ROTARY KILNS AND DRYERS

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1.0 SCOPE

This data sheet contains property loss prevention guidance for rotary kilns and dryers operating above 400°F (205°C). This category includes:

- Refractory lined kilns/calciners (high temperature) used in the production of cement, lime, activated carbon, metal ore, and similar processes.
- Rotary dryers (medium temperature) used to dry such material as stone, wood chips, sawdust, fly ash, clay, potash, grain, sodium chloride, ammonium nitrate prills and similar materials.

The term “rotary kiln” is used to represent all rotary kilns and dryers described above unless stated otherwise.

The data sheet contains property loss prevention guidance for vertical kilns and vertical annular shaft kilns (VASK) operating above 400°F (205°C) used in the production of lime, dolomite, bauxite, gypsum, and similar processes. This guidance is separated from rotary kiln guidance unless stated otherwise.

This data sheet does not cover:

- Any type of rotary/stationary kiln/dryer operating below 400°F (205°C). These are considered low-temperature applications. Examples of unfired methods include steam coils, air heat exchangers, electrical resistance heaters, and direct heating using boiler flue gases. See Data Sheet 6-9, *Industrial Ovens and Dryers* or other applicable data sheets for more information.
- The mitigation and prevention of explosions within the rotary kilns and rotary dryers. Dryers processing combustible products have an inherent fire and explosion hazard not only with the combustible product but also with the release of flammable gases, vapors, and dusts during material processing. See Data Sheet 7-17, *Explosion Protection Systems* or other applicable data sheets for more information.

1.1. Hazards

Refer to Understanding the Hazard (UTH), Rotary Kilns and Dryers (P0233).

1.2 Changes

October 2025. Interim revision. Improved specific guidance for Inspection, Testing and Maintenance (ITM), Equipment Contingency Planning (ECP), and sparing. Provided updated loss history.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

The recommendations in this data sheet apply to rotary kilns, rotary dryers and vertical kilns; with cement and lime rotary kilns being the most prominent types.

2.1.1 FM Approved Products

Use FM Approved (see Appendix A for definition) fire protection equipment, building materials and assemblies, and miscellaneous equipment whenever applicable and available. Select and install FM Approved products and services in accordance with the *Approval Guide* listing. For a list of FM Approved products and services, refer to the *Approval Guide*, an online resource of FM Approvals.

Examples of FM Approved equipment applicable to rotary kilns are fuel safety shutoff valves, supervisory switches, and combustion safeguards.

Because of the size and arrangement of many of the installations, FM Approved equipment may not be available to meet specific installations or operating conditions. In these cases, select equipment from a reliable manufacturer with proven, satisfactory field experience.

2.2 Equipment and Processes

2.2.1 Combustion Safety Controls and Equipment

2.2.1.1 Purge Permissives and Fan Interlocks

2.2.1.1.1 Provide a mandatory pre-ventilation period to purge the rotary kiln, the components of the exhaust gas system, and any horizontal ductwork leading to the stack. A repurge is not needed if the rotary kiln temperature is above 1400°F (760°C). Make sure the purge:

- Consists of at least five volume changes of fresh air for a continuous period. The purge time is calculated based on the airflow rate and volume of the system.
- Provides an airflow rate of at least 25% of that required for firing at maximum output. (Measuring airflow is not necessary for this purpose; 25% damper opening or 25% fan speed is all that is needed.)

In addition, ensure that the purge time is programmed into the controller and cannot be changed by an operator. On older systems, verify that the purge time setting has not been reduced.

2.2.1.1.2 Provide interlocks to satisfy the following purge permissives before allowing the purge timer to start:

- For oils and gaseous fuels, at least one main burner and igniter safety shutoff valve is closed if over 150,000 Btuh.
- All required dampers are open to the purge position as applicable. (Interlock not necessary with manual burner operation.)
- All fans required for purging including the induced draft fans, primary air or combustion fan, cooling fans, and preheater fans are running by means of airflow/pressure sensors/switches or shaft rotation switches. Use devices that are not subject to mechanical binding if subjected to a harsh environment. Also, electrically interlock the motors to prove motors are running.
- If any permissive interlock is lost during the purge cycle, the purge must be restarted.

2.2.1.1.3 Provide interlocks to ensure that the stoppage of an induced draft fan or other required air fans (primary and secondary) shuts down any fan following it in the order of actuation (except for needed cooling fans). They should also shut off and lock out all fuel and ignition systems. If the rotary kiln main baghouse I.D. fan stops, the rotary kiln I.D. fan should stop. This sequence should stop the firing of the rotary kiln and precalciner, stop the feed and reduce cooling airflow.

2.2.1.2 Igniters

2.2.1.2.1 Interlock purge with the ignition cycle so that the ignition cycle can begin only after purge is complete.

2.2.1.2.2 Provide an additional minimum airflow interlock set at 25% of the full load mass airflow if the purge airflow rate exceeds 25% of the full load mass airflow. The additional interlock allows the airflow to be reduced to a minimum level for fuel light-off if the purge flow is higher than this. All fan interlocks must be satisfied before and during the ignition period.

2.2.1.2.3 Provide igniters that can promptly ignite the main burner at startup. Solid fuels such as pulverized coal can be ignited by the warmup burner. On older rotary kilns where the warmup burner is ignited manually, do not allow the fuel to enter the combustion chamber more than approximately 10 seconds if it does not ignite. Allow at least one minute between attempts to lightoff and assure airflow is proper for lightoff. Igniters might be impractical on precalciners burners that do not have a detectable flame. Some burner designs may require a low fire start interlock to help ensure an optimum fuel-air mix near the pilot flame. Ignition energy requirements will vary, depending upon the location of igniter with respect to the main burner, main burner fuel input, and the firing conditions for which igniter operation is required, e.g., interrupted, intermittent, or continuous operation. Refer to Data Sheet 6-4 *Oil- and Gas-Fired Single-Burner Boilers*.

2.2.1.2.4 Preferably use an interrupted pilot that deenergizes when the main flame trial-for-ignition period is over. If an intermittent pilot is used, provide separate flame supervision. If a Class 1 igniter is used (ignition energy is at least 10% of the main fuel input), it is only necessary to supervise the pilot flame.

2.2.1.2.5 Install igniters and flame sensing element(s) securely so that the position of each with respect to the main flame will not change. Provide observation ports so that these positions can be easily observed when igniter and/or main burner are firing. These units should be readily accessible for inspection and cleaning.

2.2.1.2.6 Provide an interlock to prove automatic retractable igniters are fully inserted before the ignition cycle can proceed.

2.2.1.2.7 All fuel interlocks must be satisfied before the ignition cycle can proceed.

2.2.1.3 Flame Supervision

2.2.1.3.1 Provide combustion safeguards and flame scanners to supervise the pilot and main burner flames, and to provide an acceptable sequence of operation during purge, ignition, firing and shutdown.

2.2.1.3.2 Arrange the combustion safeguard to shut off all fuel supplies and ignition sources whenever any interlock is not satisfied. Flame scanners can be bypassed when the rotary kiln operating temperature is stabilized above 1400°F (760°C); provide an interlock to prohibit bypassing below this temperature and to activate scanners if the temperature drops blow this value. Poor combustion is not always recognized by a flame scanner; operators must be relied upon to verify proper combustion.

2.2.1.3.3 Use optical (infrared) pyrometer/color TV cameras in lieu of flame scanners where harsh conditions (e.g., dusty environments) make the use of flame scanners impractical. Air can be used for cooling scanners and can help to keep scanner cells clear of dust.

2.2.1.3.4 For manual operations, follow procedures to ensure proper purge and other conditions necessary for a successful lightoff.

2.2.1.3.5 Use oxygen, carbon monoxide, carbon dioxide and combustible analyzers as an operator aid to help determine if combustion conditions are safe both during warmup and normal operation. These types of devices can be found at the back end of the rotary kiln, and in the precipitator. Continuous emissions monitoring (CEM) of the exhaust may also be required by environmental regulatory agencies such as the EPA.

2.2.1.3.6 Prove igniter flame at a location where it will effectively ignite the main burner. A main burner should ignite immediately, even when the igniter is reduced to a minimum of flame capable of holding the flame sensing relay of the combustion safeguard in the energized (flame present) position.

2.2.1.3.7 Limit the pilot trial-for-ignition period to 10 seconds for gaseous fuels and light oils, and 15 seconds for heavy oils (no. 5 and no. 6).

2.2.1.3.8 Limit the main flame trial-for-ignition to 15 seconds for heavy oils. Limit the main flame trial-for-ignition to 15 seconds for gaseous fuels and light oils, if the fuel input is 2,500,000 Btuh or less; limit it to 10 seconds if the fuel input is greater than 2,500,000 Btuh. If extra time is needed for fuel to travel through a long burner pipe, the trial-for-ignition period can be increased to account for this.

2.2.1.3.9 A recycle type of combustion safeguard with one attempt to reignite (recycle) is permitted on automatic-lighted burners for units with a fuel input of 2,500,000 Btuh or less.

2.2.1.4 Safety Shutoff Valves (Oil and Gas)

2.2.1.4.1 Install two safety shutoff valves, one with proof-of-closure, for each gas- or oil-fired main burner and fuel-fired igniter greater than 400,000 Btuh fuel input (one valve with proof-of-closure from 150,000 Btuh to 400,000 Btuh).

2.2.1.4.2 Provide permanent and ready means for making periodic tightness checks of the main gas safety shutoff valves. This can be accomplished manually using test cocks downstream of each valve, or automatically by means of a device which does a pressure test between the safety shutoff valves at each startup and shutdown.

2.2.1.4.3 For a multiburner arrangement where the burners operate as a single system, provide two safety shutoff valves, one with proof-of-closure, or one main safety shutoff valve with proof-of-closure and one safety shutoff valve for each burner. It is desirable to have safety shutoff valves located as close as possible to the burners. If the distance between the main safety shutoff valves and a burner is more than approximately 10 ft (3 m), consider installing an individual safety shutoff valve at the burner.

2.2.1.5 Fuel Interlocks

2.2.1.5.1 Provide high and low pressure interlocks for gas and low pressure interlocks for oil (where the oil pump is not integral with the burner assembly) for both main and igniter fuel supplies (if the igniter fuel input is greater than 2.5 million Btuh or is not an interrupted type). Set switches at no more than 150% of normal pressure for high pressure, and no less than 50% of normal pressure (just after the regulator) for low pressure. Interlock with the fuel safety shutoff valves. See Figures 2.2.1.5.1-1 and 2.2.1.5.1-2

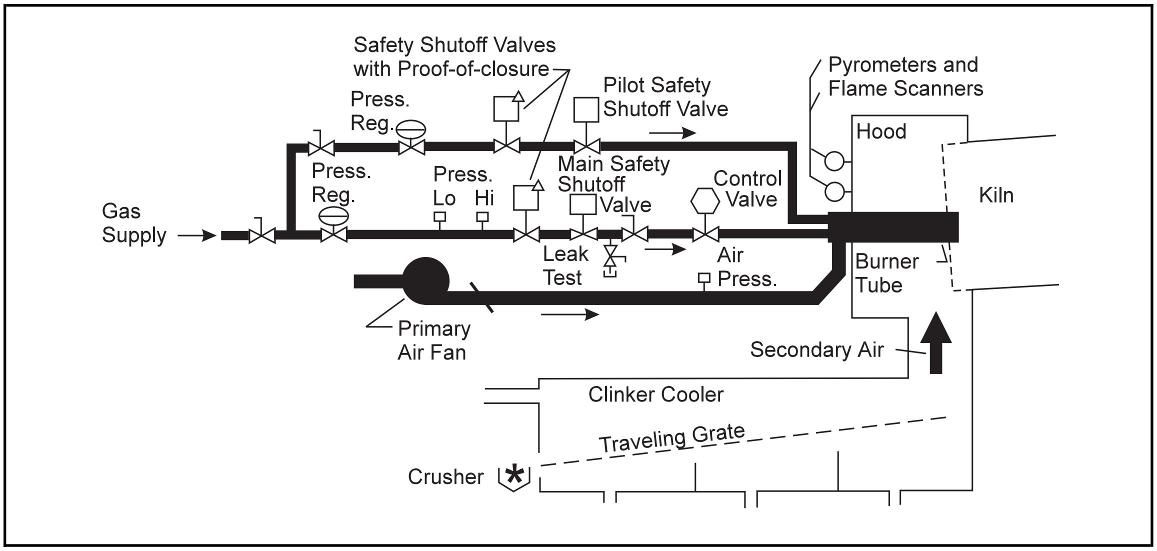


Fig. 2.2.1.5.1-1. Typical natural gas-fired burner arrangement.

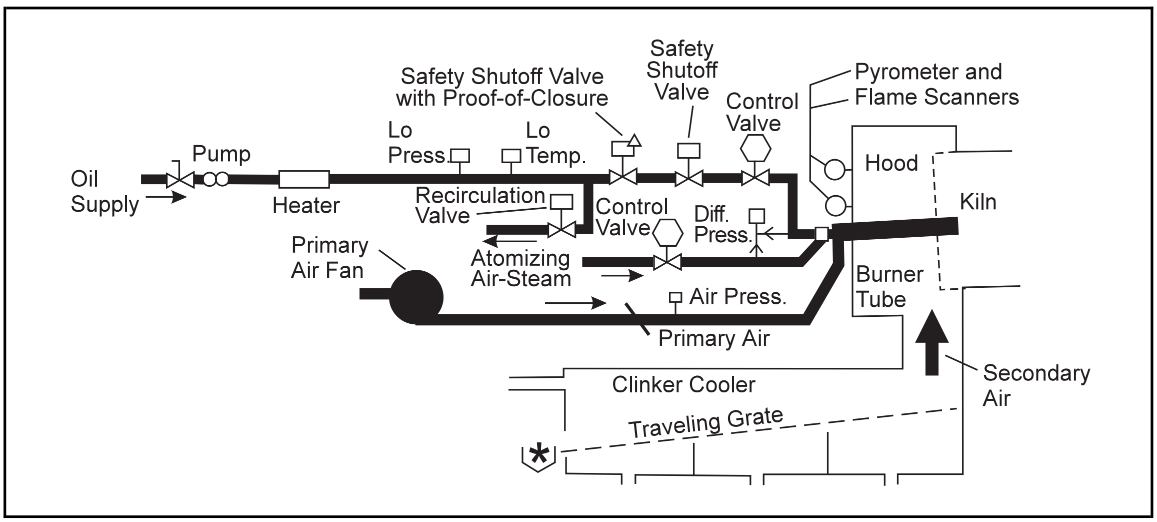


Fig. 2.2.1.5.1-2. Typical oil-fired burner arrangement. The igniter is not shown. See Figure 2.2.1.5.1-1 for a typical igniter arrangement.

2.2.1.5.2 Provide a low atomizing pressure or atomizing medium-oil differential pressure interlock for steam- or air-atomized fuel oil burners. This prevents fuel oil from entering the burners when the atomizing medium is lost or impaired.

2.2.1.5.3 Provide a low and high temperature interlock for oil that must be heated for proper atomization. A low temperature condition should result in shutting off the supply of oil to the burner. A high oil temperature condition should result in either shutting off the supply of heat to the oil heater or bypassing the heater to avoid overpressurization of the oil piping. If there is a constantly attended control room, these interlocks can be used for alarm purposes only, giving the operator time to take corrective action.

2.2.1.6 Pulverized Coal-Fired Burners

2.2.1.6.1 Provide gas- or oil-fired pilots or igniters to ensure the pulverized coal ignites reliably. A Class 1 igniter is preferred, but a Class 2 igniter should be provided as a minimum. Pulverized coal can be ignited by the warmup burner that is used to bring the rotary kiln up to normal temperature. See Figure 2.2.1.6.1.

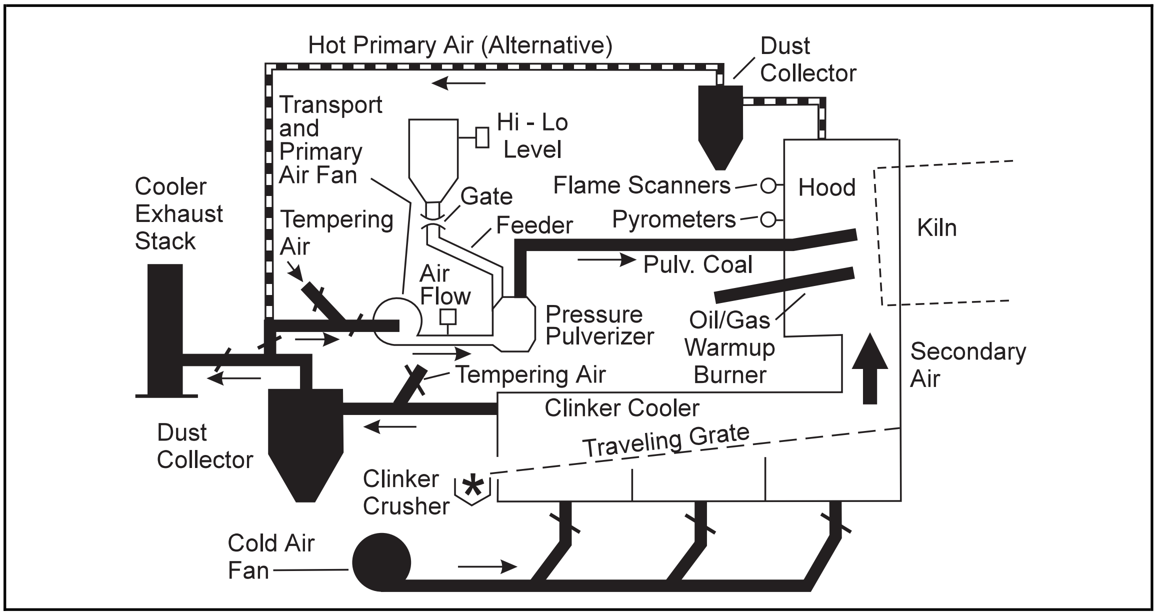


Fig. 2.2.1.6.1. Typical coal-fired burner arrangement.

2.2.1.6.2 Provide flame supervision for the pulverized coal burner. Two flame scanners may be arranged so that either one will alarm when flame outage is detected. Detection of flame outage by both should cause a burner trip. Upon loss of all flame from the igniters, supplementary burners and the pulverized coal burner, a master fuel trip of all fuel inputs should be activated.

In some types of rotary kiln burner systems, such as cement, providing flame supervision for the pulverized coal-fired burner can be difficult or impractical. The combined interference of the clinker dust and unburned pulverized coal prevents the infrared or ultraviolet detectors from operating reliably without nuisance shutdowns.

For these types of rotary kiln burner systems, provide flame supervision for the gas or oil igniters in main burners at least until the main combustion zone is heated above 1400°F (760°C) and the pulverized coal burner combustion has stabilized. Above 1400°F (760°C) the temperature of the combustion zone is an ignition source for most fuels including gas, oil, and pulverized coal, and the flame scanners can be bypassed. Provide a temperature interlock to act as a permissive for bypassing; if temperature drops below 1400°F (760°C), the flame scanner logic should automatically come back online.

Pyrometer or TV camera monitoring of the burner flame can be used in lieu of conventional flame scanners after the warmup period when above 1400°F (760°C). For some rotary kilns, this might be a more practical type of flame monitoring. Flame shape is particulary important not only for proper rotary kiln operation, but also for refractory life. This type of flame monitoring will help the operator to better control the flame shape.

2.2.1.6.3 Provide interlocks to ensure operation in the order given below. If failure occurs during the sequence, interlocks should automatically shut down all the equipment in the order of operation.

1. Start the induced draft, forced draft (or secondary air) and recirculation fans, and open dampers to purge the rotary kiln, coolers, preheaters, and exhaust processing equipment. Some ancillary equipment may be purged and started as an individual unit when isolated from the rotary kiln system.
2. Purge according to Section 2.2.1.1.
3. Start direct-fired air heaters where provided. Appropriate combustion safety controls should be provided for the air heater burner systems.

4. Start the gas or oil igniters.
5. Start the primary air fan.
6. Start the coal pulverizer.
7. Start the coal feeder. Adjust the coal feed to the burner for the equivalent of a low fire start.

2.2.1.7 Alarms, Indicators, Combustible Analyzer Interlocks and Communication

2.2.1.7.1 Provide adequate means for communication between the control center and the rotary kiln and preheater burners, raw material feeder, and coolers. This is especially important on remote controlled units. Public address systems, plug-in telephone units, carrier current, and two-way portable radios may be used. Explosions can occur if the activities of the equipment operator at the burners are not communicated to the control center operator. This is particularly true during critical operations such as lighting-off, bringing the unit up to temperature, or during upset conditions involving flame instability.

2.2.1.7.2 Monitor the status of operating equipment, including position of valves, vital damper settings, rotational speed, raw material feed, and other operating conditions. This will allow the operating situation to be evaluated.

2.2.1.7.3 Provide adequate annunciators and alarms to aid normal operation and warn operators of abnormal conditions developing. Provide alarm systems that give both audible and visual indication of abnormal conditions. Means may be provided to silence the audible alarm, but the visual indication should remain until the condition has returned to normal.

1. Provide ‘‘First Out’’ indication for all safety interlocks that will initiate a fuel trip to help the operator determine the initiating condition.
2. Provide similar interlocks to initiate an alarm when off-normal conditions are detected that would result in a burner trip if left uncorrected. Although not required as a tripping interlock, important alarms in this category include failure of a burner valve to close following a burner trip; loss of power to combustion control system; loss of rotary kiln drive system and loss of raw material feed.
3. Provide oxygen and combustible analyzer-recorders to monitor the rotary kiln exit flue gas. Alarm at 5000 ppm combustibles, or 2000 ppm carbon monoxide (CO) if the analyzer detects only CO and not hydrogen (or methane (CH_4) when burning coal). Attention must be given to this type of instrument to consider it reliable. Some analyzers do not respond very quickly, especially if sampling lines are too long or are plugged. Analyzers can give poor readings if any air leaks into the back end of the rotary kiln or into the sampling line, causing dilution of the sample. See Data Sheet 6-11, *Thermal and Regenerative Catalylic Oxidizers* and Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems*, for recommendations on combustible analyzer maintenance.
4. When an electrostatic precipitator (ESP) is provided on the rotary kiln exhaust system, depower the precipitator preferably at 1% (10,000 ppm) flammable gas concentration and no more than 2% (20,000 ppm) maximum. If the analyzer only detects CO, the above levels should be reduced by half because the total flammable content might be more than double that of the CO level. The LEL of the gas mix will be much lower than that of CO alone. Also reduce the alarm and trip setpoints if the response time is more than 10 seconds. A response time of two to three seconds is considered very good. If the percentage of LEL is used as a unit for alarm readouts rather than parts per million, the setpoints should also consider that the LEL is lowered (about 20% should be adequate) due to elevated temperatures of the exhaust gas. Consider shutting down the burner system when 2% flammable gas concentration is detected. Oxygen should be sensed in the precipitator and alarmed at 5%. Oxygen levels of 8% or higher significantly increase the explosion potential. Air leakage will cause such high O_2 levels in the ESP. During startup and shutdown, O_2 levels will normally be high.
5. Monitor the rotary kiln drive motor for amperage. Activate an alarm if the amperage exceeds the maximum full load for more than 20 seconds. High amperage can indicate increased load. This condition can be caused by excess coating buildup inside the rotary kiln (for refractory-lined with coatings) or improper raw material mix but can also be caused by mechanical problems. Excess coating will increase temperature, and the burner fuel must be cut back. In a cement rotary kiln, if the clinker load liquifies, a reaction breaks down the refractory and overheats the shell. On dual drive rotary kilns, the amperage difference between the two drive motors should be within a tolerance specified by the manufacturer.

6. Monitor product feed rate versus fuel input (for temperature control).
7. Alarm dry feed level on the feed conveyor where applicable; low level could result in a feed interruption. For slurries, monitor feed tank level, scale weight and flow to the rotary kiln.
8. Monitor bearing temperatures of critical components such as the carrying rollers, drive gear set and I.D. fans.
9. Monitor vibration of critical fans and motors or take readings by hand monthly. This is particularly important for I.D fans subject to dust buildup on the blades. Vibration trending should be used in making decisions to perform maintenance. Vibration limits should be specified by the equipment manufacturer.

2.2.2 Temperature Control

2.2.2.1 Monitor the outside of a refractory-lined rotary kiln shell for temperature along its full length, including under the shroud at the discharge end. A traveling or rotating infrared camera permanently mounted outside the rotary kiln is commonly used for this purpose. Shut down the rotary kiln if the shell temperature is excessive.

2.2.2.2 Install a temperature sensor or pyrometer in the rotary kiln burning zone or dryer combustion chamber. Doing so will assure normal operating temperature before startup of raw material feed, monitor temperature during normal operation, provide a process control input for automated systems and to provide a signal to a high temperature cutout. For calcining rotary kilns, the temperature in the drying and calcining zones must also be monitored for process control and early detection of upset conditions. Feed temperature or gas temperature can be monitored depending on the depth of the thermocouple well. Normally gas temperature will be monitored at the cooler end of the rotary kiln.

2.2.2.3 Monitor rotary kiln back-end gas temperature. Temperature should be steady for a constant material feed. Rotary kiln stability is closely related to back-end temperature in a calcining rotary kiln.

2.2.2.4 Interlock exhaust temperature to open the exhaust cooling water flow valve (if so equipped) wide on excess temperature, and to depower the electrostatic precipitator and shut off the supply of fuel to the rotary kiln.

2.2.2.5 Install thermocouples on the discharge side of the rotary kiln cooler. These monitor product discharge (such as clinker) temperature or ambient air temperature above the product or clinker. They also alarm upon high temperature (about 10% over normal) of the feed leaving the cooler and discharging to a conveyor. A high, high temperature (about 20% over normal) condition should be interlocked to stop product or clinker discharge from the cooler and divert it to a bypass chute. Normal temperature is typically about 150°F (65°C).

2.2.2.6 Monitor primary air temperature for ignition/flame stability, combustion efficiency, fuel efficiency and nitrogen oxide emission control. Monitor secondary air temperature for energy recovery, thermal balance, burner performance and process diagnostics (to identify a cooler issue or air leakage).

2.2.3 Preheaters/Precalciners

2.2.3.1 Protect fired preheater combustion equipment according to Section 2.2.1. Fuel injection into a precalciner might not produce a visible flame, however, the stabilizing burner should be equipped with flame supervision at least during warmup if practical. Fuel injection flow should also be monitored. Use a thermocouple if flame scanning is impractical.

2.2.3.2 Install a high temperature switch/sensor interlocked to shut off the supply of fuel to a fired preheater/precalciner. If the preheater outlet temperature exceeds its setpoint, stop precalciner firing and reduce or stop rotary kiln firing.

2.2.3.3 Monitor flow of feed material through the preheater and alarm high/low feed flow conditions. Control of raw materials is important. For example, high alkalis, chlorides and sulfates in the raw material for a cement process can contribute to plugging of the preheater. Bypassing some of the rotary kiln exit gases around the preheater sometimes controls alkalis (See Figure 2.2.3.3). Some alkalis are needed to promote coating formation.

2.2.3.4 Alarm all fans for low airflow including the bypass gas fan and quench air fan as applicable. Also monitor and alarm secondary airflow through cooler recoup and branch ducts as applicable. Damper and variable orifice positions should be monitored.

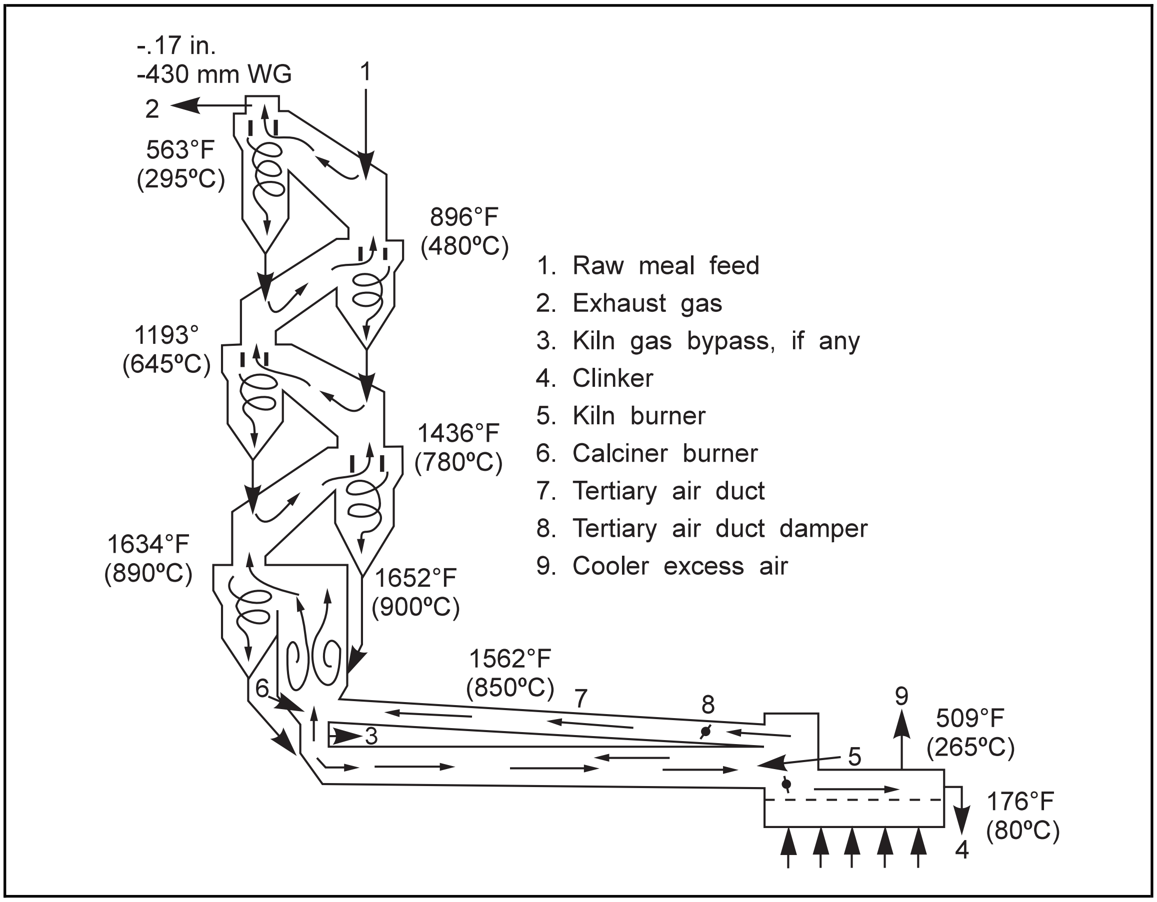


Fig. 2.2.3.3. A five-stage suspension preheater system with an in-line calciner for a dry-process rotary kiln. Courtesy of the Fuller — F.L. Smidth Co.

2.2.3.5 Monitor and alarm fired preheater exit gas for O_2 out of range (limits set by the manufacturer) and high CO (2000 ppm).

2.2.4 Grate Type Outlet Coolers

2.2.4.1 Monitor/alarm the cooler for high undergrate pressure. High pressure indicates increasing product (clinker) depth and improper cooling.

2.2.4.2 Maintain slightly negative hood air pressure above the grate using cooler exhaust damper control. If secondary air temperature becomes dangerously high, it might be necessary as a last resort, to introduce extra cooling air into the cooler. This will result in positive pressure.

2.2.4.3 Maintain control of cooling air and grate speed such that the grates, cooler drive, clinker crusher and cooler walls do not become overheated.

2.2.4.4 Alarm for loss of cooler grate speed. For dry rotary kilns, if the cooler stops, the rotary kiln should shut down.

2.2.4.5 Alarm the clinker breakers/hammermills for low rotational speed.

2.2.5 Product Discharge Belt Conveyors

2.2.5.1 Protect conveyors against fire in accordance with Data Sheet 7-11, *Conveyors*.

2.2.5.2 Monitor product conveyors for excessive temperature. High (H) temperature should cause an alarm. High-high (HH) temperature should be interlocked to either activate cooling water spray or direct material exiting the rotary kiln cooler away from the conveyor. Shut down the rotary kiln as a last resort or if the conveyor stops. If the rotary kiln is shut down, engage the auxiliary drive.

2.2.5.3 Replace worn conveyor belts because frayed belts are more easily ignited.

2.2.5.4 Interlock and alarm conveyor belts for speed. A loss of belt speed should divert discharge away from the conveyor, or shut down the rotary kiln, including the material feed, the supply of fuel and discharge from the cooler. The auxiliary drive must be engaged if the rotary kiln is shut down.

2.2.5.5 If a combustible belt conveyor is used rather than a noncombustible conveyor such as a pan or plate type conveyor, use a high temperature belt material. It is preferable to arrange the conveyor such that the belt is turned over each time around, allowing for better cooling of the belt.

2.2.6 Waste Incineration and Oxygen Enrichment

2.2.6.1 Interlock waste fuel (such as tires, medical waste, noncondensable gases [NCGs], turpentine byproducts etc.) feed with temperature. The rotary kiln should be at normal operating temperature (1400°F [760°C] minimum) before starting waste fuel feed.

2.2.6.2 Provide safety shutoff valves (per Section 2.2.1.4) interlocked with temperature, and fuel interlocks (per Section 2.2.1.5) for gaseous and liquid fuels. For solid fuels, provide gates interlocked with temperature.

2.2.6.3 Provide two safety shutoff valves for oxygen injection lines. Interlock with the main fuel safety control circuit and with high/low temperature. Also provide a pressure regulator and high pressure switch interlocked to shut off the supply of oxygen. The rotary kiln should reach operating temperature (1400°F [760°C] minimum) before oxygen feed to the rotary kiln is permitted. Monitoring back-end O_2 is important.

2.2.6.4 On NCG systems, provide a flame arrester as close as possible to the rotary kiln burner. On low volume high concentration (LVHC) systems, provide rupture disks in the ductwork spaced at a distance less than the ‘‘run up’’ distance for transition to detonation.

2.2.7 Vertical and Annular Shaft Kilns (non-rotating)

2.2.7.1 Protect combustion equipment according to Section 2.2.1.

2.2.7.2 Inspect support members and perform NDE (VT, MT, or UT) on support member welds at a frequency determined by the kiln’s asset integrity program or every five years if practical. Pay particular attention to support beams that hold inner cylinders in place. Inspect the combustion chamber support members for damage and cracking if the refractory that insulates these members is damaged and when refractory is being replaced.

2.2.7.3 Inspect refractory for damage and thinning during shutdown periods.

2.2.7.4 Monitor the vertical/VASK kiln for product plugging and temperature.

2.3 Electrical

2.3.1 For electrical installations, conform to NFPA 70, the National Electrical Code (NEC®) or other locally accepted code.

Note: NEC® is a copyrighted publication of the National Fire Protection Association (NFPA), Quincy, MA 02269.

2.3.2 Ensure both AC and DC safety control circuits are two-wire types, one side grounded, and not over nominal 120 volts (in the U.S.) or the voltage specified by local standards. Ensure all safety control switching is in the hot ungrounded conductor and overcurrent protection is provided. In addition, ensure noncurrent carrying metal parts, such as equipment enclosures and conduit, are grounded.

2.3.3 In unusual cases where an ungrounded DC power supply cannot be avoided, locate all switching in one conductor and provide ground fault protection.

2.3.4 Contain electrical equipment in dust-tight enclosures when exposed to a dusty environment to prevent malfunction of electrical contacts. Burner front areas are not normally classified as hazardous.

2.4 Protection

2.4.1 Arrange fuel supplies safely as outlined in the following data sheets:

- Data Sheet 7-32, *Ignitable Liquid Operations*
- Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tank*
- Data Sheet 7-54, *Natural Gas and Gas Piping*
- Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) Storage in Stationary Installations*
- Data Sheet 7-4, *Paper Machines and Pulp Dryers*
- Data Sheet 6-13, *Waste Fuel-Fired Facilities*
- Data Sheet 8-10, *Coal and Charcoal Storage*

2.4.2 Keep the gaseous and liquid fuels free from all foreign matter. Remove welding beads, chips, scale, dust and debris from both newly installed fuel piping and piping that has been opened for alteration or maintenance. Install suitable strainers, filters, drip legs, etc. Vent air from piping to prevent difficulty lighting off.

2.4.3 Provide each oil- or gas-fired burner with a manually-operated fuel shutoff valve for emergency closing in case of fire. Prominently mark the valve and locate it for easy access, preferably outside the firing building.

2.4.4 Recognize the fire hazards of oil piping leaking or rupturing near the burner. Pay particular attention to flexible connections, hoses, swivel joints, etc. Housekeeping is important to minimize the combustible loading in the area where a leak could occur.

2.4.4.1 Inspect braided oil hoses periodically according to manufacturer's recommendations, and commit to a replacement frequency based on usage and consultation with the hose or burner manufacturer.

2.4.4.1.1 If the OEM supports the upgrade, replace combustible (e.g., rubber) hoses with double-braided, noncombustible hoses during the next periodic replacement of the hoses.

2.4.4.1.2 Older hoses may not flex properly and may cause leaks to develop at threaded connections in the fuel piping, especially if there are 90 degree bends. Hoses that are bulged, stiff or corroded may indicate this condition. Hoses are subject to both tensile and compressive stresses, to internal pressure, and to the extremes of temperature, vibration, corrosive atmospheres, physical impact and reactive forces. Replace hoses that are in poor condition (wear, excessive bend, etc.).

2.4.4.2 Use double braided, noncombustible hoses. Hoses should be designed for the oil being fired and should be capable of withstanding four times the normal maximum operating pressure. Hose couplings and fittings and minimum bending radius should be in accordance with manufacturer's instructions. If 90 degree bends are necessary, use 90 degree elbows. Valves should be installed upstream of hoses. Flexible hoses are a likely place for a fuel leak to develop and should be examined carefully.

2.4.5 Provide portable dry chemical or CO_2 fire extinguishers for manually fighting liquid fuel fires at the burner hood. Also, provide a small hose station located out of the weather, or a hydrant with hose and nozzle located in a housing near the discharge end of the rotary kiln.

2.4.6 Provide fire protection at oil- or other liquid fuel-fired burners that are located indoors. Automatic sprinklers, or a water deluge system activated from the control room, can be used. Consider the potential for freezeup when deciding what type of fire protection scheme to use. For density requirements, refer to Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*.

2.4.7 Provide a heat detector above oil burners if fire protection is not provided. Select a temperature rating approximately 50°F (30°C) above the highest anticipated ambient temperature. The detector may be wired as an interlock into the combustion safeguard circuit, or as an alarm to an annunciator panel in a constantly attended control room. Operators should have the ability to remotely secure the flow of oil to the rotary kiln. If nuisance tripping caused by faulty detectors is a concern, two detectors mounted at the same location may be wired such that the activation of one detector will bring in an alarm, and activation of both detectors will cause a trip. Detectors should have visible indication to show when one has been activated.

2.4.8 Provide automatic sprinkler protection or another acceptable method of cable fire protection, such as Approved fire protective coating, inside cable tunnels located beneath kilns. Refer to Data Sheet 5-31, *Cables and Bus Bars*.

2.4.9 Do not keep ignitable liquids including bearing oil for the carrying rollers inside piers unless stored properly.

2.4.10 For wood chip rotary dryer systems, refer to Data Sheet 7-10, *Wood Processing and Woodworking Facilities* for fire and explosion detection/protection recommendations. Spark detection/extinguishing, equipment water spray deluge, high temperature interlocks and process isolation are needed. Install separators to remove heavy or metallic particles from the dryer feed, particles that could cause impact sparks.

2.4.11 Install thermocouples inside rotary dryers and bakers to detect temperature excursions and fires. Install them also inside off-gas ducts leading from these units to incinerators. If it is impractical to install thermocouples inside, monitor the inlet and exit temperatures.

2.5 Operation and Maintenance

2.5.1 General

Establish and implement a rotary kiln inspection, testing and maintenance (ITM) program in accordance with Table 2.5.2. This table is a guide and may not encompass all required activities for a specific rotary kiln. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program.

2.5.2 Rotary Kiln ITM Strategy

For rotary kilns, major breakdowns are often avoidable through the proactive identification of minor issues. Early identification and corrective action before a breakdown occurs is key to maintaining rotary kiln integrity, particularly for areas of the rotary kiln subject to high stress during operation. Defective equipment or poor maintenance can result in more frequent maintenance intervals, requiring equipment shutdown or the removal of control components from service. Out-of-service control components increase the exposure of the unit to operating hazards.

Section 3.1 has more information on the basis for these ITM activities.

Appendix E has a sample of a rotary kiln inspection plan for three scenarios: operating, shutdown and dismantled.

The ITM activities in Table 2.5.2 below are sorted from most to least frequent.

Table 2.5.2 Rotary Kiln Inspection, Testing and Maintenance

Parameter	*Frequency*	*Activity*	*Acceptance Criteria*	*Additional Information*
Shell and Riding Ring (Tire) Temperature	Continuous	Remotely Monitored from Control Room. Data is automatically recorded to the OT network. Throughout shift, Control Room checks temperature profile. Periodically looks at historical trends, particularly related to investigating a degraded condition.	Compare baseline temperature profile to current temperature readings. Compare the margin from alarm setpoints. Temperature readings should be consistent over time; degraded trends identified for corrective action. For example, reduce temperature excursions by placing cooling fans under the shell.	Thermography cameras scan the length of the kiln including under the shroud. Temperature elements (probes) may be used in lieu of a camera, particularly under the shroud where a camera installation may not be feasible. For riding rings, an increase in temperature can be an indicator of reduced creep. For the shell, used primarily for assessing refractory health and functionality. An increase in temperature can be an indicator of refractory thinning or dislodgement.
Main Drive Motor Amperage	Continuous	Remotely Monitored from Control Room Data is automatically recorded to the OT network. Throughout shift, Control Room checks amperage. Periodically looks at historical trends, particularly related to investigating a degraded condition.	In steady state operations, motor amps should remain constant.	Increase in motor current draw could be a result of increased friction, binding, or other failure mechanisms the motor must overcome to maintain kiln speed.
General Inservice Inspection	Daily	Routine Operator Walkdown: Visual, auditory, checking oil levels, grease adequacy and logging key local indicators.	No new degraded conditions since the last routine inspection. Can include a previously identified issue getting worse, wear, cracks, high temperature, vibrations, foreign material on mating surfaces, lubrication loss/ contamination, uneven contact/alignment of pads/ gears, general deteriorating conditions, out of service sensors and unusual sounds (grinding, clicking, squealing, etc.) Take corrective action as appropriate for the magnitude of the condition identified (e.g., increased monitoring, scheduled repair, or immediate shutdown).	Listening to the equipment while it is rotating and identifying unusual sounds is an effective way to detect problems early. Unusual sounds are often the first clue that an issue has arisen (grinding, clicking, squealing, etc.). Operators who regularly spend time around the equipment can notice subtle changes that a general plant employee may not. Thus, very minor issues can be corrected before they escalate to major failures.

Table 2.5.2 Rotary Kiln Inspection, Testing and Maintenance (continued)

Parameter	*Frequency*	*Activity*	*Acceptance Criteria*	*Additional Information*
Carrying Roller to Riding Ring Contact	Daily	Visual Inspection during routine operator walkdowns.	Mating surfaces are flat, smooth, and parallel. Report and initiate correction of “V” openings.	Excessive “V” opening can cause wear and concentrated stress, resulting in cracking and chipping. If left unattended, it may require resurfacing or frame adjustment.
Carrying Roller Even Thrust	Daily	Visual Inspection during routine operator walkdowns.	All rings are being pushed in the same direction (uphill). Report if any rings are pushing in the opposite direction (downhill). Corrective adjustments by a qualified technician are advised.	Uneven push on riding rings can cause stress on the retaining bar/ blocks and cut into the ring, causing it to lock. Even loading of the carrying roller helps prolong the life of the roller and ring.
Carrying Roller Bearing Temperature	Daily	Handheld temperature measured during routine operator walkdowns and logged for trending.	Temperature is (or is trending to go) outside of its normal operating band. Report the condition, verify that the cooling system is functioning and oil levels are adequate.	Bearing temperature can indicate loss of lubrication, excessive thrust, or loss of cooling. Remote continuous monitoring is an acceptable and better alternative than local handheld devices.
Carrying Roller Base Cleanliness	Daily	Visual Inspection during routine operator walkdowns.	The area is clean, with no accumulation of any materials.	Excessive accumulation of dirt, oil, water can affect the life of lube oil seals, then allowing contamination to enter oil. This results in overheating the bearing and rollers and accelerating roller surface wear.
Thrust Roller to Riding Ring Contact	Daily	Visual inspection during routine operator walkdowns.	Roller has full contact with the riding ring face.	Poor contact results in high localized pressure and ring or thrust roller chipping with subsequent cracking. The thrust roller should receive most of the downhill thrust unless the manufacturer allows “floating” the kiln. Moving one side of the carrying roller bearing assemblies inward (“cutting the roller”) will change the thrust of the kiln either up or down depending on the direction of rotation of the kiln; this is done when “floating” the kiln.
Ring Gear and Pinion Inservice Inspection	Daily	Visual inspection during routine operator walkdowns.	Proper gear alignment, meshing and tooth contact. Lubrication systems are clean, filled, and functioning. Proper grease layer. No unusual noise or vibration.	Change gearbox oil per OEM recommended frequency or when the oil is contaminated as indicated by oil tests. If the oil contains abrasives, gear tooth wear will be excessive. This is especially true for high torque, low speed gears. For ring gear spray on grease, reapply per OEM recommended frequency or when indications show grease is needed.

Table 2.5.2 Rotary Kiln Inspection, Testing and Maintenance (continued)

Parameter	*Frequency*	*Activity*	*Acceptance Criteria*	*Additional Information*
Creep Check of Riding Rings	Weekly (Note 1)	Chalk across shell and riding rings. Measure the separation distance over a set time. In lieu of chalk, electronic Creep monitoring equipment may be used.	Creep is within the specified OEM tolerance. A proper grease layer exists on the sides of riding rings.	A gap between the kiln shell pads and the riding ring is necessary to prevent necking the shell and damaging the refractory. Excessive creep can lead to large ovality and affect the refractory. Greasing the sides of the riding rings prevents wear between the rings and retaining bars. See Section 2.5.3.1 for more information on creep measurement.
Auxiliary Drive **Uncoupled**	Weekly	While uncoupled from the main gearbox, energize the auxiliary drive motor or engine from its station blackout power source and run it for a few minutes. Inspect associated engine batteries for proper charge level. Reference Data Sheet 5-28, *DC Battery Systems*, for more information.	Option 1 - Generator powering Auxiliary Drive Electric Motor: Both start on first attempt, reach the required output, and run for 15 minutes or until the engine is warmed up (reaches steady state). Option 2 - Auxiliary Drive Internal Combustion Engine: Starts on first attempt, reaches the required rotational speed, and runs for 15 minutes or until the engine is warmed up (reaches steady state). Neither option has adverse conditions such as multiple attempts to start, leaks, excessive vibration, overheating or dead batteries.	Station blackout power source is either an internal combustion generator powering an auxiliary drive electric motor or a dedicated auxiliary drive internal combustion engine whose output shaft couples to the main gearbox. Auxiliary drives with automatic clutch require the clutch to be deactivated for testing. The purpose of this test is to circulate the fluids in the engines and prove the power source is expected to function when called upon. Auxiliary drives are normally uncoupled from the main gearbox. The kiln would need to be stopped to engage the auxiliary coupling for a full train test. **This type of test is not expected to be conducted weekly.** See “Auxiliary Drive Coupled” (below) for the full train test on a less frequent basis.
Shell Runout Measurement	Yearly (Note 2, 3)	Measure shell distortion and temperature at multiple points. Measuring points are determined by kiln history.	Shell is within shell and refractory OEM requirements.	Used to assess active warping of the shell or to determine if shell alignment or replacement is needed. Actions may include correcting the riding ring lifting from carrying rollers during an upcoming outage, a full alignment or replacement of a section of the shell. See Section 2.5.3.2 for more information on shell runout measurement.

Table 2.5.2 Rotary Kiln Inspection, Testing and Maintenance (continued)

Parameter	*Frequency*	*Activity*	*Acceptance Criteria*	*Additional Information*
Kiln Alignment Survey	Yearly (Note 2, 4)	Check elevation, slope and level at each pier. Verify kiln's vertical and horizontal alignment. Verify thrust roller alignment.	"As Found" alignment meets OEM requirements. Report any out of specification measurements. Perform corrective adjustments to return to OEM requirements. "As Left" alignment meets OEM requirements.	A hot kiln alignment survey is preferred. The settings and tolerances are kiln specific, depending on the design and operation. Ensure the tolerances are available for each specific kiln. See Section 2.5.3.3 for more information on kiln alignment surveys.
Safety Controls	Yearly (Note 2)	Calibration and testing of instrumentation, trip signals and control room alarms, including: - Over travel switch - Loss of flame - Temperature sensors - Combustion gas sensors - Thrust roller presence sensor	Equipment proven functional. Failures or excessive instrument drift are reported and corrected.	Testing is performed by Instrumentation and Electrical (I&E) technicians that activate the device and ensure signals are received at the control room. Some devices require measurement of the signal intensity. For overtravel switch and safety sensor testing, the signal is received in the control room; and the operator should verify the correct alarm or trip response was triggered. Flame detection – closes the main fuel valve and alarms at control room.
Auxiliary Drive **Coupled**	Yearly (Note 2, 5)	Energize the auxiliary drive motor or engine from its station blackout power source, and couple it to the main gearbox with power being transferred to the pinion and ring gear. With the kiln fully loaded, run the train for the time specified to cool down the shell prior to starting the test.	The train proves functional, particularly the coupling to the main gearbox. Report and correct any signs of excessive vibration, overheating, looseness, excessive electric current, etc.	This test is normally performed at shutdowns (after cooling down the kiln) or during the positioning of the kiln for certain maintenance activities. Fully Loaded means the kiln containing the regular amount of process material inside
Pier Structural Integrity	Yearly (Note 2)	Visual inspection by qualified personnel.	Piers remain functional with minor degradations, which are trended with future inspections. Report excessive pier settling, grout deterioration, exposed rebars, cracking, spalling, footing washout/ sinkholes, or other indications of an unstable support structure. If major damage is observed, consult with a structural engineer to determine if the pier is fit for continued service.	Age and cycling fatigue may affect the integrity of the concrete. In rare occasions, mobile equipment can cause impact damage.

Table 2.5.2 Rotary Kiln Inspection, Testing and Maintenance (continued)

Parameter	*Frequency*	*Activity*	*Acceptance Criteria*	*Additional Information*
Ovality	Yearly (Note 2, 6)	Measure the ovality to verify the shell distortion caused by the difference in shell and ring diameter and the position of the carrying rollers. Ovality (%) = (Maximum shell deflection / Kiln diameter) × 100.	Less than 0.5% OEM ovality guidelines supersede this criterion.	Excessive ovality can cause refractory looseness and collapse over time. Larger diameter kilns experience more ovality.
Refractory	Yearly (Note 2)	Visual inspections of refractory, kiln internals. Measure thickness to compare to OEM specifications.	Refractory thickness is within specifications and secured to the shell.	Refractory thinning or dislodgement is usually the precursor to shell hotspots, burn through or cracking. Refractory is a consumable item, so periodic replacement is unavoidable. These inspections verify the wear rate is as expected. Proactive inspections allow for adequate planning time to replace refractory with excessive thinning before it dislodges.
Ring Gear and Pinion Meshing Inspection	Yearly (Note 2)	Relevant measurements taken at four ring gear positions while meshed with the pinion (normally at 0, 90, 180 and 270 degrees.) At a minimum, check for: - Alignment - Tooth contact pattern - Mounting tolerance - Backlash - Wear (qualitative) Degree inspection locations can be aligned with the four locations of the “Ring Gear and Pinion Visual Inspection” task below for efficiency.	Teeth remain functional with minor degradations, which are trended with future inspections. Conditions warranting further review before putting back into service: - Active pitting - Digging on teeth valley - Uneven contact across the entire teeth - Backlash outside of OEM specifications	Adequate gear meshing is critical for proper torque transfer, lubrication and even wear, and to prolong the life of the gear. Uneven wear can be caused by misalignment, shell deformation, excessive runout, or looseness. Uneven wear can cause cracking, fracturing and pitting. If gear or pinion are new, follow the OEM’s recommendations for initial wear in. Usually, this involves a controlled load increase over 1-to-3-days until reaching normal levels.

Table 2.5.2 Rotary Kiln Inspection, Testing and Maintenance (continued)

Parameter	*Frequency*	*Activity*	*Acceptance Criteria*	*Additional Information*
Ring Gear and Pinion Visual Inspection	Yearly (Note 2)	Visual Inspection of these areas (Note 7): - Ring Gear Teeth: Scope: Representative sample (four locations minimum, changing degree locations each outage for a cumulative full inspection spread across multiple outages) - Pinion Teeth: Scope: All	Acceptance criteria per applicable industry standards. Expand outage inspection scope if concerning defects are identified in this routine periodic inspection. Manage the condition using a deficiency management process that includes evaluating fitness for service, remaining useful life and/or root cause analysis.	The main goal of visual inspection is to catch slow-developing defects caused by aging and wear. Because the gears are always rotating, wear tends to be evenly spread across the teeth, making sampling a practical approach. The pinion, however, has more surface contact during operation so a full inspection is recommended. The pinion's smaller size and accessibility. This inspection is usually done at the same time as the ring gear and pinion meshing inspection during a scheduled outage. To extend the life of the ring gear and pinion teeth, the kiln should operate within its design limits. Proper alignment, ovality, creep, shell temperature, and roller contact help reduce extra stress on the drive system. Misalignment or overload is a common cause of faster gear wear.
High Stress Areas Visual Inspection	Yearly (Note 2)	Visual Inspection performed on these areas if they are part of the kiln's construction (Note 7): Scope: Full - Ring gear support members - Carrying rollers - Riding rings - Girth welds - Planetary cooler attachment welds - Clinker crusher grinding drum where thickness changes near the discharge opening - Retaining ring welds for dryers having an inner drum - Inner tube or dryer drums - Other areas not listed but recommended by the OEM - Monitoring of a previously identified deficiency	Acceptance criteria per applicable industry standards. Expand outage inspection scope if concerning defects are identified in this routine periodic inspection. Manage the condition using a deficiency management process that includes evaluating fitness for service, remaining useful life and/or root cause analysis.	The primary goal of this visual inspection is to identify slow progressing surface defects in high stress areas before uncontrolled propagation occurs. These locations are qualitatively considered higher risk, because their failure could result in extended downtime with ensuing damage of other subcomponents of the kiln. For inspection scope and frequency, consider trending of results, taking a condition-based approach. More frequent inspections may be necessary on a case-by-case basis

Table 2.5.2 Rotary Kiln Inspection, Testing and Maintenance (continued)

Parameter	*Frequency*	*Activity*	*Acceptance Criteria*	*Additional Information*
Nondestructive Examination (NDE)	Condition-based	Application of NDE methods (including ultrasonic, eddy current, magnetic particle, and/or liquid penetrant testing), is based on the inherent kiln hazards and resulting damage mechanisms. It focuses on key areas of the kiln under higher stress and/or those that are key to kiln operation (e.g. drive systems). Condition-based NDE considers the following contributing factors: - Current outage's ITM/ visual inspection and/or NDE identified a deficiencies - Deficiency management (identified deficiencies are evaluated and tracked to closure) - OEM recommendations - Asset integrity program scope for NDE areas of higher stress and/or areas key to kiln operation (e.g., drive systems). - Verify the viability of repairs based on acceptable standards and suitability for intended service. This category includes welded repairs, both temporary and permanent.	Acceptance criteria per applicable industry standards. Manage identified deficiencies using a deficiency management process that includes evaluating fitness for service, remaining useful life and/or root cause analysis.	The frequency and scope of kiln NDE (following a condition-based approach) considers the cumulative impacts of multiple contributing factors. It should include ITM results, OEM recommendations/best practices, operating history/trending, runtime, environment, repair history for areas of high stress, process operating conditions/transients (e.g., hard stop of kiln; overloading) and materials of construction. ITM/NDE program baseline and trending results can be used to determine the scope and actual frequency of NDE for various kiln components, case by case. Upset operating conditions that place stress on a particular component could damage kiln integrity. This is an example of a trigger condition to activate the NDE examination (initial and possible follow-ups). (e.g., Vertical misalignment at one pier could excessively load the carrying rollers, or a warped shell might cause excess ring gear stress.). A qualified engineer should determine whether the damage identified (e.g., a cracking) should be monitored or repaired as part of a fitness for service evaluation. NDE as part of the kiln maintenance strategy will identify deficiencies not detectable by visual inspection alone. This early identification allows for proactive corrective actions to reduce the likelihood and consequence of a kiln breakdown.

Table 2.5.2 Notes:
1. The frequency may be extended depending on the padding design and recent measurement trends. Operating history and OEM guidance are also key factors when evaluating a frequency extension.
2. Frequency may be aligned to the regular outage window but should be no greater than two years.
3. Align frequency as a pre-outage task, so corrections can be made during the outage window. Runout measurement may be completed more frequently to monitor a degraded condition.
4. To extend frequency beyond two years, kiln history must be exceptional with a solid technical justification. This justification is kiln-specific, evaluated on a case by case basis.
5. Usually, the test is performed at the very beginning of the outage; because the kiln is loaded as it normally would be to simulate a real event.
6. Ovality shall be checked after alignment adjustments or more frequently for a known issue affecting riding ring and rollers (deficiency management strategy).
7. The following NDE methods are acceptable alternatives to visual inspection, based on the expected damage mechanisms: ultrasonic, eddy current, magnetic particle and liquid penetrant testing. The applicability of the alternate technique to test area shall be verified with the OEM or a reputable NDE company.

2.5.3 Rotary Kiln ITM Supporting Information

2.5.3.1 Creep Check of Riding Rings

If using cold clearance measurement of the pads at top dead center to calculate the difference (Δd) between shell outside diameter (including pads) and carrying roller bore, reduce this measurement to account for relative expansion of the shell and riding ring. Ovality of the shell must also be considered. The clearance measurement is not equal to the difference between riding ring bore and shell (including pad thickness) diameters. Clearance = $\Delta d(\pi)/2$.

Do not lubricate the pad surfaces unless recommended by the manufacturer to reduce wear caused by creep. A powder type of lubricant mixed with water or solid bar type are typically used. Lubrication will cause the shell pads to slip inside the riding ring bore and will prevent the riding rings from being driven by friction with the shell pads. If a shell section is choked inside a riding ring, lubrication is not a valid solution. This practice will hide mechanical problems and might also make creep measurements irrelevant.

2.5.3.2 Shell Runout Measurement

Shell runout indicates the degree of shell distortion or warping (not ovality). It is the deviation of the rotary kiln shell from a true circular rotation as it turns. Temperatures must be equalized on both sides of the rotary kiln or measured and recorded at each measurement point. Runout measurements are taken at several locations along the length of the rotary kiln. The distance between the shell and a fixed reference is measured at twelve positions around the shell circumference at each location. The average runout is calculated first. Then the difference between each runout measurement and the average is taken. The total runout is calculated by determining the difference between the most positive and most negative reading. Temperature differences must be used to determine if any temporary warping has occurred.

2.5.3.3 Rotary Kiln Alignment Survey

Depending upon the procedure used, a rotary kiln alignment survey can be conducted during operation or after shutdown. A hot survey is preferred, because it will indicate conditions experienced during normal operation. Pier elevation, pier centerline, pier transverse levelness, pier downhill slope, rotary kiln horizontal and vertical alignment and thrust alignment should all be checked. Qualified personnel should perform the corrections/repairs of carrying roller, pier, frame or grouting. The pier elevations must be correct, according to plan. The pier centerlines must line up, the piers must be level within a specified tolerance across their width, and the piers must conform to a specified slope. The rotary kiln shell should line up with the pier centerlines and should slope the same as the carrying roller frames (vertical alignment).

2.5.3.4 Pier Structural Integrity

The long-term solution is to repair the piers, rather than compensating for their misalignment by roller adjustment. The roller adjustment would likely be temporary; as the base continues to degrade, misalignment returns.

2.5.3.5 Ovality

Ovality is expressed as a percentage of shell diameter. It equals the clearance divided by the inside diameter. Ovality is the result of clearance and sag from the unsupported part of the rotary kiln at top dead center, and excessive load where the rollers support the shell (near the 5 and 7 o'clock positions). Ovality, or flattening of the shell and tire, can occur at the top and bottom due to inadequate tire cross sectional area or increased load.

2.5.3.6 Refractory

If installed, check refractory thickness when internal rotary kiln entry is permitted. Refractory thickness normally varies between 4.5 in. (11.3 cm) at the cold end and 12 in. (30 cm) at the hot end. Insulated, two-layer systems are now used on new rotary kilns and are beneficial if installed on older rotary kilns.

During inspection, verify that burners are aligned to prevent flame impingement on the refractory.

2.5.4 Operation

2.5.4.1 Operators

Establish and implement operator training programs. See Data Sheet 10-8, *Operators*, for guidance on developing operator programs. Train and re-train operators to run the rotary kiln and its ancillary equipment following documented standard operating procedures (SOPs) and emergency operating procedures (EOPs). Always Ensure SOPs and EOPs are current and readily available to operators.

2.5.4.2 Operational Considerations During Startup/Shutdown Modes

The following items should be considered during startup/shutdown:

2.5.4.2.1 Provide a sufficient startup and shutdown period to prevent thermally induced stress by following the manufacturer's ramp up and cool down tables. This timeframe is even more critical in cold climates. Allow more time during cold spells for very large rotary kilns or rotary kilns with extra thick refractory linings. The refractory does not expand as fast as the rotary kiln shell and can be damaged if warm-up and cool-down periods are not long enough. The auxiliary drive must be engaged after shutdown. At first, the auxiliary drive will turn the rotary kiln continuously for a specified time. Then, a specified jacking schedule will be followed. When the jacking schedule is complete, the rotary kiln must be turned one half a turn at least every 24 hours.

2.5.4.2.2 Heating a rotary kiln too rapidly can also damage the shell, because the pads choke in the riding ring bore. (The ring will not expand at the same rate as the shell.) Follow manufacturer recommendations.

2.5.4.2.3 Do not operate the rotary kiln at full speed until it reaches normal operating temperature.

2.5.4.2.4 Startup sequence of the clinker cooler or secondary air fans should be controlled to prevent excessive flowrate from extinguishing the burner flame.

2.5.4.3 Operational Considerations during Normal Operation Mode

2.5.4.3.1 Do not operate the rotary kiln for long periods with known misalignment or other problems such as a badly warped shell, excess clearance between riding rings and filler pads, broken ring gear spring plates, hot spots and damaged refractory. These types of problems can lead to mechanical breakdowns and should be corrected as soon as practical. Cool hot spots with air and repair refractory as soon as possible. Repair all large cracks including riding ring cracks, shell cracks and pad weld cracks during shutdown periods. Welding can induce stress in large cast parts. A decision must be made whether to monitor cracks for growth or repair.

2.5.4.3.2 A badly warped (distorted or bent) shell can be indicated in several ways. The ovality near a carrying roller should be no more than 0.3%-0.5% based on the rotary kiln diameter. (See Section 2.5.2) A runout reading of 1 in. (25 mm) near a carrying roller or the main gear is considered excessive; this much runout further away should be monitored. A runout reading of 3 to 4 in. (75-100 mm) midspan is normally considered excessive.

2.5.4.3.3 For refractory-lined rotary kilns, if material flow to the rotary kiln is interrupted, reduce the burner fuel supply to prevent overheating. The rotary kiln should be shut down if an interruption to the feed exceeds 10 minutes for a wet or dry kiln, or three minutes for rotary kilns with preheater/precalciners. Feed hopper level should be monitored.

2.5.4.3.4 Operating personnel complete routine daily walkdowns in accordance with Table 2.5.2. See Section 3.1 for information on why these inspections are critical.

2.5.4.3.5 Operate the rotary kiln to minimize the formation of dust rings. Dust rings form for different reasons. Operating the rotary kiln in a stable manner with minimal upsets and cycling should help. Temperature transients can be a significant factor. Proper burning is important. Control of raw material alkalis and fineness can have a positive effect also. Rings should be knocked down gradually to prevent the cooler overload. Knocking down these rings floods the cooler, resulting in higher than normal undergrate pressure and increased temperature. The rotary kiln speed is usually decreased to reduce the increased temperature. When this method fails, use water to cool the outlet conveyor and shut down the operation if necessary. Back-end draft can indicate the formation or loss of rings. Note that draft will be affected if a back-end inspection door or a fuel chamber door has been opened, or a cooling air damper (sometimes used to cool the I.D. fan) position has been changed.

2.5.4.3.6 Maintain a documented procedure to address product slides that can interfere with combustion.

2.5.4.3.7 For rotary kilns that use chains for heat exchange, monitor the chain temperature (measure product temperature after chains). (See Figure 2.5.4.3.7) If the chain temperature exceeds 1600°F (871°C), and excess oxygen is 4% or greater, the chains will burn. Oxygen levels must be kept low during shutdown while the temperature is high. A wet shutdown (rotary kiln is shut down before empty) is preferable and will keep the chains cooler (more cleanup is needed after shutdown, however). Enrichment oxygen, if used, must be tightly secured.

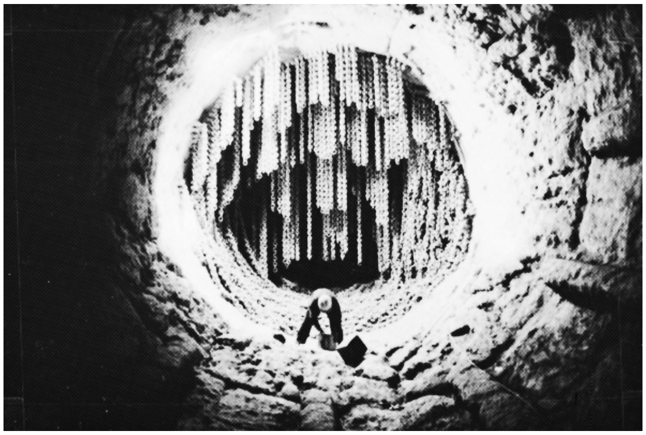


Fig. 2.5.4.3.7. Chains in a dry process cement rotary kiln

2.5.4.3.8 Inspect the feed and discharge end seals daily. Excessive leakage into the back-end will result in unreliable exhaust readings (temperature, CO, CO_2, O_2). The operator relies on these readings for proper operation. Tramp air entering the rotary kiln's front end can also lead to improper combustion. Lubrication of seals using a powdered lubricant is often done to minimize friction and wear.

2.5.4.3.9 Provide a backup instrument air supply if it is critical to process, burner or safety control.

2.5.4.3.10 Grease combustion hood slide runners (if applicable) in accordance with manufacturer's recommendations to facilitate ease of rotary kiln expansion.

2.5.4.4 Operational Considerations During Emergencies

EOPs should address conditions that can lead to an upset and take appropriate action based on the three main rotary kiln (for typical large rotary kilns) operating variables (back-end temperature, burning zone temperature, and back-end oxygen).

2.5.4.5 Process Control for Calcining Rotary Kilns

2.5.4.5.1 Control the three basic variables (back-end temperature, burning zone temperature and exit gas oxygen) by varying the fuel rate, I.D. fan speed and/or rotary kiln speed. See Figure 2.5.4.5.1 for an illustration of typical rotary kiln instrumentation. Modern rotary kilns are fully automated using control schemes such as PID and fuzzy logic. The operator must still monitor the operation and be knowledgeable enough to control the rotary kiln manually if the automatic control system malfunctions or is unable to handle an upset.

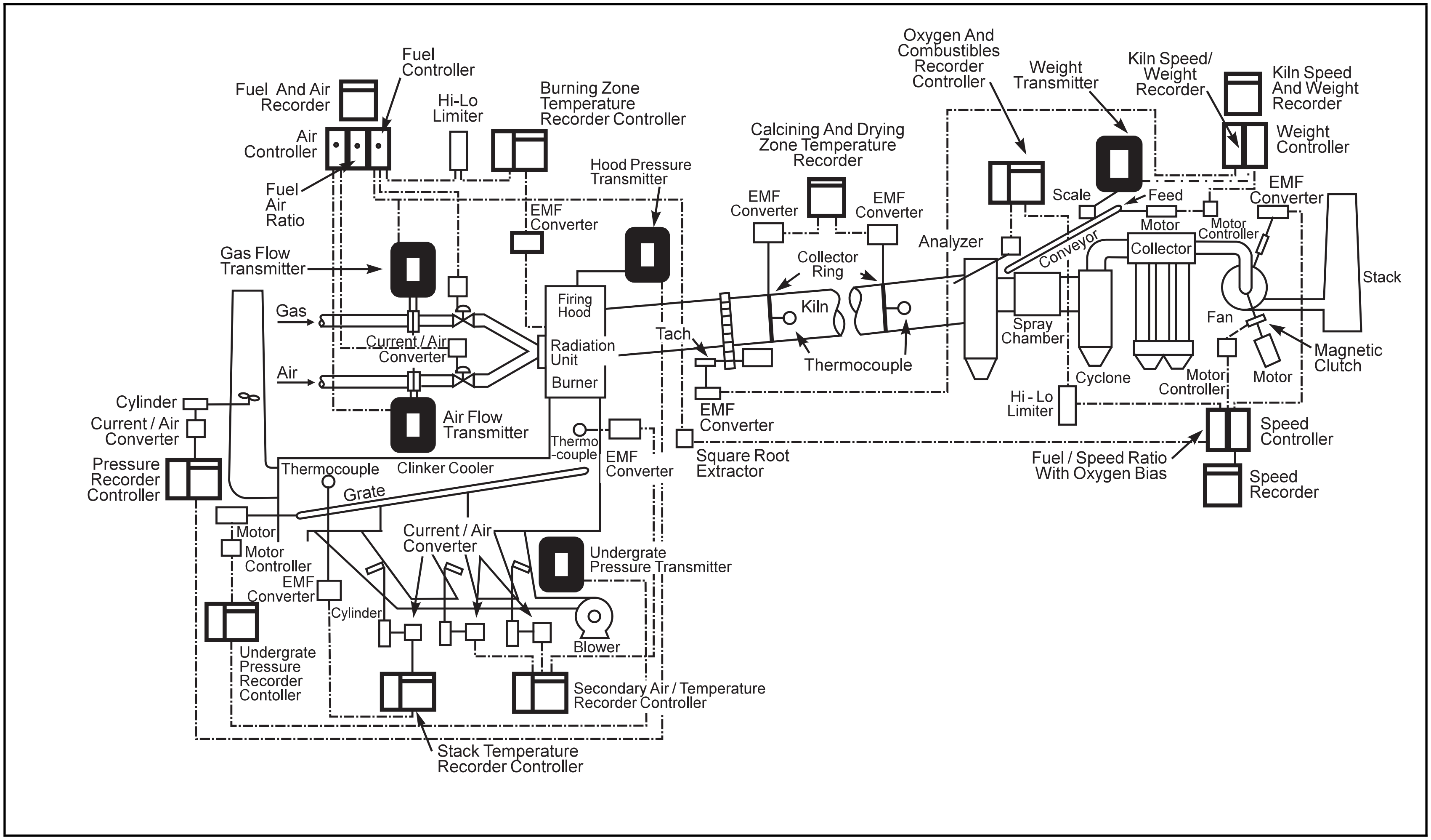


Fig. 2.5.4.5.1. Typical instrumentation for cement kiln and cooler. **Note:** Combustion safety controls and cooler baghouse not shown. (Courtesy of The Foxboro Co.)

2.5.4.5.2 Maintain rotray kiln stability by properly controlling back-end temperature and by operating the rotary kiln with a small amount of excess oxygen (0.4 to 2.5% is the normal range needed for a stable operation). Normally feed is not varied, but it might be better to slow down the rotary kiln if necessary and make small changes to maintain rotary kiln stability rather than allow a rotary kiln upset and cycling to occur.

Cycling is an unstable condition. The burning zone temperature cycles up and down despite (and possibly because of) corrections made by operators. In a calcining rotary kiln, product feed temperatures vary along the length of the rotary kiln; firing rate changes affect these temperatures. When the feed arrives in the burning zone several hours later, this zone will in turn be affected by higher or lower than normal feed temperature. Fuel changes should be gradual to prevent an upset. Too much fuel can also lead to rotary kiln overheating or poor combustion. Sometimes production must be slowed down to prevent an upset leading to cycling. It is also possible that if the rotary kiln is not running at full capacity, an increase in production can cause the rotary kiln to stabilize because it will inherently operate better at full load.

Changes to the feed rate or feed composition can lead to cycling if operators do not anticipate the changes. Adjustments should never be delayed. A steady feed rate is essential to rotary kiln stability. Dust return should also be steady by using a surge bin or metering device.

If dusty conditions prevail, observe feed under and behind the flame before making decisions after an upset occurs.

2.5.4.5.3 Ensure that operators are thoroughly familiar with actions to be taken based on the combinations of the three basic variables (high, low or normal). These actions will also depend upon whether the burning zone temperature is slightly high or low and whether the oxygen is in the upper part or lower part of the normal range (when normal). These guidelines should be readily available in the control room.

2.5.4.5.4 Adjust flame whenever small red spots appear on the rotary kiln shell. Air cooling of the shell can help to promote coating formation. If the size and/or temperature of the hot spot continues to degrade, the rotary kiln must be shut down. If the rotary kiln is rotated intermittently after shutdown, rotate the rotary kiln until dark, cooler feed covers the hot spot. Then the rotary kiln can be jacked over according to the regular schedule; however, full turns will be needed to make sure that the hot spot is always on the bottom when the rotary kiln is stopped, until the rotary kiln is cooled down.

Adjust flame direction in small steps and only during stable conditions. The flame should not impinge on the coating or the feed bed. Once the flame is stable, the primary air pipe position should be left alone.

2.5.4.5.5 Normally secondary air temperature is held constant, however, maintaining normal temperature should not be attempted if the rotary kiln has been slowed down due to an upset because cooler overheating will result when less feed is being discharged from the rotary kiln.

2.6 Contingency Planning

2.6.1 Equipment Contingency Planning

When a rotary kiln breakdown would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop and maintain a documented, viable rotary kiln equipment contingency plan (ECP) per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process of developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental, and redundant equipment mitigation strategy guidance in that data sheet.

In addition, include the following elements in the contingency planning process specific to rotary kilns:

Consider the type of operation, conditions, and design (including materials of construction), drive system (including auxiliary drive) key component availability, and qualified contractor availability with specialized equipment for repair/replacement of key components. Also consider the replacement of rotary kiln shell sections, drive systems and refractory repair/replacement.

Evaluate equipment breakdown sparing of key components as part of the ECP's recovery options/mitigation strategy, given the potential for longer lead times with these large, specialized components. See sparing guidance in Section 2.6.2.

2.6.2 Sparing

Sparing can be a mitigation strategy as part of the ECP to reduce the downtime caused by a rotary kiln breakdown depending on the type, compatibility, availability, fitness for the intended service, and viability of the sparing. For general sparing guidance, see Data Sheet 9-0, *Asset Integrity*.

Evaluate the following components for equipment breakdown sparing as part of the contingency planning process for the ECP.

- Shell, Refractory Lining and Internals
- Drive System
  - Ring gear (full 360 degrees, if segmented)
  - Pinion gear (to drive the ring gear)
  - Internals for gear reducer
  - Main/auxiliary motors and couplings/clutches
  - Emergency internal combustion engine to drive auxiliary motor
- Support Systems
  - Riding rings (tires)
  - Carrying rollers (trunnions) with associated bushings (bearings)and rotors
  - Thrust rollers with associated bushings (bearings) and rotors
- Cooling and Dust Control Systems
  - Induced draft fan with associated rotors, bushings and couplings
  - Forced draft fan with associated rotors, bushings and couplings

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Rotary Kiln ITM Strategy Basis

3.1.1 General Strategy

Loss history shows many rotary kiln losses start as minor issues that are either not identified or are left to progress without adequate intervention or deficiency management. Proactive monitoring is the best way to ensure reliability. The overarching strategy is centered around attentive monitoring with a low threshold for reporting problems. This threshold allows for problems to be addressed before escalating into a rotary kiln breakdown.

3.1.2 Shell and Riding Ring Temperature

Continuous, remote infrared monitoring is the most powerful tool to assess real-time health of the rotary kiln shell, refractory, and reduced creep of riding rings. It allows for live indication of temperature deficiencies with data that can be trended to quantify the rate of degradation. Additionally, alarms can notify the control room of temperature excursions. Hot spots (temperature differentials) are usually indications of the refractory thinning or becoming dislodged.

This monitoring capability would allow for appropriate corrective action, commensurate with the severity level identified (e.g., increased monitoring, operational change, maintenance adjustment, scheduled repair, or immediate shutdown). Operational changes can include rotational speed, cooling flow, etc.

3.1.3 Main Drive Motor Amperage

Motor amperage monitoring allows for proactive and early identification of abnormal conditions before they deteriorate to trigger a motor trip setpoint. An increase of motor amperage can be indicative of increased friction within the dynamic surfaces of the rotary kiln. Bearing failures, misalignment, riding ring cracks and loss of lubrication are some examples that could increase amperage. The motor will draw more amperage to overcome this friction.

If the motor trips are due to binding and the auxiliary motor is unable to rotate the rotary kiln, the damage will increase exponentially with stationary sagging of the rotary kiln's shell. In addition, severe damage can occur to the thrust roller and carrying roller thrust plates. If the rotary kiln is started with a warped shell after repairs are completed, damage to the carrying roller assemblies, gear teeth, thrust roller, and rotary kiln end seals can occur. If a section of shell is replaced, the other sections must be aligned (no bend or dog leg) and not warped.

3.1.4 General Inservice Inspection

Routine operator walkdowns are arguably the most important ITM strategy for early identification of issues. They are a strong input to the general strategy. Operators are familiar with what normal operation includes, and they can use all their senses (sight, hearing, smell, touch) to determine when something is “off.” Remote indications are unlikely to ever replace the value that a walkdown provides.

3.1.5 Carrying Roller to Riding Ring Contact

The routine visual Inspection of uniform contact between the carrying roller and the riding ring ensures even load distribution. This inspection helps detect early signs of uneven wear, cracks, excessive wear, misalignment and mechanical failure. In addition, corrective action can be taken sooner, before the condition worsens.

If the skewing angle is in the wrong direction at any roller, causing opposing thrust at that roller, the roller and riding ring surfaces will wear excessively.

If a “V” opening exists between the roller and riding ring, the point contact and concentrated loading can result in serious damage if left uncorrected. This problem can occur because of roller and riding ring surfaces that are out of true, a tilted carrying roller support frame (caused by pier settling or grout deterioration), a bent frame (with rigid bearings), riding ring wobble or worn bushings.

3.1.6 Carrying Roller Even Thrust

The routine visual inspection of carrying roller even thrust allows for early detection of thrust imbalances. Roller adjustments can be made before significant damage occurs. The misalignment of the carrying rollers will have a cascading effect that causes excessive wear on the riding ring and thrust rollers.

A poorly adjusted carrying roller will thrust against the retaining bar, creating friction. Too much friction can wear the riding ring into the retaining bars, which will eventually cut the riding ring and lock the riding ring and retaining bars together. If this situation occurs at a thrust riding ring, the main gear and pinion might move off center as the retaining bar wears. This scenario excessively wears the teeth.

Thrust imbalance will result in carrying roller internal parts that assist with lubrication being damaged as the shaft moves forward due to excessive thrust washer wear. This situation will interrupt lubrication to both the uphill and downhill bushings, causing noise at both sides of the roller assembly. If a roller continues to turn without lubrication to the bushing, the bushing bolts can shear, allowing the bushing to rotate until the shaft is no longer supported and drops onto the housing, causing substantial damage. Drive amperage of the main motor will rise suddenly in this case.

3.1.7 Carrying Roller Bearing Temperature

Elevated temperature is an indication of lubrication loss, excessive thrust, or a loss of cooling. Early identification allows for corrective action before a major failure occurs.

All carrying rollers must be monitored after an adjustment is made, especially if the roller was adjusted to relieve a high temperature condition. Bushings wear during startup and from abrasives. The bushing contour will change to match the radius of the shaft. If wear is excessive, the bushing will have the same contour as the shaft and will be thinner in the middle section. (See Figure 3.1.7-1) Ridges will develop on the bushing.

Also, if too much shaft pressure is applied to the bushing, the resulting high temperature can cause a ripple-like distortion to the shaft and bushing. (See Figure 3.1.7-2) When adjustments are made to rollers, the pressure from the shaft to bushing changes the angle. This change can cause the shaft to rise when it contacts the high part of the bushing where it changes from being worn to unworn. (The middle of the bushing will be thinned and worn into the shape of the shaft.) If the shaft and bushing have distortion ripples, the high spots will come into contact. If either of these two things happen, concentrated loading, interference with lubrication and high temperatures will result. This situation can cause bushing failure and even more serious damage if the bushing bolts shear as previously described.

Maintaining parallel alignment between the bushing and the shaft is crucial. If the bushing cannot pivot (the support beam on which the bushing rests has a permanent coating of lubricant), point contact and concentrated loading will occur diagonally at the ends of the bushing. (See Figure 3.1.7-3) This problem occurs with rigid, independent, half-sleeve bushings and not with connected, self-aligning bearing assemblies. Spherical, antifriction bearings are also used occasionally. They are self-aligning.

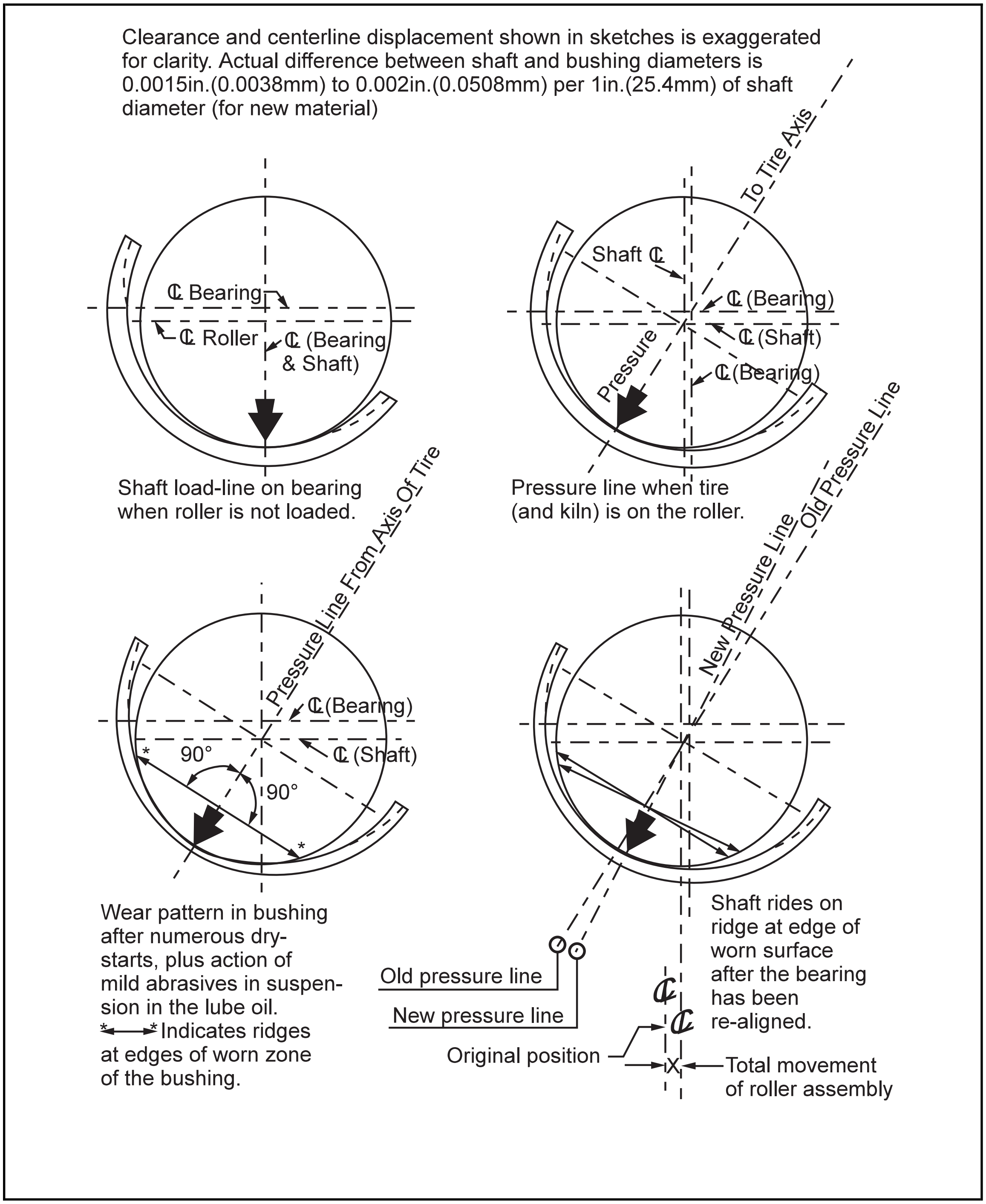
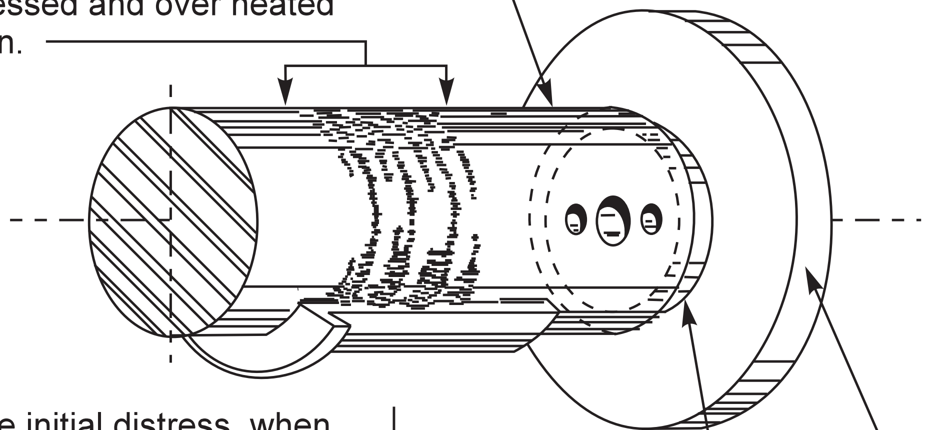
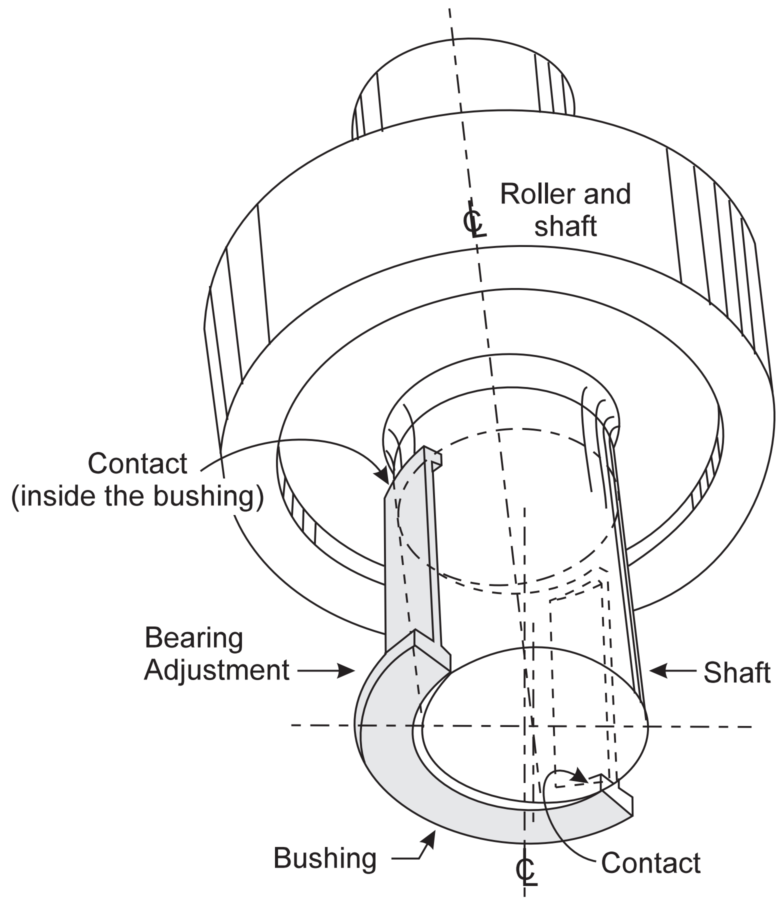


Fig. 3.1.7-1. Carrying roller load angles and bushing wear patterns. Courtesy of the Fuller Company.



The corrugation pattern, shown above, may be at a very low profile and the actual condition may not have been noticed (or reported) for maintenance records. When the shaft travels away from the loaded thrust washer, pressure increases when crown and groove contours are joined as the shaft moves along the bushing. It is possible that there will not be a totally dry contact condition (with an audible distress signal), but extreme pressure will be indicated by sight and odor when hot oil vapor excapes from the bearing housing. Metal and oil temperatures will rise rapidly, possibly above 300°F(149°C) in this situation. Roller adjustment which led to this condition, must be reversed for gradual relief from pressure and heat. The shaft must be repaired for normal operation with a new bushing.

Fig. 3.1.7-2. Carrying roller shaft distortion due to plastic flow. Courtesy of the Fuller Company.



Sketch shows misalignment of shaft and bushing when the bearing base does not pivot to remain parallel to the shaft during skew adjustment work periods. Bushing can be destroyed by dry contact, abrasion and high temperature.

Fig. 3.1.7-3. Carrying roller shaft-misalignment. Courtesy of the Fuller Company.

3.1.8 Carrying Roller Base Cleanliness

Inspections help to prevent operational environment debris from damaging the oil seals of the bearing housing. Once the seals become damaged, oil has a path to exit and contaminates have a path to enter the bearing housing. A simple yet effective way to mitigate this situation is by routine visual inspections.

3.1.9 Thrust Roller to Riding Ring Contact

Routine visual inspection of uniform contact between the thrust roller and the riding ring ensures even load distribution. Early detection of uneven wear, cracks or deformation allows corrective action to be taken before increased wear, misalignment or mechanical failure are induced.

3.1.10 Ring Gear and Pinion Inservice Inspection

If the main gear and pinion centerlines do not match (part of the teeth do not mesh when the gear and pinion extend over the ends of each other), uneven wear will result; and step patterns will form along the length of the teeth. If a variation in the rotary kiln thrusting then causes the relative gear positioning to change, gear teeth can overstress and break if high spots mesh.

Rotary kiln misalignment and mechanical problems such as a warped shell will cause ring gear and pinions to misalign. This situation will cause increased wear and possibly overload gear teeth. Overloaded gear teeth can result in pitting fatigue, which will interfere with lubrication, accelerate wear and cause tooth breakage.

The driving pinion usually wears more quickly than the ring gear due to its gear ratio. Pinions are smaller and have fewer teeth, so each tooth engages more frequently. For example, a pinion gear may complete 30 revolutions per one revolution of the ring gear. A lower surface area means higher contact stress per unit area. Also, pinions are more suspectable to sliding friction damage. These shear forces drag metal away from the pitch line.

3.1.11 Creep Check of Riding Rings

Creep indicates how well the rotary kiln shell is moving relative to the tire (riding ring). This measurement helps identify problems and provides time to plan for repairs ahead of scheduled shutdowns.

Proper creep ensures that the tire can expand and contract freely with temperature changes, preventing stress buildup. Too little creep can indicate the tire is binding or the pads are too tight, which can cause shell deformation or cracks. Too much creep may indicate excessive clearance or wear in the support system, leading to instability.

3.1.12 Auxiliary Drive Uncoupled

The auxiliary drive must be available to prevent shell warpage in case of power loss or main drive failure. A separate auxiliary motor should be available to drive the rotary kiln in case of main motor failure, not merely a backup generator powering the main motor.

3.1.13 Shell Runout Measurement

Excessive runout can lead to uneven wear on tires and rollers, increased vibrations, and mechanical stress on components. Measurement results can be used initially to decide whether a section of the shell must be replaced, or whether a rotary kiln alignment is needed.

3.1.14 Rotary Kiln Alignment Survey

This type of survey is essential for maintaining the mechanical integrity and operational efficiency of rotary kilns. They help detect misalignments that can cause uneven load distribution, leading to premature wear of tires, rollers, and bearings. Proper alignment ensures smooth rotation, reduces vibration, and minimizes stress on the rotary kiln shell, which then protects the refractory lining from damage due to flexing or hot spots. Regular surveys also support preventive maintenance, reduce unplanned downtime, and extend the overall lifespan of the rotary kiln. Additionally, they provide valuable baseline data for tracking changes over time and planning for future maintenance.

Rotary kiln misalignment will lead to continuous trouble with the shell, riding rings, carrying and thrust rollers, and possibly the ring gear and pinion. Poor thrust alignment and carrying roller maladjustment will accelerate the wear of the carrying rollers. Misalignment caused by deformation at the riding rings can sometimes be corrected by pad (filler bar) replacement.

3.1.15 Safety Controls

Failure to periodically check can result in fire or explosion damage, mechanical or electrical breakdown, and can also contribute to accidental shutdown and production loss. See Data Sheet 7-17, *Explosion Protection Systems*, for more information. For example, loss history shows that rotary dryers in ethanol plants can become extremely explosive when ethanol vapors are inadvertently carried into them.

3.1.16 Auxiliary Drive Coupled

This train must be tested periodically to prove the coupler engages properly and the auxiliary motor rotates the rotary kiln. In an emergency, this action will prevent the rotary kiln from sagging.

3.1.17 Pier Structural Integrity

If a “V” opening exists between the roller and riding ring, the point contact and concentrated loading can result in serious damage if left uncorrected. This problem can arise from a tilted carrying roller support frame, caused by pier settling or grout deterioration.

3.1.18 Ovality

Rotary kilns operate under high temperatures and heavy loads. Over time, the kiln shell can deform from a perfect circle into an oval shape due to thermal expansion, mechanical stress and wear. Excessive ovality can lead to cracks in the shell or refractory lining, reducing the kiln’s lifespan.

The goal of ovality inspections is identify minor deficiencies before they progress to a major event such as a refractory collapse, shell cracks, excessive stress on components, or reduction in process efficiency.

3.1.19 Refractory

Internal inspections verify the shell infrared monitoring trends accurately represent refractory health.

Damaged refractory is the most serious type of rotary kiln upset. Therefore, a preventative strategy is important to reliability. Refractory failure is likely at the riding ring sections due to ovality pinch points. Damaged refractory can cause shell warpage and vice versa. Coating fallout or overheated coating can also damage the refractory.

3.2 Loss History

3.2.1 Loss Data

The following loss review is based on 92 losses of rotary kilns and rotary dryers over a recent 40-year period (1985 through 2025). This loss review focused on fire, explosion, and boiler and machinery related perils. The loss amounts were indexed to 2025 US dollar values.

3.2.2 General Overview of Loss Causes

The loss causes are process related (fire and explosion) or related to the subsystem where the loss was initiated. The goal of the categorization is to show what has driven losses and provide context for loss prevention prioritization.

The categories are:

- Fire and Explosion: The rotary kiln sustains damage due to the accumulation/ignition of combustible vapors, fuel or dust, oils, or process blockages.
- Shell/Internal: Structural supports within the rotary kiln, chains, refractory (thinned or dislodged), shell hotspots and shell cracks.
- Drive: Ring gear, pinion, gearbox, main drive motor, auxiliary drive motor, couplings, driveshafts, clutches, drive chain, and auxiliary drive internal combustion engine and batteries.
- Support: Riding Ring (tire), Rollers (trunnions) and Bearings.
- Fans: Induced Draft (ID) and Forced Draft (FD).
- Other: Upstream disruptions, blockages, service interruptions, utility/support issues, etc.

Table 3.2.2 shows the loss causes listed in descending order by the number of losses.

Table 3.2.2. Rotary Kiln Loss Cause Overview

Loss Cause	*Number of Losses*	*Number of Losses (% of total)*
Shell/Internals	32	35%
Explosion	16	17%
Support	14	15%
Other	14	15%
Drive	8	9%
Fire	5	6%
Fans	3	3%
Total	92	100%

The table shows that losses are most frequently caused by shell/internal issues. This reason is understandable, because refractory is consumable. It is prone to thinning and dislodgement. Also, the shell is constantly under mechanical and thermal stress as it rotates.

3.2.3 Loss Causes by Process Overview

Table 3.2.3 shows the percentage of loss causes for each process. In each process category, the causes are listed in descending order by the number of losses.

- Lime Rotary Kilns are primarily in the pulp and paper industry where the recausticizing of lime mud creates quick lime, which is recycled back into the pulping process.
- Cement Rotary Kilns are in the cement industry where raw materials are heated to create clinker nodules. These nodules are a base material for cement.
- Rotary Dryers in ethanol plants take the wet distiller grains (a biproduct of ethanol distillation) and apply heat to create dried distiller's grains with solubles (DDGS).
- Other Rotary Dryers, Rotary Kilns, Rotary Calciners include industries such as food, coal, gypsum, stone, waste, and wood chips.

Table 3.2.3. Loss Causes by Process

Process	*Loss Cause*	*Number of Losses*	*Number of Losses (% of Process's Total)*
Lime	Shell/Internals	20	65%
	Other	5	16%
	Drive	3	10%
	Support	2	6%
	Fans	1	3%
	Explosion	0	0%
	Fire	0	0%
	Total	31	100%
Cement	Support	9	30%
	Shell/Internals	9	30%
	Other	4	13%
	Drive	4	13%
	Explosion	3	10%
	Fans	1	3%
	Fire	0	0%
	Total	30	100%
Other	Other	5	24%
	Fire	5	24%
	Explosion	3	14%
	Support	3	14%
	Shell/Internals	3	14%
	Drive	1	5%
	Fans	1	5%
	Total	21	100%
Ethanol	Explosion Total	10	100%

The table shows that loss drivers are different by process category. For lime rotary kilns, shell/internal issues is the top loss cause at 65%. For cement rotary kilns, supports and shell/internal share the top loss cause at 30% each. A sizable gap exists between these top loss causes and the next highest loss cause for the process (Lime: 65% to 16%, Cement: 30% to 16%).

Rotary kilns, with their process categorized as Other, had the loss causes evenly distributed.

For ethanol dryers, 100% of the failures were due to explosions. These were primarily caused by ethanol carryover, which created an explosive environment within the dryer. This trend has been improving due to safety interlocks and operator training. Refer to Data Sheet 7-111A, *Fuel-Grade Ethanol*, for ethanol explosion risk management, which is beyond the scope of this data sheet.

3.3 Routine Spares

Ensure the viability of routine spares by storing and maintaining them in accordance with the original equipment manufacturer's instructions. Refer to Data Sheet 9-0, *Asset Integrity,* for additional guidance. The following are common routine spares for rotary kilns:

A. Refractory and associated anchoring system components. These are consumable.

4.0 REFERENCES

4.1 FM

Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*
Data Sheet 5-17, *Motors and Adjustable Speed Drives*
Data Sheet 5-20, *Electrical Testing*
Data Sheet 5-31, *Cables and Bus Bars*

Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems*
Data Sheet 6-2, *Pulverized Coal-Fired Boilers*
Data Sheet 6-4, *Oil- and Gas-Fired Single-Burner Boilers*
Data Sheet 6-5, *Oil- and Gas-Fired Multiple Burner Boilers*
Data Sheet 6-9, *Industrial Ovens and Dryers*
Data Sheet 6-11, *Thermal and Regenerative Catalytic Oxidizers*
Data Sheet 6-13, *Waste Fuel-Fired Facilities*
Data Sheet 7-10, *Wood Processing and Woodworking Facilities*
Data Sheet 7-11, *Conveyors*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-54, *Natural Gas and Gas Piping*
Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) Storage in Stationary Installations*
Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tanks*
Data Sheet 8-10, *Coal and Charcoal Storage*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 13-7, *Gears*
Data Sheet 13-18, *Industrial Clutches and Clutch Couplings*
Data Sheet 13-24, *Fans and Blowers*

4.2 NFPA Standards

NFPA 30, *Flammable and Combustible Liquids Code*
NFPA 54, *National Fuel Gas Code*
NFPA 70, *National Electrical Code*
NFPA 85, *Boiler and Combustion Systems Hazards Code*
NFPA 86, *Standard for Ovens and Furnaces*

4.3 Others

ANSI B31.1, *Power Piping*.

APPENDIX A GLOSSARY OF TERMS

Approved: references to ''Approved'' in this data sheet means the product and services have satisfied the criteria for FM Approval. Refer to the *Approval Guide*, a publication of FM Approvals, for a complete listing of products and services that are FM Approved.

Burning zone: the hottest part of a cement rotary kiln near the discharge end where combustion takes place. Many chemical reactions take place here, and feed is transformed or ''burned'' into the finished product such as cement clinker.

Bushing: typically a 180° sleeve type bearing used to support carrying roller shafts. The bushings can be independent or a connected assembly type. Some rotary kilns have spherical anti-friction type bearings.

Calcining: part of the process that takes place inside lime, cement and alumina rotary kiln systems. CO_2 is driven off the product during this stage of rotary kiln pyroprocessing. In long dry or wet process rotary kilns, calcining occurs near the middle of the rotary kiln. In suspension preheater rotary kilns, the calciner is either part of the extended riser duct, or a separate vessel integrated with the riser duct and the bottom cyclones.

Carrying roller: also called trunnion, support roller or plain roller. Two rollers are mounted at each rotary kiln support pier. The rotary kiln riding rings (tires) rotate on these rollers. The rotary kiln vertical load and part of the axial thrust load is supported by the rollers.

Carrying roller assembly: consists of the roller, shafts, uphill and downhill bearing, bearing housing, thrust plates and mounting frame.

Combustion hood: front end section of rotary kiln which supports the burner pipe and where secondary air enters. The hood is sometimes allowed to roll over a slide runner for expansion, and an air seal is provided between the rotary kiln shell and the hood.

Cooler chimney: used to exhaust excess grate cooler air and maintain proper hood pressure by means of a damper. **Note:** These are not used anymore because the cooler excess air is not allowed to escape to the atmosphere. Modern pollution control equipment is used to protect the environment and to fulfill the functions of the former chimney damper.

Drive: the main motor and reducer gears that turn the pinion which engages with the ring gear.

Dust rings: solid rings often form inside some rotary kilns such as cement and lime rotary kilns. This usually occurs in the rear of the burning zone and sometimes in the chain section. The formation of dust rings is not fully understood. Alkalies in the feed and dust return are factors. Uneven heating (temperatures being varied too much) can contribute to the problem. Dust rings can benefit the rotary kiln operation because they form natural dams, which increase the residence times of the feed in various parts of the rotary kiln. Dust rings breaking off can trigger an avalanche of feed towards the discharge end, flood the cooler and initiate a rotary kiln upset. Rings can break off naturally or be knocked down intentionally by different methods.

End seals: air seals at either end of the rotary kiln installed to prevent leakage of tramp air into the rotary kiln.

Feeder: delivers material being processed to the top of the rotary kiln.

Grate cooler: a moving grate type cooler with air blown in from underneath. Used to cool product discharged from the rotary kiln. Every second or third row of grate plates moves forward and backward to transport the clinker across the cooler grates.

Grout: cement or epoxy material installed between pier tops and roller assembly subplates to maintain alignment and protect shims from moisture. The material selected should be shrink proof.

Hot alignment: carrying rollers are adjusted when the rotary kiln is operating and up to normal temperature.

Hot survey: rotary kiln alignment checks are made when the rotary kiln is operating and up to normal temperature. (Depending on the methods used, some checks such as an internal survey will have to be performed when the rotary kiln is shut down.)

Induced draft (I.D.) fan: main fan that creates the draft for pulling combustion air into the rotary kiln and exhausting their products of combustion to pollution control equipment.

Pads: also called filler bars. Plates welded or bolted to the shell and shaped to fit the shell contour. The pads support the riding rings. They provide a wear surface for the shell and correct for shell irregularities.

Pier: cement structure for supporting the rotary kiln at several locations along its length.

Pinion: the gear which drives the rotary kiln ring gear. Can be reversed to extend service life.

Planetary cooler: also called a satellite cooler or integral tube type cooler. One of a series of large tubes attached to the discharge end of a rotary kiln for cooling the product discharged from the rotary kiln using direct-contact air cooling. The tubes (usually about ten) are supported by frames welded to the rotary kiln shell. These coolers can be found on lime rotary kilns.

Precalciner: used to calcine the preheated raw meal in a suspension preheater before it enters the rotary kiln. Different types of precalciner systems are integrated with the bottom (hot) part of the preheater.

Preheater: equipment used to preheat raw meal before it enters the rotary kiln. The preheater typically consists of several stages of cyclones connected via riser ducts. Modern systems utilize four to six stages. The raw meal is fed in at the top and is then preheated by the exhaust gases that rise counterflow to the feed. The calcining is initiated at the bottom stage.

Primary air fan: supplies primary combustion air to the rotary kiln's firing zone through the primary air pipe of the burner. In coal-fired systems, it is also used to convey the coal.

Retainer bars: also called stop bars. Used to prevent riding rings from slipping off the pads.

Riding ring: also called a tire or tyre. It is used to support the rotary kiln and rotates on the carrying rollers. The riding ring is mounted over the shell pads, and the shell pads drive the riding ring through friction. Can be a single piece or segmented (2 pieces).

Ring gear: also called girth gear. Main rotary kiln gear attached to the shell using a firmly mounted flange or a flexible spring plate system. Used for rotating the rotary kiln. Normally a straight spur gear that is reversible. Mounted near the thrust riding ring.

Secondary air: secondary combustion air is supplied by undergrate cooling air fans (with a grate type cooler). The air is heated as the clinker is being cooled. The air then enters the rotary kiln's firing zone.

Shims: hardware used to minimize excess pad clearance.

Skewing: also called canting or cutting. Adjusting a carrying roller so that its longitudinal axis is at an angle to the axial centerline of the rotary kiln rather than parallel to the centerline. Rollers are skewed to control thrust and uphill-downhill movement of the rotary kiln.

Tertiary air: combustion air for a fired precalciner. The air is supplied by the secondary air system via a tertiary air duct.

Thrust roller: used to absorb most of the rotary kiln axial thrust and typically mounted on the pier nearest the ring gear. Iftwo thrust rollers are provided, one is uphill and one is downhill of the riding ring. Otherwise, one thrust roller is mounted downhill of the riding ring. The latter is equipped with a hydraulic actuator for automatic adjustment.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

October 2025. Interim revision. Improved specific guidance for Inspection, Testing and Maintenance (ITM), Equipment Contingency Planning (ECP), and sparing. Provided updated loss history.

July 2023. Interim revision. Minor editorial changes were made.

January 2023. Interim revision. Minor editorial changes were made.

July 2021. Interim revision. The following significant changes were made:

A. Clarified the difference between a lime kiln and a cement kiln.

B. Updated the equipment contingency plan and sparing guidance for lime kilns.

January 2021. Minor editorial changes were made.

July 2020. Interim revision. Updated contingency planning and sparing guidance.

April 2012. Terminology related to ignitable liquids has been revised to provide increased clarity and consistency with regard to FM Global's loss prevention recommendations for ignitable liquid hazards.

January 2008. Appendix B ″Document Revision History″ was updated.

May 2005. OS/DS renumbered from 6-17/13-20 to 6-17.

May 2003. Minor editorial changes were made for this revision.

January 2001. The following changes were made:

- Some information was added to Section 3.2.3 on the use of analyzers and temperature monitoring for a safe startup. It has also been stated that operators must have authority to shut down the kiln during abnormal conditions (3.2.3 and 2.5.1.1).

September 2000. This revision of the document was reorganized to provide a consistent format.

September 1999. Minor revision. Editorial.

May 1999. Added recommendation to section 3.4 Preheaters/Precalciners and 3.18.3 Shut down Inspections.

January 1999. Minor editorial changes.

October 1998. Rewritten.

September 1998. Revision.

January 1998. Minor revision. Corrected DS cross-references.

June 1990. The August 1979 publication of this Data Sheet is reaffirmed.

APPENDIX C TROUBLESHOOTING

Troubleshooting information for various mechanical problems are in Table C-1. Figure C-1 provides information for solving tire-retainer wear problems. Figure C-2 provides solutions for abnormal shell rotation and improper gear mesh. Figure C-3 provides solutions for hot roller bearings.

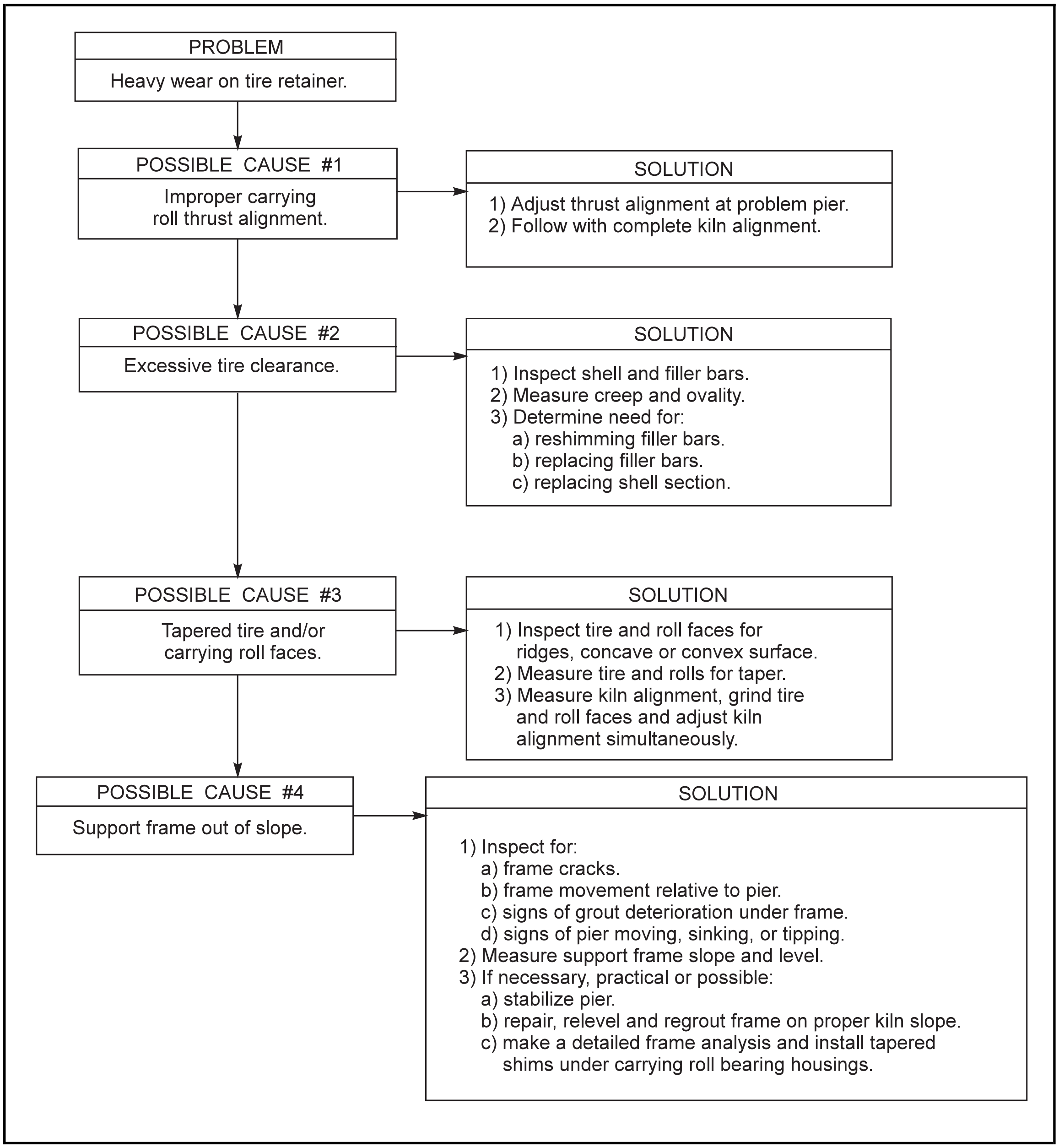


Fig. C-1. Troubleshooting problems with excessive riding ring (tire) wear. Courtesy of A-C Equipment Services Corp.

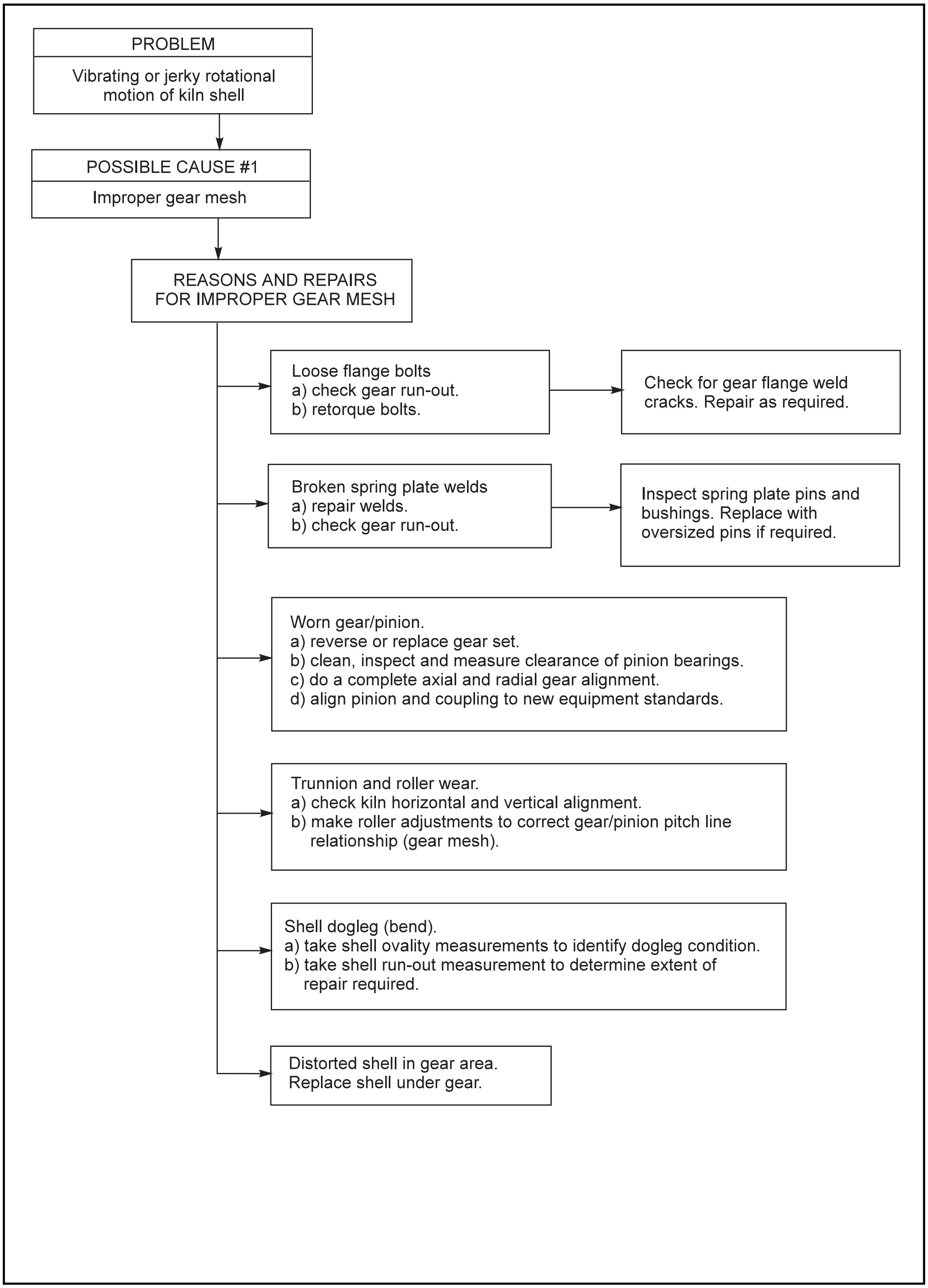


Fig. C-2. Troubleshooting problems with abnormal shell rotation. Courtesy of A-C Equipment Services Corp.

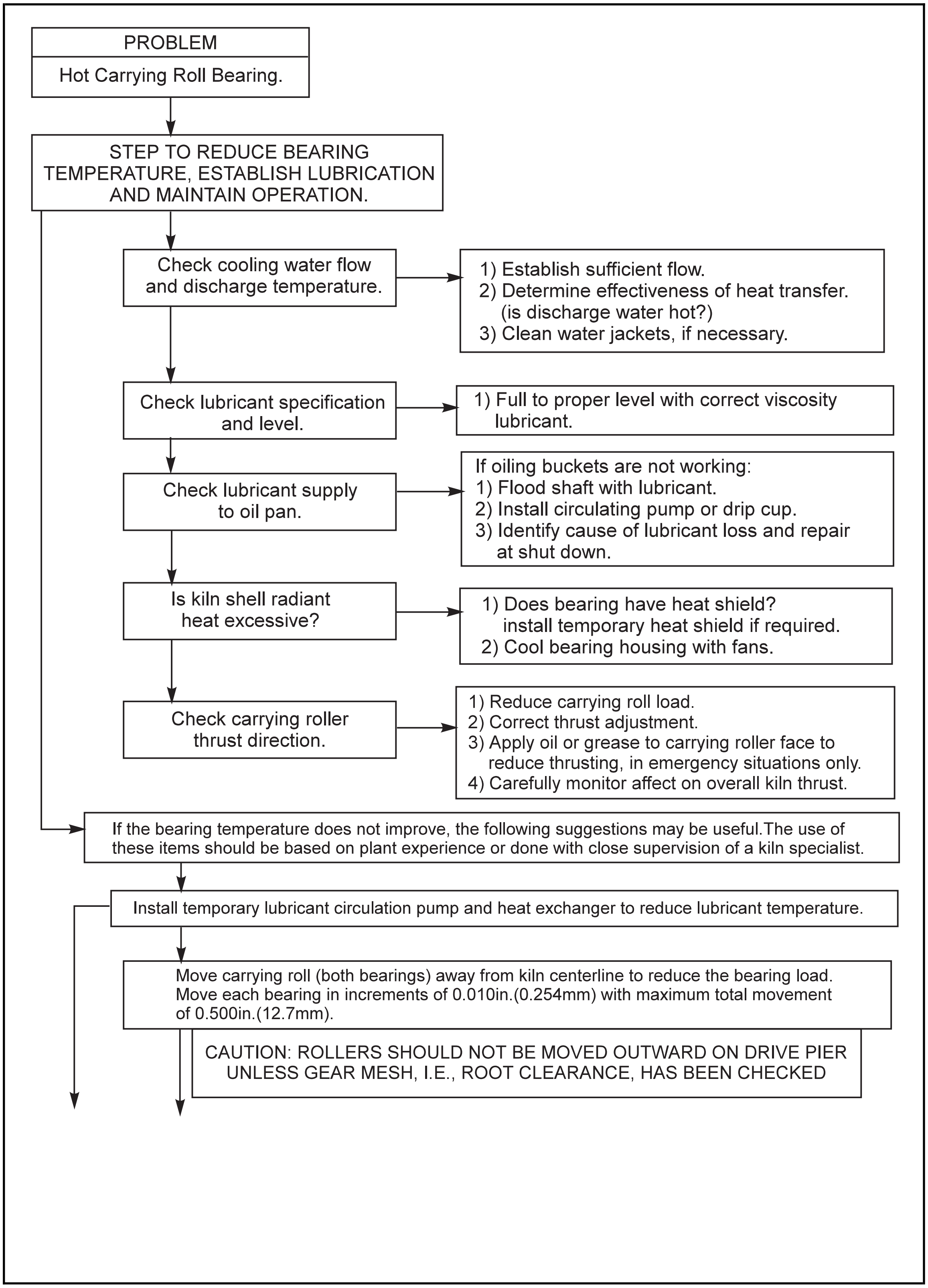


Fig. C-3. Troubleshooting problems with hot carrying roller bearings. Courtesy of A-C Equipment Services Corp.

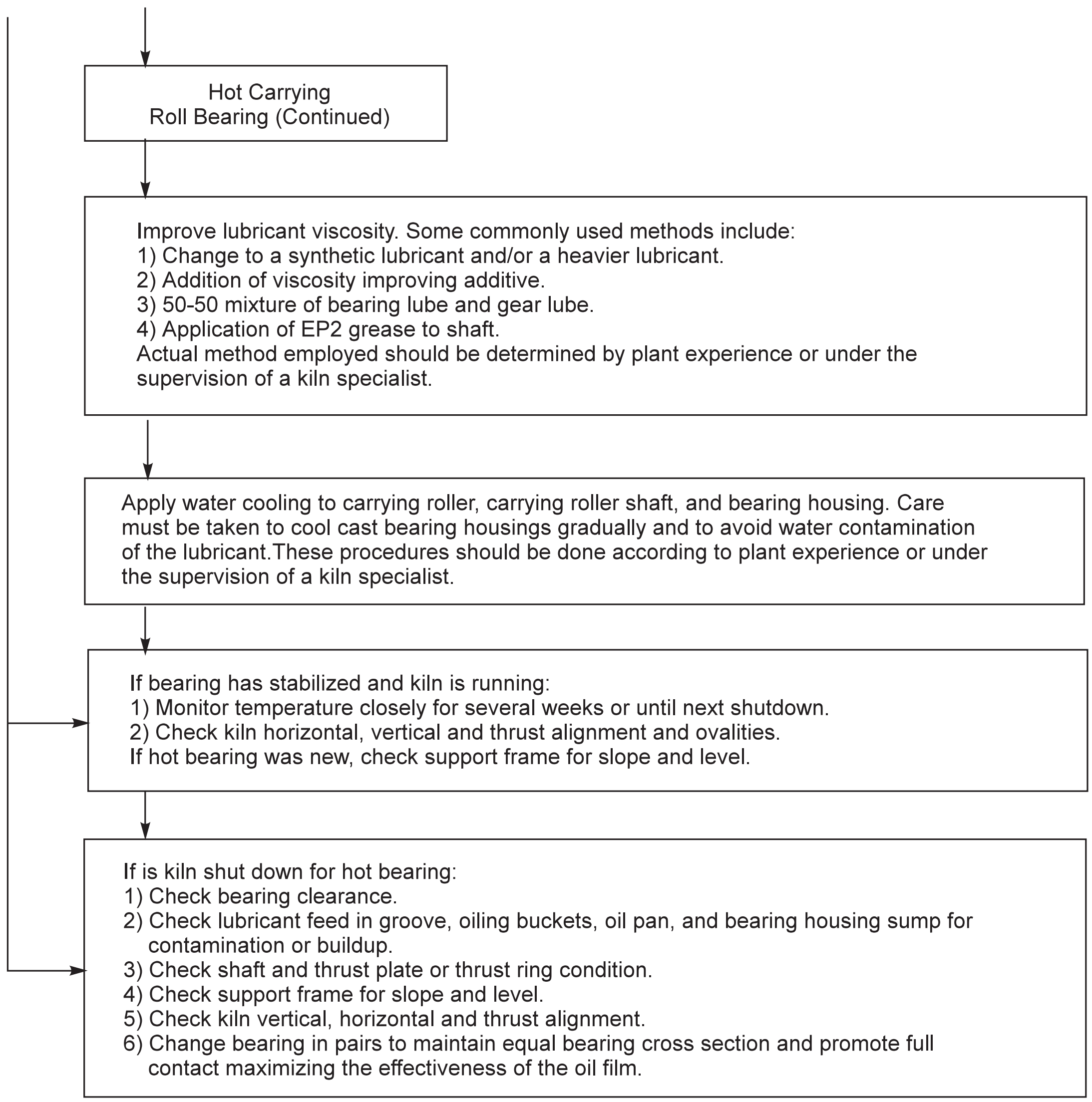


Fig. C-3. Troubleshooting problems with hot carrying roller bearings. Courtesy of A-C Equipment Services Corp. (continued)

Table C-1. Troubleshooting Various Mechanical Problems
Courtesy of A-C Equipment Services Corp.

Problem	*Cause*	*Solution*
Large swings in drive motor amps and kiln R.P.H.	1) Uneven buildup in kiln.	1) Requires correcting one of the following areas: a) operating parameters b) raw mix composition c) coal ash content d) burner pipe positioning
	2) Shell dogleg (bend).	2) Take shell ovality measurement to locate dogleg. Measure shell run-out in affected area to determine extent of problem.
	3) Imbalance of kiln internals.	3) Replace affected chain, dam, etc. Investigate cause of chain deterioration, i.e., temperature, metallurgy, kiln atmosphere.
	4) Kiln misalignment.	4) Check horizontal and vertical kiln alignment.
Excessive wear and/or air infiltration at air seals.	1) Kiln shell run-out.	1) Measure shell run-out at seal. Determine need for: a) shell replacement or realignment b) installation of alternative design seat c) modification of sealing surface to correct run-out condition
	2) Seal component wear.	2) Replace components as needed to renew seal effectiveness
	3) Seal lubrication.	3) Lubricate seals and check for proper movement of rollers if applicable.
	4) Seal counterweight (if applicable).	4) Check counterweight for freedom of movement. Check for proper amount of weight.
Filler bar chunking or slugging.	1) Embedded contaminants 2) Plate laminar tearing.	Lubricate tire inside diameter with graphite/water slurry. No oil.
Tire/roll face scaling.	Lack of graphite lubricant.	1) Replace or clean graphite lube block. 2) Free up the lube block in its holder.
Insufficient tire/roll face contact.	1) Kiln misalignment.	1) Complete check of horizontal, vertical and thrust alignment.
	2) Tapered or out of round tire or roll faces.	2) Regrind tire and roll faces.
	3) Support frame or pier problems.	3) See Tire Retainer Wear possible cause #4, Figure 10.
Thrust roll lifting out of bearing.	Roll positioned toward the uprunning side of the kiln centerline.	Position thrust roll 1/16-⅛ in. (1.59-3.175 mm) off kiln centerline toward the downrunning side.
Thrust roll face spalling or bearing hot.	1) Improper kiln thrust adjustment.	1) Check and adjust carrying roller thrust alignment.
	2) Kiln shell dogleg (bend), causing changes in kiln thrust.	2) Measure shell ovality/run-out to determine extent of problem.
	3) Low oil level.	3) Refill oil to the correct level.
	4) Contamination/wear	4) Disassemble, clean and inspect at shutdown.
Carrying roll oil seals leaking.	1) Contamination in seal area.	1) Maintain a clean shaft in area between roller side face and bearing housing.
	2) Seal worn or damaged.	2) Replace seal.
	3) Shaft worn in seal area.	3) Rebuild and remachine shaft or replace shaft
Repeated refractory failure in same area.	1) Excessive kiln shell ovality, due to: a. clearance or shell distortion b. excessive load	1) Measure ovality to identify problem. a. reshim or replace filler bars or shell as required b. measure and adjust kiln centerline alignment
Coupling grids/teeth worn, dry and coated with powdery residue.	1) Oil separated from carrier in grease.	1) Relube with grease formulated especially for couplings.
	2) Coupling misalignment.	2) Realign coupling. Misalignment should be no more than 25 of coupling manufacturer's recommended maximum misalignment.

APPENDIX D NFPA STANDARDS

Additional information concerning fuel explosion prevention may be found in NFPA[1] 85, *Boiler and Combustion Systems Hazards Code*, and NFPA[1] 86, *Standard for Ovens and Furnaces*. NFPA[1] 85 includes recommendations for direct-firing systems for rotary kilns. Consult these standards for a more detailed explanation of system requirements and operating philosophy. With minor exceptions as to fuel gas-train arrangements, FM has no known conflicts with these standards.

Other related standards include NFPA[1] 54, *National Fuel Gas Code*; NFPA[1] 30, *Flammable and Combustible Liquids Code*; NFPA[1] No. 70, *National Electrical Code*; and ANSI[2] B31.1, *Power Piping*.

APPENDIX E SAMPLE OF A ROTARY KILN INSPECTION PLAN

E.1 Inspections

Rotary kiln inspections are grouped under three headings:

1. Operating — performed with the unit in service.

2. Shutdown — performed with unit not operating. Reasons may be routine idle periods, routine maintenance, service modification or partial dismantle for corrective maintenance. Inspection should include a startup if possible.

3. Dismantle — performed as part of a “take-apart” inspection. There is not a specific time frame; the time can vary with manufacturer’s recommendation, operating conditions, type of service, age of unit, and equipment failure experience.

E.2 Operating Inspections for Fully Assembled Equipment

- Compare the following items with the parameters established by the manufacturer of the equipment.

- Verify availability of startup and shutdown procedures (standard and emergency). Operators should use these procedures and have the authority to make critical decisions.

- Verify operating conditions are within the manufacturer’s parameters for load, speed, temperature (hot zone and back end), and back-end oxygen.

- Look for hot spots (easier to spot at night on both preheater equipment and the rotary kiln), especially near the hot end of the rotary kiln. Look for flat spots or blisters, especially near each riding ring. These indicate a hot spot and breakdown of refractory. Examine the shell for repairs, verify repairs were completed correctly, and document any follow-up activity.

- Visually check supporting piers for indications of settling and/or tipping. Check for pier vibration and movement of the carrying roller frames.

- Visually check thrust rollers. Check if riding ring floats between the thrust rollers (commonly done, but not always recommended) or if one of the rollers is rotating. If rotation or the thrust roller and carrying roller surfaces are not smooth, the thrust roller shaft and bushing may be damaged. If the thrust roller is tilted, there could be excess bushing wear caused by overloading of the thrust roller. If the thrust roller rises up during rotation, it is probably not adjusted properly (thrust roller centerline should be about 1/16-1/8 in. (1.6-3.2 mm) and no more than 1/4 in. (6.4 mm) past the carrying roller frame centerline in the direction of the downward side of rotary kiln rotation. An uphill thrust roller rotating could be a sign of misadjusted and overloaded carrying rollers. If the rotary kiln is equipped with a hydraulically-actuated thrust assembly, the thrust roller will automatically adjust the thrust; the carrying rollers should not be adjusted to move the rotary kiln uphill. If the rotary kiln floats, it will periodically move up and down between the thrust rollers. If the rotary kiln is equipped with a single, hydraulically-operated thrust roller, the roller will be adjusted automatically using a limit switch.

- Visually check carrying rollers for wear and pitting. Look for eccentric movement of the riding rings and check if both rollers remain in full contact during a complete revolution. A warped shell can lift a riding ring off the roller or wear can cause incomplete contact across the face of the roller. Look for spalling or corrosion indicating poor contact or incorrect skewing. Making sure skewing is parallel will correct this condition if done

[1] *NFPA 30, 54, 70, 85 and 86 are copyrighted publications of the National Fire Protection Association (NFPA), Quincy, MA 02269.*
[2] *ANSI B31.1 is a copyrighted publication of American National Standards Institute, Inc., New York, NY 10018.*

soon enough. If the rollers are convex and the associated riding ring concave, rollers may be overadjusted. This condition will cause problems when the rotary kiln is being warmed up or shut down. Check both bearing assemblies of each roller for abnormally high temperature and squealing noises. Check for shaft cleanliness between the roller and bearing housing. Check to see if a riding ring is riding over the edge of the tire on one side.

- Check each carrying roller to see if it is thrusted uphill or downhill by measuring the distance between the roller and housing on both sides. Or tap on the end of each carrying roller assembly with a hammer; the thrusted end will sound more solid. Some rotary kilns have an inspection cap to view the thrust position. Most rotary kilns should be thrusted against the downhill carrying roller bearing, causing the rotary kiln to be pushed uphill. If some of the uphill bearings are thrusted, the rotary kiln will be pushed downhill, and the thrust roller could be overloaded. (If it is carrying any load, the thrust roller will be rotating.)

- Visually check pad and retaining bar welds. Check if the retaining bars are worn or cutting into the tires.

- Verify that graphite blocks used to lubricate carrying rollers are in contact with the roller and free to move in their retainers.

- Check creep at each riding ring. Compare with recent records. Look for large differences between readings at each pier.

- Check for oil leaks at each carrying roller bearing end seal.

- Visually check the driving gears (ring and pinion) for lubrication and wear. Pinion teeth wear more rapidly than the ring gear teeth. Worn pinion teeth will accelerate the wear of ring gear teeth. Check if the gear and pinion centerlines match. If the centerlines are not lined up, the ring gear pitch line might be worn off if the gear rubs against the guard. Check if pitch lines are separated (preferable) or matched or even overlapping; align gears if overlapping.

- Verify that the auxiliary drive system is functional in the event of main drive failure.

- Verify the auxiliary drive motor is started and run at least weekly. Verify that there is an auxiliary drive motor rather than just a generator that powers the main drive motor. The generator, typically diesel powered, should be tested. Maintain an adequate fuel supply. It might not be practical or advisable to run the auxiliary drive motor itself unless it can be operated without being engaged to the main reducer gears.

- Visually check auxiliary drive gears for lubrication, clearance, and wear, if applicable.

- Inspect reducer gear oil levels and bearing temperatures.

- Check the adequacy and operation of gear lubricating oil system and check for leaks. Oil should be changed as indicated by testing. If it is a spray type system, install an operational warning device to indicate air pressure loss and test the device periodically.

- Check water or air cooling system of the carrying and thrust roller lubricating system, if installed. If it is water cooled, review winter (cold climate) operating procedures such as lay up.

- Inspect drive motor per Data Sheet 5-17, *Motors and Adjustable Speed Drives,* Section 2.4.2, Routine Visual Inspection.

- On small rotary kilns/dryers with annular synchronous motor and rotor secured to shell (no gear set or clutches) pay special attention to maintaining acceptable air gap. On dual drive rotary kilns, pay attention to dual drive synchronization. Amperage should be steady. Monitor the voltages or currents of the field and armature for each motor for periodic variations that can indicate an imbalance. There might be a slight difference in amperage between the two motors due to instrument errors; this should remain within a certain tolerance during steady state conditions. Properly aligning both gear sets is important. Rotary kiln drive motors are normally DC; however, some installations are using variable frequency AC motors; the variable frequency drives stay balanced inherently.

- Check maintenance and cleanliness of dust filters on air intakes for drive motors.

- Inspect raw material feed pumps and motors. A feed interruption can lead to a serious upset.

- Inspect all fans including the induced draft fans, primary air fans, forced draft fans, recirculating fans, combustion fans, cooling fans and preheater fans.

- Verify interlocks are installed to shut down the supply of fuel in case the induced draft fan, primary air fan or other required fans (needed for proper combustion) malfunction.

- Verify interlocks are tested. Check records and observe test if possible.

- Verify periodic vibration readings on induced draft fans. Check records.

- Check for main drive and fan vibration trends.

- Visually check condition of piping, hoses, flexible connections, swivel joints, etc.

- Maintain general good housekeeping practices.

E.3 Shutdown Inspections

In addition to the feasible items included in Section E.2, observe the following items where possible during a scheduled shutdown. As applicable, witness tests or verify data from logs.

- Visually check rotary kiln shell for cracks. Visually check for indications of warping or blistering of the rotary kiln shell which would signify a hot spot and refractory breakdown. Examine old repairs. Verify whether follow-up activity is needed to check old repairs.

- Verify symmetrical air gap on rotary kilns with annular synchronous motors and rotors secured to shell.

- Visually check all the way around the main gear for uniform contact across the gear teeth.

- Verify pinion and main gear mesh is adjusted to remove any pitch line overlap. Account for thermal expansion effects on gear mesh at full operation.

- Inspect refractory for failure or excessive wear including abrasion, spalling, chemical attack, slagging, proper installation to allow flexing of shell and thermal expansion and proper refractory composition for each rotary kiln zone.

- Visually check the chain shoe system.

- Observe chains for oxidation, scaling, and fluxing.

- Inspect drive motors, gears, and fans.

- Inspect the primary air pipe for warping.

- Inspect raw material silo (preheater/precalciner) walls and conical bottoms for thinning and corrosion of steel plating.

E.4 Dismantle Inspection of Rotary Kiln Components

Inspect rotary kiln components during major disassembly at regular intervals recommended by the manufacturer or when necessary, as determined by operating conditions. In addition to all possible operating and shutdown inspection items, observe or verify the following items:

- Refractory inspection and repair

- Condition of carrying roller bushings (important) and downhill thrust roller bushing. If the wear is excessive, the bushing will have the same contour as the shaft and will be thinner at the middle part of the bushing. High spots or ripples may also exist along the longitudinal axis. Worn bushings should be replaced. For spherical, anti-friction bearings, measure roller-to-race clearance.

- Condition of gas and dust seals

- Conduct NDE of all welds at riding rings if indications are present.

- Inspect ring gear and pinion for broken teeth or cracks. If indications are found, verify the condition by NDE of the entire gear. Check the ring gear flange or spring plates for cracks. Measure pinion bearing roller-to-race clearance.

- Conduct undercover inspection of enclosed gear reducer.

- Condition and balance of I.D. fan rotor

- Alignment of piers/carrying frames

- Verify horizontal and vertical alignment of shell, together with proper contact and loading of the carrying rollers and the thrust roller.

- Perform motor, gear and fan checks.

- When service is performed by any entity (contractor, mill staff, OEM, etc.), retain a copy of the completed work order to verify what was done during the ITM activity. Make these work orders a part of permanent plant records.

- After satisfactorily testing and operating the unit (following major dismantling), compare existing baseline data with present temperatures and vibration signature to verify proper operating condition.