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Performance evaluation techniques for paper machine liquid ring vacuum systems

Scope

This document describes general techniques for the evaluation of performance of liquid ring vacuum systems on paper machines. Its intent is to give papermakers a procedure for seeking and eliminating bottlenecks in liquid ring vacuum systems and implementing optimum vacuum performance by reducing operating costs and increasing productivity.

Definitions

1. *ACFM*: Actual Cubic Feet per Minute. The measurement of vacuum pump volumetric flow at a vacuum level
2. *Orifice Test*: Vacuum pump testing method. See TAPPI TIP 0420-12
3. *Dwell Time*: The amount of time it takes for the felt to travel from the leading edge to the trailing edge of a suction box slot.

Materials

The following materials are recommended for following the guidelines:

- Flat plate orifice testing equipment, described in TIP 0420-12
- Analog (with a needle) vacuum gauges

Safety precautions

Caution should be taken when performing the orifice plate test. Vacuum may pull the tester's finger into the orifice hole.

Content

Vacuum Pump Testing

Liquid ring vacuum pumps are the key components of every vacuum system. Efficient performance is necessary for maintaining optimum airflow and vacuum levels throughout the paper machine. Performance should be monitored to ensure that liquid ring vacuum pumps are consuming minimum energy to remove maximum water from the paper sheet or felts. The most effective liquid ring vacuum pump performance test that can be performed in the paper mill is the flat plate orifice test method. This test must be done with the testing of the liquid ring vacuum pump isolated from the paper machine.

To summarize, an orifice plate or plates are placed on the liquid ring vacuum pump inlets. These plates contain a series of bored holes that are calibrated to allow specified air flows over the entire range of vacuum levels of a liquid ring vacuum pump. This test gives the papermaker performance data to compare to the manufacturer's performance curve of the liquid ring vacuum pump and to insure that necessary air flow requirements are being met. The orifice plate test method is described in TIP 0420-12. Most liquid ring vacuum pump suppliers offer pump field tests as a service.

A boroscope can be used to visually inspect mineral or pulp deposits and corrosion or erosion of rotor and cone surfaces. A rough estimation of liquid ring vacuum pump capacity can be determined by evaluating these internal conditions. This method allows for an easier, although less accurate determination of liquid ring pump efficiency.

TIP Category: Automatically Periodically Reviewed (Ten Years)

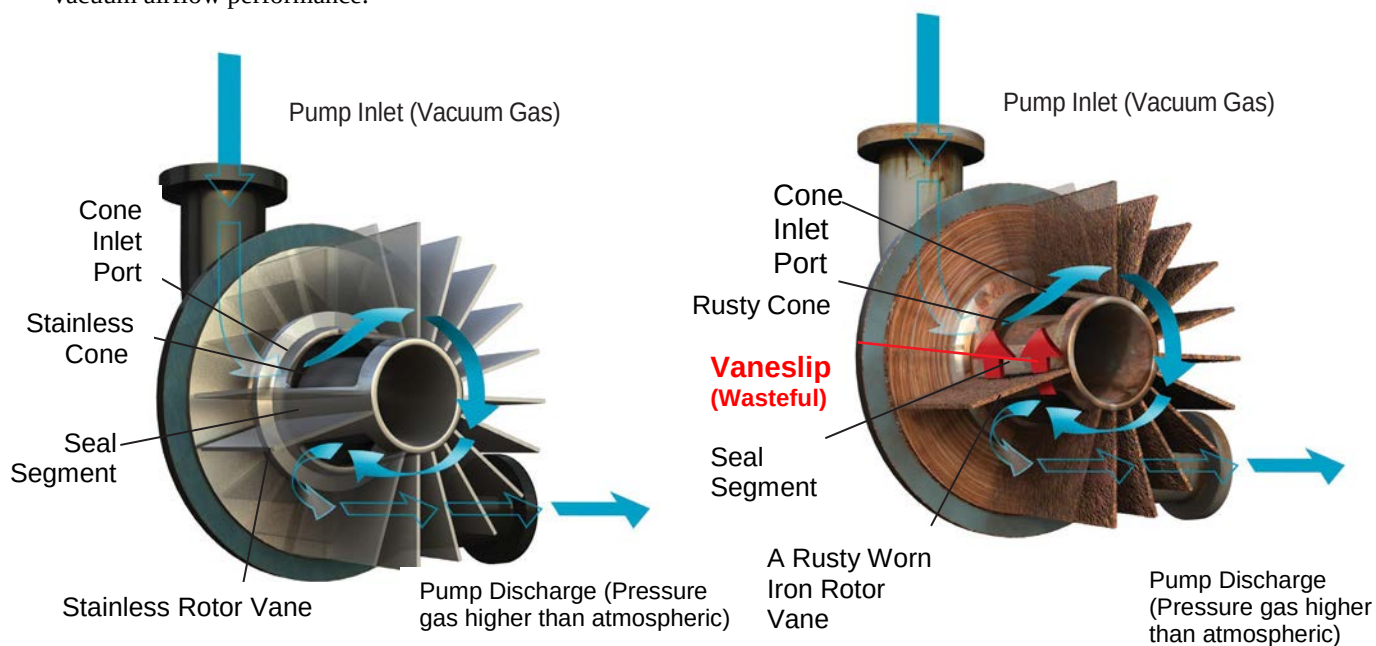
Dimensions, fixed and variable

All formula derived dimensions of the vacuum system in this TIP are calculated for design and manufacturing as fixed. There are also four very important variable dimensions that change with time. They are:

1. The clearance of rotor vane to cone surface which increases with time.
2. The radial length of the water piston in the seal segment from the inner housing wall land area to the cone surface land area which is controlled by the seal water linear regulating control valve.
3. The amount of seal water flow, gpm or liters per minute to develop maximum stable vacuum develops variable thicknesses of water between the inner vane surfaces and the cone outer surface. This very important dimension of seal water compresses gases from leaking backward to following compression chambers between vanes.
4. The seal water control valve opening which changes to develop maximum stable vacuum.

1. Rotor Vane and Cone clearance in the Seal Segment

The rotor vane to cone surface clearance distance in the seal segment is affected by corrosion – erosion and increases with time. This clearance is the most important vacuum system dimension, because with time, cast iron rotor to cone clearance widens from erosion of iron oxide (rust) and decreases new inlet vacuum airflow performance continually over years' time. An iron rotor-cone pump can easily lose 30% to 50% of original capacity over ten to twenty years, by high pressure discharge gas from the discharge segment slipping into the inlet segment and blocking new inlet gas from entering the pump. Over ten years, stainless steel holds this clearance by forming dynamically hardened chromic oxide, and may lose only 5% to 10% of vacuum airflow performance.



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2. The Radial length of the water piston in the seal segment must equal the distance from the inner surface of the housing land area to the cone surface in the seal segment. As shown above, if the length of the piston is short then Vaneslip will occur. For each side of the liquid ring vacuum pump, increasing seal water flow with two regulating valves (linear relation of % open relates to % flow) will increase the length of these pistons.
3. The sufficient variable amount of seal water needed is described as, “enough seal water to develop a maximum stable vacuum.” To see “maximum stable vacuum” two analog (with needle) vacuum gages need to be read for each end of the pump as the regulating valves are changed. If the needle flutters, then there is not enough seal water and the regulating valve needs to be opened slowly until the needle is “pegged” or still. If you continue to open the regulating valve and no more vacuum is achieved, then there is too much water, and the regulating valve can be turned back to reduce flow until the needle just begins to flutter again, then increase again slightly for maximum stable vacuum.

4. Variable control of seal water flow is a significant component (yet often overlooked) to the successful operation of the liquid ring vacuum pump for improving vacuum system productivity and reliability:
 - a. No control device usually means too much water is used in the pump
 - b. An “on – off” shut off ball valve gives no variable control, only on or off
 - c. A single orifice disc in a union joint is set for one nominal flow probably recommended by the manufacturer technical data sheet. This flow rate is given for supply planning.
 - d. A linear (% open relates to % of flow) regulating valve allows setting optimal seal water flow rate from when the pump is new to making adjustments for opening of the vane to cone surface over as is gradually will change over years of service.

Evaluating Liquid Ring Pump Tests and Performance Estimates

Capacity comparisons are made at the actual rotational speed (RPM) of the liquid ring vacuum pump. Liquid ring pump test results should be compared to original capacity at the optimum vacuum level for each application. By dividing the actual tested capacity, m³/hr (ACFM), by the capacity, m³/hr (ACFM), shown on the liquid ring vacuum pump manufacturer's performance curve, the % of original capacity obtained. For example, if a liquid ring vacuum pump designed to have a capacity of 5,950 m³/hr (3,500 ACFM) at 380 mm Hg (15 inches Hg) vacuum only tested at 5,100 m³/hr (3,000 ACFM) at 380 mm Hg (15 inches Hg) vacuum, this pump is said to be at eighty-six percent (86%) of original capacity at that vacuum level.

Calculating Vacuum Liquid Ring Vacuum Pump Operating Costs

The two primary operating costs associated with liquid ring vacuum pumps are energy and seal water. Use Equation 1 to calculate annual energy costs for liquid ring vacuum pump operation.

Equation 1:

$$\$E_a = kW \times \$UR \times hr \times day$$

where:

$\$E_a$ = Annual energy cost
 kW = pump kilowatt usage from curve
 $\$UR$ = utility rate at mill in \$/kW•hr
 hr = operation hours per day
 day = operation days per year

$$\$E_a = BHP \times 0.746 \times \$UR \times hr \times day$$

where:

$\$E_a$ = Annual energy cost
 BHP = pump horsepower from curve
 $\$UR$ = utility rate at mill in \$/kW•hr
 hr = operation hours per day
 day = operation days per year

To calculate the annual seal water costs for liquid ring vacuum pump operation, use Equation 2.

Equation 2:

$$\$SW_a = l/min \times 60 \times \$SW_r \times hr \times day$$

where:

$\$SW_a$ = Annual Seal Water Cost
 l/min = seal water flow
 $\$SW_r$ = seal water cost rate, \$/1000 liters
 hr = operation hours per day
 day = operation days per year

$$\$SW_a = gpm \times 60 \times \$SW_r \times hr \times day$$

where:

$\$SW_a$ = Annual Seal Water Cost
 gpm = seal water flow
 $\$SW_r$ = seal water cost, \$/1000 gallons
 hr = operation hours per day
 day = operation days per year

After calculating the energy and seal water costs for each liquid ring vacuum pump, they can be summed to give the total cost for operating the liquid ring vacuum pumps for the entire machine.

Calculating Wasted Operating Costs

As liquid ring vacuum pumps lose capacity due to erosion or corrosion on the rotor and cone surfaces, they continue to consume the same horsepower and require the same seal water flow as if the pump were new. The result is wasted energy and water costs. When evaluating total liquid ring vacuum system operating costs, it is important to establish how much of the operating costs are being wasted on inefficient liquid ring vacuum pumps. From the example above, the 86% capacity pump is wasting 14% of these operating costs. From the performance curve it is found that the 86% capacity pump is consuming 215 kW (160 BHP). Because the pump is producing 14% less capacity as a new pump, it is wasting 14% of the power or 30.1 kW (22.4 BHP). This principle is also true for the seal water flow. If the liquid ring pump mentioned requires 227 l/min (60 gpm) of seal water flow for operation, 32l/min (4 gpm) is being wasted on inefficiency.

The next step is to calculate the wasted operating costs by using Equations 3 and 4.

Equation 3:

$$\text{\$E}_{w_a} = \text{\$E}_a \times (1 - \%OC)$$

where:

- $\text{\$E}_{w_a}$ = Annual Wasted Energy Cost
- $\text{\$E}_a$ = annual energy costs from Eq.1
- $\%OC$ = liquid ring vacuum pump % original capacity from pump test

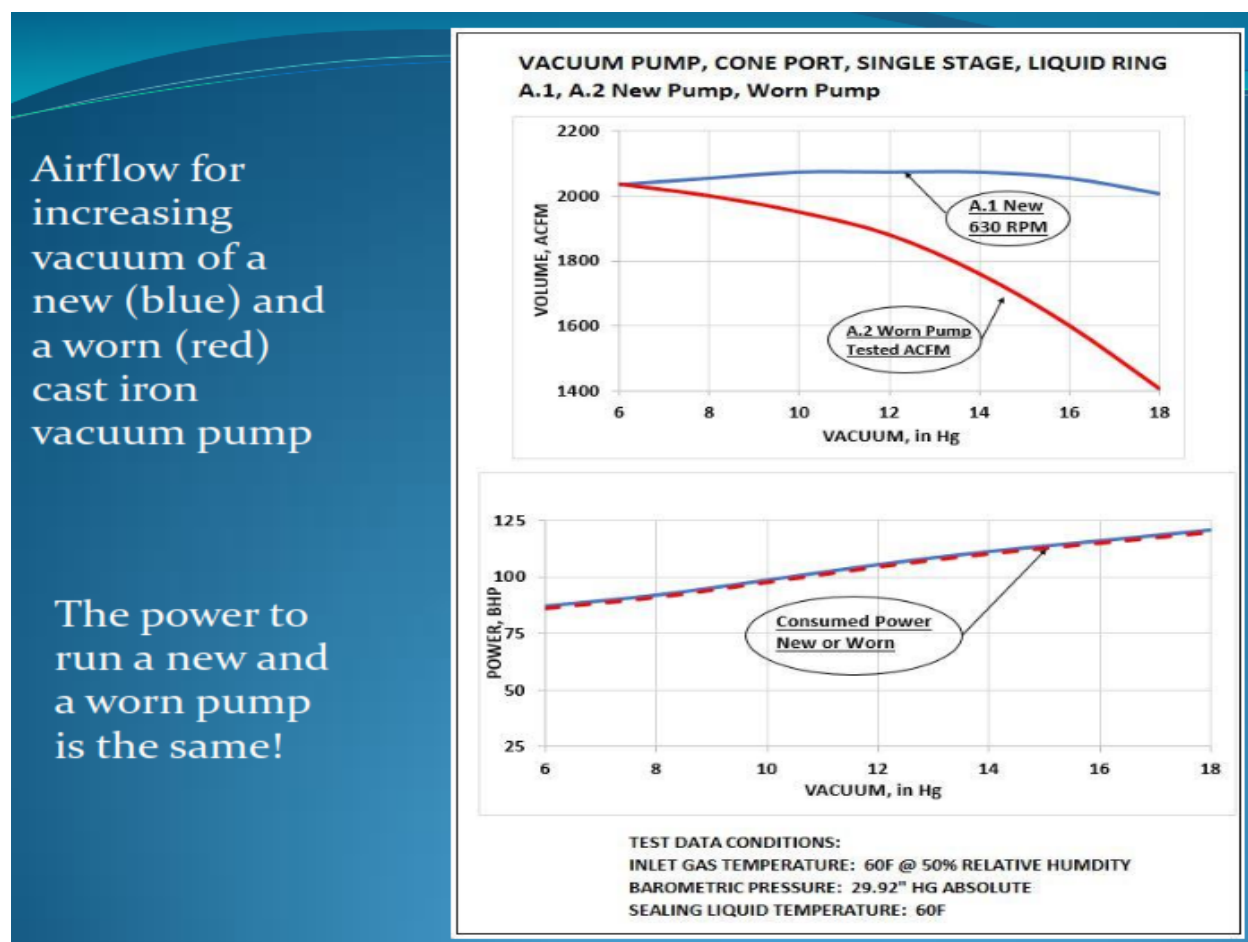
Equation 4:

$$\text{\$SW}_{w_a} = \text{\$SW}_a \times (1 - \%OC)$$

where:

- $\text{\$SW}_{w_a}$ = annual wasted seal water cost
- $\text{\$SW}_a$ = annual seal water costs from Eq.2
- $\%OC$ = liquid ring vacuum pump % of original capacity from pump test

The following figure shows vacuum pump drive horsepower is the same with a new and an old pump but that the worn pump supplies much lower volume. (6). This data was derived from Voerner's variable speed test stand, Charlotte, NC. The equal amount of power, shown for new and worn pumps, was attributed to increasing the seal water for maximum stable vacuum. For extreme poor rotor – cone clearances, increasing the seal water 100% ended up pushing the excess water out the discharge port and increased the power consumption by 10%.



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