KAPLAN TURBINES

STEPS TO IMPROVE BLADE RUNNER TRUNNION SEALING FOR INCREASED RELIABILITY

One of the most common types of turbines used in hydropower plants worldwide is the Kaplan turbine (sometimes classified as a propeller type of turbine). The Kaplan turbine is used primarily for low to mid range water head (from 2 meters to approximately 75 meters) power production but accommodates a wide range of flow conditions. The typical output range of Kaplan turbines is 0.1 MW – 200 MW. Due to operating flexibility, these turbines can be used in mini to large hydropower plants.

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SEALING CHALLENGES

There are many sealing challenges to overcome that are directly or indirectly associated with the equipment used to generate hydropower. Applying advanced sealing materials and designs can help address some of these challenges by:

- Improving mean time between repairs
- Simplifying installation
- Reducing maintenance costs
- Minimizing downtime
- Positively impacting the environment

With Kaplan turbines, in particular, **runner blade trunnion seals** play a key role in maintaining reliability, efficiency, and protecting the environment from oil seepage. A survey conducted among Kaplan turbine owners found that inefficient or failed blade trunnion seals cause more than 60% of Kaplan turbine leakage. [1.]

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In this paper, we will address best practices around selecting, installing, and supporting Kaplan blade runner trunnion seals to maximize your investments and efforts.

About Kaplan Turbines

The Kaplan turbine was developed by Victor Kaplan, an Austrian engineer, towards the beginning of the twentieth century. This turbine design was Kaplan's effort to improve upon the basic principles of the Francis turbine by adding adjustable runner blades. The Kaplan turbine allows for a transition space in which the flow direction transitions from radial to axial.

Kaplan turbines can be horizontally oriented (bulb type) or vertically oriented, depending on the water head. The vertical orientated Kaplan turbines allow for runner diameters up to 10 meters (33 feet). The efficiency can be increased by adjusting the inlet/exit angles, the turbine radius, and the blade pitch angle. These factors are unique based on the flow rate and flow scenario of each specific location.

How a Kaplan Turbine Works

To understand how to improve runner blade sealing reliability for Kaplan turbines it's good to have a quick overview of how this equipment works:

- Kaplan turbines have a runner with 4 – 8 blades in which the water flows through the turbine runner in the axial direction. The blades can be either fixed (blade pitch is fixed) or movable/variable.
- The turbines normally run at a high-efficiency rate (70 – 90%), but in the case of fixed blades, the operating range/flow range will be much more limited (50 – 100% of rated capacity).
- The operating range/flow rate of Kaplans with movable blades is more extensive (30 – 100% of rated capacity) and the efficiency curve is flat (85 – 90% expected turbine efficiency). [2.]

Kaplan turbines are what's known as a "reaction type" turbine. In this type of design, the mechanical energy is gained partly by a pressure drop of water flowing through the runners (i.e., the energy of the water is converted to mechanical energy). Further energy is partly converted from impulse force as the direction of the relative velocity (direction of water flow) changes on the runners (from inlet to outlet). [3.] *Learn more about Kaplan turbine principles*.

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Turbine System Arrangements

Typical Kaplan turbine systems are one of the following:

- Fixed blade (fixed pitch) propeller in combination with wicket gates
- Movable blade (variable pitch) propeller without wicket gates
- Movable blade (variable pitch) propeller in combination with wicket gates

In the single-regulated turbines, either runner blades or wicket gates are variable. Double-regulated turbines have variable runner blades as well as variable wicket gates.

In the double-regulated turbine systems, runner blade position (pitch) is harmonized to wicket gate position to optimize the turbine operation to the actual water flow rate through wicket gates. Runner blades typically have oscillating motion around the blade trunnion axis. The blade trunnions are supported by thrust bearings and guide bearings, which are typically cast bronze.

Kaplan runner blades have slow speed and very low frequency of oscillating movement, remaining static in most of the operating time. But the long operating periods between repairs of the turbines cause a high number of the accumulated oscillation cycles. That number in the case of a typical Kaplan turbine application can achieve and/or exceed 60,000 cycles, covering the typical runner blade trunnion motion pattern from 0 – 45 degrees. [4.]

Use of Oil

In the case of traditional double-regulated systems, the turbine hub is typically filled with pressurized oil. This oil functions to:

- Equalize pressure to the outside water pressure (protection of the turbine hub)
- Lubricate internal mechanisms (such as pitch control) and moving components
- Provide hydraulic media to the hydraulic system of the runner blade pitch control servo motor

The hydraulic servo motor of movable runner blades (for variable pitch control) is located in the hub. For "oil-based" hubs, the oil supply and feed-back mechanisms are transferred via the top of the hollow shaft to the turbine governor. The driving action/positioning of variable runner blades is provided by a fluid power transmission system (a hydraulic system with working media), including hydraulic pumps, actuators/cylinders (servo motors), hydraulic valves, housing, piping, and coupling, etc.

Environmental Concerns and Trends

Hydropower technology is known as an environmental friendly, pollution-free choice for energy generation. However, it still represents a certain level of risk for the environment thanks to the presence of petrolum-based oil.

A high volume of oil is typically used in many of the driving/positioning functions of the fluid power system and in the lubrication of moving components of the turbine hub, as described above. Without the right care this oil can escape into the water system.

Growing concerns over pollution have driven a move to eco-friendly turbines to:

1. Reduce the amount of oil that is utilized in the system (replacing the low pressure servo motors with high pressure ones)
2. Substitute petroleum-based oils with water or bio degradable, environmentally-friendly fluids
3. Switch petroleum-based oils to air by using electric servo motors and self-lubricated bearings
4. Mitigate the risk of oil leakage that causes the downstream pollution [5.]

The new technologies provide a more environmentally-safe operation with new or rehabilitated/upgraded units. However, for those using existing turbine units, the real focus is #4 – keeping the oil from leaking out and protecting the turbine hub against ingress of water.

Common Blade Runner Trunnion Sealing Issues

There are several blade trunnion sealing challenges that need to be considered to establish optimal sealing reliability. They include:

1. **Failure to keep water/contaminants out of the hub:** Poor seal fit or poor seal design and seal material are most often the culprits, along with the impact of factors below.
2. **Failure to keep oil in the hub:** Also due to poor seal fit or poor design and seal material.
3. **Not accounting for blade droop:** Due to manufacturing tolerances and running clearances of machined components, there is a certain (natural) droop of the turbine blades.

   A common bearing/bushing material for blade trunnion is cast bronze, which has relatively low Young's modulus (stiffness). The low stiffness can lead to deformation of the bearing under high load, caused by weight of the blade and by reaction force created on the blade during operation. Such bearing deformation will increase the blade droop value.

   The third factor that can impact the blade droop value is the wearout of blade trunnion bearings. If stable oil-film between the trunnion and bearing(s) ring is not ensured when the blade is oscillating, boundary friction occurs. In combination with high radial load (from the weight of the blades and reaction force on blades), this can cause excessive wear of the trunnion/bearing assembly. [4.]

   Blade droop challenges the trunnion seals, changing the original cross-section for which the seals were designed. This must be compensated by the sealing devices as well. Blade droop can have a serious impact on performance, positive sealing, and seal life expectancy.

   Such geometrical changes can lead to:

   - Radial overload of the seals (in the direction where the seal cavity cross-section has been reduced)
   - Radial opening of the seals (in the direction where the seal cavity cross-sections has been increased)
   - Excessive deformation and friction (wear out of sealing devices)

A Checklist for Optimal Runner Blade Trunnion Sealing

How do you meet these challenges to establish the best reliability possible? We recommend following the practices:

1. **Get Exact Turbine/Blade Measurements**

   One of the most basic, but often overlooked aspects of selecting runner blade trunnion seals for Kaplan turbines is accounting for the wide variation in turbines and blades when determining the seal size needed. **Make sure you obtain actual equipment dimensions both by turbines and by blades.**

   There are no technical specifications and/or international standards for designing runner blade seal stuffing boxes. As a result, sealing device manufacturers are forced to develop a range of seal geometries to accommodate actual equipment hardware.

   For this reason, and because as equipment dimensions change from the original specification after years of use, it's important to obtain actual equipment dimensions to optimize seal performance. This requires taking equipment measurements of:

   - Blade trunnion diameter
   - Stuffing box depth
   - Stuffing box closing ring nose length
   - Seal cavity cross section

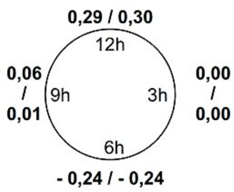
2. **Check Seal Cavity Cross Section Values Around the Blade Trunnion**

   It is important to understand that blade droop plays a factor in these measurements. The typical number of Kaplan runner is 4 – 8 blades. The natural wear of bearings and consequential blade droop values can vary blade by blade even with the same turbine.

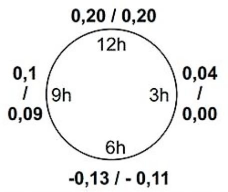
   - Since the blade droop value must be considered during the seal design process (in case of significant differences in droop values), the seals should be designed and manufactured individually
   - Because of blade droop, the seal cavity cross section values must be checked all around the blade trunnion circumference in various locations
   - In the case of a typical trunnion size range (600 – 1000 mm), the recommended number of measurements is at least 4 – 8 around the circumference [6.]. *See Figure 1.*

Figure 1 - Measuring report example for an 8-blade Kaplan turbine:

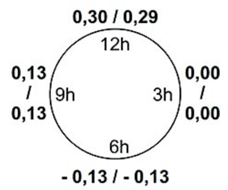
Runner blade 1		
Blade Drop	12h - 6h	0,30 - 0,24 = 0,27 mm
Groove height	range	49,11 - 49,7 mm
Protrusion	range	2,92 - 2,97 mm



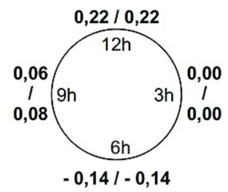
Runner blade 2		
Blade Drop	12h - 6h	0,20 - (- 0,13) = 0,17 mm
Groove height	range	49,1 - 49,4 mm
Protrusion	range	2,8 - 2,9 mm



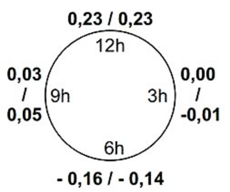
Runner blade 3		
Blade Drop	12h - 6h	0,30 - (-0,13) = 0,22 mm
Groove height	range	49,00 - 49,3 mm
Protrusion	range	3,05 - 3,17 mm



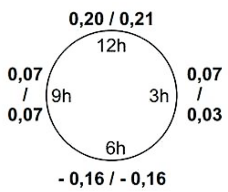
Runner blade 4		
Blade Drop	12h - 6h	0,22 - (- 0,14) = 0,18 mm
Groove height	range	49,00 - 49,25 mm
Protrusion	range	2,82 - 3,0 mm



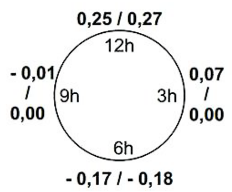
Runner blade 5		
Blade Drop	12h - 6h	0,23 - (- 0,16) = 0,19 mm
Groove height	range	49,05 - 49,16 mm
Protrusion	range	2,85 - 3,06 mm



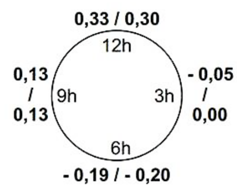
Runner blade 6		
Blade Drop	12h - 6h	0,21 - (- 0,16) = 0,18 mm
Groove height	range	48,90 - 49,60 mm
Protrusion	range	2,73 - 2,83 mm



Runner blade 7		
Blade Drop	12h - 6h	0,27 - (-0,18) = 0,22 mm
Groove height	range	49,00 - 49,50 mm
Protrusion	range	3,03 - 3,05 mm



Runner blade 8		
Blade Drop	12h - 6h	0,33 - 0,20) = 0,26 mm
Groove height	range	49,00 - 49,70 mm
Protrusion	range	2,95 - 3,08 mm



3. Check and Resolve Equipment Conditions

The next step when determining the best runner blade trunnion seal choice is assessing surface conditions and the roughness of dynamic and static counter surfaces. These uneven and abrasive surfaces can have an enormous impact on seal device performance and service life.

Runner blade trunnion seals are designed to provide tight sealing between the static surface (stuffing box) and the dynamic surface (trunnion). The surface condition (roughness) of static and dynamic hardware surfaces will have a significant impact on sealing capability and performance since sealing devices have direct, physical contact with the counter faces.

The initial (optimum) surface roughness specified for the counter faces (stuffing box and trunnion) is provided by turbine manufacturer. The optimal surface finish and surface profile help to maintain the friction on the low level, reduce the wear, and extend the service life of the sealing devices. However after years of operation, the surface roughness can change and deteriorate because of:

- Mechanical damages (scratches, scores)
- Wear out of counter surface by friction, fretting (compressed rubber seals)
- Abrasion by solid particles in the water (risk is higher in case of low water head applications)
- Corrosion and pitting corrosion by water (especially in the case of cast iron and carbon steel components)

Fretting of a stuffing box surface

Excessive surface irregularities and voids show where leak paths can occur since the sealing devices cannot conform to the irregularities.

To account for these issues, consider:

- Repairing the surface of stuffing box during the overhaul of the turbine
- Installing a stainless steel sleeve in the stuffing box for better resistance against corrosion
- Using a hydraulic seal made with a material that will conform to worn surfaces (such as *AWC825*)

4. Consider Operating/Environmental Conditions

Operating conditions of Kaplan turbines also have potential impact in seal performance and service life. Here are some common conditions and solutions:

- **Fluctuation of Turbine Pressure:** Kaplan turbines operate mostly at constant or relatively constant operating conditions, just like turbine pressure (created by the water head). But head levels drop and rise, and can periodically change the pressure load on sealing devices too, which can have an adverse impact on seal performance and reliability. A pressure responsive, flexible seal design can handle such turbine pressure fluctuation, adjusting to actual operating conditions and maintaining positive sealing capability.
- **Vibration and Cavitation**: A certain level of vibration and cavitation is standard to the operation of Kaplan turbines, but it has a major impact on turbine components, including runner blade trunion seals. Flexible seal design and elastic seal material can respond to such impact and withstand for a longer time.
- **Low Water Head Schemes:** Kaplan type of turbines are used in a wide range of water head configurations (2 – 75 meters). Low water head can represent a high risk of abrasive environment caused by high level of water contaminants, sediment, and mud. Using a seal with an abrasion-resistant thermoset polymer material can offset these abrasive effects.

5. Select the Best Runner Blade Trunnion Seal

Applying advanced hydraulic sealing technology (including materials and designs) to this area of the Kaplan turbine can significantly improve mean time between failure, and reduce meantime to repair.
In addition, the right hydraulic seal choice helps to reduce operational and maintenance costs, lower the risk of unplanned downtime, and lessen downstream pollution.

To select a high-performance runner blade trunnion seal, look for the following attributes:

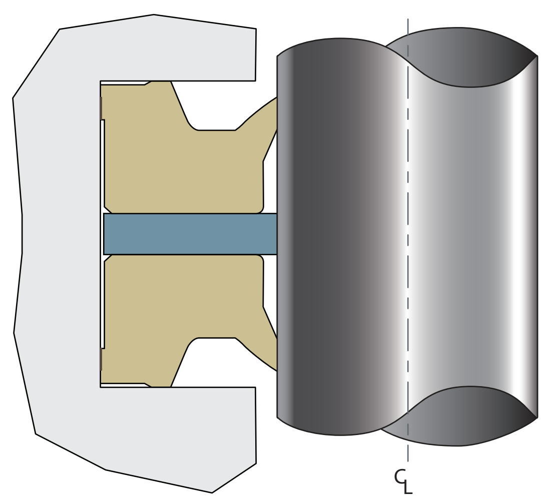
A. **Profiled Lip Seal** will make the sealing device responsive to fluctuation of the operating conditions.

B. **Flexible Lip Design** that can compensate for blade droop and possible vibration of the runner blade.

C. **Back-to-Back Design Configuration** for a double-acting function:

- Keeps the hydraulic media and lubricant in the turbine hub
- Protects the hub against the ingress of water, solid particles, and sediments

Back-to-back configuration



D. **Axial Compression** (stacking the seals in the groove): The static side of the seal is oversized in an axial direction, applying compression by seal retainer ring. This axial compression locks the seal in the seal cavity, protecting the seal against rotation and providing static sealing.

E. **Multiple Sealing Points on Static Side of the Seal:** In case of a corroded seal cavity surface, the multiple sealing points can provide tighter sealing.

F. **Split Seal Design:** While manufacturers typically deliver turbines with solid runner blade trunnion seals, a true split mechanical seal will simplify installation on-site and reduce downtime, eliminating complex welding or joint procedures.

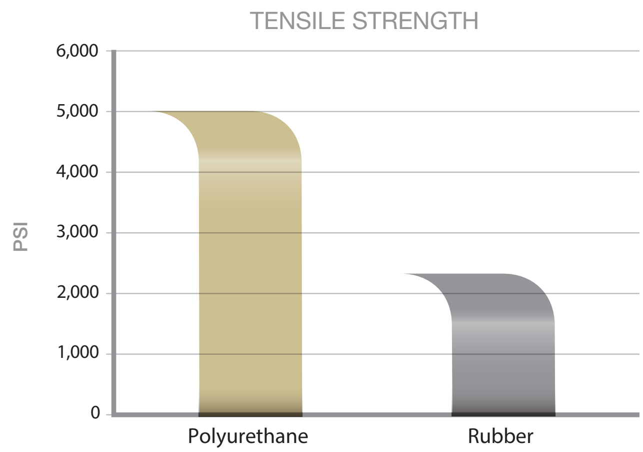
G. **Made to Order:** Geometry and dimensions of the seal are according to actual hardware arrangement and dimensions.

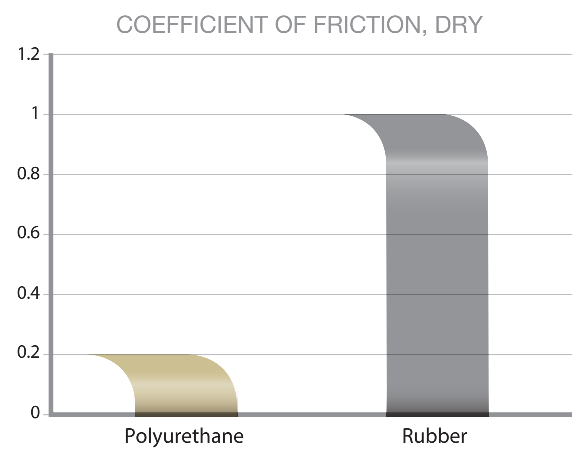
H. **A Robust Seal** helps to prevent either streching or bunching and twisting of the seal rings during installation (problems typical with either O-Rings or traditional stacked sets).

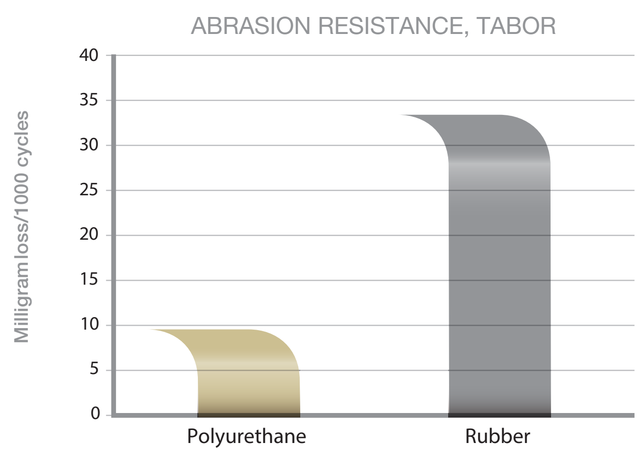
I. **High-Performance Thermoset Polyurethane Seal Material:**

- High abrasion resistance
- High tensile strength (mechanical strength of the seal material)
- Self-lubricated for low coefficient friction (less wear)
- No aging, no material degradation (shelf-life 25 years)

Typical properties of high-performance polyurethane versus rubber is demonstrated by the following graphs:







Select Your Best Solution

If you would like assistance selecting the best Runner Blade Trunnion seal solution for your specific Kaplan turbine application, feel free to contact our *Ask the Expert desk*.

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