Getting Started with Vibration Energy Harvesting

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Abstract: This paper will explain the fundamentals of Vibration Energy Harvesting as a perpetual power source for Wireless Sensor Networks used for industrial machinery asset monitoring applications.

Vibration Energy Harvesting

Simply stated, vibration energy harvesting is the process by which otherwise wasted vibration (from a piece of industrial machinery for example) is harvested and converted to useful electrical energy to perpetually power Wireless Sensor Nodes (WSN). One of the most prevailing applications for WSN's is to monitor the health and status of essential industrial machinery assets within light & heavy industrial manufacturing environments. The value of industrial WSN's is the ease and economical deployment of monitoring and measurement points in plant areas that would not be economically viable to access via traditional hard wired monitoring solutions. These assets exist in plant, near plant and in remote locations.

Today's technology is offering the OEM and end-user world more sophisticated and viable power options for WSN's. Until recently, the only power source available to power a WSN has been batteries. With their limited and non-deterministic life span, hazardous content, shipping and disposal requirements – batteries alone will not provide a power source that will last the life cycle of the WSN application without maintenance intervention. With the addition of a Vibration Energy Harvester, there will be sufficient maintenance free power beyond the life cycle of the WSN application.

Construction & internal operation of an electro-magnetic VEH

In an electromagnetic-energy harvester a coil attached to an oscillating mass traverses a magnetic field that is established by a stationary magnet. The coil travels through a varying amount of magnetic flux, inducing an AC voltage according to Faraday's law.

Perpetuum realized the other more advantageous way is to move the magnetic structure (which is inherently massive) and keep the coil fixed. Hence increasing the power output and making the electrical connections more reliable. The resulting voltage is regulated to convenient storage or usage levels.

Vibration Source

Not all vibration is equal in the world of energy harvesting. The fact that a structure or object vibrates (even at excessive levels) does not automatically make it a viable candidate as a suitable vibration source to harvest from. The source vibration must have certain characteristics for it to be usable.

The following guidelines will shed some light on how to determine if you have a suitable vibration source for optimal use:

- **Resonant Frequency** - The source vibration object should have a known and repeatable frequency component within a range. This provides the optimal tuning frequency for the vibration harvester to work at its maximum potential.

- **Vibration Level** - The RMS g level of vibration will be the next consideration. Once the Vibration Energy Harvester is frequency tuned for maximum mass/spring displacement, the RMS g level of the source vibration object will determine the power output of the VEH. The usefulness of a VEH in industrial environments will be its ability to produce sufficient power at low levels of vibration. Higher levels of vibration generate greater power output from the VEH.

Resonant Frequency: Tuning the Vibration Energy Harvester

All vibration energy harvesters (VEH) are in essence a mass/spring tuned resonator. Their effective operation is based upon the ability of the VEH to harvest from a vibration source within a repeatable and consistent frequency range and known sufficient vibration level. The vibration source frequency is used to tune the VEH to a resonant frequency (the frequency that will produce the maximum amount of displacement of the mass/spring structure enabling maximum power output of a VEH based upon source vibration level. In other words, they are factory tuned to a pre-defined **resonant frequency** range to match the vibration source of the application and maximize the power output of the VEH. Resonant Frequency –

In the industrial world, line powered machinery are excellent vibration sources to harvest from. They will have a repeatable frequency component of 60Hz (line power frequency) or 120Hz (2X line power frequency). In non-U.S. countries the frequencies are 50Hz & 100Hz. This allows the end-user to select the optimized VEH frequency to ensure maximized power output of the VEH in the target application. This is referred to as the “Center Frequency”. The operational design of a VEH should have sufficient bandwidth to accommodate actual frequencies that deviate by the slip percentage of an AC induction motor.

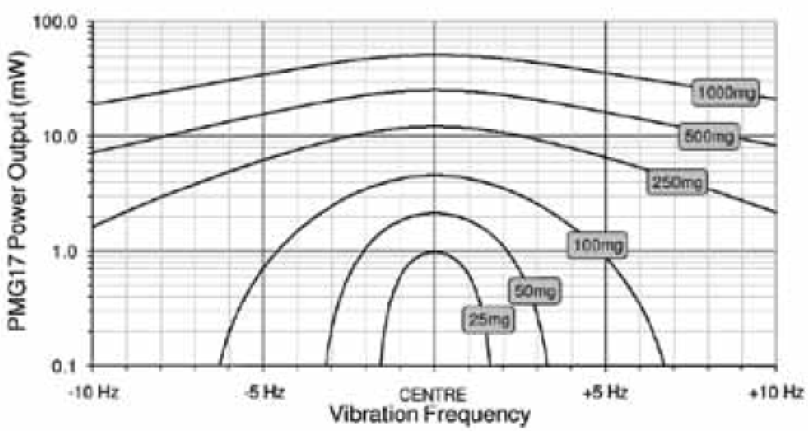
Vibration Level: Achieving maximum power output

Once the source frequency is determined (enabling the selection of a maximized VEH), the next step is to determine the level of vibration the source can/will supply. Typical balance of plant machinery will vibrate at levels below 1g. A key design requirement is to be able to produce sufficient power output from very low levels of vibration (i.e. down to 25mg/RMS on a smooth running machine) and to do it over the necessary bandwidth.

Bandwidth: Window of maximized operation

The next consideration is one of bandwidth. As seen in Fig. 1. At center frequency (i.e. factory tuned resonant frequency), the harvester achieves maximum power output (~50mW) at 1g RMS source vibration with a bandwidth of greater than +/- 10Hz. At center frequency with 25mg RMS source vibration, the power output is ~1mW with a +/- 1.0Hz bandwidth. To summarize – at low levels of vibration the power output and bandwidth will be reduced. Conversely, at higher levels of vibration (1g) the power output is maximized and the bandwidth is much greater. Frequency shifts off the center frequency at low levels of vibration will cause a decrease in power output within a small bandwidth window.

Figure 1. Power Output Spectrum



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Summary

Technology enabling maintenance free perpetual power solutions for wireless sensing & monitoring applications is now a reality.

By following the basic steps below, the Perpetuum Vibration Energy Harvester will provide perpetual power to a Wireless Sensor Node which will extend the operational life span of batteries at least 5X beyond the stated "battery only" life span.

1. Understanding of the basic operating principles of a Vibration Energy Harvester (VEH).

2. Identification of appropriate vibration source to harvest from (i.e. motor) with sufficient power for proper Wireless Sensor Node operation.

    a. The Wireless Sensor Node manufacturer will provide the average current requirement for proper operation of the WSN. (for example: 0.5mA)

    b. During site survey / installation; attach the FSH to the vibration source and read its output via a multimeter.

    c. Once a location with acceptable power is determined – attach the FSH for life-cycle independent power operation.

3. Install the Wireless Sensor Node and sensors per application requirement.

4. Connect the Wireless Sensor Node to the Perpetuum FSH.

5. Initiate the process of a proactive autonomous predictive maintenance operation.

APPENDIX 1:

Guidelines for locating suitable vibration points on industrial motors:

A **horizontally** mounted motor will experience the most amount of vibration deflection in the horizontal (side to side) Z-Axis (Green Line). The motor will be more rigid in the front to back X-Axis (Red Line) or the up and down Y-Axis (Yellow Line) directions.
Use the same theory to identify the locations for **vertically** (other) mounted motors.

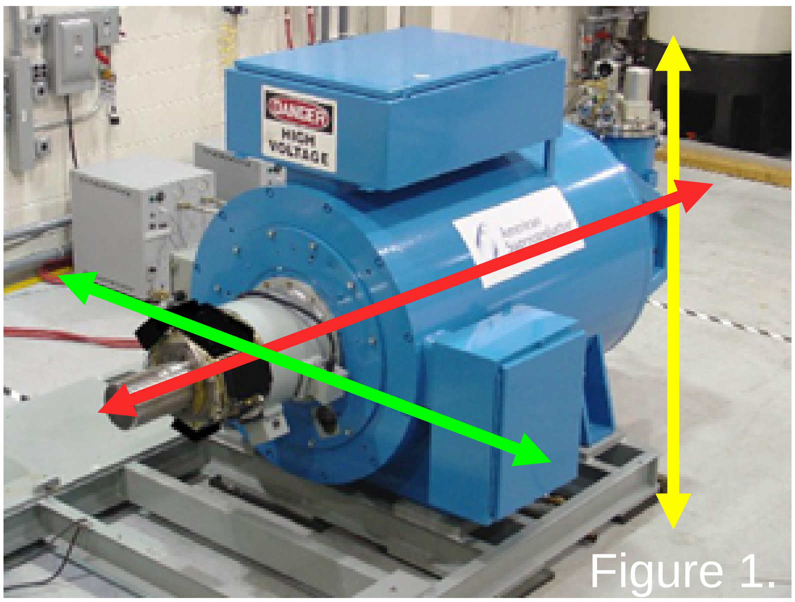

Figure 1. Depicts the direction axis of vibration on an industrial motor.

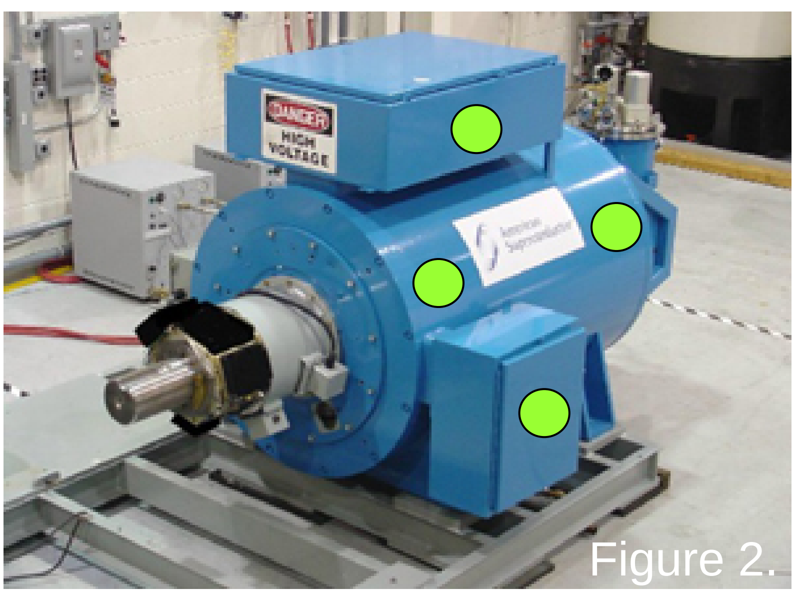

Figure 2. suggests the primary spots on the left lateral side of the motor to attach the vibration energy harvester and measure its output current. These locations would be the same or similar on the right side of the motor

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There are a many types, sizes, shapes and mounting orientations of industrial motor machinery assets. The following are general guidelines and should provide an indication of the likely locations that will produce optimized vibration for harvesting power.

1. Determine the average current requirement for the proper/desired operation of the Wireless Sensor Node. (Ask your WSN node provider - i.e. 0.5mA)
2. Identify the machine asset to be monitored or used as the vibration source for the Vibration Energy Harvester (VEH).
3. Mount the VEH at the suggested locations on the motor using the supplied magnetic mounting hardware.
4. Read the current output of the FSH with a multimeter (using the supplied cable). If the current reads (in this example) 0.5mA or greater the FSH will harvest enough power at that location to power the WSN for the life of the application.


5. If the current output is less than required (in this case, less than 0.5mA) – move to the next location and repeat step 4 until a proper location is determined.
6. Attach the VEH. Several mounting options are available.
7. Locate the optimized location for the Wireless Sensor Node.
8. Attach the FSH to the WSN (using the supplied cable)
9. Enable the WSN & start monitoring.