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State of the Art Technologies for Protection of Industrial Cooling Towers

STATE OF THE ART TECHNOLOGIES FOR PROTECTION OF INDUSTRIAL COOLING TOWERS

ABSTRACT

Cooling towers are a critical component of production in many industries today. Most towers use a horizontal electric motor driving a jack shaft into a right angle gearbox with vertical output to a large fan. Vibration monitoring of this drive train is essential to provide signals for early warning or provide shutdown when vibration levels exceed a predetermined threshold. The classic legacy solution involved the use of “earthquake” mechanical switches. These devices utilized a spring and magnet concept and were designed to mechanically trip during high vibration. Reliability becomes an issue with mechanical switches due to harsh cooling tower environments, especially in critical applications.

This paper discusses the concepts, the evolution of the technology and implementation in an Industrial Plant of a highly reliable, flexible and continuous protection methodology for cooling tower machine protection using vibration monitoring.

Keywords- Cooling Towers, Vibration Monitoring, Vibration Switches, Mechanical Vibration Switch, Electronic Vibration Switch, SMART Switch, CTI

1.0 INTRODUCTION

A cooling tower is a heat rejection device, which extracts waste heat to the atmosphere though the cooling of a water stream to a lower temperature. Common applications for cooling towers are providing cooled water for air-conditioning, manufacturing and electric power generation. The generic term "cooling tower" is used to describe both direct (open circuit) and indirect (closed circuit) heat rejection equipment. A direct, or open-circuit cooling tower is an enclosed structure with internal means to distribute the warm water fed to it over a labyrinth-like packing or "fill." The fill may consist of multiple, mainly vertical, wetted surfaces upon which a thin film of water spreads. An indirect, or closed circuit cooling tower involves no direct contact of the air and the fluid, usually water or a glycol mixture, being cooled. In a counter-flow cooling tower air travels upward through the fill or tube bundles, opposite to the downward motion of the water **[1].** In a cross-flow cooling tower air moves horizontally through the fill as the water moves downward. Cooling towers are also characterized by the means by which air is moved. Because evaporation consists of pure water, the concentration of dissolved minerals and other solids in circulating water will tend to increase unless some means of dissolved-solids control, such as blow-down, is provided. Some water is also lost by droplets being carried out with the exhaust air (drift). The process flow in a Power Plant is depicted in Figure 1.

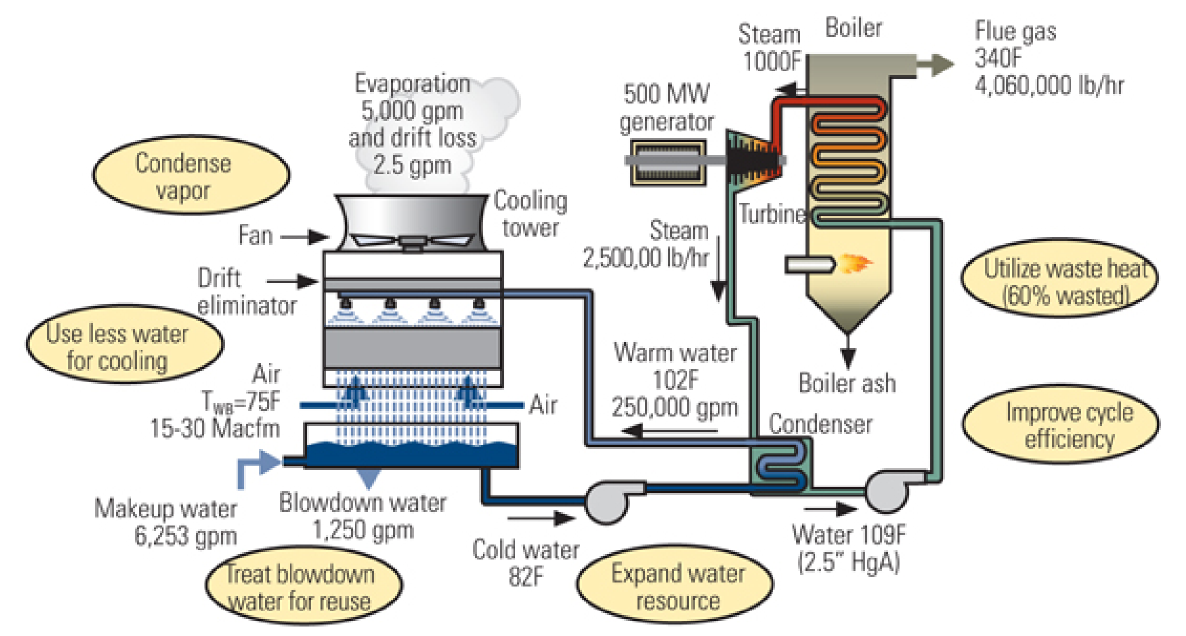


Figure 1. Cooling Tower process flow schematic

Cooling towers vary in size from small roof-top units to very large hyperboloid structures (Figure 2) that can be up to 200 metres (660 ft) tall and 100 metres (330 ft) in diameter, or rectangular structures that can be over 40 metres (130 ft) tall and 80 metres (260 ft) long.

Figure 2. Hyperboloid Cooling Towers installed in a thermal Power Plant

The hyperboloid cooling towers are often associated with power plants, although they are also used to some extent in some large chemical and other industrial plants. Although these large towers are very prominent, the vast majority of cooling towers are much smaller, including many units installed on or near buildings to discharge heat from air conditioning.

2.0 Need for Cooling Tower Machine Protection

Just like other rotating machines, Cooling Towers have to be protected against catastrophic failure due to excessive vibration. This is particularly true for large fans as found on cooling towers **[2].** Figure 3 (a) & 3 (b) shows a large Cooling Tower Fan and GearBox that failed catastrophically due to high vibrations.

Figure 3(a) A failed Cooling Tower Fan

Figure 3(b) A broken Gear Box Teeth

Most cooling towers use a horizontal electric motor driving a jack shaft into a right angle gearbox with vertical output to a large fan (Figure 4).

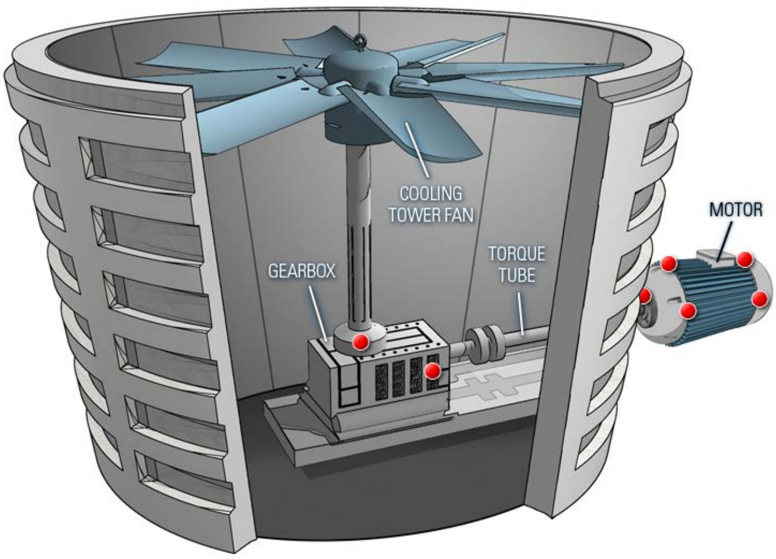


Figure 4. Cooling Tower components for an Industrial Cooling Tower

Vibration monitoring of this drive train is essential to provide signals for early warning or provide shutdown when vibration levels exceed a predetermined threshold.

Typically, the Cooling Tower failures are estimated as **[3]**

i) Motor - 60% ii) Gearbox - 30% iii) Fan - 2% iv) Other - 8%

2.1 Gearbox failures

The gearbox can be a source of excessive maintenance for several reasons. Located inside the cell, it is subjected to aerodynamic loading from the fan, misalignment of the gear to the motor and/or excessive loading on the gear teeth. Environmental factors can also contribute to gearbox degradation. Chemicals added to the water to control the pH of the cooling tower water are typically caustic. Vibration switches continuously monitor vibration on a machine and provide an alert and/or shutdown of the machine, depending on the type of vibration switch and its configuration, when vibration levels become too high.

2.2 Motor failures

Since the cooling tower motors are more readily accessible to the vibration analyst, portable measurements (magnet-mounted accelerometers) are used to monitor their condition. Motor unbalance, rotor bar defects, output shaft alignment and bearing defects are typical faults detected.

2.3 Fan failures

Fan failures, although infrequent, can be catastrophic. If undetected, the fan blades can detach and damage the cell and surrounding components.

3.0 Cooling Tower Monitoring Considerations

The specific considerations for vibration monitoring & protection of Cooling Towers can be summarised as follows **[4]-**

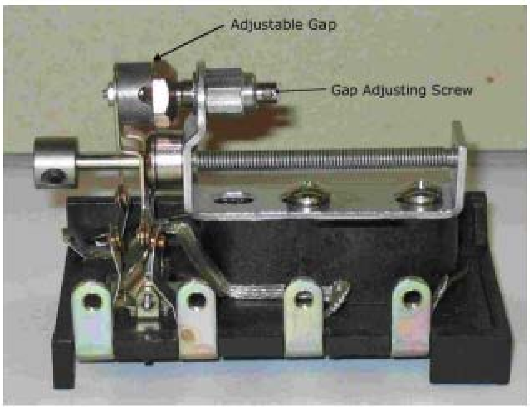
- Structurally, towers are very flexible and subject to short periods of high vibration due to external forces such as wind.
- There are high vibrations during start-up.
- Neighboring fan start-ups can temporarily increase vibrations on a unit that is running normally.
- Reversing fans in cold climates causes high vibrations for short time periods.
- Corrosion from bad pH can cause early failure of the switch.
- Water build up in blades causes high vibration on start-up.
- Since fan speeds are often relatively slow (generally based on diameter) a low frequency response is required to reliably monitor vibrations.
- Complex gearboxes (1800/120 RPM) require a sensor with a wide frequency range to monitor all of the potential fault frequencies.

4.0 Cooling Tower Protection Methodologies

Normally Cooling Towers across Industries employ some form of a Vibration Switch for protection against mechanical failures arising out of excessive vibration as discussed in previous section. A Vibration Switch is a simple protection device that senses vibration and triggers an alarm or shuts down a machine if the vibration exceeds a preset threshold level. The vibration switch can sense vibration due to faults such as unbalance, misalignment, looseness, worn bearings, cracked gears, or lack of lubrication. Vibration switches or vibration switches with built in transmitters (4-20 mA output) are often used for machinery protection.

4.1 Mechanical Vibration Switches- The classic legacy solution involved the use of "earthquake" mechanical switches (as shown in Figure 5). A mechanical vibration switch is a fairly simple device consisting of a magnet mounted on a spring loaded lever arm, which in turn is attached to mechanically activated electrical switch contacts, as shown in Figure 6. The switch is held in an armed position when the location of a magnetic plate is adjusted so it is close enough to the magnet to overcome the force in the spring loaded arm **[5].**

Figure 5 Mechanical Vibration Switch installed on a Cooling Tower Fan



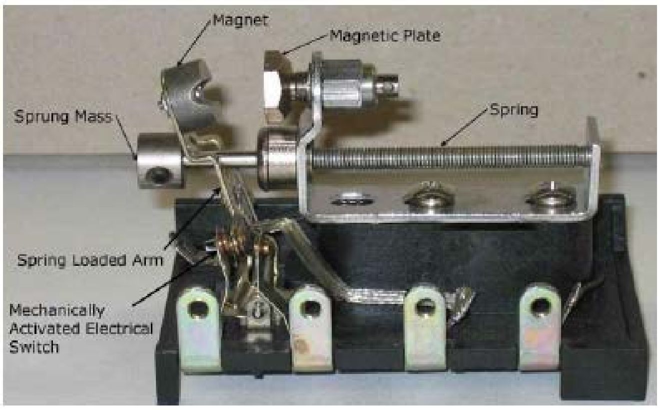


Fig. 6(a)Armed mechanical switch mechanism with labeled parts	**Fig. 6(b) Tripped mechanical switch mechanism with labeled parts**

The gap between the magnet and magnetic plate can be adjusted by an external screw adjustment to increase or decrease the magnetic force holding the spring loaded arm in an armed position. Unfortunately, not all mechanical switches have the same maximum gap or force adjustment per turn. Some switches that this author looked at had a maximum gap of only 4.3 to 5.1 mm beyond which the magnetic force is not strong enough to overcome the spring force. Other mechanical switches had gaps as high 2 mm. To make matters worse, the sensitivity adjustment is also a function of the threads on the adjusting screw and some had fine and some had course threads. The typical procedure for setting the trip sensitivity is by turning the adjusting screw in ¼ turn increments until the switch does not trip on startup. Thus, sensitivity can vary widely between switches.

When motion occurs, the magnet on the spring loaded arm and the sprung mass generate inertial forces that oppose the magnetic force holding the switch closed (armed) and are governed by Newton's Second Law of Motion $F = ma$. When the acceleration level is high enough to generate an inertial force that is greater than the magnetic force, the switch trips. The spring loaded arm rests against a sprung mass that can move in three directions as shown in Figure 7. Thus, mechanical switches are sensitive in all three axes, however, not equally. The sprung mass was moved for this photo to show functionality. Note: the sprung mass does not move in the negative X.

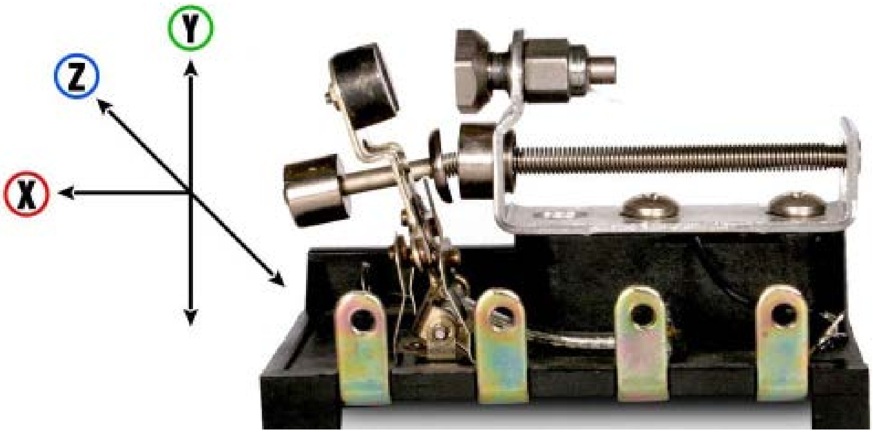


Figure 7 The spring mass in a Mechanical Vibration is sensitive to motion in three axes

The above discussion highlights a key problem with mechanical vibration switches. At low operating speeds, as seen for example in large cooling tower fans, the acceleration is so low that the inertial forces never get high enough to trip the switch in a pure unbalance condition, but, they do trip, so what's happening to cause them to trip? If the unbalance gets high enough, there are secondary effects, typically impacting, that generates enough acceleration to cause the switch to trip. However, since motion in the –X direction tends to close the switch when it stops abruptly (hits a stop) and doesn't cause the sprung mass to move, it is much less sensitive in that direction.

CTI Standard [6] - Section 4.2 of the CTI *Standard for Vibration Limits in Water Cooling Towers* states the primary Fan Rotational Speed for cooling towers is 70 to 400 RPM (1.2 to 6.7 Hz). The "C" Zone Classification (unacceptable) balance limits in the Fan Speed Displacement Tables run from about 11.5 mils on slower speed, 70 RPM, concrete cooling towers with pedestal mounting to about 15 mils on wood and fiberglass towers. On higher speed units, 400 RPM, it runs from about 4.1 mils on the concrete towers to about 6 mils on the wood and fiberglass units. When those displacement limits are used and the associated accelerations computed, they are found to be incredibly small as shown in Table 2 below that use the worst case displacements at each speed.

Table 1 Acceleration and velocity levels corresponding to unacceptable balance conditions in the CTI Standard on cooling towers

Filtered 1X Fan Vibration (Fan Balance)				
Fan Speed				
1X	1x	"C" Limit	Alarm	Alarm
rpm	Hz	mils p-p	ips pk	g pk
70	1.2	15	0.0550	0.0010
100	1.7	15	0.0785	0.0021
150	2.5	15	0.1178	0.0048
200	3.3	9	0.0942	0.0051
250	4.2	9	0.1178	0.0080
300	5.0	6	0.0942	0.0077
350	5.8	6	0.1100	0.0104
400	6.7	6	0.1257	0.0136

Using the highest displacement, unbalance for each fan speed, it is clearly seen that the acceleration levels are too low to cause enough inertial force on the mechanical switch lever or inertial mass mechanisms to trip the switch. Thus, in a pure unbalance condition, a mechanical switch cannot trip the tower. The velocity levels, however, are measureable with accelerometers and thus an electronic switch that uses a PE accelerometer will catch a balance condition in most cases.

4.2 Electronic Vibration Switch - Electronic vibration switches, as shown in Figure 8, are much more accurate and repeatable than mechanical vibration switches.

Figure 8 Electronic Vibration Switch mounted on a Cooling Tower Motor

They utilize a calibrated piezoelectric accelerometer, typically embedded in the switch housing, for sensing vibration and can integrate the signal to get velocity and in some cases displacement. A typical Electronic Vibration Switch internals, are shown in Figure 9. As shown in the Table 2 above, unlike the mechanical switch, the electronic switch can, in most cases, accurately measure the balance condition of the fan and respond based on its amplitude.

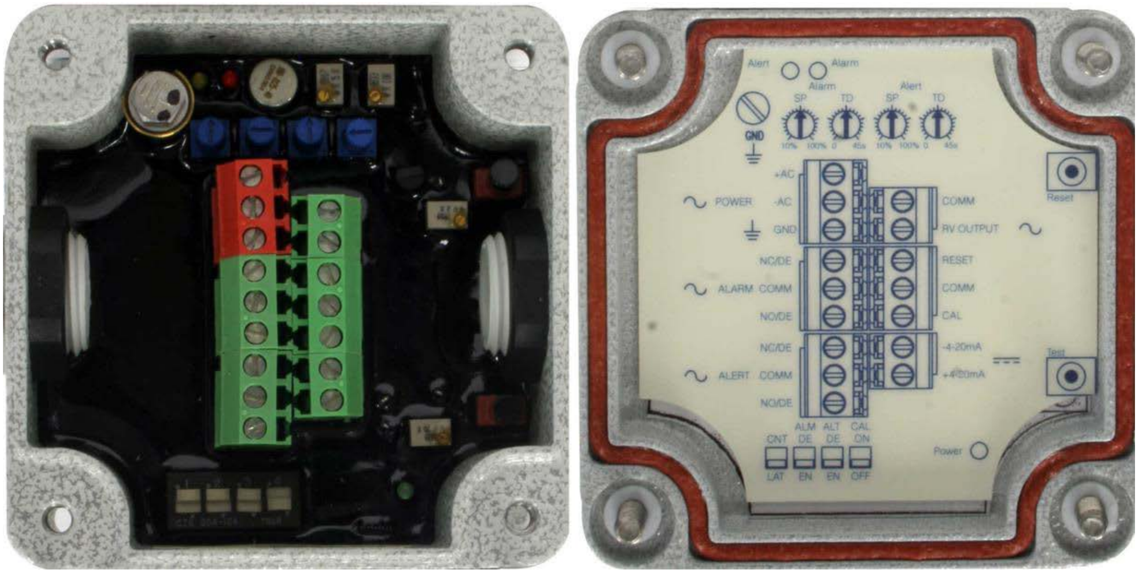


Figure 9 Electronic Vibration Switch internals

CTI Vibration Standard [6] – The Table 3shows “Broadband Vibration Limits” or overall vibration amplitudes from the CTI *Standard for Vibration Limits in Water Cooling Towers* for field erected wood, fiberglass framed, factory assembled steel and fiberglass cooling towers.

Table 3 Broadband Vibration Limits from the CTI Standard for Field Erected Wood or Fiberglass Framed Cooling Towers and Factory Assembled Steel or Fiberglass Cooling Towers

Severity Zone	Condition	Velocity in/sec		Velocity mm/sec	
		Peak	rms	Peak	rms
A	Low	0.35	0.25	8.9	6.4
B	Acceptable	0.50	0.36	12.7	9.1
C	Alarm	0.60	0.43	15.2	10.9
D	Shutdown	0.70	0.50	17.8	12.7

As can be inferred from the table, the shutdown limit is specified at 0.7 ips (17.8 mm/s) peak velocity. But, we should note that this is a derived peak velocity that is calculated as 1.414 X RMS and is not the true peak velocity. This value is provided since many vibration data collectors compute peak velocity in this manner and many analysts prefer it to RMS velocity. **This is the vibration shutdown level that an electronic vibration switch should be set to. It should also be noted that this specification cannot be met with a mechanical vibration switch.** That is not to say that a machine or cooling tower cannot be protected with a mechanical switch, it just implies that greater accuracy will be achieved with an electronic switch and the Standard can be met. However, we should note that the frequency response of the electronic switch, most are accurate down to 2 to 3 Hz (120 to 180 RPM).

Many electronic vibration switches have some or all of the following options available making them more versatile, effective, and providing better protection than mechanical vibration switches.

- Warning and critical (shutdown) alarms
- Time delays
- Latching and non-latching switch operation
- Raw vibration output
- 4-20 mA output

4.3 Programmable Electronic Vibration Switches

Programmable electronic vibration switches generally have a much better accuracy and provide better control over trip levels and delays than traditional electronic vibration switches allowing the user to tailor the response as desired. However, they may not have all of the other features of traditional switches. Figure 10 shows a SMART Vibration Switch mounted on the fins of an electrical motor.

The unit incorporates a piezoelectric accelerometer, signal conditioning electronics, a microprocessor, and a solid-state switch with a 500 mA current capacity in a single housing. This unit is quite small compared to traditional electronic vibration switches at only ~ 70 mm high, a ~ 32 mm hex diameter, and weighing around ~ 200 grams. It has wide frequency response 180 to 60k CPM (3 to 1000 Hz) and low cross axis sensitivity, unlike traditional units.

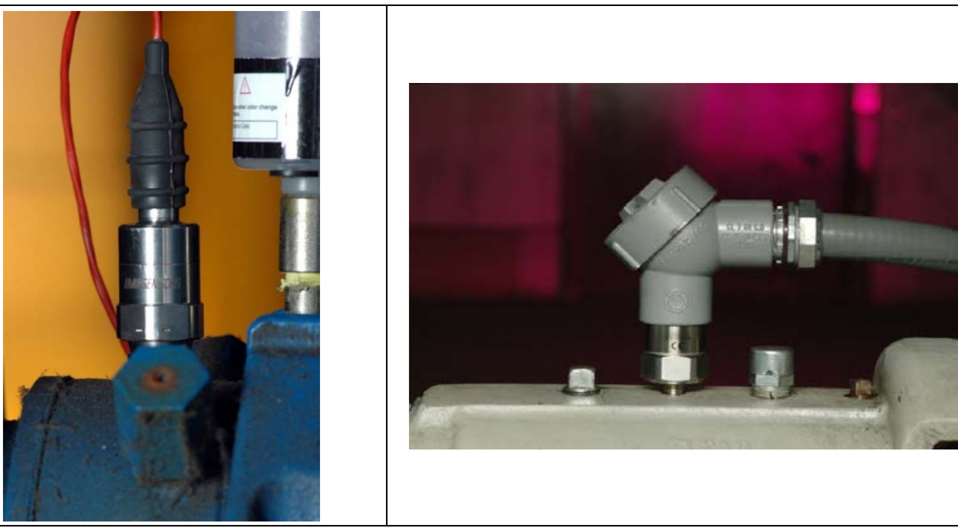


Figure 10 SMART Vibration Switch mounted on a machine casings

The Smart Vibration Switch should be mounted like an industrial accelerometer in the horizontal direction on the motor and fan bearings at the location of highest load for the best performance.
The Smart Vibration Switch operates over two wires and installs in series with a load and its power source to form a loop. A typical connection schematic of a SMART Switch is shown in Figure 11 **[7]**

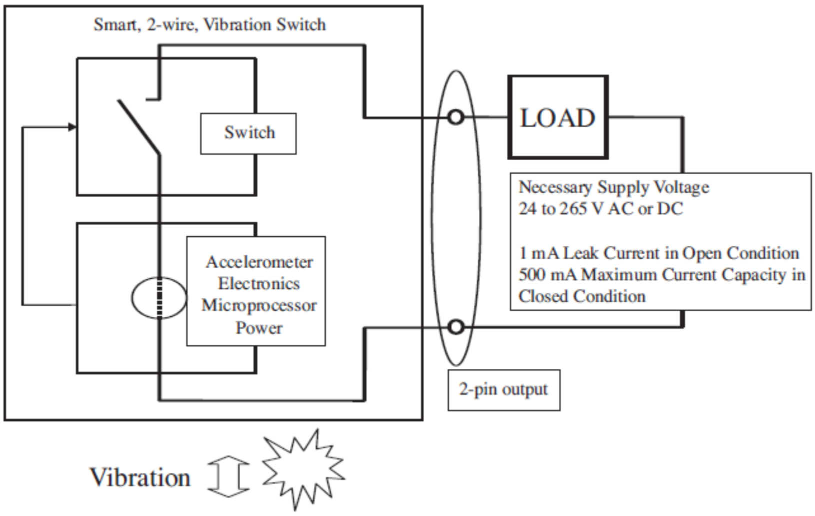


Figure 11 Typical connection schematic for a SMART Vibration Switch

The load is typically the alarm or shutdown device, such as a PLC, annunciator, or relay coil. Since the switch is mounted in series, its power is scavenged from the load's power source. When the vibration exceedance criteria are met, the microprocessor changes the state of the internal relay contacts from their normal position (normally open or normally closed). This triggers the desired alarm or shutdown action.

The SMART Switch's parameters which could be programmed in the field are-

- Alarm threshold level & hysteresis
- Power-on, startup, & operating delays
- Normally open or normally closed
- Latching or non-latching
- Residual vibration level

Also, the relay contacts can be configured as NO or NC . These features and options provide the operator in the plant better reliability and repeatability of Cooling Towers.

After discussing the types of Vibration Switch technologies, it is pertinent to ask which switch to select for the Cooling Tower Vibration monitoring. Table 3 summarizes the features of the three types of Vibration Switches discussed with the characteristics.

Characteristics	Mechanical Vibration Switch	Electronic Vibration Switch	SMART Switch
2-Wire operation	Yes	No	Yes
Relays (Latching Operation)	Yes	Yes	Yes
Relays (Non-latching)	No	Yes	Yes
Remote Reset	No (or optional)	Yes	Yes
Precision Measurements	No	Yes	Yes
Alarm on Velocity	No	Yes	Yes
Power on Delay	No	No	Yes
Start-up Delay	No	Yes	Yes
USB Programmable	No	No	Yes
Small Footprint	No	No	Yes
4-20mA Output	No	Yes (Optional)	No
Raw Vibration O/P	No	Yes (Optional)	No

5.0 Conclusion

Special application and monitoring considerations of Industrial Cooling Towers warrant the use of Vibration Switches for 24X7 Protection. Various Vibration switch technologies viz. Mechanical Switch, Electronic Switch, SMART Programmable Switch have been discussed and pros and cons of each have been discussed in detail. The features and considerations for the proper selection of the Vibration Switches based on criticality of equipment, cost, monitoring required or not etc. have been discussed in detail.

6.0 References

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