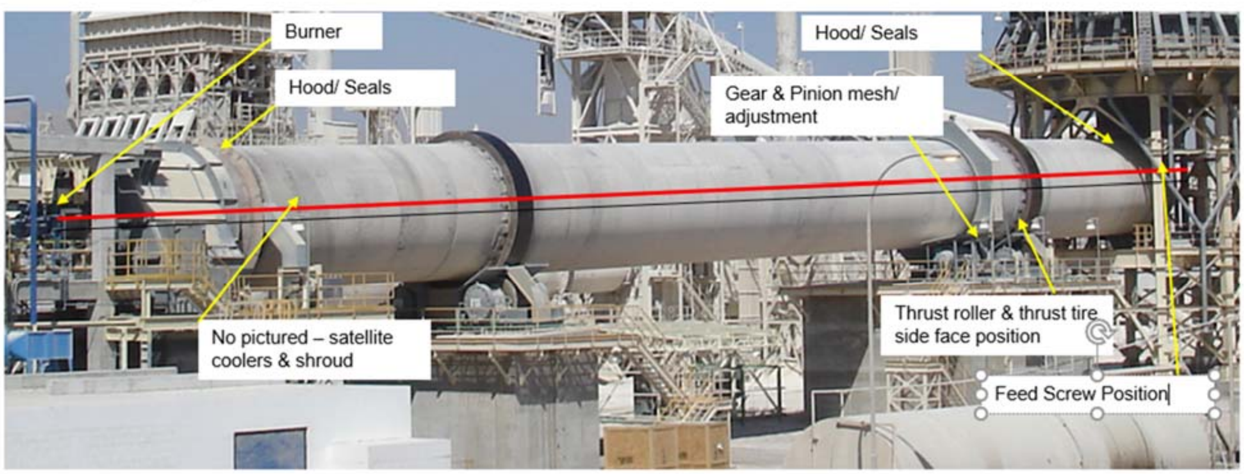


Green line represents elevation increase required to maintain kiln vertical alignment with filler bars being added to Pier 2

Black line represents alignment of kiln if Pier 2 receives filler bars and no adjustment to carrying rollers occurs

Appendix 5

Black line is the original kiln elevation
Red line is new kiln elevation – arrows are interference points when raising kiln elevation



Gateway to
the Future

Examining upgrade options when rotary kiln tires are mounted on the kiln shell with no filler bars.

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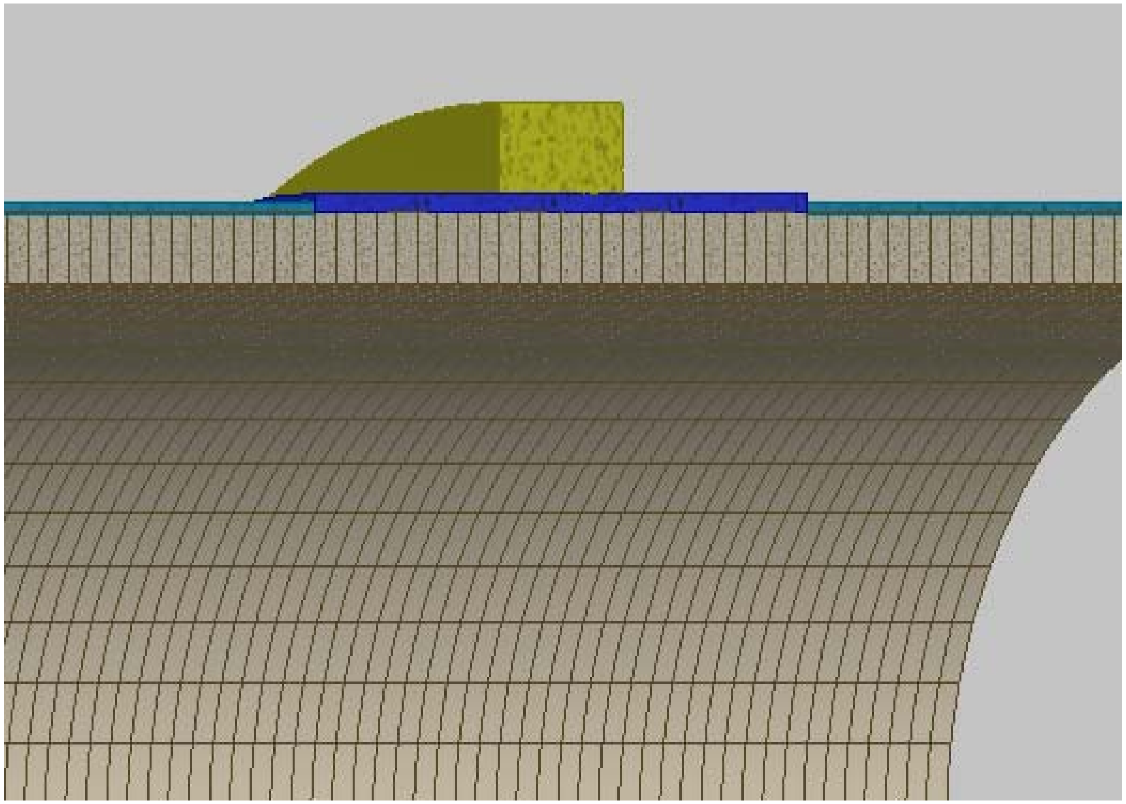
Lime Recovery Kilns

Supplied with tire mounted directly on the kiln shell – no filler bars

- Began in late 1960's
- Still continues to this day
- Cuts cost on equipment supply
  - Removal of filler bars and associated components
  - Possible to reduce size of tire by ~ 2% weight



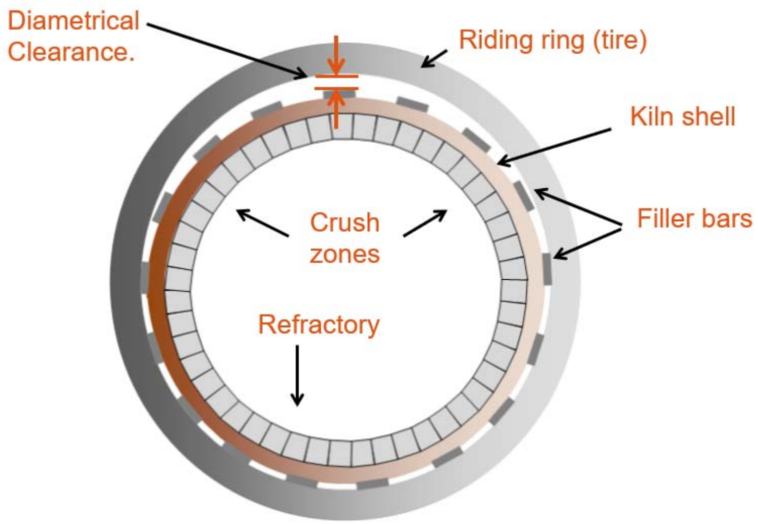
Why do we recommend having filler bars

Are they required – obviously not…

But it is impossible to control diametrical clearance (tire migration/ creep) without them.

Whatever is supplied from new will be the result, and once the diametrical clearance becomes great, the only option is replacement

Versus – Filler Bars can be shimmed to reduce diametrical clearance

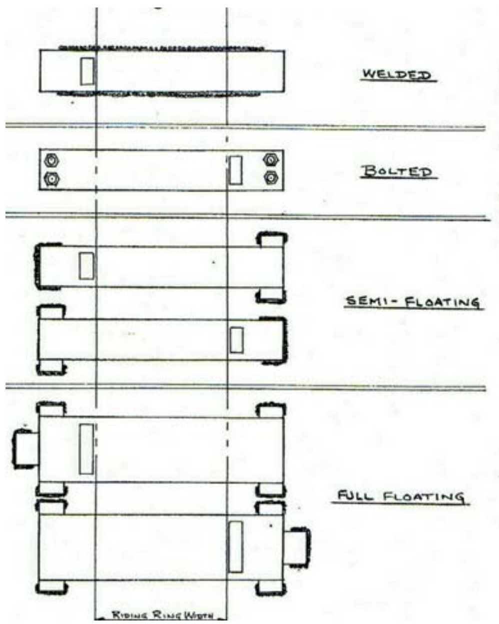


Types of filler bar systems

Newest design is "full floating" everyone has a different type, style, arrangement that does the same thing.

1890s – 1930s

1930s - 1980s



1980s - Today

How often do we perform services on Rotary Kilns

Wide range of dates – completely dependent on quality of supply, install, and maintenance of the Rotary Kiln

- Kiln Alignment & Mechanical Survey – every 1-3 years
- Tire retainer replacement – typically 5 -10 years
- Shimming of filler bars – typically 5 - 15 years
- Filler bar replacement – typically 15 - 25 years
- Kiln Shell & Tire – typically 30 – 40 years

Numbers can vary greatly from guidelines – but normally signs component replacement is needed in the near future will be noticed.

When it’s time for a shell section – what can be done?

Replace as is – or upgrade to filler bars

- Before replacement is discussed – what’s the issue?
  - High Ovality & Shell Cracking?
  - If you’re constantly loosing brick, and it’s causing severe downtime and production issues, then it’s probably time to replace – next 2 slides
  - If you notice high ovality and some shell cracking, it’s probably not time to panic – yet. Monitoring the condition is extremely important, and this is why OEMs and repair companies sell Kiln Alignments and Kiln Mechanical Analysis Packages. To figure out root cause and what’s going on.

If you got this situation – it's probably time to replace……

Cracked Tire

Cracked Shell

Cobblestoned Refractory (Crushed)

You needed to replace this yesterday….

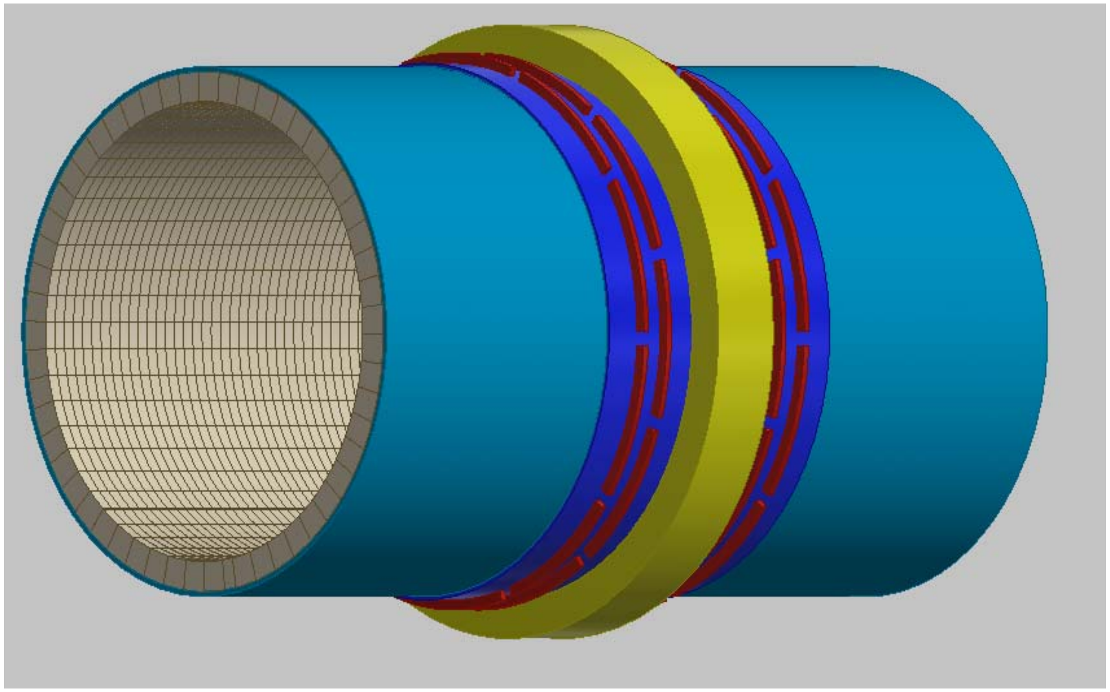
Before replacement consider….

Segmented stiffeners on the kiln shell to hold the current ovality

When higher levels of ovality are noticed – it might be worth while to install segmented shell stiffeners on the outside diameter of the kiln shell – this will help stabilize shell flexing.

The goal !– to allow the plant to properly evaluate what the best repair plan will be to achieve long term goals of the plant

And to budget for the fix – typically buying to parts in one fiscal year, and installation in another fiscal year to spread out the financial impact



Okay – I've added stiffeners, and my brick is still not holding up, now what?

First consideration – replace as is…

The original components without filler bars do work. Not many people are a fan of the design. And it's kind of hard to argue that no filler bars is actually better than a kiln with filler bars – (arguments for non-filler bars allowed)

If your kiln was able to get 40 years without filler bars, there is a good chance you could get close to the same life out of a replacement again…

But always remember – quality of part, quality of install, and quality of maintenance must be maintained during the process. If the diametrical clearance is off, and the parts are going in, you're stuck with it until you replace it again…

But I really want filler bars!!

Great – then there are options to consider!

- First – it's worth the money to do a load study.
  - This will tell you the current loading of the kiln at each pier.
  - It will also tell you if the component design oversized, just right, or possibly undersized – if it's undersized you probably already know this through various mechanical issues.

  - Once you know that components are good, or oversized or even undersized you can make a more informed decision on how to replace – next slide…

Over sized components..

That's a good situation to be in.

- There are cases where filler bars have been added to rotary kilns by simply reducing the thickness of the tire. (increasing inside diameter of the tire). This was possible because the originally supplied kiln tire was oversized for that pier. (Lucky for that mill in the Southern United States of America who will remain anonymous…)

- Pretty easy to add filler bars in this situation – you might be able to reuse the tire (if the tire is in good mechanical condition) – Reuse of tire is normally not recommended – especially for a tire that is 20 plus years old. Simply due to the life remaining of the component.

Undersized components

We’ve got some challenges ahead

- If your tire or even your roller diameters are undersized, then an increase in diameters will be recommended.
  - If you want to add filler bars, the outside diameter of the tire will need to get even larger!
  - When the outside diameter starting growing by 3, 4 or more inches, the possibility to put the components back in the same elevation is diminishing, and at this point reducing the base elevation will be recommended.
    - More on this in a bit.

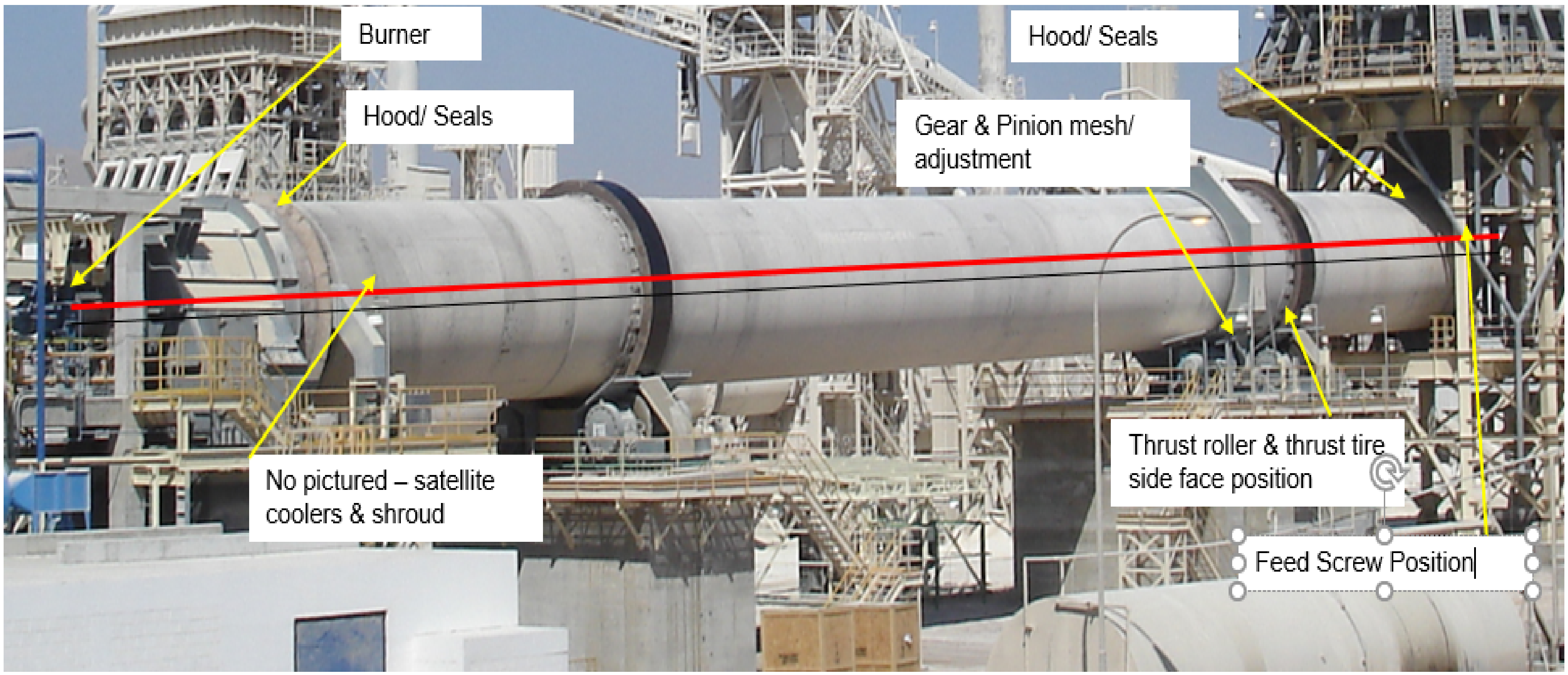
Components are just right?

Well – that's a majority of kilns out there – and it's okay

- To add filler bars, the diameter of the tire will need to increase, and again the elevation of the kiln center point will need to be corrected, but how?
  - First step – adjust the carrying rollers out at that pier. Determine (using math!) how much adjustment you have and how much that will lower the kiln
  - Second step – if you need to lower the elevation more than what is possible by adjusting carrying rollers outwards. Consider raising the overall kiln centerline by adjusting the other piers carrying rollers inwards. (Again use math) and consider all the parts this will affect – burner, seals, hoods, thrust roller, gear set etc….
  - But there's still not enough room – then my friend – it's time to lower the base frame… Or is it??

Areas to consider when changing kiln elevation

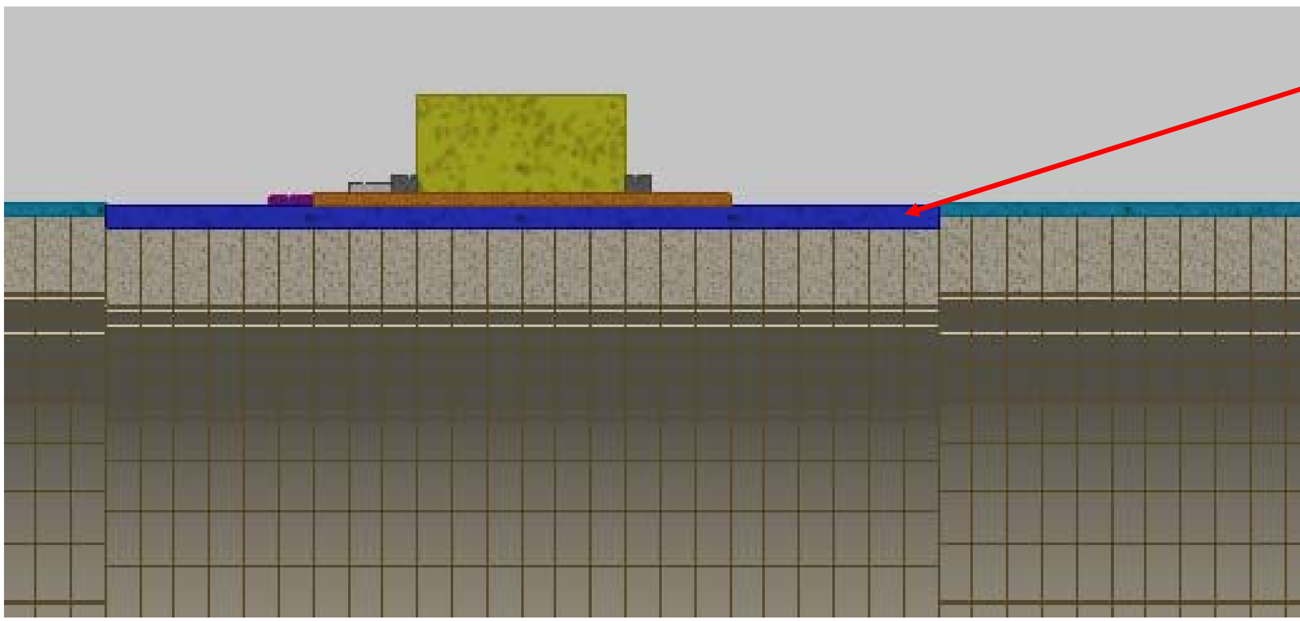
Black line is the original kiln elevation
Red line is new kiln elevation – arrows are interference points when raising kiln elevation



We need to change the diameter of the tire to fit the filler bars – right?

Not so fast – why can't we change the diameter of the kiln shell?

- Keep the thickness of the kiln shell the same, and reduce the outside and inside diameters to gain that extra bit of room required to make the system fit – without the need to change a base?



Shell is stepped on inside of the kiln -

Why hasn't anyone done this before

But it has been done -

- There are two examples of this option (that I know of)
  - One plant has installed a reduced diameter on the kiln shell (which created a step) and thus a varying brick radius – this mill is not in the USA or Canada
  - One mill had the parts supplied, but the parts were not installed –United States

  - There maybe others in the world that this has been done – so anyone with experience please step forward!

Potential issues to overcome

The step inside the kiln will be at max the thickness of the filler bar ~ 1.5” or less…

- Refractory installation
  - There will be a small step on inside of the kiln shell that will need to be overcome
  - The brick will require a different radius at this section
  - The brick may require a special cut to fit
  - Brick retaining rings maybe recommended by the brick supply company.
- Shell Install
  - Alignment of the old to new shell – it’s not flat on the inside now – more caution will be required

There is no mechanical reason this cannot be accomplished. But arguments are welcome.

What I would do?

Complete kiln analysis before any decision is made accompanied by a load study…

- Step 1 – determine how much adjustment of the carrying rollers away from the kiln center line at the pier receiving filler bars
- Step 2 – determine how much the kiln elevation can be raised without make serious changes to the kiln components like gear set, seals, hoods, burner etc.
- Step 3 – reduce tire thickness if possible by the information provided by load study.
- Step 4 – whatever is remaining – reduce diameters of the kiln shell. The step at this point will be minimal – probably less than 1” and closer to ½”.
  - ½” step is not difficult to overcome.
- Ultimate goal – not replacing a base to reduce kiln elevation if possible due to the cost.

Costs to do the project – Parts Supply

Exact figures cannot be presented and each kiln is different. But generally

- 1 – Segmented stiffeners – low cost for supply and install – About 20% of the cost of a shell section replacement – Item 2. This is not a permanent fix and should be treated as temporary to allow time for budgeting of a proper solution.
- 2 – New kiln shell with no filler bars, reuse tire – greatest risk, lowest cost for supply
- 3 - New kiln shell with smaller diameters, supply filler bars, reuse tire ~ 50% more expensive than item 2.
- 3 – New kiln shell & tire with no filler bars ~100% more expensive than item 2
- 4 – New kiln shell (with smaller inside diameter), tire, filler bars ~ 150% more expensive than item 2
- 5 – New kiln shell, tire, filler bars, base frame ~ 200% more expensive than item 2

Costs cont.

Installation

- 1 – New kiln shell & tire, no filler bars – lowest installation cost
- 2 – New kiln shell, reuse tire, no filler bars – 10% higher installation cost than item 1 – to remove existing tire from shell add installation time & crane time.
- 3 – New kiln shell (smaller inside diameter), tire, and filler bars –10-20% higher installation cost than item 1– aligning joint and welding properly from inside and extra brick work.
- 4 – New kiln shell (smaller inside diameter), filler bars, and reuse tire – 20-30% higher installation cost than item 1 – remove old tire from shell to reuse, aligning joint and welding properly from inside and extra brick work.
- 5 - New kiln shell, tire, filler bars, & base – 75 – 100% higher installation cost – project duration is approximately 3-4 days longer to replace a base frame. Crane costs to perform the base frame work.

Costs Cont

Production

- Only relevant if Kiln work is critical path on the shutdown.
- The first 4 options (from previous slide) can be completed in relatively the same time frame. Option 4 may require an extra 24 hours for installation.
- Option 5 (from previous slide) could cost up to 4 days or more of production. If the kiln shell replacement is the critical path for the mill to restart this translates to 4 days of makeup lime purchases for the white liquor plant.
- If the rotary kiln is not the critical path, then production costs can most certainly be reduced or eliminated.

Note - Poor fresh lime can cause downstream process issues resulting in poor performance

Thank you.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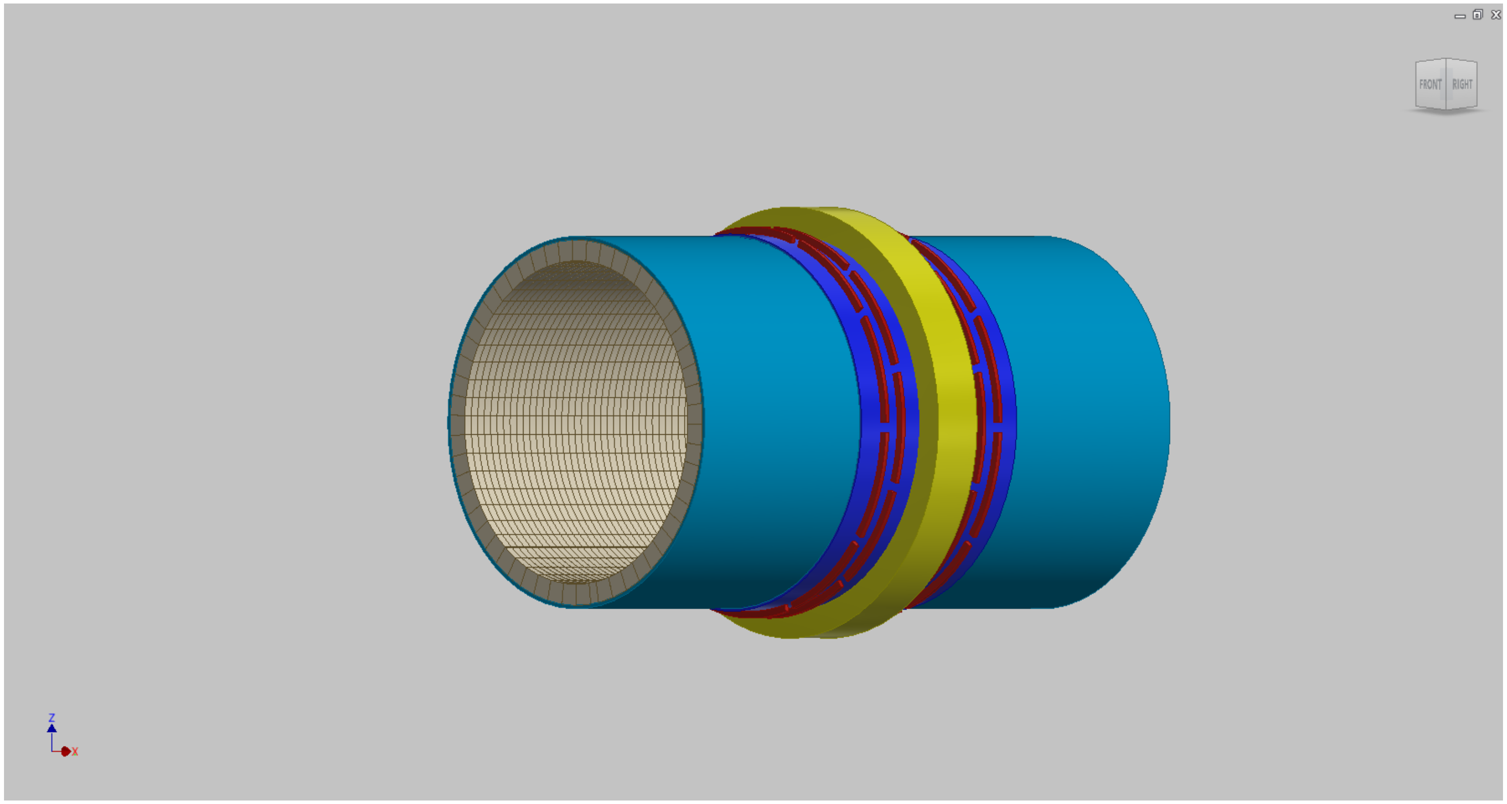
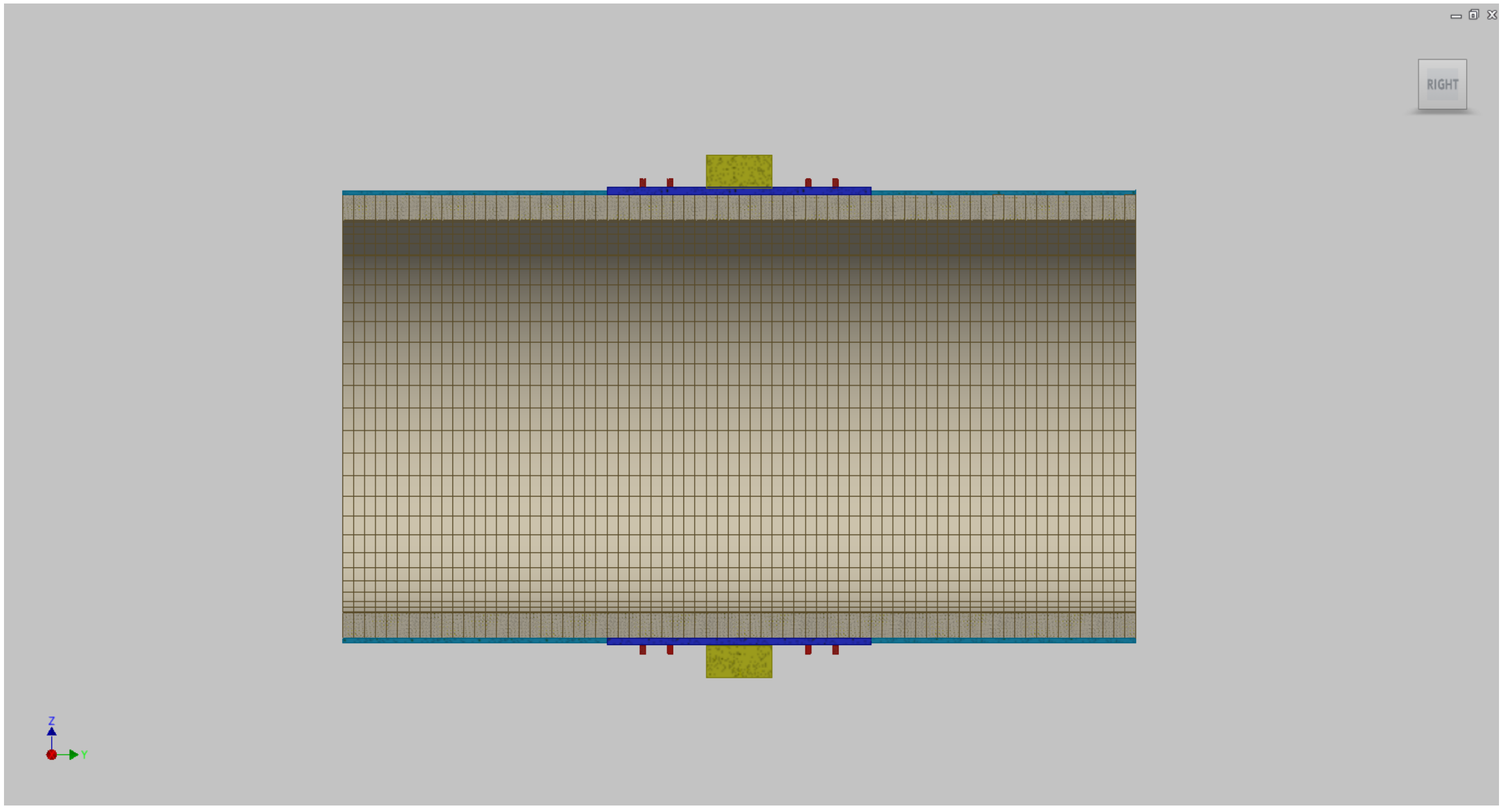
"UNBREAKABLE"
THE APPRENTICES QUICKLY
DETERMINED THAT WAS A LIE

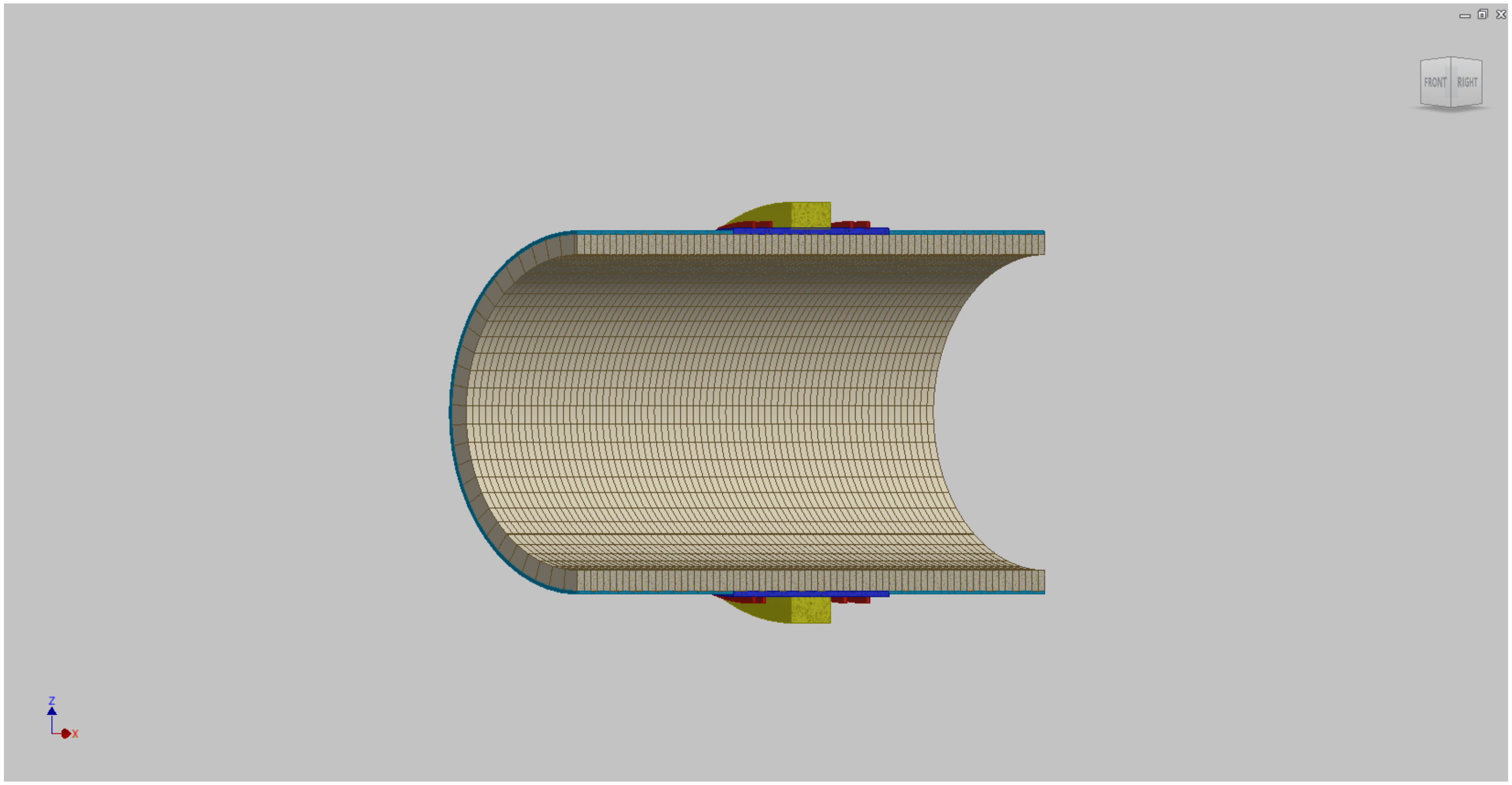
Tire Mounted Rotary Kiln



Tire Mounted Rotary Kiln

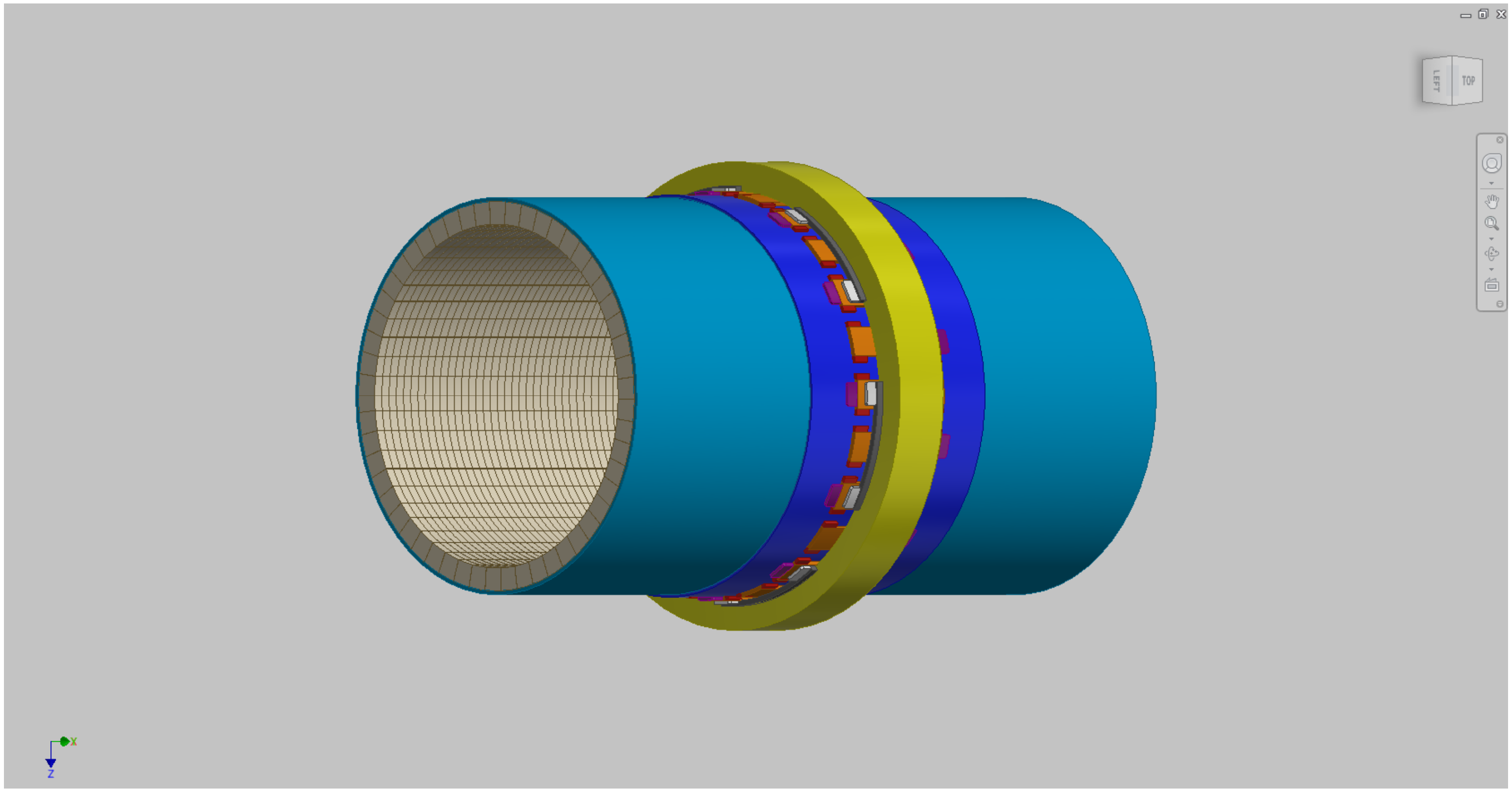


Tire Mounted Rotary Kiln



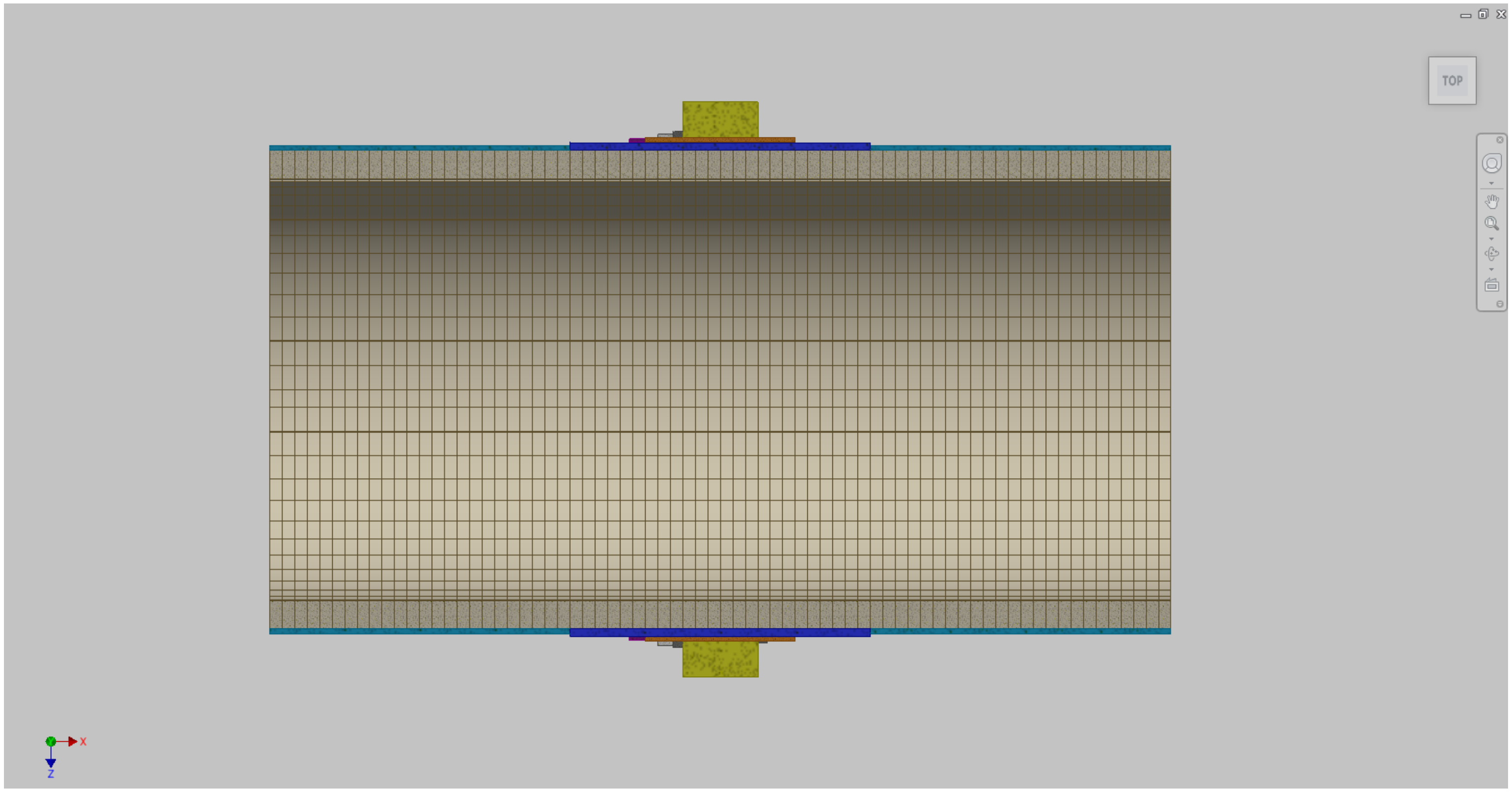
Filler Bar Mounted Rotary Kiln

Increased Tire Diameter



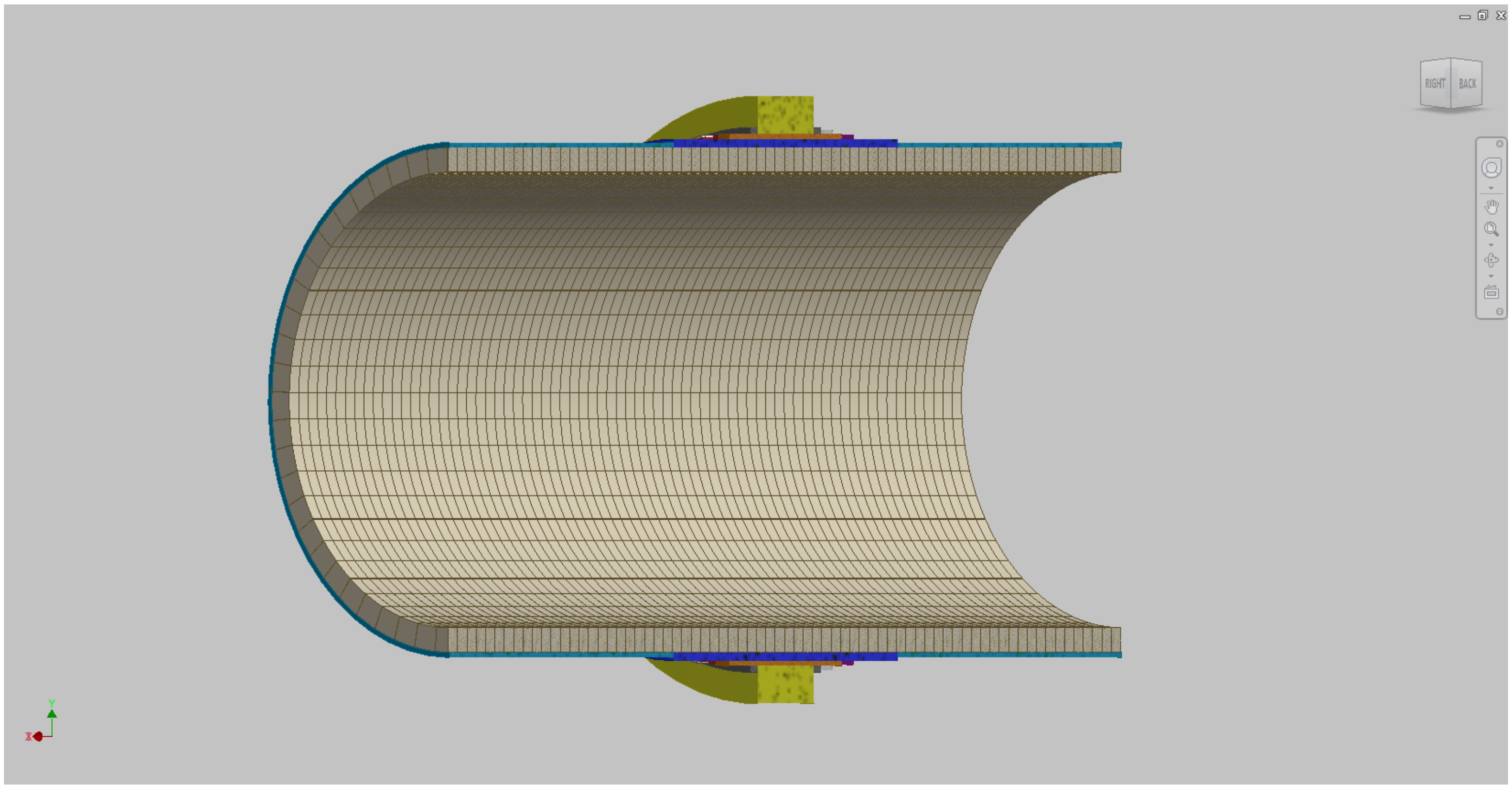
Filler Bar Mounted Rotary Kiln

Increased Tire Diameter



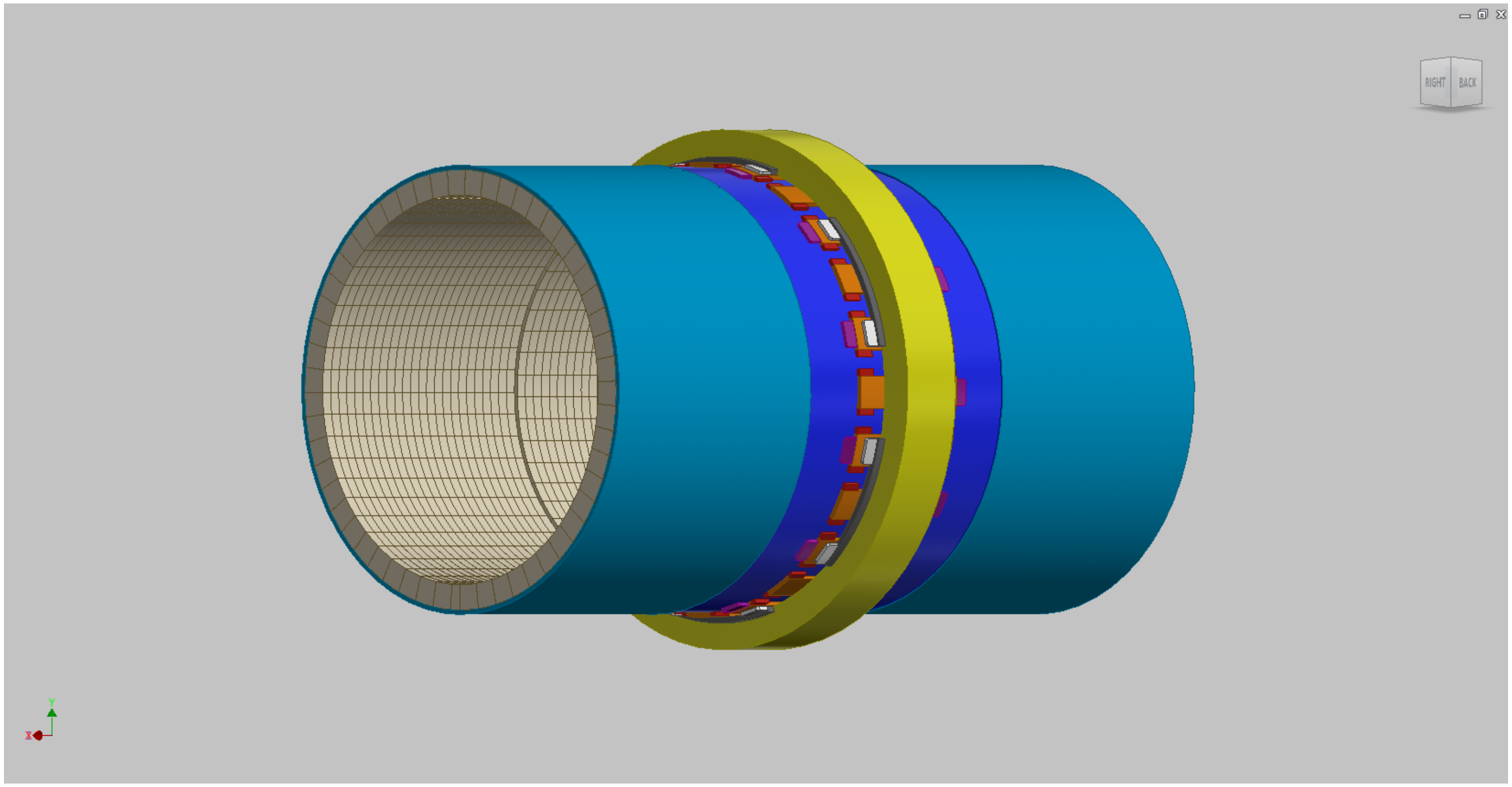
Filler Bar Mounted Rotary Kiln

Increased Tire Diameter



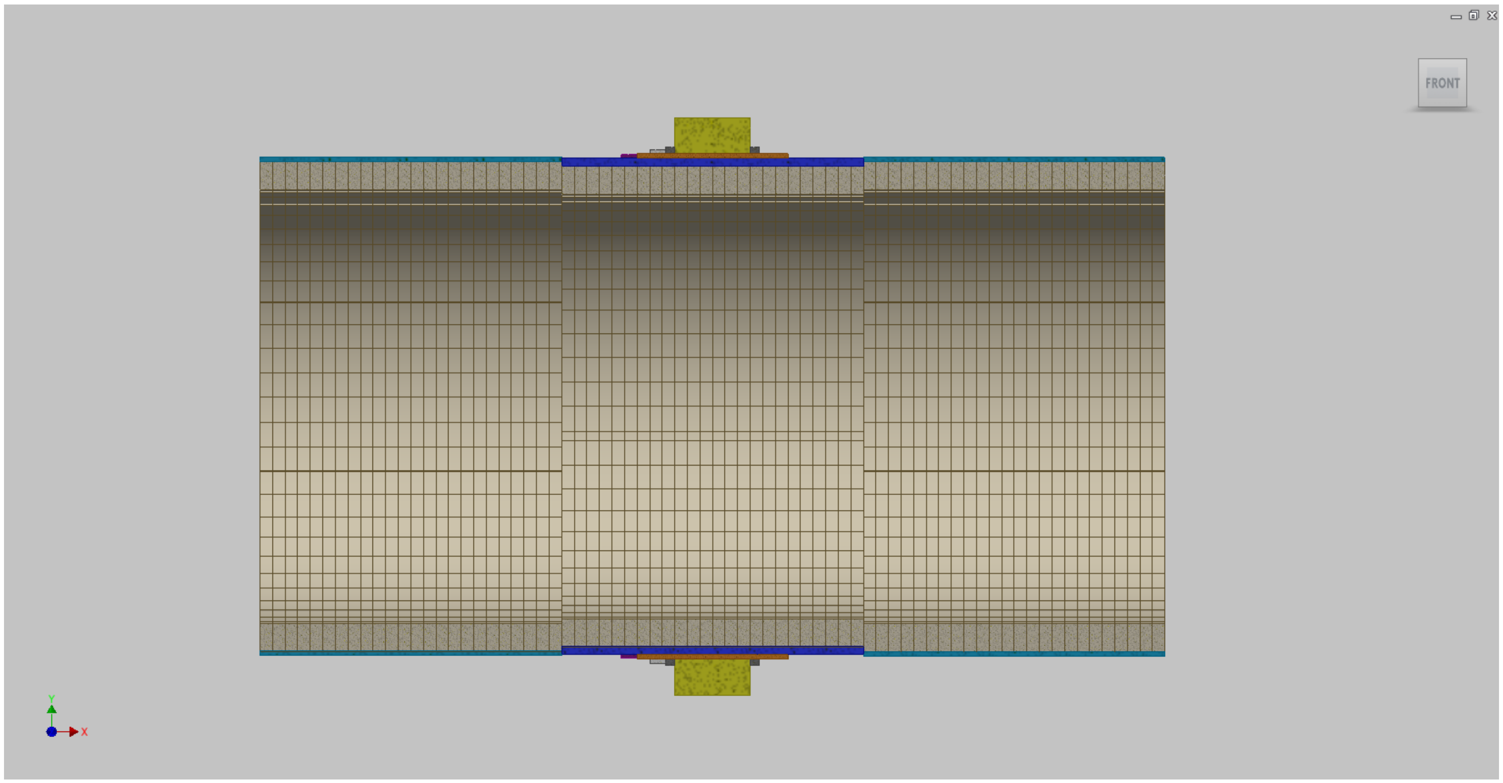
Filler Bar Mounted Rotary Kiln

Decreased Tire Plate Diameter



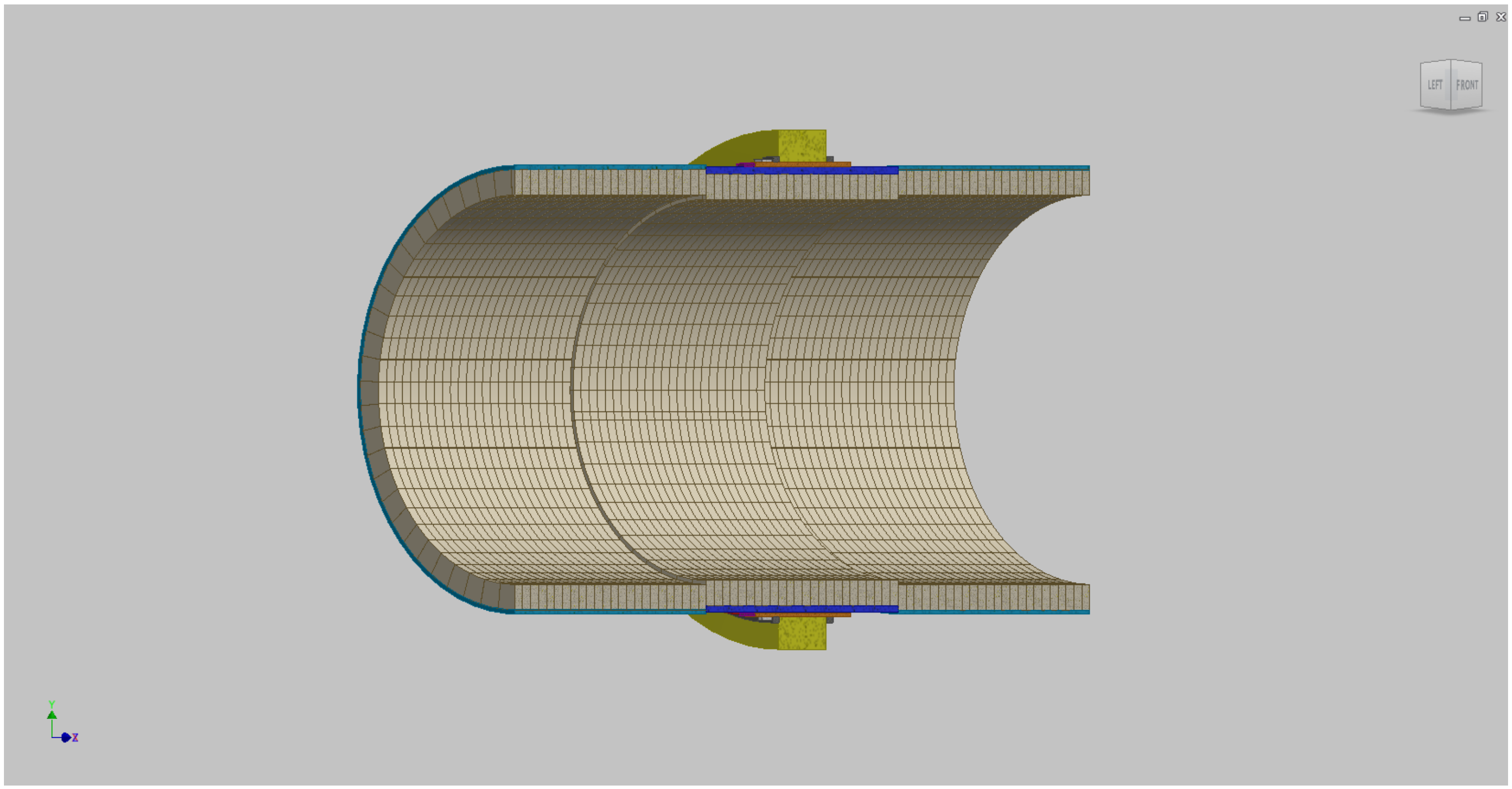
Filler Bar Mounted Rotary Kiln

Decreased Tire Plate Diameter



Filler Bar Mounted Rotary Kiln

Decreased Tire Plate Diameter



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