STEAM TURBINE SEALS EXPLAINED

By Sydney Gross

Pressure differences are fundamental to all turbomachinery. It is therefore critical to performance to effectively isolate regions of different pressure since we know from Bernoulli that fluids will flow in the direction of decreasing pressure gradient. The challenges in sealing turbomachinery include consideration of rotating and stationary parts and their associated clearances as well as material compatibility and relative thermal growth. The following paragraphs are a general discussion of how seals work and the various types of seals in a steam turbine.

Although there are several seal designs that employ such mechanisms as disc pumping and the inclined plane in the form of screw type threads to impede the leakage of fluids, this discussion will focus on throttling type seals which are most common to steam turbines. Throttling is a process that involves a restriction of the flow area between two regions of larger volume and differing pressure. As seen in figure 1, fluid in the higher pressure region will flow to the lower pressure region through the narrow passageway connecting the two. The flow rate is dependant upon such factors as the size and configuration of the restriction, the pressure

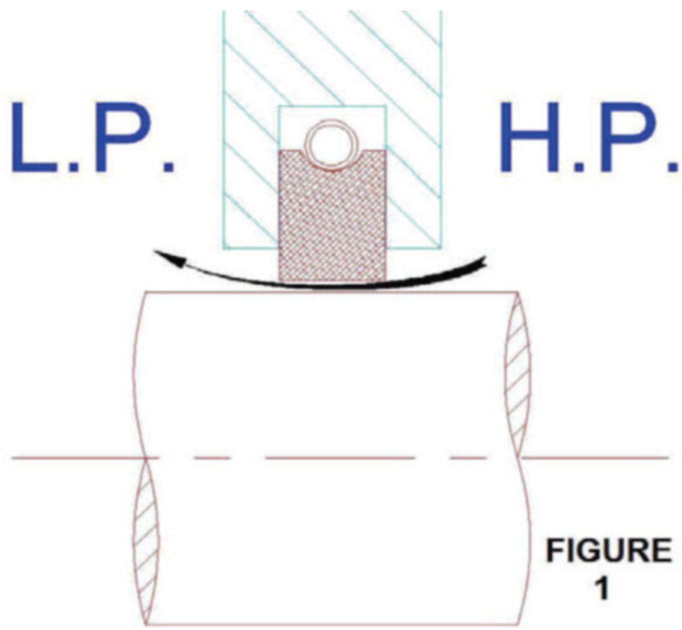
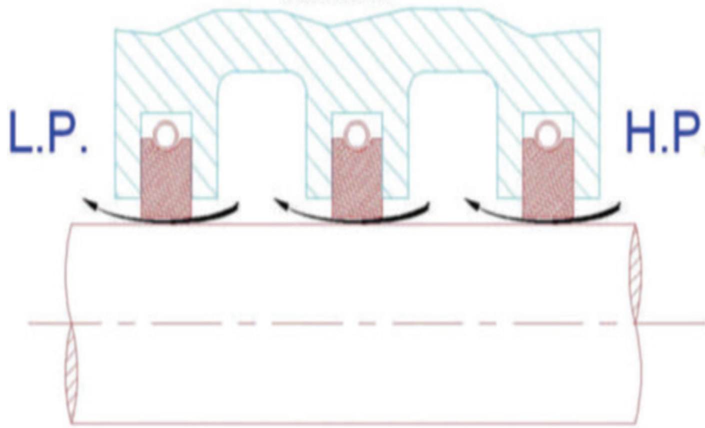


FIGURE 1

differential and the fluid viscosity. Not only is the rate of flow impeded by the restriction, its velocity is accelerated through the contraction and then suddenly dissipated by the action of emptying into a much larger cavity. As we know from piping calculations, this process involves fluid losses which effectively decrease the energy in the fluid resulting in a lower pressure. If we stack together several of these "restricted" chambers in series as in figure 2, we can progressively decrease the fluid pressure to a point where leakage between chambers is at an acceptable level.

One may ask, why not decrease the area of the restriction

FIGURE 2



to a point where leakage is acceptable with only one throttling. The answer is that the restriction must be formed between a rotating and a stationary component where contact is not acceptable lest serious damage be done to the equipment. Therefore, minimum clearances are dictated by manufacturing and assembly tolerance, vibration displacement levels especially transient, and rub tolerance.

Where is sealing important in a turbine? Anywhere there is a cavity or area that is formed between the rotor and the stationary components containing fluid at a pressure different from its surroundings that would negatively effect the performance if the fluid were allowed to escape through a path other than the one it is intended to go. I think I covered just about everything with that statement. In a steam turbine we're talking about where the shaft ends exit the casing, through the space between the diaphragm ID and the shaft and across the rotor blade tips and sometimes the base of the rotor blades (see figure 3).

It's necessary to prevent the higher pressure steam from leaking past the shaft ends to prevent the loss of working fluid, minimize the impingement of steam on the bearings to prevent water contamination of the lube oil, and provide a safe and comfortable work

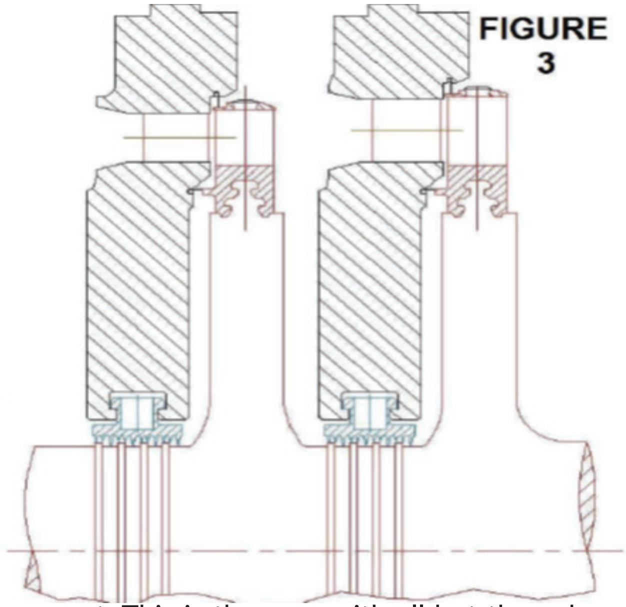


FIGURE 3

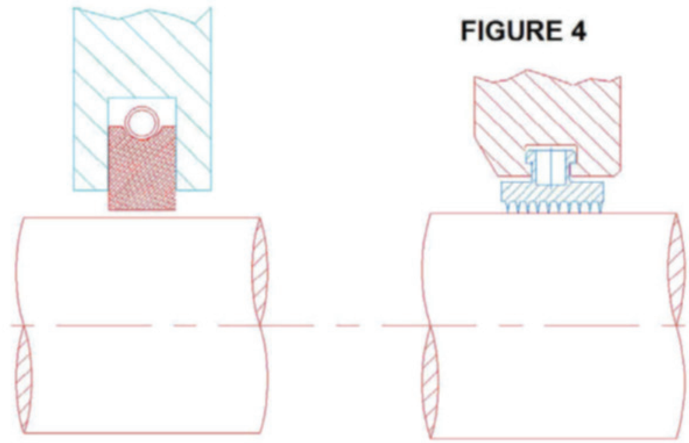


FIGURE 4

environment. This is the case with all but the exhaust end of a condensing turbine. Because a vacuum exists in the exhaust casing of condensing turbines, steam would not naturally travel along the exhaust shaft end out to the environment. Rather, the vacuum would draw air into the turbine. The condenser which provides the exhaust vacuum would have its performance significantly degraded by mixing air with the steam. The seals therefore prevent air from entering the turbine through a system we will discuss in more detail later.

If you will recall the principal of impulse turbine stages, a large pressure drop occurs across the stationary nozzle or diaphragm while little or no pressure drop occurs across the rotating blades. Steam will want to circumvent the diaphragm at its interface with the rotor, the diaphragm ID. If one were to allow significant leakage across the ID of the diaphragm, the performance of the stage would be negatively effected by the loss of working fluid in the flow path and a decrease in the pressure gradient across the diaphragm. Sealing at this location is critical.

As reaction in the stage increases, so increases the pressure drop across the rotating blade. Sealing between diaphragm and the rotor blade tip and hub becomes increasingly important to prevent the working fluid from circumventing the rotor blade.

The most common types of seals found in industrial steam turbines by far are Carbon ring and labyrinth (or laby) seals (see figure 4).

Carbon rings are exactly that, rings made of Carbon. They "float" on the shaft due to their large OD clearance to the casing. They are also very soft compared to steel so that a rub will wear the carbon rather than the shaft. For these reasons, a Carbon ring can have very close clearance and provide an excellent seal. Typical Carbon ring seal clearances are such that the Carbon ring ID is 0.0015" per inch shaft diameter larger than the shaft. However because it is soft, it is limited to approximately 15 psid and shaft speeds of approximately 200 ft/sec. Otherwise the steam flow will rapidly erode the Carbon. Also, because they are fragile, they are found on the shaft ends where they can be accessed without significant disassembly of the turbine. Carbon rings are typically split in 3 sections with a garter spring encircling the segments to hold them together.

Labyrinth seals are typically made of bronze, stainless steel or Ni-resist depending on conditions. Because they are harder and not as rub tolerant as Carbon, they do not operate with such tight clearances. Typical labyrinth clearances are in the range of 0.001" to .002" radial per inch of shaft diameter. They do not provide as effective a seal as Carbon rings but have a pressure drop limit of 4 to 6 times Carbon. In higher pressure differential applications, one will normally find stepped or high-low type labyrinth seals as shown in figure 5. The steps provide a more tortuous path for the steam and are

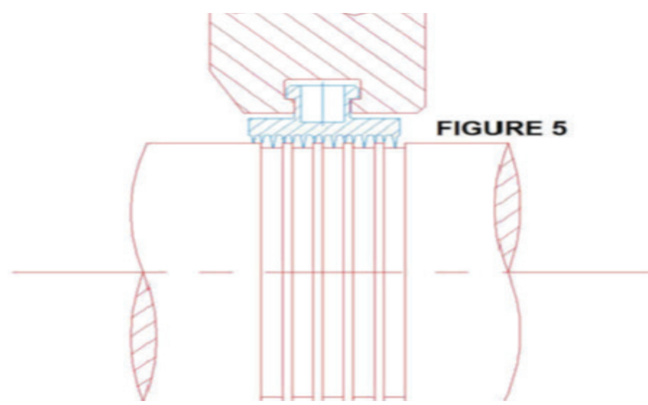


FIGURE 5

more effective than straight through labyrinths. Stepped labyrinths are typically used on the high pressure shaft end seals and in the diaphragms on the high pressure end of the turbine. Stepped labyrinth seals, while more effective than straight through labyrinths, complicate the axial alignment of the rotor. Where differential axial growth between rotor and casing is significant, as in the exhaust end of the turbine, stepped labyrinths may not be practical.

Another type of seal which has gained popularity in steam applications is the brush seal, long a staple of the gas turbine industry. The brush seal is constructed of many small diameter, tightly packed wire bristles, typically stainless steel, sandwiched in an outer ring. The bristles point inward toward the shaft at an angle off radial (see figure 6). They can be floating or fixed, maintain a tight clearance akin to Carbon seals, are rub tolerant, durable, and are not limited in pressure differential. They are currently available as "drop-in" retrofits on some smaller turbines and can be applied with engineering in areas where Carbon rings have proved troublesome.

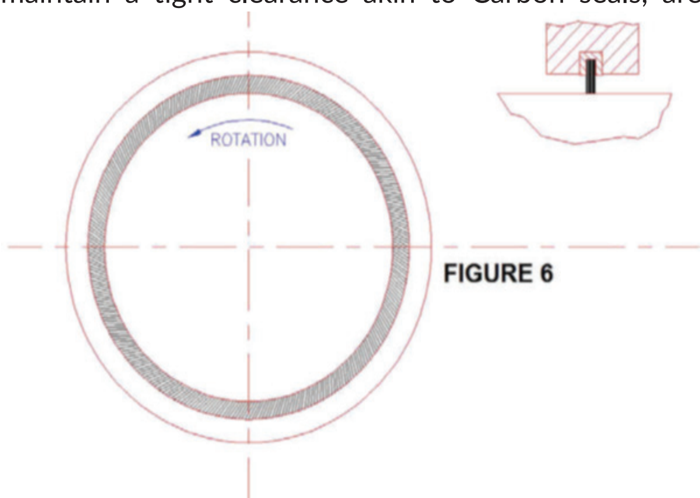


FIGURE 6

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