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Performance evaluation techniques for paper machine vacuum systems

Scope

This document describes general techniques for the evaluation of performance of vacuum systems on paper machines. Its intent is to give papermakers a procedure for seeking and eliminating bottlenecks in 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.
2. *Orifice Test*: Vacuum pump testing method.
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
- Tape measure

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

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 pumps are consuming minimum energy and water while removing maximum water from the paper sheet or felts. The most effective 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 vacuum pump isolated from the paper machine.

To summarize, an orifice plate or plates are placed on the 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 vacuum pump. This test gives the papermaker performance data to compare to the performance curve of the 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 vacuum pump suppliers offer pump field tests as a service.

A boroscope can be used to visually measure rotor and cone clearances. A rough estimation of vacuum pump capacity can be determined by evaluating these clearances. This method allows for an easier, although less accurate determination of pump efficiency.

TIP Category: Automatically Periodically Reviewed (Ten Years)

Evaluating Pump Tests

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 pump manufacturer's performance curve, the % of original capacity is obtained. For example, if a 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. Capacity comparisons are made at the actual rotational speed (RPM) of the pump.

Calculating Vacuum Pump Operating Costs

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

Equation 1:

$$\text{\$E}_a = \text{kW} \times \text{\$UR} \times \text{hr} \times \text{day}$$

where:

$\text{\$E}_a$ = Annual energy cost
 kW = pump kilowatt usage from curve
 \\$UR = utility rate at mill in $\text{\$/kW}\cdot\text{hr}$
 hr = operation hours per day
 day = operation days per year

$$\text{\$E}_a = \text{BHP} \times 0.746 \times \text{\$UR} \times \text{hr} \times \text{day}$$

where:

$\text{\$E}_a$ = Annual energy cost
 BHP = pump horsepower from curve
 \\$UR = utility rate at mill in $\text{\$/kW}\cdot\text{hr}$
 hr = operation hours per day
 day = operation days per year

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

Equation 2:

$$\text{\$SW}_a = \text{l/min} \times 60 \times \text{\$SW}_r \times \text{hr} \times \text{day}$$

where:

$\text{\$SW}_a$ = Annual Seal Water Cost
 l/min = seal water flow
 $\text{\$SW}_r$ = seal water cost rate, $\text{\$/1000 liters}$
 hr = operation hours per day
 day = operation days per year

$$\text{\$SW}_a = \text{gpm} \times 60 \times \text{\$SW}_r \times \text{hr} \times \text{day}$$

where:

$\text{\$SW}_a$ = Annual Seal Water Cost
 gpm = seal water flow
 $\text{\$SW}_r$ = seal water cost, $\text{\$/1000 gallons}$
 hr = operation hours per day
 day = operation days per year

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

Calculating Wasted Operating Costs

As 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 vacuum system operating costs, it is important to establish how much of the operating costs are being wasted on inefficient vacuum pumps. For 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 pump mentioned requires 227 l/min (60 gpm) of seal water flow for operation, 32 l/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:

$$\text{\$Ew}_a = \text{\$E}_a \times (1 - \text{Eff})$$

where:

$\text{\$Ew}_a$ = Annual Wasted Energy Cost
 $\text{\$E}_a$ = annual energy costs from Eq.1
 Eff = vacuum pump efficiency from pump test

Equation 4:

$$\$SW_{w_a} = \$SW_a \times (1 - \text{Eff})$$

where:

$\$SW_{w_a}$ = annual wasted seal water cost

$\$SW_a$ = annual seal water costs from Eq.2

Eff = vacuum pump efficiency from pump test

More detail is available regarding vacuum pump operating cost in “The Full Operating Costs of Liquid Ring Vacuum Pumps” located in the 1995 TAPPI Engineering Conference Proceedings.

Suction (Uhle) Box Sizing

Properly sized felt suction or uhle boxes are critical to insure that felt de-watering is maximized. There are two sizing parameters that should be evaluated: box diameter and slot width.

Box Diameter

The velocity of the water/air mixture flowing through the felt suction box should be below 1,065 m/min (3,500 ft/min). By knowing the airflow, m³/hr (ACFM), supplied from the vacuum pump, minimum box diameters can be calculated using Equation 5:

Equation 5:

$$\text{Minimum Box Diameter (mm)} = \sqrt{\text{flow}(m^3 / hr) \times 19.89}$$

$$\text{Minimum Box Diameter (inch)} = \sqrt{\text{flow}(ACFM) \times 0.052}$$

Slot Width

Suction box slot widths should be sized to maintain a dwell time of 2 to 4 milliseconds. Dwell time is the amount of time that it takes for the felt to travel across the slot. Maintaining a dwell time within this range will allow enough time for the water in the felt to travel through the felt and into the suction box. If the dwell time is greater than 4 milliseconds, felts will tend to drag across the box and could experience premature wear. An exception to the 2 – 4 millisecond dwell time “standard” is on tissue machines. Many tissue machines operate well with only 1.0 – 1.5 ms of uhle box dwell time. This is because felts on tissue machines often operate at much higher moisture levels than paper or board.

Calculating correct slot width sizing base on a specific dwell time is done using Equation 6:

Equation 6:

$$\text{Slot Width (mm)} = \frac{\text{Dwell time (ms)} \times \text{machine speed (m/min)}}{60}$$

$$\text{Slot Width (inch)} = \frac{\text{Dwell time (ms)} \times \text{machine speed (ft/min)}}{5000}$$

Slot widths should not be less than 13 mm (0.5 inch) or greater than 25 mm (1.0 inch). If the slot width is calculated to be greater than 25 mm (1.0 inch), multiple slots should be used.

Vacuum Pump Sizing

There are several types of vacuum applications on the wet end of a paper machine. The most common applications are as follows:

Fourdrinier Machine

<u>Application</u>	<u>Purpose (with vacuum)</u>	<u>Vacuum Levels (HgV)</u>
Wire (Flat) Boxes	Consolidate sheet by high volume water removal	25-380 mm (1-15 inches)
Couch Roll	Consolidate and strengthen sheet by water removal	255-510 mm (10-20 inches)
Suction Pick-Up	Transfers sheet from wire to felt	255-510 mm (10-20 inches)
Suction Press	Dewater sheet with pressing and vacuum	255-510 mm (10-20 inches)
Felt Suction Box	Dewater felt for cleaning	205-455 mm (8-18 inches)