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Understanding Vibration Switches

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Abstract: The paper presents the basics of Mechanical, Electronic, and Programmable Electronic Vibration Switches. It explains their basic design, how they work, and shows where they are and are not effective especially as it relates to fan balance. It also discusses frequency response, particularly as it relates to low speed fans, along with the major differences in the responses of mechanical and electronic switches. Finally, it shows how the various switches will or will not comply with CTI Standard 163 for Vibration Limits in Water Cooling Towers. A video is available on the IMI website that shows how the various vibration switches respond to unbalance using a long-stroke vibration shaker.

Why Vibration Switches - Vibration switches are relatively simple instruments used to protect rotating machinery against catastrophic failure due to excessive vibration. This is particularly true for large fans as found on cooling towers. 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. Figure 1 shows a large fan that failed catastrophically due to high vibration.

Figure 1: Catastrophic failure of a large fan due to high vibration

Types of Vibration Switches - There are two basic types of vibration switches: mechanical and electronic, Figures 2 and 3. However, with today's microprocessor technology, electronic vibration switches can be further subdivided into two types, traditional electronic and programmable electronic vibration switches. Newer programmable electronic vibration switches provide more accuracy and features than most traditional electronic vibration switches, Figure 3. Additionally, this paper introduces a new mechanical vibration switch design called a Linear Adjust Mechanical Vibration Switch that allows better and finer adjustment of the trip level.

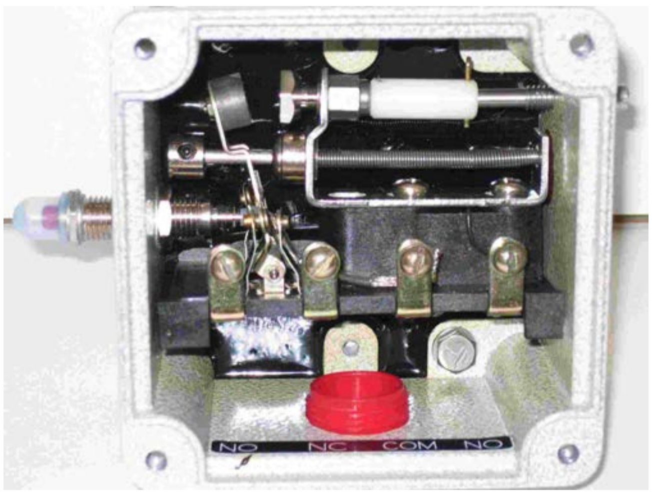

Figure 2: Traditional IMI Mechanical Vibration Switch

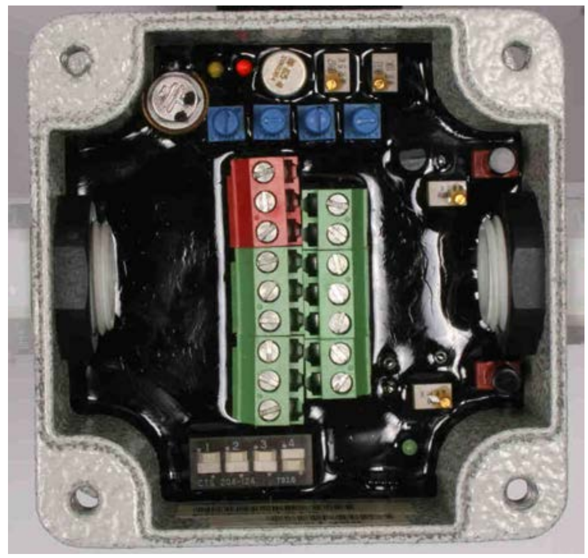

Figure 3: Traditional IMI Electronic Vibration Switch

Figure 4: IMI USB Programmable Smart Vibration Switch mounted on a motor

Mechanical Vibration Switches - 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, Figures 5 and 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.

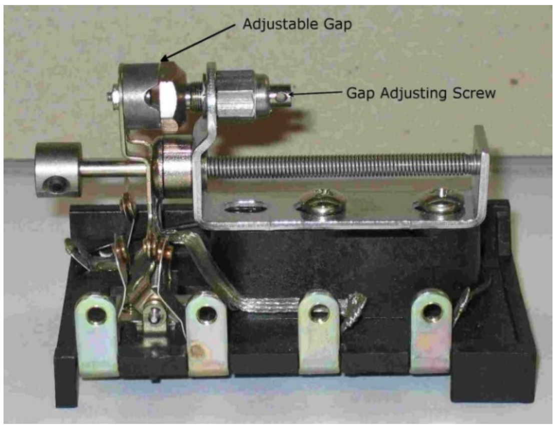

Figure 5: Armed mechanical switch mechanism with labeled parts

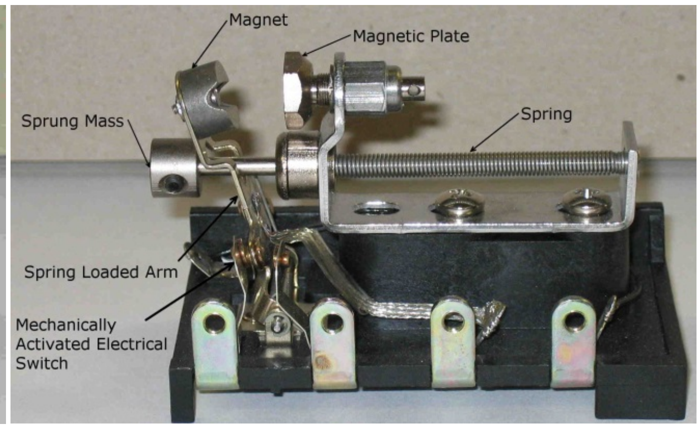

Figure 6: Tripped mechanical switch mechanism with labeled parts

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 0.017 to 0.020 inches (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 as 0.080 inches (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 as will be shown later in this paper. The sprung mass was moved for this photo to show functionality. Note: the sprung mass does not move in the negative X direction, thus there is a large difference in the shock required to trip the switch in the plus and minus X directions. This can be problematic since mechanical switches often trip due to shock.

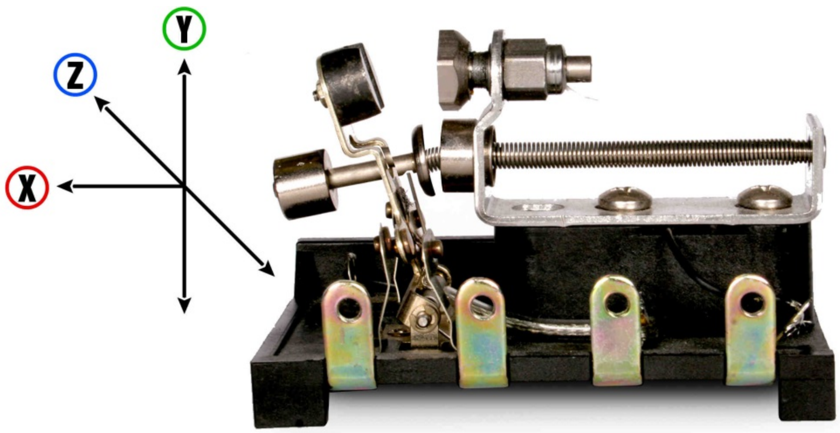

Figure 7: The sprung mass is sensitive to motion in three axes.

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 (takes less shock or vibration) than in the +X direction as shown below.

Advantages and Disadvantages – The advantages of mechanical vibration switches are cost, simplicity, and two-wire operation unless a remote reset is required. It is also sensitive to vibration in all three axes of motion, although not equally as is often believed by users. The following impact test, Figure 8, was set up to determine the difference in sensitivity in the X, Y, and Z directions.

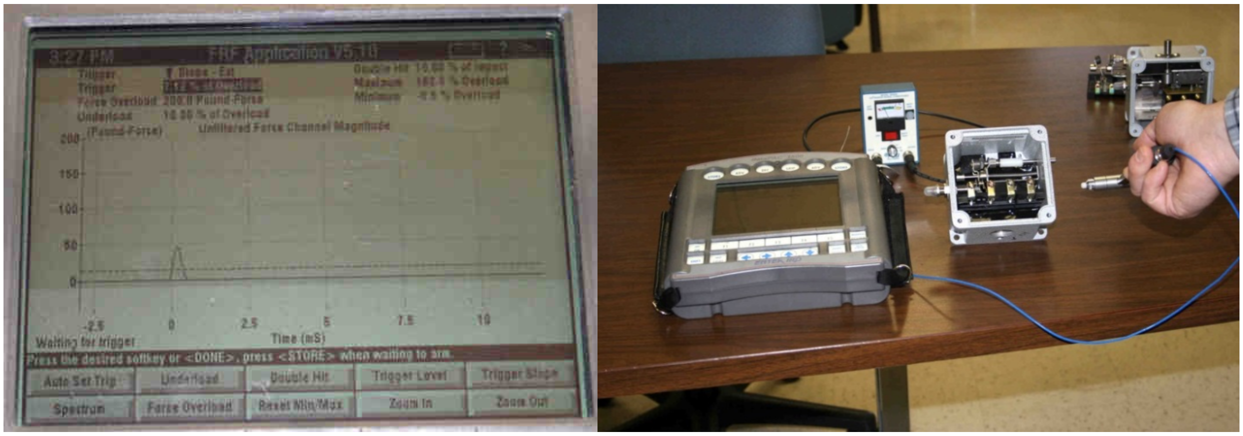

Figure 8: Impact test for mechanical vibration switches

The mechanical vibration switch was set to a somewhat arbitrary trip level but fairly low. The switch mechanism was armed and then the housing was impacted using an IMI calibrated Modally Tuned® Impact Hammer in four directions: +X, −X, Y, and Z. The force levels required to trip the switch were recorded for each direction. This test was run for both the traditional mechanical vibration switch and the new linear adjust mechanical vibration switch. The results are shown in Table 1. It is clear that in the X direction, it takes about half the shock or impact to trip the switch depending on the direction of the impact plus or minus. Also, it takes about 3 times the shock or vibration to trip the traditional switch in the Y or Z axes. The directionality of the linear adjust switch seems to be much better.

	Force Required to Trip Switch (pounds)			
Switch	+ X	- X	Y	Z
Traditional	50	25	160	160
Linear Adjust	60	30	75	85

Table 1: Force required to trip the switches in three axes

The sensitivity in the axis perpendicular to the surface of the magnet and plate, X direction, is much more sensitive than the other two axes, particularly in the case of the traditional mechanical vibration switch because the inertial force due to shock and vibration is acting on both the inertial mass and the magnet in that direction. Since the inertia of the magnet from a shock in the -X direction helps to “open” the switch and one in the +X direction to close it, the vibration required to trip the switch is less in the -X than in the +X direction. This means that if there is some impacting due to excessive vibration, such as in a severe fan unbalance condition, the direction in which the impacting occurs will have a direct effect on the trip level. This is not a desirable outcome.

The major disadvantages to a mechanical vibration switch are there is no accuracy in setting a trip level, it has different sensitivities in the various directions, it is not very repeatable, it will not trip due to a pure unbalance condition without secondary effects, and environmental sealing can be an issue due to the mechanical adjustment screw. Poor or no sealing compounds the problem due to moisture ingress causing corrosion and a change in switch sensitivity, often making it less sensitive to shock and vibration.

CTI Standard - 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.

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

Table 2: Acceleration and velocity levels corresponding to unacceptable balance conditions in the CTI Standard on cooling towers

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 modern piezoelectric accelerometers (PE) and thus an electronic switch that uses a PE accelerometer will catch a balance condition in most cases.

Note: When using an electronic switch or piezoelectric accelerometer to measure vibration, be sure to look at the low frequency response specification to make sure it meets your requirements.

Electronic Vibration Switches

Electronic vibration switches, Figure 9, are much more accurate and repeatable than mechanical vibration switches. 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. 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.

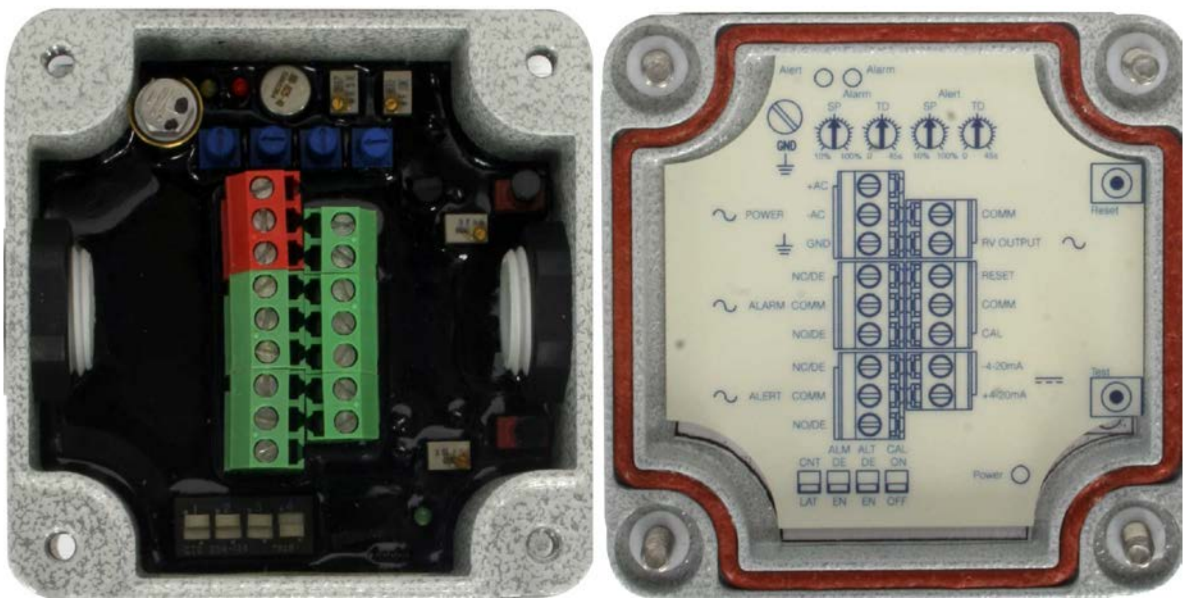

Figure 9: Traditional electronic vibration switch with potentiometer and DIP switch adjustments

CTI Vibration Standard – The table below shows “Broadband Vibration Limits” or overall vibration amplitudes from the proposed CTI *Standard for Vibration Limits in Water Cooling Towers* for field erected wood, fiberglass framed, factory assembled steel and fiberglass cooling towers. The shutdown limit for these types of towers is specified at 0.7 ips (17.8 mm/s) peak velocity. Note: 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. A word of caution, be sure to look at the frequency response of the electronic switch, most are accurate down to 2 to 3 Hz (120 to 180 RPM). Below those frequencies, the sensitivity of the switch drops off.

Table 1 - Broadband Vibration Limits from proposed *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

Table 3: Broadband vibration limits for cooling towers from Table 1 of the proposed CTI Vibration Standard

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

Dual Alarms - When a vibration switch shuts down a machine, it will more than likely come at an inopportune time. By having two alarm levels and associated relays, a warning level can be specified that will trip a relay and provide an indication in the form of a light, audible sound, or annunciator that will warn the user that the machine is getting close to a shutdown level allowing them time to react prior to an unexpected shutdown.

Time Delays - Time delays are a big advantage of electronic vibration switches. There can be one or more delay types in electronic vibration switches with the most common being start up and alarm delays. The startup delay allows a fixed or programmable (depending on the switch) amount of time where the vibration level is ignored to allow the machine to startup where it may have higher vibration prior to steady state operation. The alarm delay will require that the vibration level be above the alarm level for a certain amount of time prior to tripping. This would avoid a shut down for some random transient event like bumping into the machine. Additionally, some electronic vibration switches allow a maximum vibration level to be set during the startup delay, higher than the normal running level, but still protecting the unit should the levels get excessively high.

Latching and Non-latching – Mechanical vibration switches, by default, are latching, meaning once they trip they stay tripped until reset by someone. An electronic vibration switch can operate this way as well but can also be set to non-latching. This means that after a relay is tripped, it will automatically reset itself when the vibration level drops below the alarm level.

Raw Vibration Output – This provides the broadband analog time waveform directly from the embedded piezoelectric accelerometer for diagnostic purposes. A vibration data collector or other analysis device can be connected to the output for analysis.

4-20 mA Output – While the switch is providing protection, a 4-20 mA signal proportional to the overall vibration level can be sent to a PLC or other plant monitoring device in a control room for vibration monitoring purposes.

Accuracy – As can be seen in Figure 9, alarm levels and time delays in traditional electronic vibration switches are often set using potentiometers and thus have some degree of uncertainty, ≥10%. As will be shown with the newer programmable electronic vibration switches, setting are done via USB programming and are quite accurate.

Programmable Electronic Vibration Switches

Programmable electronic vibration switches generally have a little 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 4 shows a hermetically sealed IMI Model 686B USB Programmable Smart Vibration Switch mounted on a motor. Figure 10 shows its programming screen and the large number of options there are for tailoring the alarm levels and delays.

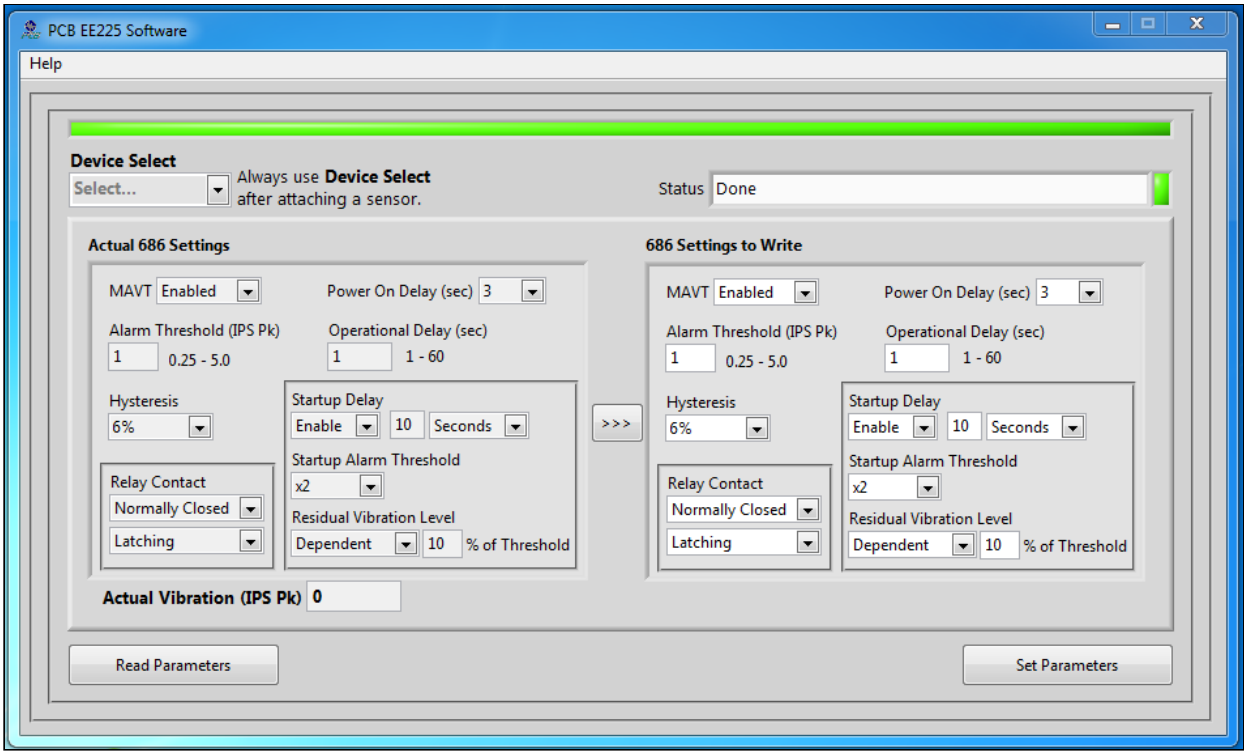

Figure 10: Programming screen for USB programmable electronic vibration switch

Conclusion – Any vibration switch offers protection against damaging vibrations if set and used properly. Electronic vibration switches are more accurate, can directly protect against a pure unbalance condition, and many can meet the CTI Standard 163 for Vibration Limits in Water Cooling Towers. Traditional electronic vibration switches currently have more options than programmable units but also cost more. The new IMI Model 685A09 Linear Adjust Mechanical Vibration Switch provides better sensitivity adjustment and improved 3–axis protection than traditional mechanical vibration switches. It is up to the user to determine what vibration switch is best for their application.

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