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Practical Insights for Vibration Switch Selection

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Abstract

This paper outlines the purpose, design, and application of different vibration switches used to detect and mitigate damaging vibration conditions in rotating machinery. It explores three main types—mechanical, electronic, and programmable electronic—and delves into their internal mechanisms, benefits, and limitations. Special attention is given to low-frequency conditions in large cooling tower fans, where compliance with CTI Standard 163 is often required. The paper also presents results from an impact test demonstrating the multidirectional sensitivity of mechanical switches. Finally, it provides practical tips on evaluating low-frequency specifications, establishing thresholds, and selecting the right switch for a given application.

Keywords:
Vibration Switches, Mechanical Vibration Switch, Electronic Vibration Switch, Programmable Switch, Cooling Tower, Fan Balance, CTI Standard, Machinery Protection, Low-Frequency Response

1. Introduction

Vibration switches are relatively simple instruments, ranging from mechanical designs to more complex electronic versions, used to protect rotating machinery from catastrophic failure caused by excessive vibration. This is especially critical for large cooling tower fans, which often run at slow speeds (70–400 RPM) and can incur major downtime costs if they fail unexpectedly.

These switches continuously monitor a machine’s vibration level and provide an alert and/or shutdown signal when vibration surpasses a preset threshold. CTI Standard 163 for Water Cooling Towers offers guidance on acceptable vibration levels at various speeds, underscoring the importance of choosing a switch that can capture the low-frequency vibrations typical of large fans (best measured using a velocity output).

2. Types of Vibration Switches

Vibration switches typically fall into one of three categories:

1. Mechanical Vibration Switches
2. Electronic Vibration Switches
3. Programmable Electronic Vibration Switches (also called “Smart Switches”)

Each design has unique strengths and weaknesses regarding cost, accuracy, ease of installation, and suitability for slow-speed or higher-temperature, intrinsically safe applications. Additionally, both mechanical and electronic switches commonly share similar enclosure and sealing properties; fully hermetic sealing is generally reserved for some programmable (smart) designs.

2.1 Mechanical Vibration Switches

Mechanical vibration switches detect excessive vibration through the movement of a magnetically held lever arm. When the inertial force from vibration overcomes the magnetic attraction, the switch “trips” and opens an electrical contact.

Key Components:

- Magnet on a Spring-Loaded Lever Arm
- Magnetic Plate (magnet’s force holds the arm in an “armed” position)
- Switch Contacts (open once inertial force outweighs magnet’s holding power)

2.1.1 Mechanism & Sensitivity

When the machine vibrates, the lever arm (and any attached mass) experiences inertial forces in response to acceleration. If that force exceeds the magnet’s holding power, the arm shifts away from the plate, causing the switch to open (trip). In many cases, slow-speed sinusoidal motion may not generate enough shock or impact to trip the switch unless there are secondary impacts (e.g., blades contacting an enclosure).

Adjustment Mechanism:
An external screw modifies the distance between the magnet and plate, affecting how much force is needed to overcome the magnet. This can introduce some non-linearity, as small distance changes can lead to disproportionately large variations in holding force. Sensitivity also depends on magnet size, spring force, and thread pitch.

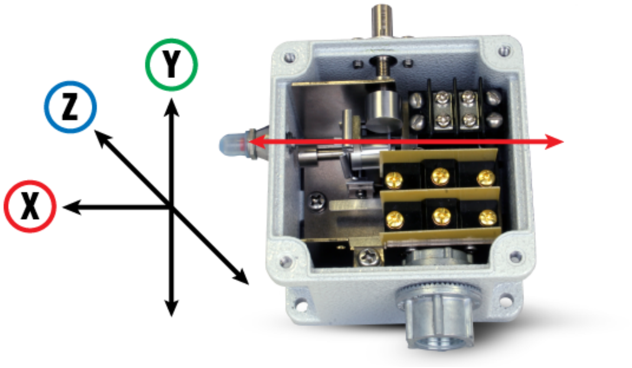


Figure 1: Illustration of inertial forces affecting the mass.

2.1.2 Impact Test (Multi-Directional Sensitivity)

Mechanical switches can exhibit uneven sensitivity across different axes. In first-generation designs, the magnet and magnetic plate are oriented parallel, introducing two main flaws:

- Non-linear Adjustment: Changing the gap between parallel surfaces causes a non-linear change in magnetic force.
- Directional Bias: Inertial forces may release the arm more easily from one direction than another.

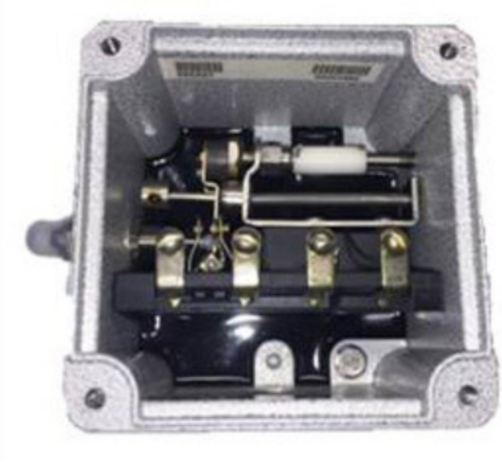


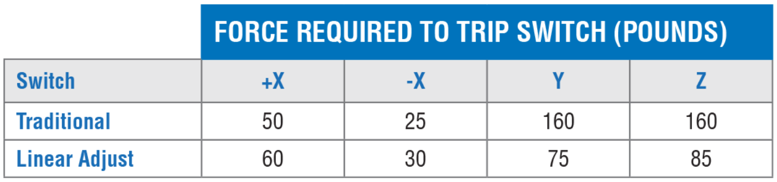
Figure 2: Mechanical design with parallel magnet to magnetic material orientation

Recent advancements incorporate a perpendicular (or “linear adjust”) arrangement, which improves resolution. Instead of varying the gap, the overlap between the magnet and plate changes, creating a linear relationship between the adjustment knob and holding force. This design also reduces directional bias.

Figure 3: IMI 685 Series “linear adjust” vibration switch with a perpendicular magnet to magnetic material orientation

Impact Test Setup:
A calibrated hammer applied forces in +X, –X, Y, and Z directions to compare a traditional (parallel) switch and a linear adjust (perpendicular) switch. The force required to trip each device was recorded:

Table 1: Results of impact testing on traditional and linear adjust mechanical switches.



	FORCE REQUIRED TO TRIP SWITCH (POUNDS)			
Switch	**+X**	**-X**	**Y**	**Z**
Traditional	50	25	160	160
Linear Adjust	60	30	75	85

Key Findings:

- Traditional Switch: Directional bias was evident (e.g., –X required the least force to trip).
- Linear Adjust Switch: More consistent across all axes, but still subject to the inherent low-frequency limitations of mechanical devices.

2.1.3 Mechanical Switch Benefits

- Low Cost & Simplicity: Ideal for budget-sensitive applications.
- No External Power Required: Relies solely on spring and magnetic force.
- Multi-Directional Sensitivity: Reacts to motion in multiple axes (though older designs may be uneven).
- Optional 4–20 mA Output: Some mechanical switches include an integrated sensor that provides a 4-20 mA or raw vibration signal, enabling real-time diagnostics in addition to a basic trip function.

2.1.4 Limitations

- Coarse Sensitivity Adjustment: Threaded external screws can be imprecise.
- Less Effective at Low Frequencies: Slow sinusoidal motion often fails to surpass the force threshold.
- Environmental Sealing Concerns: Moisture and corrosion can degrade performance.
- No Built-In Time Delays: More susceptible to false trips during transient events (startup, brief surges).

2.2 Electronic Vibration Switches

An electronic vibration switch uses a piezoelectric accelerometer (internal or external) to measure real-time vibration. When the amplitude surpasses a preset threshold, a relay or solid-state contact triggers an alarm or shutdown.

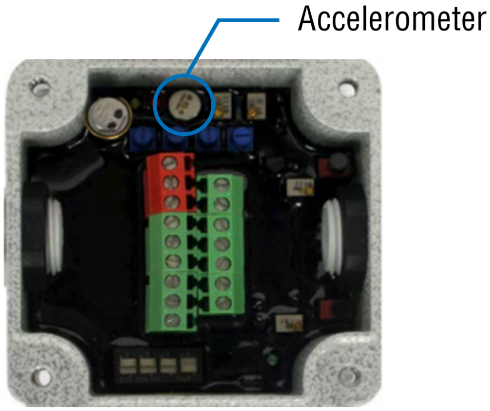


Figure 4: Traditional electronic vibration switch with potentiometer and DIP switch adjustments.

2.2.1 Key Advantages

- Higher Accuracy & Repeatability: Reliably measures vibration amplitude across a broader range.
- Time Delays: Startup or operational delays minimize nuisance trips.
- Dual Alarm Levels: Often includes separate warning and shutdown thresholds.
- Better Environmental Sealing: Typically robust enclosures for industrial use.

2.2.2 Low-Frequency Response

In slow-speed machinery like cooling tower fans, it is crucial to choose an electronic switch with a low-frequency cutoff (e.g., 2 or 3 Hz). Without this specification, the sensor may not capture the subtle vibration signals that occur at low rotational speeds. Piezoelectric technology excels at measurements in this range.

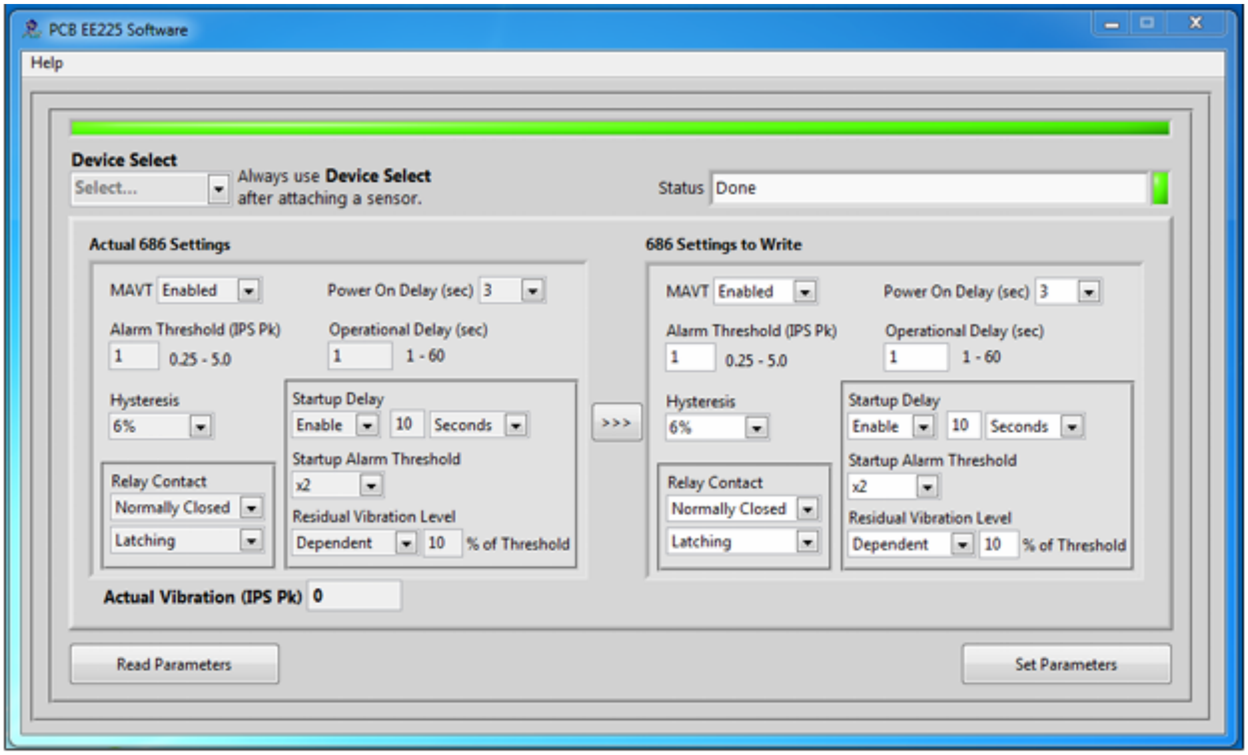
2.3 Programmable Electronic Vibration Switches

A programmable switch builds on standard electronic designs by adding a microprocessor and software-based configurability (e.g., USB programming). An example is the IMI 686 Series USB Smart Vibration Switch, featuring a sealed enclosure, advanced time delays, and fine threshold control.

Figure 5: IMI USB-Programmable Smart Vibration Switch mounted on a motor.

2.3.1 How It Works

- The embedded piezoelectric accelerometer measures vibration.
- The microprocessor compares the reading against user-defined thresholds and triggers its relay when conditions exceed set limits.
- Software allows precise numeric input for trip points, delay periods, and latching vs. non-latching options.



Device Select
Select...
Always use **Device Select** after attaching a sensor.
Status: Done

Actual 686 Settings
MAVT: Enabled
Power On Delay (sec): 3
Alarm Threshold (IPS Pk): 1 (0.25 - 5.0)
Operational Delay (sec): 1 (1 - 60)
Hysteresis: 6%
Startup Delay: Enable, 10 Seconds
Startup Alarm Threshold: x2
Residual Vibration Level: Dependent, 10 % of Threshold
Relay Contact: Normally Closed, Latching
Actual Vibration (IPS Pk) 0

686 Settings to Write
MAVT: Enabled
Power On Delay (sec): 3
Alarm Threshold (IPS Pk): 1 (0.25 - 5.0)
Operational Delay (sec): 1 (1 - 60)
Hysteresis: 6%
Startup Delay: Enable, 10 Seconds
Startup Alarm Threshold: x2
Residual Vibration Level: Dependent, 10 % of Threshold
Relay Contact: Normally Closed, Latching

Figure 6: Programming screen for IMI USB Compatible Smart Vibration Switch

2.3.2 Benefits & Typical Features

- Finer Threshold Control: Users can specify exact trip levels rather than adjusting by potentiometer or DIP switches.
- Customizable Time Delays: Power-on, startup, and operational delays can be tailored to the machine's operational profile.
- Sealed Housings: Many programmable switches are hermetically sealed for harsh or high-moisture settings.

2.3.3 Limitations

- Requires Initial Programming: Slightly more setup complexity than mechanical or standard electronic models.

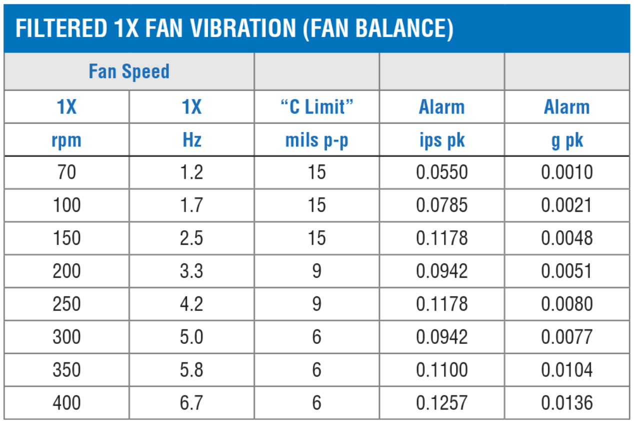
3. Consideration of CTI Vibration Standards

The Cooling Technology Institute (CTI) Standard 163 details acceptable vibration limits for cooling tower fans operating in the 70–400 RPM range. These often translate to extremely low accelerations, making it challenging for mechanical switches to detect purely sinusoidal unbalance.

3.1 Filtered 1X Fan Vibration for CTI "C" Limit

By converting the maximum displacement values from the Fan Speed Displacement Tables into equivalent velocity and acceleration figures, we can see how minimal these accelerations are, especially at lower speeds.

Table 2: CTI Standard: Unacceptable cooling tower acceleration and velocity levels.



FILTERED 1X FAN VIBRATION (FAN BALANCE)

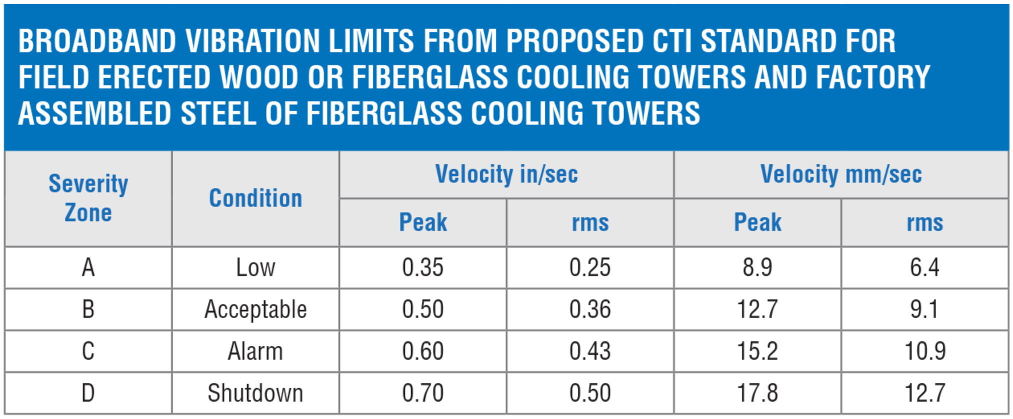
Fan Speed				
1X	1X	"C Limit"	Alarm	Alarm
rpm	Hz	mils p-p	ips pk	g pk
70	1.2	15	0.0550	0.0010
100	1.7	15	0.0785	0.0021
150	2.5	15	0.1178	0.0048
200	3.3	9	0.0942	0.0051
250	4.2	9	0.1178	0.0080
300	5.0	6	0.0942	0.0077
350	5.8	6	0.1100	0.0104
400	6.7	6	0.1257	0.0136

In a purely sinusoidal unbalance, such low acceleration levels often fail to trigger a mechanical switch. However, modern piezoelectric accelerometers can reliably measure the corresponding velocity levels, which makes electronic (particularly programmable) switches significantly more effective in detecting these subtle vibrations.

3.2 Broadband Vibration Limits

In another part of the proposed standard, broadband vibration limits for field-erected wood/fiberglass framed and factory-assembled steel/fiberglass cooling towers are given. These recommend a shutdown limit at 0.7 in/s peak velocity (calculated as 1.414 × RMS):

Table 3: Broadband vibration limits for cooling towers.



BROADBAND VIBRATION LIMITS FROM PROPOSED CTI STANDARD FOR FIELD ERECTED WOOD OR FIBERGLASS COOLING TOWERS AND FACTORY ASSEMBLED STEEL OF 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

Because mechanical switches cannot be accurately calibrated to such specific amplitude limits, electronic and programmable electronic switches are recommended to meet these shutdown criteria—again emphasizing the significance of low-frequency sensor response for slow fan speeds.

4. Conclusion

Selecting a suitable vibration switch depends on machine speed, vibration characteristics, environmental demands, and budget constraints. Mechanical, electronic, and electronic programmable (smart) switches each present distinct advantages:

1. **Mechanical Vibration Switches**
    - **Pros**: Lowest cost; simple; no external power needed
    - **Cons**: Course sensitivity adjustment; can be heavily direction-dependent; limited low-frequency response; not hermetically sealed
    - **Ideal for**: Cost-sensitive applications or where basic shutdown protection is sufficient
2. **Electronic Vibration Switches**
    - **Pros**: Greater accuracy; adjustable time delays, suitable for low-frequency detection
    - **Cons**: Requires external power; can be bulkier; typically not hermetically sealed
    - **Ideal for**: Applications needing broader frequency response and configurable alarm/shutdown settings

3. **Programmable (Smart) Electronic Vibration Switches**
    - **Pros**: Precise threshold control; robust time delay options; hermetically sealed for harsh environments
    - **Cons**: Requires setup/programming via software
    - **Ideal for**: Critical cooling tower fans and other machinery where reliable low-frequency detection is paramount.

Where slow-speed fans or strict industry standards (e.g., CTI Standard 163) apply, electronic and programmable electronic switches provide better reliability and compliance than mechanical alternatives. Mechanical switches remain viable for simpler applications where shock-based tripping is sufficient. Operators should closely evaluate the low-frequency response, axis sensitivity, and sealing requirements for their specific use case to ensure that the chosen vibration switch offers robust, long-term protection.

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