ICSV14
Cairns • Australia
9-12 July, 2007

14th International Congress on Sound & Vibration

INTELLEGENT TWO WIRE VIBRATION SWITCH – NEW CLASS OF MONITORING DEVICE

Dr. George Zusman,
PCB Piezotronics, Depew, NY 14043, USA
gzusman@prodigy.net

Abstract

This intelligent, two-wire vibration switch is a new type of device for machinery condition monitoring and protection. It has been designed to be a cost effective tool for generating an alarm or initiating shutdown of small to medium-size machinery, such as electrical motors, pumps, cooling towers, fans, and compressors. The vibration switch is designed like universal unit, including an acceptability of any supply voltage from 24 till 265 VAC or VDC, and it is field configurable thru the same two operation wires (pins) by using special USB programmer. Additionally to programmability, vibration threshold of the device is adjustable electronically by external magnet sensor activation technology (Patent and Trademark pending). Construction of the devise provides possibility of electrical connection in series or/and in parallel several units for different applications. The device is entirely self-contained within hermetically sealed, stainless steel housing. The unit's appearance is very similar to industrial accelerometer and has the same simplicity of installation. In the same time it is based on true RMS vibration velocity measurements switch providing virtual universal compatibility with any type of load, relay, monitoring system, or control device.

1. INTRODUCTION

Rotating machinery are often subjected to damaging forces that lead to costly failures when abnormal operating conditions or minor faults go unnoticed. A problem as simple as dirt buildup on fan blades can result in huge centrifugal forces that are transmitted to the bearings resulting in inefficient operation and premature failure. These damaging forces, however, generate vibrations on the machinery that if monitored, can provide sufficient warning so that corrective action can be taken before catastrophic failure occurs. Vibration switches are often used to monitor vibrations and shutdown equipment before damage can occur.

2. VIBRATION SWITCHES

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.

One of the most popular switches has traditionally been the mechanical vibration switch. Mechanical switches are popular because they are low cost, easy to install (requiring no electrical power) and, if installed properly, provide some basic protection. These switches do, however, have the following problems. They can not be calibrated to accurate and repeatable vibration amplitude. In fact, they respond better to shock than vibration, and are often tested in the field by "dropping a sledgehammer". Mechanical switches do not reliably trip even at high vibration levels, require a person to climb the tower to reset the unit or change trip levels, are often set too high to avoid false trips, and have no trip delay capability.

Other category of vibration switches is an electronic vibration switch which typically uses a built-in precision accelerometer to accurately monitor vibration levels, although, units are available that use external sensors. The switch consists of an accelerometer, circuit boards, and one or more mechanical or solid state relays housed normally in a NEMA or other environmental electronics enclosure. The internal circuitry monitors the sensor's vibration level and compares it to a preset threshold or alarm value. When the vibration level exceeds the threshold, the relay is activated.

A typical electronic vibration switch has several advantages over a mechanical unit. It has no moving parts, is more reliable, and has a much higher degree of both accuracy and repeatability. Time delays can be used to avoid false trips during switch power up, equipment startup, operational changes, and chance occurrences of short term vibration increases. Signal conditioning can be employed to integrate the accelerometer output to a more stable velocity signal and compute a more repeatable RMS signal. The drawbacks of electronic switches are cost (which can run about three or more times the cost of a mechanical unit), they require electrical power, and must be wired to their respective PLC or alarming device. Additionally, while smaller than many mechanical switches, they are still bulky.

3. INTELLEGENT TWO WIRE VIBRATION SWITCH

A new two-wire, solid-state intelligent vibration switch (which we will call also briefly in this article: Smart Vibration Switch) has been developed that has all of the advantages of the electronic switch, overcomes many of their shortcomings, and includes new features to further enhance its advantages over existing devices. This new switch will be considered on example of cooling tower applications which accumulates issues partly we could see on other applications like fans, motors, compressors etc. It is important to note that the following requirements for cooling tower use, some of which can cause unwanted trips. A Table is included at the end of this paper that compares how the various types of vibration switches and other monitoring configurations address these requirements.

- Structurally, towers are very flexible and subject to short periods of high vibration due to external forces such as wind.
- There are often large distances between the motor, gearbox, and fan making them difficult to monitor with a single switch.
- There are high vibrations during startup.
- Neighbouring fan startups 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 startup.

- 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.
- There can be very long distances between the switch and control room.

The Smart Vibration Switch has the following features to address these requirements. Each of them is described in detail in this paper. The Smart Vibration Switch is housed in a small hermetically sealed stainless steel package with an embedded precision accelerometer. It is durable in harsh environments, accurate, repeatable, and has a wide frequency range. It is easy to install, universally powered (24 to 240 VDC or VAC), and has 2-wire operation that allows parallel operation for cost effective use. It has three user settable delays (switch Power On, equipment Start Up and Operational) to avoid false trips and its cost is lower than typical electronic vibration switches.

The Smart Vibration Switch is completely self-contained (sensor, electronics, and relay) in a robust hermetically sealed, stainless steel housing that is very similar in appearance to an industrial accelerometer, Figures 1. It has a standard 2-pin MIL style electrical connector or 2-wire integrated cable that is used for both normal operation and programming the unit. It is simple to install using a single ¼-28 or M6 stud, and universally compatible with any type of load, relay, monitoring system, or control device. In many cases, the Smart Vibration Switch will be the only device necessary for permanent machinery protection.

Figure 1 – Smart Vibration Switch

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 2.75 inches high (~ 70 mm), a 1-1/4 inch (~ 32 mm) hex diameter, and weighing only 7 ounces (~ 200 g). It has wide frequency response 180 to 60k CPM (3 to 1000 Hz) and low cross axis sensitivity, unlike traditional units. Detailed specifications and drawings for the 686A series of Smart Vibration Switches are available at www.imi-sensors.com/vib_switch.asp. 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.

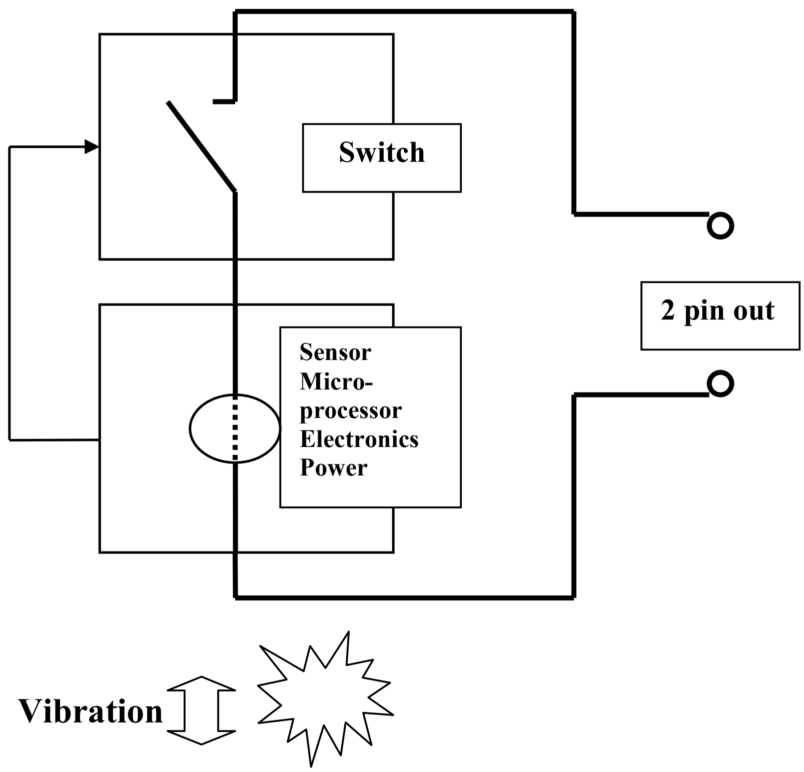

Figure 2 - Smart Vibration Switch Operating Principle

4. OPERATING PRINCIPLE AND APPLICATION

The Smart Vibration Switch operates over two wires and installs in series with a load and its power source to form a loop. 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.

4.1 MAVT™

The programmed threshold value is the upper limit of acceptable vibration for a specific machine operating at a particular condition. This value may be different for dissimilar machines, or identical machines operating under different conditions. If an acceptable vibration limit can be determined, then a vibration switch with a fixed threshold value can be deployed. Often, however, this limit is not exactly known, making field adjustment of the threshold a requirement. The Smart Vibration Switch can be provided with a smart field adjustment option called Magnetically Adjustable Vibration Threshold (MAVT™).

The MAVT™ option adds a magnetically actuated sensor within the housing of the Smart Vibration Switch. The sensor is activated by touching the housing of the switch, at the proper location, with a strong permanent magnet. This action initiates a process within the microprocessor to change the threshold value. During this process, the vibration measured by the Smart Vibration Switch is averaged over a fixed sample period of approximately 30 seconds. The microprocessor then sets the new threshold value to twice the measured value.

This process is entirely automatic and requires no additional calibration instrumentation or knowledge of vibration analysis. With MAVT™ capability, the Smart Vibration Switch can simply be installed onto a machine that is operating normally and activated with a strong permanent magnet. About 30 seconds later, it is accurately set to protect the machine.

If a more precise set-up of the threshold value is required (e.g., per a standard), the Smart Vibration Switch can be mounted to a controlled vibration shaker. Simply shake the switch at ½ the required vibration threshold level and use MAVT™ to reset the level. Since it sets it to exactly two times the measured vibration level, the switch will be set to the proper threshold level.

4.2 Installation

As previously mentioned, the Smart Vibration Switch derives its excitation power from the power source used to energize the load that the switch it is connected in series with and serves to restrict the amount of current passing through the switch, which is limited to 500 mA.

The Smart Vibration Switch can be powered by any source that outputs 24 to 240 volts, either DC (positive or negative polarity) or AC (50 or 60 Hz). This permits use with most types of loads, such as a PLC, annunciator lamp, alarm device, electromechanical relay, or solid-state relay. With the switch in an open condition, there is a leak current of approximately 1 mA to operate the electronics. In a closed condition, the switch can pass a current of up to 500 mA with a voltage drop of approximately 8 volts. In circumstances where a lower voltage drop is required, a version of the Smart Vibration Switch can be supplied that operates from 10 to 30 VDC and has a voltage drop in the closed condition of 1.5 VDC (pending).

4.3 Electromechanical Relay Considerations

Vibration switches are often used in conjunction with electromechanical relays for machinery shutdown. These relays operate with a drop-out current that is less than their pull-in current. For some relays, the drop-out current can be close to or even less than the 1 mA leak current required by the Smart Vibration Switch for operation. In this case, even though the Smart Vibration Switch is open (off) the 1 mA leak current prohibits the electromechanical relay from resetting. The special 100 ms current cut used to reliable operating in such condition.

4.4 Large Distances between Components

Some machinery, in particular cooling towers, often have large distances between the motor, gearbox, and fan making them difficult to monitor effectively using a single vibration switch. Vibrations due to a fault condition on one component may not be seen on another because of this physical separation. Ideally, it would be better to have vibration switches on each of the critical machinery components to better monitor them. For example, in order to monitor all of the bearings in the system, gears problems, and fan unbalance in a typical cooling tower with a long motor to gearbox shaft, a minimum of two switches would be recommended. Due to the small size, easy mounting, and wide frequency response of the Smart Vibration Switch, it will do an excellent job of monitoring all of the normal faults encountered in cooling towers.

This scenario is handled easily and economically with the Smart Vibration Switch since multiple switches can be installed in a parallel circuit arrangement as shown in Figure 8. Since multiple switches can be connected to a single, two-wire cable, the installation is relatively easy and very cost effective. This single cable can be routed to a control area, and for hazardous areas, only one protection barrier is required. Using this arrangement, an alarm from any switch will cause a common alarm, annunciator, or shutdown of all the machinery in the loop simultaneously.

4.5 Delays

Transient vibrations or electrical signals can cause unwanted trips of normally operating equipment. To guard against this, the Smart Vibration Switch incorporates three delays: Start Up, Operational, and Power On.

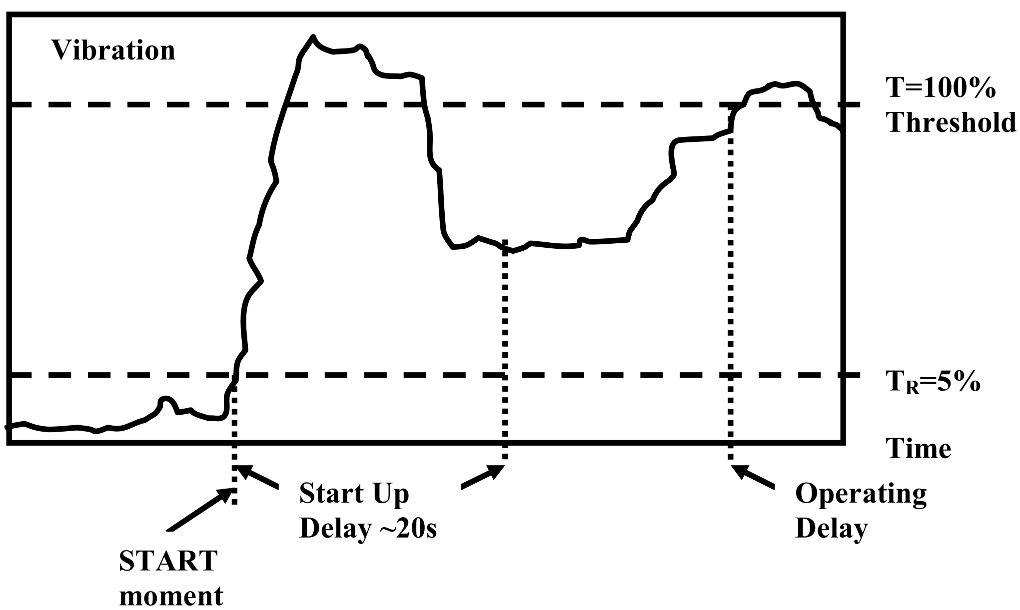

Figure 3 - Diagram of the Smart Vibration Switch trip conditions

After the Start Up Delay period, the Smart Vibration Switch begins normal vibration monitoring of the machine. The switch can be set to trip immediately after the vibration exceeds the threshold level or can be programmed with an Operational Delay. The Operational Delay can be factory preset or programmed by the user to 3, 6, 9, 12 or other number of seconds. If it has an Operational Delay, the vibration level must remain above the threshold level for the entire delay period before a trip occurs (see Figure 3). If the vibration drops below the threshold level before the Operation Delay period is up the switch will not trip. Further, once it exceeds it again, it must remain above for the entire period before a trip occurs.

When the vibration exceeds the threshold level for the required period of time, the switch closes which in turn energizes the load (for example, electromechanical relay coil). This action causes the normally closed relay contacts to open and shut down load, for example magnetic starter along with the corresponding motor. Since the Smart Vibration Switches in this example are latching, the coil will remain energized even when the vibration amplitude drops below the threshold level after shutdown. When the RESET button connected in series to vibration switch is pushed, power is removed from both the switches and relay coil. This causes both the switches and relay to reset to their normal conditions. When the RESET button is released, power is returned to the switches; however, they will not be sensitive to vibrations until after the Power On Delay period.

4.6 Vibration Coupled Machine

Machinery often operates in very close proximity to each other resulting in vibration cross effects between them. In cooling towers, this condition is exacerbated since there is often more than one fan in a single cooling tower. Thus, starting a fan can cause vibrations in nearby units that are high enough to shut them down even though they are operating properly. Smart Vibration Switches could be operated in a parallel circuit arrangement that eliminates this problem.

5. FEATURES AND SPESIFICATION

The following are key performance features of the Smart Vibration Switch. Some are user selectable and some are factory set based on application requirements.

5.1 Main Features

- Universal Power: 24 to 240 volts, either DC (+/– polarity) or AC (50/60 Hz)
- Housing: Stainless Steel, Hermetically Sealed
- Velocity Threshold: selectable 0.25 to 6.0 ips pk (4.5 to 112 mm/s rms)
- Relay Action: Latching or Non-Latching
- Switch Contacts: Normally Open or Normally Closed
- Operating Delay: selectable 3, 6, 9, and 12 seconds
- Power-On Delay: 20 seconds
- Start Up Delay: 0 or 20 seconds
- Frequency Response: 180 to 60,000 CPM (3 to 1000 Hz)
- Transverse (cross-axis) Sensitivity: <3%

5.2 Optional Features

- Magnetically Adjustable Vibration Threshold (MAVT™)
- User programmable via the 2-pin MIL connector to a PC (requires a special USB programmer)
- Raw Vibration Output: 100 mV/g analog vibration output signal for FFT analysis and diagnostics. This unit will have a 3-pin connector pin and will require 24 VDC power (pending).

6. CONCLUSION (Switch Comparison)

Table 1 shows a comparison of how the various types of vibration switches and other monitoring configurations handle the particular requirement for cooling tower monitoring as described earlier in this paper. The left column describes the requirements of cooling towers. The regular type is the specific cooling tower requirement. The *italic* type is the Smart Vibration Switch feature that addresses this requirement.

Table Key

*   Indicates the relative cost of the units, thus ** is about twice the cost of *
+   The unit has this feature
-    The unit does not have this feature
+/- Some units have the feature and some do not

Table 1 – Comparison of Vibration Switches to Cooling Tower Requirements
Refer to the list on page 3 for a more complete description of the requirements.

Cooling Tower Requirement	Mechanical Vibration Switch	Electronic Vibration Switch	Smart Vibration Switch (New)	ICP® Accelerometer & Transmitter w/Relay	4-20 mA Output Vibration Sensor & Transmitter w/Relay
Cost	*	***	**	****	***
Towers are very flexible causing high short periods of high vibration *Operating Delay*	-	+	+	+	+
Large distance between fan, gear box & motor requires multiple switches *Easy parallel or in series hook up*	+	-	+	-	-
High vibration during startup *Power On Delay*	-	+/-	+	-	-
Start UP Delay	-	-	+	-	-
Neighbouring fan startup effects normally operating fans *Parallel switch operation w/EM Relays blocks coupled vibrations*	-	-	+	-	-
Reversing fans in cold climates *Operating Delay*	-	+	+	+	+
Corrosion from bad pH *SS housing, Hermetically sealed*	-	-	+	+	+
Water build up in blades *High Threshold Level*	+	-	+	+	+
Speeds are slow and based on fan diameter *Monitor vibration velocity & wide frequency response*	-	+	+	+	+
Complex gearbox (1800/120 RPM) with high frequency faults *High frequency response of switch and mounting configuration*	-	-	+	+	+
Long distances from the switch to the control room *High level signal in the cable allows long cable runs*	+	+	+	-	+/-