ABSTRACT

In the papermaking process, paper is dried on rotating, steam-heated, cast iron drying cylinders. Steam is supplied to each of these drying cylinders through a rotary joint and the steam that has condensed inside the dryers is removed by a syphon system that extends out through either the same rotary joint or a rotary joint on the other dryer journal. These rotary joints and syphons must provide reliable service to minimize unplanned downtime, control operational costs, and support mill sustainability. This paper discusses factors that contribute to a successful paper dryer section rotary joint and syphon maintenance program.
Dryer section rotary joints require periodic inspection and replacement of wearing parts. Rotary joints contain “consumable” parts, but great strides have been made over the years by rotary joint manufacturers to develop new sealing materials and rotary joint configurations to reduce the repair frequency and extend the operating life. Although most advanced seal materials are proprietary offerings of the rotary joint manufacturers, advances in rotary joint design have been memorialized in the patent archives (1-19).

For over a generation, rotary joint research was focused on developing seal rings that would last longer and longer. This work required developing unique seal ring materials and unique rotary joint configurations. For steam applications, the life of a rotary joint seal ring improved from a few days (some papermakers will remember those days) to over five years.

Today, the wear rate of the seal ring is often not the limiting factor for rotary joint life, at least not when modern seal materials are used with modern rotary joint configurations. With rotary joints that have piston-type seal configurations (14) and high-performance seal rings and rigid rotary joint supports, other less visible parts (O-rings, gaskets, seal plates, secondary seals, and steam insulating sleeves) have surfaced as the primary limiting factor for long rotary joint life.

On traditional self-supported, pressure-loaded rotary joints, however, seal ring life remains as the primary limit to rotary joint life, but improvements in seal materials have extended the life of these older rotary joint technologies as well. Also, paying attention to the details of best practice installation techniques, such as proper flex hose arrangements and anti-rotation rods, have helped to increase the operating life.

Based on extensive audits (20) of the dryer sections of the majority of papermaking machines in the USA, the best performing paper machines with self-supported rotary joints will have less than 5% of their dryers out of full service. That is, 95% of the dryers will have no leaks and will be operating under control. For rotary joints that are rigidly supported by the machine frame, the number of dryers out of service should be below 3%. The benchmark for dryers out of service for top-performing paper machines is 3% for self-supported rotary joints and 1% for externally-supported rotary joints.

Although the rotary joint is the visible part of the dryer drainage system, the dryer syphons also have a significant effect on the dryer section performance. The syphons have a direct effect on the rate and uniformity of dryer heat transfer and also on many steam system design parameters, such as pipe, separator, and valve sizing, system configuration, and control actions. Modern steam systems can take
advantage of well-understood syphon performance curves to minimize blow-through steam flow rates. Reduced blow-through steam reduces the erosion of system components and increases the life and reliability of the system components.

An unintended but fundamental consequence of long rotary joint and syphon life is less attention is needed or given to the dryer steam systems and related equipment. As a result, there is a growing lack of knowledge about selection, installation, repair, maintenance, and operation of rotary joints, syphons, and steam systems. Fewer people are exposed to the nuances of an excellent installation of rotary joints. Too often, dryer hardware decisions that affect paper machine performance are not factually based, nor do they consider the total cost of ownership of the related component parts.

**ROTARY JOINT LIFE**

The life of a rotary joint depends on many parameters, but the primary process parameters are steam pressure, steam temperature, and the rotational speed of the dryer. Rotary joint manufacturers have run extensive series of tests to quantify the impact of each factor, individually and in combination. Kadant Johnson, for example, has developed a testing protocol that uses five pre-defined combinations of process variables. One type of rotary joint may have its longest life with one set of conditions while another type of rotary joint has its shortest life with the same set of conditions. Further, tribological performance is inherently variable. Natural variations that occur in the processing of seal materials and seal mating surfaces can produce a wide distribution of rotary joint life. For this reason, testing programs must be based on extensive seal testing that can quantify both repeatability and reproducibility.

The expected life of a rotary joint is not a single value, for example, two years. Under a given set of operating parameters, the rotary joint life will form a normal distribution. A typical distribution is shown in Figure 1. As shown in this figure, the rotary joint life can range from 2 months to 16 months, with an average life of about nine months.
As expected, a few rotary joints fail shortly after they are installed ("infant mortality"), but most will fail only after an extended period of operation, about nine months in the above example. Similarly, when new rotary joints are installed on all of the dryers at the same time, there should be a period in which there are few or no failures. As time goes on, however, the number of failures will increase and eventually reach a peak. As the rotary joints are progressively repaired or replaced, the number of failures per shutdown will eventually stabilize, with a smaller number of repairs for those rotary joint configurations that have a long expected seal life, and with a larger number of repairs for those rotary joint configurations that have a short expected seal life.

Once this "stable" period is reached, the average life of a rotary joint can be calculated based on the average number of rotary joints that are repaired or replaced at each machine shutdown, using the following equation:

\[
\text{Average life} = \frac{N \times t}{52 \times R}
\]

where:
- Average life is expressed in number of years
- \(N\) = Number of rotary joints on the machine
- \(t\) = Average number of weeks between shutdowns
- \(R\) = Average number of rotary joints repaired or replaced per shutdown

If a paper machine has (80) dryers with (160) rotary joints (one rotary joint on each dryer journal), and if 10 rotary joints are repaired at each shutdown, and if there are six weeks between shutdowns, then the average rotary joint life is:
Average life $= \frac{160 (6)}{[52 (10)]} = 1.85$ years

That is, even for a rotary joint with “good” life of nearly two years, there will still be on average 10 rotary joints that must be repaired or replaced at each scheduled shutdown.

There are, however, different models for managing the maintenance program for rotary joints, ranging from the “run-to-failure” model that leads to the normal distribution of failures described above, to a formal predictive preventative maintenance program in which the rotary joints receive scheduled maintenance before failures occur.

**UNDERSTANDING TOTAL COST OF OWNERSHIP**

The total cost of ownership (TCO) includes both direct costs and indirect costs over the life of the product. The direct costs associated with the run-to-failure model include the purchase of parts, direct labor, contract labor, and indirect labor costs incurred at each scheduled and some unscheduled shutdowns. The indirect cost is the cost of lost production, if the lost production is caused or extended by the equipment failures.

The direct cost associated with a formal predictive preventative maintenance program would typically be higher for the work done during a single shutdown, but, with fewer shutdowns requiring work, the total direct cost is invariably lower. Further, the indirect costs associated with unscheduled and extended shutdowns can be eliminated, making the TCO significantly lower.

A typical maintenance program is managed based on an annual maintenance budget. The annual budget is often established based on the costs incurred during the previous budget period. In a growing number of cases, maintenance budgets are cut each year as an incentive to reduce costs. Mills attempt to minimize maintenance costs to stay within these budgets. This can lead to running parts to failure in an attempt to get the maximum life out of the parts. Rotary joints are a common example of a product where paper mills run the parts to failure rather than replacing or repairing the parts before they fail. This “run-to-failure” approach, however, generally ends up with the highest TCO, not the lowest.
This is for several reasons: When one part fails, it can damage adjacent parts that may be quite expensive. This is particularly true with rotary joints, where the rotary joint housings can be severely damaged from steam cuts that result from unaddressed steam leaks. Also, rotary joint failures can result in the paper machine being totally shut down to allow operators to safely and properly valve out the dryer with the damaged rotary joint. Still further, the unplanned maintenance will often result in a higher cost of expediting replacement parts for the shutdowns and premium rates for contract labor and overtime rates for internal labor not scheduled in advance.

By replacing wearing components before they fail, the higher costs of running to failure can often be avoided, saving both time and money in the long run.

**ROTARY JOINT INSPECTIONS**

The challenge with any preventative maintenance program is knowing how and when the replacement cycle should be executed. This is the key to predicting and controlling costs.

For example, the most effective strategy for anti-friction dryer bearing maintenance is focused on maintaining the proper flow, temperature, viscosity, and cleanliness of the lubrication oil. The L10 life of dryer bearings can be over 50 years, if based only on classical fatigue failure and not on other failure modes such as lubrication starvation, improper mounting, contamination, etc. Routine efforts to maintain the lubrication system are supplemented by efforts to detect pending failures. Correspondingly, dryer bearing inspections, vibration surveys, and contaminant testing of spent lubricants are common tools in a preventative maintenance program for dryer bearings.

The maintenance cycle for air filters, by contrast, can be established by the air filter manufacturer’s recommendations. These recommendations are often based on testing and experience with the specific style of filter in the specific industrial environment. These recommendations reflect advances in filter materials and construction. The recommended maintenance cycle is then adjusted based on experience with the specific application and augmented by periodic inspections (visual inspection or measurement of operating pressure drop).

Similarly, a proper preventative maintenance program for rotary joints requires a comprehensive approach, one that uses the rotary joint manufacturer’s seal test results as the benchmark, periodic inspections for qualification, and operating history to establish the repair cycle. Seal test results set the benchmark for rotary joint life and establish the
initial repair cycle for new installations.

It is easy to identify external rotary joint failures by visual inspection, looking for external steam leaks. To identify rotary joint failures in advance of seal ring failure, the remaining seal ring life can be measured directly on many modern rotary joint configurations. These measurements can then be coupled with the predicted life from the rotary joint manufacturer to form an upgrade cycle appropriate for each papermaking dryer section. In addition, the rotary joint manufacturer can provide technical support for identifying other pending or cause of failures of other component parts (o-rings, packing, insulating sleeve, syphon pipes, wear plates, and internal sealing systems).

ADDRESSING ROTARY JOINT FAILURES

Ideally, a rotary joint that shows signs of external seal leaks would be repaired or replaced as soon as it is detected. Only on very rare occasions, however, would a papermaking machine be shut down to fix a leaking rotary joint. Instead, the rotary joint would be valved off or just allowed to continue leaking until the next scheduled outage. When a rotary joint or component fails, the mill typically has only one decision to make: Valve the rotary joint out of service and continue running, or allow the rotary joint to continue to leak and continue running. There are significant costs associated with both of these options.

Cases where dryers are valved out of service: When a dryer is valved out of service, a portion of the machine’s drying capacity is lost. When the machine production is limited by drying capacity, valving out dryers translates directly to a loss in production. The amount of the loss in production depends on which dryer was valved out of service, the grades being produced, machine speed, and machine width. For large, high-production machines, the lost production from having just a few dryers out of service can be worth over a million dollars per year.

Even if the machine production is not limited by drying capacity, a dryer valved out of service can still cause a significant loss in production, particularly if the machine is producing lightweight paper grades at high speed. A dryer valved out of service will be lower in temperature than adjacent dryers that are steam-heated and it will therefore be physically smaller in diameter. If the dryers are geared together (a common configuration for conventional dryer sections), this
“cold” dryer will run with a slightly slower surface speed. Sheet runnability will suffer from sheet wrinkles and tensile breaks, the load on the dryer gears will increase, the dryer gear wear will accelerate, and the gears will eventually fail.

If the dryer that is valved out of service is in the critical warm-up drying zone, further sheet quality defects such as cockle and grainy sheet surfaces can result.

As a special note: When a dryer is valved out of service, the dryer should be isolated from both the steam supply line and the condensate drain line. The ideal way to do this is a double isolation configuration, often called a “double block and bleed” configuration, as shown in Figure 2. This arrangement is the best way to isolate a dryer from the steam supply and condensate drainage headers and prevent the dryers from filling with steam or back-filling with condensate.

![Dryer Isolation Configuration](image)

Figure 2. Dryer Isolation Configuration.

**Cases where dryers are kept in service:** If a dryer is kept in service when a rotary joint is leaking, the dryer can still be pressurized. If the leak is large, however, it is possible that the dryer may not hold full pressure and there is a corresponding loss of differential pressure, which leads to dryer flooding. Partial flooding will lead to a loss in drying capacity. Production losses in these cases can be substantial even though the dryers are “active” and are perceived to be “hot” when they are in a partially flooded configuration and provide little contribution to drying paper. A dryer fully flooded will also have increased drive loads that can cause dryer gear failures. The increased drive loads can also cause line shaft speed variations, sheet breaks, and dryer drive kick-outs.

There are also mechanical risks caused by continuous steam leaks. The leaking condensate and steam can migrate into the oil system through the labyrinth seals on the bearing housing covers. This can be especially true when steam sleeves are leaking with certain types of bearing cover designs. This water can overwhelm the water separators
and driers in the lubrication system. Mills with water in the oil systems have been known to have large increases in oil/water separator costs and in losses in failed dryer bearings.

When the oil lubrication system is not tight and significant oil leakage occurs, steam leaks can also blow oil onto the sheet, causing losses due to sheet defects. One paper mill experienced losses over $1.5 million per year from this type of defect.

If a rotary joint is allowed to leak, there will also be direct energy losses to the atmosphere. The associated losses include the cost of treating incoming makeup water, the cost to heat this water into useable steam, boiler chemical treatment costs, and the value of returned condensate. For an average steam leak of 500 pounds per hour, the total cost can easily be as much as $29,000 per year (at $7/million BTU total steam cost).

Continuous steam leaks can also cause failures of other mechanical equipment. If, for example, a dryer journal insulating sleeve fails and the dryer is kept in service, the dryer bearings can overheat and fail (21), resulting in an unplanned outage that could last several hours. Each failed bearing can have a total cost of up to $250,000 or more (for parts, contract labor, and lost production).

Steam leaks can also overheat and damage other equipment in the area, including electronics for valves, transmitters, positioners, camera systems, and other critical operating components.

Besides property damage, rotary joint failures can cause injuries to operating and maintenance personnel. If a rotary joint fails catastrophically, the resulting flying debris and flashing steam can cause serious injuries to personnel. The lack of proper repair parts and procedures can lead to catastrophic failures of flexible hoses, rotary joints, and the components within rotary joints.

The environment around a running paper machine is hot, humid, and noisy. As a result, steam leaks can cause a further decrease in situational awareness in the mill. Further, high-pressure steam leaks can be nearly invisible, making them particularly dangerous. Compromising the selection of equipment and replacement parts and using unqualified installation and maintenance procedures can lead to high risk of dryer, vessel, and rotary joint decompression and personal injury.

Minor uncontrolled steam leaks can also present risks to the safety of operators and maintenance personnel. The leaking condensate, particularly when mixed with oil on the floor, will present a slip hazard. Even the act of valving out a dryer joint that has failed can expose operators to increased risk from the hot pipes, hot valves, and leaking steam and condensate. It is best to avoid failures and the problems associated with these failures.
In summary, the total cost of ownership includes capital and installation costs (sunk costs) and maintenance and repair costs (the ongoing costs). The on-going costs include replacement part costs, expediting costs, direct labor for installation, indirect labor for planning and supervision, lost production, injuries, and failures of associated equipment.

Spreadsheet programs can be used to estimate the total cost of ownership and assess alternative approaches to maintenance, utilizing specific machine and operating parameters, along with factors that reflect the style of rotary joint and experience with the rotary joint performance. Such spreadsheets are often available from the rotary joint manufacturer.

COST OF PREVENTATIVE MAINTENANCE

Having discussed the cost of failures, this section covers the factors relating to the cost of preventing failures.

Whether a mill performs its own maintenance work or has the work completed by an outside contract firm, the cost of labor is a significant part of the total cost of repair and the time required for organizing and scheduling the work is often longer than the time required for the repairs. This highlights three important points:

1. Use genuine, qualified, original equipment parts. The life-cycle cost of parts from third-party companies making copy machine parts is invariably much higher and even the initial cost is often higher as well.
2. Use contractors certified by the original equipment manufacturer (OEM). The OEMs have a vested interest in having their products perform well and not in improving the utilization of an inflated workforce.
3. Minimize the number of times rotary joints must be repaired. This can be accomplished by moving from a “run-to-failure” maintenance program to a proper preventative maintenance program.
MINIMIZING THE NUMBER OF REPAIRS

If the rotary joint maintenance cycle can be reduced from 8 times per year (for example, at every shutdown every 6-weeks) to only one or two cycles per year, then there is an immediate and direct reduction in the cost and time associated with planning and scheduling, the cost of workforce mobilization and demobilization, the cost of multiple part procurement cycles, and the excessive staffing levels required to complete the work during short shutdowns.

By scheduling a preventative maintenance program for an annual shutdown or other major scheduled down, the work can be completed with a certified crew with less total time spent in coordinating contractors, in schedule planning, and in managing the project. Most importantly, repairing all or a significant portion of the rotary joints at one time puts all of the rotary joints back on a predictable pattern of performance. Using the example at the beginning of this paper, rather than having ten rotary joints require work at each six-week shutdown, there may be none.

A good analogy for this approach is the maintenance of tires on an automobile. Today, automotive tires have long tire life and the tires rarely fail unless there is some unforeseen event, such as a nail in the road causing a blow-out. And even those types of failures occur infrequently today because of advancements in tire quality (steel belted radial construction). Correspondingly, tire tread wear is monitored and all four tires are replaced together, before the first of them reaches its end of life. This avoids the risk of a catastrophic failure, the inconvenience of an unexpected failure, the extra time in scheduling the repairs, and the extra costs of having to realign steering components multiple times.

In a similar way, maintaining all of the rotary joints during a predetermined cycle can avoid catastrophic failures, damage to related equipment, extra planning, and higher overall repair costs.

Because rotary joint life typically extends over multiple budget cycles, the total cost of a rotary joint repair / replacement program should be in a five-year maintenance plan. Alternatively, if maintenance capital is approved annually, the cost can be distributed over several budget cycles with a maintenance accrual, with a rotary joint manufacturer’s service agreement, or with sequenced repairs (for example, one quarter of the rotary joints are repaired each year, if the average rotary joint life is four years).

The concept is to complete the preventative maintenance work before the rotary joints reach the point of failure. Some would argue this increases costs because there is some remaining life in some of the component parts, but the savings in part prices from running all parts to failure is completely lost in the higher cost of labor, damaged parts, downtime, and lost production.
COST OF REPAIR PARTS

As already discussed, labor is a significant part of the total cost of a preventative maintenance program. To get the most rotary joint operating life out of this work, the service work must be done by trained, qualified, and certified technicians.

The cost of replacement parts, however, is often the highest direct cost. To get the most operating life out of replacement parts, the replacement parts must be of top quality, meeting the original design tolerances, material specifications, and code requirements.

But there is even more to this point. Although advancements in seal materials, wear surface treatments, and elastomeric parts have been applied to older style rotary joints, the basic rotary joint configurations continue to be dated. There are dryer sections in North America that continue to use rotary joints that were designed over 50 years ago. The performance of these rotary joints is better than it was 50 years ago, when the advancements provided by the OEM are used, but the performance remains well below modern design standards. Still further, the replacement parts for obsolete, old-technology rotary joints are often more expensive than equivalent parts for the latest new-technology rotary joints.

This point deserves additional comment. In an attempt to reduce the cost of replacement parts, some mills will have local machine shops attempt to duplicate the old parts. This approach to cost reduction is inherently flawed. A perfect copy of a worn part is another worn part. Even a perfect copy of a new part is at best a copy of one part, which may have been manufactured at the extreme limit of the original manufacturer’s allowable dimensional tolerances.

Still further, a perfect copy of an obsolete part is still no better than an obsolete part. It incorporates none of the material or design enhancements supplied with a new part from the OEM. Instead, the expected benefit of cheaper parts is offset by reduced life and the loss of improvement available from the OEM part supply. One mill in the Southeast USA documented that copied parts supplied by a local machine shop were approximately 20% lower purchase cost than OEM parts, but many of the parts did not fit, many failed on startup, and all had much shorter service life. The initial purchase savings were more than offset by the increased cost of incremental direct and indirect labor, increased downtime, loss of drying capacity, and the frustration of continued repair requirements.

Although not as apparent in a purchasing transaction, the parts supplied by local machine shops or other non-OEM suppliers may not satisfy the code requirements met by the OEM parts. In Canada, for example, provincial design approval is required for all pressure vessels and their replacement parts. Similarly, the European Community Pressure Equipment Directive requires design review by a Notified
Body in the European Community. In the USA, rotary joints that are manufactured under the ASME pressure vessel code must use materials recognized under the ASME code. There is no guarantee or OEM design support for the material selections made by local machine shops copying OEM parts.

If the surface finish treatment that is applied to sealing surfaces by the local machine shops misses the standard applied by the OEM, service life of the rotary joints will drop even further, thereby offsetting any possible savings in buying copies of OEM replacement parts. In Mexico, the nitrocarburizing case hardening surface treatment provided by the OEM to a wearing surface was “duplicated” by the local machine shop by spraying black paint on the surface. Clearly, this was not an equivalent part, but it was lower in cost. As one would expect, the part provided much shorter service life. The cause of the premature failures was not identified until the OEM was asked to help improve the rotary joint life.

Even for the case of “commodity” soft parts (such as gaskets, packing, and O-rings), there can be significant difference in performance between parts supplied by the original equipment manufacturers and “equivalent” parts supplied by local distributors. Gasket dimensions and materials are selected by the OEM to match the gasket seating surfaces of the rotary joint. The “M” and “Y” factors for the gasket material must meet the code requirements for each specific flange configuration.

Similarly, O-ring dimensions and materials are selected by the OEM to meet the specific requirements of the sealing application. Not all O-rings with the same nominal dimensions and color are created equal. The OEM companies have invested significant research, development, and experience in selecting the exact gasket and O-ring materials necessary to ensure best life cycles. Saving a few dollars on an O-ring and gasket and risking failure and shutdown of a paper machine is a poor investment.

A large paper mill in the Southeast USA suffered from this “investment” in savings. The mill switched from the parts supplied by the original equipment manufacturer to a local gasket and O-ring supplier and reduced the purchase price. This change resulted in premature rotary joint failure and compromised safety. Only after the OEM was brought in to troubleshoot the problem was the true source of the problem (sub-standard material selection) identified.

One final point on this topic: The technical life of a rotary joint is about 10-15 years, as evidenced by the changes in rotary joint design over the past decades (1-19). Once the “run-to-failure” model has been broken and the rotary joint repair is on a preventative maintenance program, there can be economical opportunities to upgrade to the next generation of rotary joint technologies. The OEM can assist in identifying economical upgrade opportunities, while the local machine shop would continue to turn out obsolete replacement parts for obsolete joints.
CHANGE IN REPAIR CYCLE

After a machine has undergone a complete replacement of rotary joints, as with a major rebuild, the rotary joint replacement and maintenance costs will be, or at least should be, zero for an extended period. Often top performing rotary joints will have no repair or service cost or losses for five years or more. During this time, it is easy to forget about rotary joint maintenance. The maintenance budget for rotary joints, when based on historical costs, will be reduced to zero. When some rotary joints reach their end of life and repair costs begin to appear, there may be no budget in place to cover more than a few parts, driving the mill to a “run-to-failure” mode. In cases where the maintenance staff has been reduced in size, the remaining staff may not have the knowledge and experience to troubleshoot, repair, and replace critical rotary joint components. The rotary joints then have become a victim of their own success.

There are several different methods for dealing with the varied but somewhat predictable life of rotary joints, ranging from a completely reactive maintenance program to a highly analytical and proactive predictive preventative maintenance program. A few examples are summarized below:

- **Run-to-failure.** A mill can operate the paper machine with no rotary joint maintenance until the first rotary joints fail. The rotary joints that fail are then repaired and a minimal number of repair parts are stocked, based on the requirements determined in the initial repairs, and the other rotary joints are repaired or replaced as they fail. Eventually, the repair pattern settles into one in which a predictable portion of all of the rotary joints on the machine are repaired at each shutdown. Most mills use this methodology, although often not intentionally. The penalty for this approach is that the total cost of ownership, which includes extra costs for labor mobilization and demobilization and the associated costs discussed earlier in this paper, are typically the highest of the options.

- **Sectional Upgrades.** An alternative to running each rotary joint to failure is to run the machine until the first failures appear and then launch a systematic approach, repairing one or two dryer sections at a time. This reduces the risk of rotary joint failures in the sections that are repaired and correspondingly reduces the total cost of ownership. Whether done on an annual or on a regularly scheduled short outage, repairs are completed in a controlled, planned manner. Some would argue that this approach increases the cost of parts (as there is some life left in some components that were replaced), but in reality this approach alleviates many of the previously identified risks of running to failure. Until this program has gone through one complete cycle, there will be a higher percentage of rotary joint failures in the sections that have not yet been repaired, but this remains a good way to ease into a
preventative maintenance program that is both effective and efficient. This program can be coordinated with the annual dryer internal inspections required by mill safety programs and insurance carriers to achieve additional labor savings and help to ensure that a regular repair schedule is maintained. This approach has the advantage of not only reducing the total cost of ownership, but also incurring the same cost each year.

- Capital Repair Project. At this end of the spectrum, all of the rotary joints on the machine are repaired immediately following the first signs that the rotary joints are reaching their end of life. This work can be done during a regular annual outage. If the average life is four years, then this project would be executed every four years. The execution of this type of repair is similar to a capital project in that the one-time expense is significant, budgeted, and planned. When properly executed, this approach will normally have the lowest total life cycle cost because there is only one mobilization and demobilization of labor, few rotary joint failures between maintenance cycles, and correspondingly less risk of lost production.

UNDERSTANDING THE HARDWARE

As outlined above, the total cost of ownership can be reduced by implementing a proper preventative maintenance program. This will reduce the cost to the minimum for the equipment installed, but this is not necessarily the lowest possible cost. A comprehensive maintenance program should also include an analysis of the causes of failures. Only when the causes of failures are also addressed, is it possible to achieve the lowest possible cost of ownership.

The causes for rotary joint failures can be varied, even for a particular type of rotary joint and dryer syphon on a particular papermaking machine. For conventional pressure joints, piping strains and misalignment are the most common causes (24), as indicated in figure 3.
A modern, piston-type, balanced seal rotary joint is not subject to piping strains or misalignment and correspondingly has a much longer operating life than the older style pressure rotary joints. For these types, the most common causes of failure today are non-qualified parts and having repairs made by unqualified technicians, as indicated in the graph below.
In addition to the above factors that cause failures with an existing style of rotary joint, other steam system components can also be the source of failure. Following is a listing of several common causes, beginning with the style of rotary joint that is being used.

- **Type of rotary joint.** There have been many enhancements over the years to improve the life and performance of rotary joints. Modern rotary joints have a much lower cost of ownership than rotary joints based on old sealing technologies. Upgrades from older technologies to modern rotary joints can often be justified by the reduction in total cost of ownership, particularly when the conversion is executed as part of a proper preventative maintenance program.

- **Type of dryer syphon.** There are three basic types of dryer syphons: Rotating, stationary, and scoop. Each has a range of applications in which its performance is the best. As machine operations change, the type of syphon that provides the best performance may also change. For example, scoop syphons are often applied to machines that are being converted from paper grades to pulp grades. Rotating syphons are often used in dryers that have increased speed to where the condensate is just starting to rim. And stationary syphons are often applied to machines that are operating at speeds well above rimming. The proper syphon type will not only improve dryer performance, but also improve equipment reliability. Changes from one type of syphon to another are normally associated with a major dryer section rebuild and often requires an upgrade to the steam system as well. These rebuilds offer good opportunities to begin full preventative maintenance programs for the rotary joints.

- **Type of syphon shoe.** Many older stationary syphons have gray cast iron or ductile iron pickup shoes. These shoes erode over time. Their service life depends on dryer speed, shoe construction, and, most importantly, on the condensate chemistry. Eventually, however, all of these shoes erode. As they do, the dryers will begin to flood intermittently, carrying a higher condensate layer, reducing drying capacity, and causing drive kick-outs, yet evacuate when the dryers are slowed or stopped. As the syphon shoe performance degrades, the operating differential pressures must increase, resulting in increased blow-through steam and an increased rate of erosion. Syphon shoes should be inspected as part of a routine dryer inspection program and replaced at the first sign of erosion. These syphon shoes can be replaced with the same syphon design, or upgraded to one of the configurations that do not experience erosion, for example, Teflon shoes with stainless steel clamp pads.
• **Extent of rotary joint repairs.** When a rotary joint is repaired, it is common to replace the seal ring. The remaining seal ring life can be readily gauged by comparing its thickness to the OEM standard and inspecting the surface finish. Internal seals (such as gaskets, O-rings, and internal seals), however, can be more difficult to evaluate for remaining life. These internal components can also wear out, degrading over long periods of time, and result in rotary joint leaks. For some types of rotary joints, these leaks may be internal and not be readily apparent from an external inspection, but still cause dryer flooding to occur. The normal response to flooding dryers is increasing differential pressures, resulting in the by-pass of more blow-through steam, internal erosion, and even an increase in dryer flooding. A root cause analysis, with the support of the rotary joint OEM, can often identify repair procedures and frequencies that will extend the life of the rotary joints.

• **Source of repair parts.** As outlined in the previous sections, rotary joint life can be maintained at the design levels by using parts designed, qualified, and supplied by the rotary joint OEM. By using OEM parts, the repair will take advantage of any newer materials and design upgrades introduced since the original equipment was supplied.

• **Type of dryer bars.** Although this paper is focusing on rotary joints, dryer bars are a closely related component of the drying process. Older design dryer bars were made of low carbon steel, used threaded fasteners to hold the bars to the hoops, and had coil or Bellville springs to load the hoops against the bars. Each of these components should be inspected periodically for erosion, cracking, or failures. It is best to identify problems early. If dryer bars fail, they will often damage the syphon and the rotary joint and require an immediate shut down to replace the failed bars. It is normally not economical to repair failed dryer bars. When it is time for replacement, an upgrade to modern bars, such as the stainless steel Turbulator® Tube™ bar configuration, will provide much longer service life and a much lower cost of ownership.

• **Flex hose configuration.** Also important is the proper selection and installation of flexible hoses on the dryers. Flex hoses are installed to minimize externally-applied stresses on the rotary joints, not just to make fit-up easier. As supply pipe is heated, it grows. Unless the piping configuration was designed to accommodate this growth, the resulting stresses on the piping runs can be high enough to cause failure of the pipes. The flex hose (length, size, orientation, and configuration) must also be designed to allow for thermal growth, not only of the adjacent piping, but also the movement of the dryer and the rotary joint. Many mills have achieved significant improvements in rotary joint life (particularly on machines with self-supported rotary joint types) by closely following the recommendations of the rotary joint supplier for the flex hose arrangements (26).
- **Equipment installation.** Not to be ignored are equipment installation procedures. Often, fasteners are designed to have specific torque values applied to them to provide the best chance to seal against the temperatures and pressures involved. Specific gasket designs are chosen for different sealing application requirements, as no one gasket is perfect for every application. Sufficient torque values are required to seat the gaskets and seal the joints. Applying higher torque values can degrade clamping forces due to over-compression of gaskets or deformation of flanges and damage to the newly installed parts. If an original equipment manufacturer provides torque and gasket specifications, they should be followed to minimize risk. Ideally, the service work should be provided by technicians certified by the rotary joint manufacturer or under the supervision of the rotary joint manufacturer.

**SYSTEMS INFLUENCES ON RELIABILITY**

A review of rotary joint reliability is not complete without mention of the systems that supply steam to the dryers and drain condensate from the dryers. Rotary joints and dryer syphons have a direct impact on the design of the steam and condensate system and the performance of the steam and condensate system has a direct impact on the reliability of the joints and syphons. The sizing and physical behavior of the syphons dictate steam and condensate system sizing and operational requirements. Stationary syphons and rotary syphons have vastly different requirements. If the syphons are poorly chosen, either in size or in application, excessive blow-through, high differential pressures, and venting steam can result. The two-phase steam and condensate flow from the dryers can be highly erosive/corrosive to both the syphon and joint components. For this reason, many rotary joint steam leaks and component failures are seen on the condensate side of the steam system and not on the steam side.

Blow-through steam flow rates should be kept to the minimum required for stable dryer drainage. These minimums are dictated by the machine operation, dryer hardware, and system design. If blow-through rates are allowed to increase, the component degradation increases exponentially. Piping erosion leads to pipe wear and leaks. A typical response to a leaking pipe is to replace it with pipe that has a heavier wall thickness, but this reduces the flow area, increases the internal flow velocity, and escalates the rate of erosion. A better solution would be to replace the steel piping with stainless steel piping, to eliminate erosion. The best solution would be to control the blow-through steam and differential pressures to the levels required and not allow them to increase to higher levels.
The proper control of blow-through steam and differential pressure requires accurate transmitter readings. Unfortunately, it is common to find pressure, flow, and differential pressure measurements to be significantly in error. What may appear to be minor installation details for the pressure, flow, and differential sensing lines can make significant differences in measurement accuracy and reliability. Poor instrumentation quality (inability to trust and/or maintain differential and pressure set points) leads to increased differentials and blow-through as operators increase the set points to “safe” levels where dryer flooding is not occurring. This may seem to work well in preventing “problems”, but always results in increased erosion of piping and parts.

Over time, poor instrumentation and the resulting change in set points will lead to a loss in drying capacity, especially in cascade type steam systems where increased differentials lead to lower cascade pressures.

Because of the complexity of steam system design and the complex reaction of steam system response to operating conditions, even those operators who have a good fundamental understanding of the processes that occur within the steam system lack the time to make the appropriate adjustments to optimize the system performance. The best solution takes the expertise of the steam system designer and uses an active supervisory control system that can make rapid and rational changes to all of the system controls in direct response to the process demands. (22-23)

**SUMMARY**

The lowest cost of ownership of any dryer system requires attention to a number of important details. Life cycle, replacement costs, system design, part supply, maintenance strategy, and component reliability all affect the dryer system operation, the ability to minimize total cost, and the overall mill sustainability. A good partner for this work is the company that developed, designed, manufactured, optimized, installed, and provided the control systems for the drying process and equipment.
REFERENCES


Kadant Johnson is a global leader in the design, manufacture, and service of dryer drainage systems, rotary joints, syphon systems, and related equipment for the dryer section of the paper machine. For more information about Kadant Johnson products and services, email info@kadant.com or visit www.kadant.com.

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