UNIT ALIGNMENT: OPTIMIZE THE USE OF YOUR ELECTRONIC LEVEL

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ABSTRACT

For the maintenance of hydrogenerators as well as for new unit assembly, the use of proper tools and techniques can help significantly to obtain accurate measurements, make the right corrections for the unit alignment, and reduce the outage time.

This paper explains and shows how to use an electronic level for various applications related to hydrogenerator works. The main and most attractive use of the electronic level in a power plant is to accurately measure the shaft system verticality, eliminating the need for the four wires technique. There are various other uses for the electronic level in a power plant, like leveling brackets, setting-up for machining, verifying seating flange flatness and even checking wicket gate bore alignment, with a simple device designed by the author.

Every application explained in this paper is supported with a calculation example. Once the principle is understood, calculations are fairly simple, and accuracy is excellent.

1. INTRODUCTION

Having used an electronic level for more than 6 years, many new and old hydrogenerator units have been aligned, with an accurate measurement of their verticality. Over the years, many particular applications have involved using the electronic level as shown in this paper, but there is one application that was repeated time after time, and is still not very well documented. This application consists of mounting an electronic level on the shaft of a vertical unit and making manual rotations, with stops at 90 degrees intervals to obtain easily and quickly the verticality of the axis of rotation of the unit. This method is referred to as the standard method thereafter and is surrounded by additional explanations in an attempt to answer the most frequently asked questions.

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2. THE ELECTRONIC LEVEL INSTRUMENT

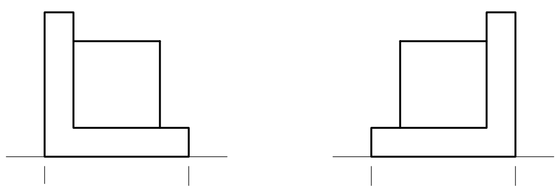
For the selection of the electronic level, we need to consider that the tightest tolerance for verticality or level ever used in a hydrogenerator plant is 0.02 mm/m or 0.00025 in/ft.
There are a few models of electronic levels from different manufacturers that have the following sensibility values: 0.2 arcsec (0.001 mm/m), 0.5 arcsec (0.00003 in/ft) and 1 arcsec (0.005 mm/m). These sensibility values represent respectively 5%, 12% and 25% of the tightest tolerance and therefore they should all be suitable, although the last one is borderline but acceptable.

In order to help with slope and verticality units, the last page of this paper contains conversion factors between each unit.

In the selection of a base, an angular prismatic base of 6" long and 6" high (150 mm x 150 mm) is suitable to take readings on the side of a shaft or on a flat surface. The vertical member can be made magnetic for easier mounting on the shaft. The horizontal member should not be magnetic to allow sliding on a flat surface.

2.1 Getting familiar with using a level

In order to understand the level instrument, we can look at two readings taken in one location, with the second reading (B) being the reversal measurement of the first reading (A).



Slope = (A – B) / 2

Offset = (A + B) / 2

Example:

- Reading A = +0.030 mm/m,
- Contour of the level is marked on the surface and the level is rotated 180 degrees to take reading B at the same position.
- Reading B = -0.020 mm/m
- Slope = (A – B) / 2 = (0.030 - (-0.020))/2 = +0.025 mm/m
- Offset = (A + B) / 2 = (0.030 + (-0.020))/2 = 0.005 mm/m

The important value in this example is the slope of the surface being 0.025 mm/m. Using the reversal measurement technique made it possible to measure accurately the slope of the surface even if the instrument had a small offset.
The offset of the instrument can be corrected. It is normally called zero setting. In the example above, readings A and B would have been +0.025 and -0.025 mm/m if the offset had been eliminated by zero setting the instrument.

All the examples in this paper use reversal measurements for level and flatness measurements. For the verticality measurements, we use readings taken on opposite sides and it is equivalent to reversal measurements. Therefore the offset of the instrument does not influence the level and verticality results.

2.2 Zero setting

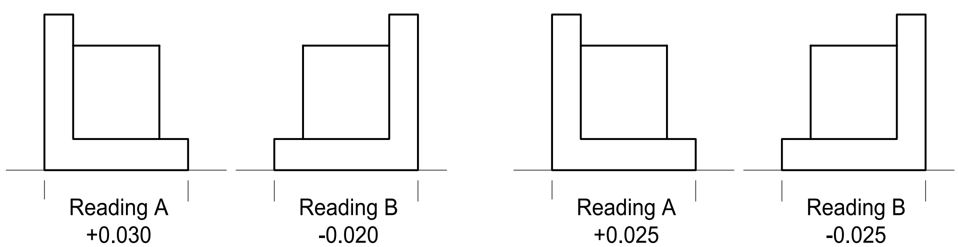
When using the techniques shown in this paper, it is not necessary to proceed with zero setting of the instrument every time that the electronic level is used, because it does not affect the results.

It is a good practice anyway to do the zero setting regularly. It is also recommended to do it every time the instrument has been shipped, or has been knocked, or has been stored for a long period. (Note: some levels require being stored in the upright position as per the manufacturer's instructions.)

Zero setting is to be done on the field when needed. Choose a good surface, flat and leveled. Review the instructions from the instrument manufacturer to make the adjustment. It should be relatively straightforward, using a knob or a pushbutton to adjust the zero point.

With the example above, one could do the zero setting by taking the readings A and B a few times to make sure that the values 0.030 and -0.020 mm/m are accurate. Then after doing the calculation for the slope (0.025 mm/m), set the level for the A reading and make a zero adjustment to change the reading from 0.030 to 0.025 mm/m. Then rotate the level and verify that the reading B is -0.025 mm/m. Repeat this process until the same value is obtained for both readings, with inverted signs.

Another equivalent method for setting the zero, is to adjust the reading A value to 0, then read the B value and divide by two, and adjust the B reading to the calculated value, and then retake the A reading to verify that the value is the same but with inverted sign. Then small adjustments can be done until the value is the same for both readings.



Before Zero setting
Slope = +0.025, Offset = 0.005

After Zero setting
Slope = +0.025, Offset = 0.000

2.3 Choice of range and sensibility

Electronic levels usually offer two ranges. Higher sensibility and accuracy is obtained when selecting the narrow range or fine range. The choice of the range depends on the application. As a rule of thumb, we try to use the narrow range for a better accuracy, especially when we measure the shaft verticality or the level of the thrust bearing bracket level for which the tolerance is small.

A problem occurring from times to times is to have a fluctuating reading on the electronic level because of high surrounding vibrations, normally caused by adjacent units in operation. When the fluctuation is not too large, we can look at the readout values and select a reading representing the average. When the fluctuation is more important, the wider range can be used if the sensibility corresponding to this range is still high enough for the application.

For example, if a level with a sensibility of 0.2 arcsec is being used, and we consider using instead the wide range with a sensibility of 2 arcsec. The largest reading error can be estimated at half of the smallest reading, 1 arcsec in that case. If this reading error happens on one or more readings, the largest error on the verticality calculation would be 1 arcsec. If we are working with a small tolerance of ¼ mil/ft or 0.00025 in/ft, this is equivalent to 4.3 arcsec. Therefore in this case it is quite acceptable to switch to the wide range, if it helps to take the readings.

In some instances it may be necessary to wait until the adjacent hydrogenerators creating vibrations operate at a different load or are stopped. This is rarely necessary but it can happen. There is also a possibility of connecting a cable to the electronic level and averaging the output signal. It works well but was never really required in many years of using the electronic level.

3. VERTICALITY MEASUREMENTS

There are a few different ways of measuring the verticality of a shaft with an electronic level. The most intuitive method is to simply take the level and apply it against the shaft at different positions around to shaft and calculate the shaft verticality. This method can be useful sometimes and is described below as the shaft verticality by the static method.

But the most accurate and preferred method is to install an electronic level on the shaft and to make manual rotations with stops to records the electronic level readings. This method is called below the standard method and provides readings to calculate precisely the verticality of the axis of rotation.

When using an electronic level, the four wires technique is normally abandoned for shaft alignment. The method with the electronic level gives the verticality of the axis of rotation very precisely and quickly but it does not give information about the runout of the shafts and the shaft line straightness like it was possible to get from the plumb wire technique. This information is rather obtained from micrometer readings or dial indicator readings. Once the runout of the shaft at different elevations is known, the shaft line straightness can be calculated if necessary.

3.1 Standard Method – Verticality of the axis of rotation

This method consists of mounting an electronic level on the shaft of a vertical unit and making manual rotations, with stops at 90 degrees intervals to obtain the verticality of the axis of rotation of the unit. It really makes no difference if the level is set on the generator shaft or the turbine shaft. We normally set it where it is the most convenient to read.

The electronic level can be equipped with a prismatic angular base which makes it easy to mount on a shaft. It is maintained against the shaft with a nylon strap equipped with a ratchet type puller for tightening the strap in order to make a firm set-up. If the angular base is not magnetic, a square magnetic base normally used for dial indicators is installed right under the electronic level to prevent it from sliding. There could be different set-ups but this one is very simple and works well.

The steps to measure the verticality of the axis of rotation are:

- Bring the unit at zero degree.
  - Normal convention is to have rotor pole no. 1 aligned with upstream but that may vary from one site to another.
- Prepare the unit for manual rotations.
  - Usually four bearing segments of the generator guide bearing nearest to the thrust bearing are adjusted to hold the shaft, and the position of the shaft should be chosen so that the turbine runner is fairly centered to ensure that the runner will remain free during the rotations.
  - Other guide bearings and shaft seals are not in place during the rotation.

- Install the electronic level on the shaft, aligned with the upstream position, and read it. Record the value and the sign.
- Make a full rotation, by intervals of 90 degrees, and read the level at each position.
  - If an oil injection system is used for the manual rotations, stop that system every time before taking a reading on the electronic level.
- Verify that the level reading after a full rotation (360 deg.) is practically equal to the initial value at 0 degree.
- IMPORTANT: Verify that the sum of the opposite values in the Y axis is practically equal to the sums of the opposite values in the X axis.
  - A small difference of the order of 2 arcsec, or 0.01 mm/m, or 0.01 mil/in is acceptable. A larger difference should be looked at. It may indicate a reading error or the absence of freedom of the shaft or runner during the rotations, or any other factor that can affect the precision of an alignment, like temperature changes etc. This difference can also be the result of a lack of precision for the 90 degrees intervals. Repeat the readings if necessary.
- Calculate the verticality of the axis of rotation. It is obtained by taking the reading value in one axis less the value on the opposite side and dividing the result by two.
  - $\text{Vert. Y} = \dfrac{(\text{rdg at } 0 - \text{rdg at } 180)}{2}$ $\quad$ $\text{Vert. X} = \dfrac{(\text{rdg at } 90 - \text{rdg at } 270)}{2}$
  - Preferably always use the same sign convention for verticality readings. That sign convention may depend on the level that is being used. For some electronic levels, the value becomes positive and larger when the bottom of the shaft is pulled in the direction of the level. Therefore when using this level and the above

formulas, a positive result of the verticality in the Y axis means that the bottom of the shaft is leaning towards the positive Y axis (0 degree) and a positive verticality in the X axis means that the bottom of the shaft in leaning towards the positive X axis (90 degrees).

Example:

Position (deg)	Readings (mm/m)
0	0.072
90	0.090
180	0.095
270	0.075
360	0.070

The first verification is that the value at 360 degrees is very close to the value at 0 degree. Then we compare the sums in the Y and X axis.

Sum Y (0-180°) = 0.167
Sum X (90-270°) = 0.165 o.k.

Then the verticality is calculated:
Vert Y = (0.072 - 0.095)/2 = -0.012
Vert X = (0.090 - 0.075)/2 = +0.008

Axis	Verticality (mm/m)	Direction
Y (0-180°)	-0.012	Downstream
X (90-270°)	0.008	3 o'clock
Resultant	0.014	146 deg. (CW)

The resultant verticality is obtained by finding the hypotenuse of the two vectors:

Resultant = $[(-0.012)^2 + 0.008^2]^{0.5}$ = 0.014
Angle = 180 -arctan (0.008 /0.012) = 146

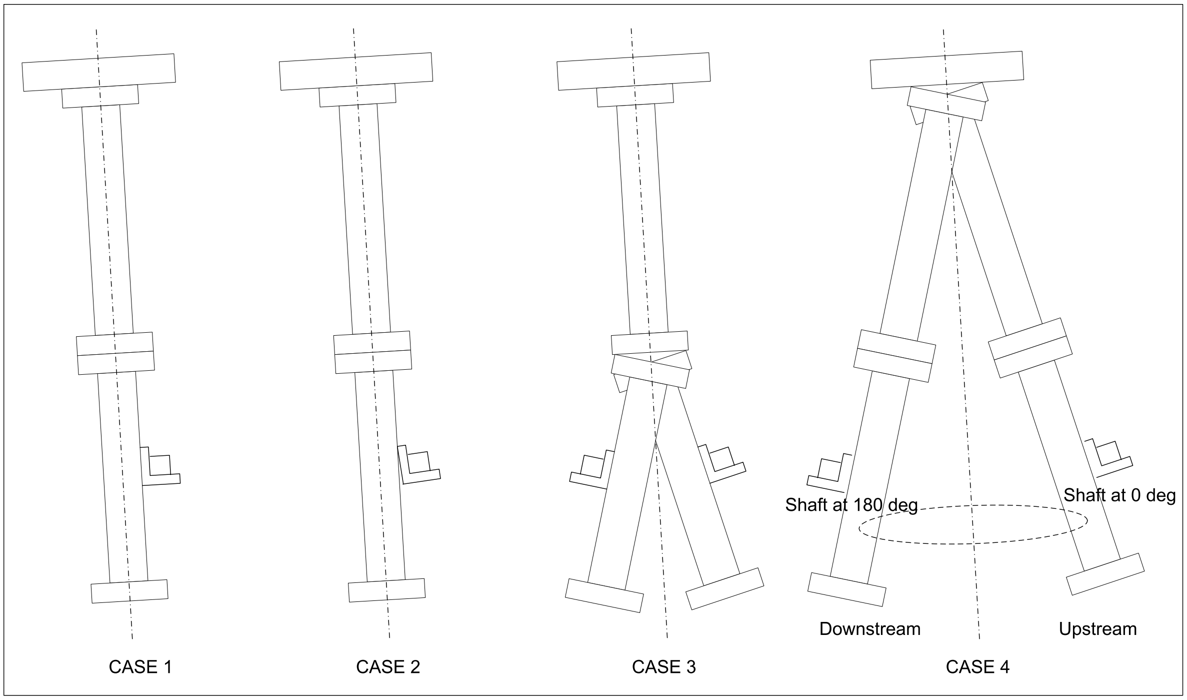
Additional explanations

By using this method, we do not obtain the shaft verticality in any position, but we rather obtain the verticality of the axis of rotation. This is all we really need for the adjustment of the unit verticality. The axis of rotation is the same for the generator and turbine shafts and measurements of the verticality is needed only on one of them.

To better understand the details of these verticality readings and calculations, let us review a few hypothetical cases, as seen on the picture on the next page. For each of the four cases shown on this picture, a reading is taken on the level when the unit is positioned at 0 deg, and then at intervals of 90 degrees when the unit is rotated manually.

Case no. 1 represents a perfect shaft and a perfect thrust bearing, but with a slight inclination of the thrust bearing bracket so that the runner is leaning towards upstream, with a shaft inclination of 0.030 mm/m. Before doing any rotation, an electronic level is perfectly mounted on the turbine shaft at the upstream position (0 degree). The first value read on the electronic level is 0.030 because of the inclination in the upstream-downstream axis, assuming also that the zero setting of the level was done perfectly. Then the other readings are 0.000 mm/m, -0.030 mm/m and 0.000 mm/m as shown in the table. The inclination is clearly of 0.003 in one axis and is null in the other axis.

All cases are explained briefly below the table.



Unit Position	Case 1	Case 2	Case 3	Case 4
Upstream (0°)	0.030	0.040	0.050	0.050
3 o'clock (90°)	0.000	0.010	0.020	0.020
Downstream (180°)	-0.030	-0.020	-0.010	-0.010
9 o'clock (270°)	0.000	0.010	0.020	0.020
Sum Y axis	0.000	0.020	0.040	0.040
Sum X axis	0.000	0.020	0.040	0.040
Vert. Y	0.030	0.030	0.030	0.030
Vert. X	0.000	0.000	0.000	0.000

Verticality in Y axis = (readings upstream – downstream)/2
Verticality in X axis = (readings 3 o'clock – 9 o'clock)/2

Case no. 1: perfect shaft, perfect electronic level set-up on shaft, perfect zero-setting of the instrument, shaft and rotation axis inclination of 0.030 mm/m in the Y axis.
Case no. 2: same as case 1 except that the set-up of the level instrument on the shaft or the zero-setting of the instrument is not perfect and a reading error of 0.010 mm/m is added to all readings.
Case no. 3: same as case 1 except that a defect is simulated at the coupling of the two shafts, creating a runout and making a change to all readings by 0.020 mm/m.
Case no. 4: same as case 1 except that a defect is simulated at the coupling of the generator shaft and the thrust block, creating a runout and making a change to all readings by 0.020 mm/m.

Observations and analysis from the above cases:

- For each case, the sums in X and Y axes are equal, independently of the alignment or set-up defect.
- The calculation from the electronic level readings gives a correct value for the verticality of the rotation axis, independently of the alignment and shaft defects.
- The set-up error of the level and the zero setting of the instrument have no impact on the verticality result. Therefore a perfectly square support is not required.
- By comparing cases no. 3 and 4, it is clear that the electronic level readings do not give information about the shaft runout or the shaft line. This should be obtained from micrometer or dial indicator readings.

The verification that the sums of opposite values in both axes are equal is a good way to validate that the readings are accurate. It confirms at the same time that the shaft and turbine runner were free in all four positions during the rotations. During the manual rotations, any point on the shaft or any of the rotating component travel on a circle centered on the rotation axis. It may happen that the rotation axis has a small lateral movement or translation during the rotations, but the verticality readings are not affected by this, as long as the shaft and runner remain free during the rotations.

This method is the most accurate because the set-up of the instrument on the shaft has no influence on the verticality calculation. As long as the set-up of the instrument remains the same for all the measurements, any error or variation coming from the set-up of the instrument is eliminated in the calculation.

With this method, there is no need to take readings in more than four locations. This is enough to obtain the verticality in the two planes and the resultant verticality and its angle can be calculated accurately.

3.2 Method with 2 levels

This method is interesting because it eliminates the need to stop at every 90 degrees position during the manual rotations. Two levels are mounted 90 degrees apart on the shaft, preferably at upstream and 3 o'clock positions, and the unit is rotated by 180 degrees and the verticality in both axes can be calculated by taking the difference of the readings in opposite positions and divide the result by two.

Other measurements can be taken on the unit at that time, like runner clearances and micrometer readings from the shaft to the bearing housings in order to find out the runout and concentricity of the unit. Then the unit can be rotated by another half turn (to 360 degrees) to bring it back to its original position. This allows recalculating the verticality in both axes and the result should be the same as found for the first half rotation.

Again for this method, the set-up error and zero setting error of the instruments have no effect on the verticality result. A small inconvenience of that method is that we cannot use the sums of the opposite readings in both axes to validate the accuracy of the readings because these sums can be different, since it is measured with a different level. This is the reason why it is recommended to repeat the readings by bringing the unit back to its original position, and it is important to make sure that the shaft and runner are free when taking the level readings in order to obtain an accurate verticality of the axis of rotation.

Occasionally, we may be interested in getting the verticality of the axis of rotation when all the guide bearings are installed, but normally we measure the verticality of a unit when only one guide bearing is maintaining the unit centered and the other bearings and shaft seals are removed to leave the shaft free.

Example with two levels:

Readings		
Shaft position	0 deg level (mil/ft)	90 deg. level (mil/ft)
0	1.84	2.46
180	1.53	3.76
180	1.39	3.83
360	1.74	2.46

Verticality calculations	Y (mil/ft)	X (mil/ft)
from 0 to 180 deg	0.16	-0.65
from 180 to 360 deg	0.17	-0.68
Average	0.17	-0.67
Resultant verticality:	0.69 mil/ft at 284°	

In that example, the unit was stopped at 180 degrees for a long time. Therefore the level readings at 180 degrees had to be retaken prior to do the second rotation from 180 to 360 degrees. The reading on the level at 0 degree had changed and the level may have been touched but it did not affect the verticality calculation. The results from both rotations can be considered as totally independent measurements.

Verticality in Y axis = (1.84-1.53)/2 = 0.16
Vert. X = (2.46-3.76)/2 = -0.65 mil/ft

For the second rotation,
Vert. Y = (1.74-1.39)/2 = 0.17
Vert. X = (2.46-3.83)/2 = -0.67 mil/ft

Verification of two electronic levels

Whenever we have two electronic levels, we can verify that they give identical results. The following test is equivalent to a field calibration by comparison and can be done rather easily.

The two levels are mounted on a flat surface of a lathe table and their readings are recorded. Then the machine table can be moved laterally by a few feet or one meter, without having to touch the levels. Normally the levels will indicate a small change of inclination of the machine table, and we can verify that the change on both levels is the same.

Example :

Readings with table to the right end

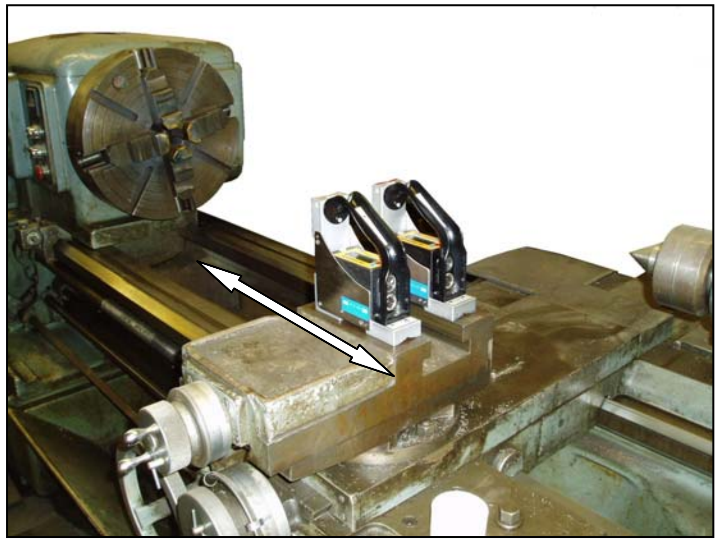
Level 1: 0.336 mm/m
Level 2: 0.246 mm/m

Readings with table to left end

Level 1: 0.232 mm/m
Level 2: 0.142 mm/m

Differences between right and left positions:

Level 1: 0.104 mm/m
Level 2: 0.104 mm/m



These two levels give identical results regarding the change of inclination of a common piece being moved and therefore they can be considered as accurate. The zero setting of each level can be rechecked and adjusted individually if desired, without affecting their accuracy.

3.3 Shaft verticality by static method

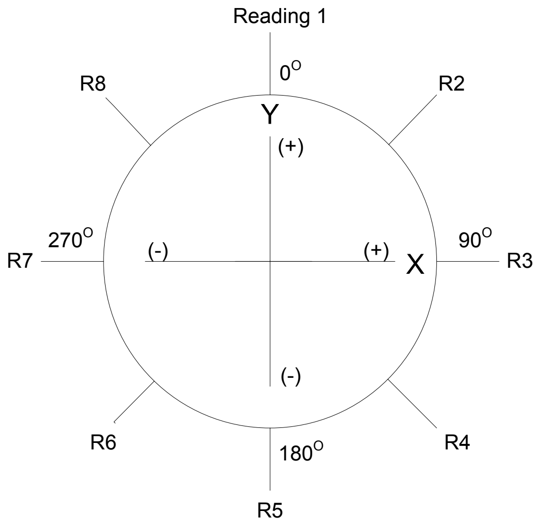
This method consists of taking a series of eight readings equally spaced on the circumference of the shaft without any rotation of the shaft. Four readings in theory would be sufficient but eight readings are recommended to compensate for the possibility of reading errors. The set-up on the shaft can make a significant variation on the readings. It is needed to set the level vertical and mark the contour of the level so that the reading can be rechecked.

Unlike the other method with the instrument being rotated with the shaft, this method is influenced by the way the instrument is set against the shaft for taking the reading. In order to be able to verify or repeat these readings, the position of the level for each reading should be marked precisely on the shaft, using a felt to trace the contour of the instrument. The use of a level equipped with a magnetic base makes it easier to take repeatable readings.

Zero setting of the instrument is not important for this method either, as long as it remains unchanged for all the readings. After a series of 8 readings, it is a good practice to recheck the first reading to make sure that nothing has changed.

This method is used for some particular cases, when unit rotation is not practical, or for example to get a reading of the shaft verticality prior to do any rotational checks. In one particular case, it was successfully used to measure the verticality of a generator shaft and a turbine shaft prior to uncoupling the two shafts and just after re-coupling of the two shafts. The results of these measurements showed that the alignment condition of this newly aligned machine had been restored to its original condition, eliminating the need to repeat rotational checks.

Example: 8 readings taken on a shaft.



Reading No.	Angle (deg)	Readings (mm/m)
1	0°	0.119
2	45°	0.153
3	90°	0.150
4	135°	0.140
5	180°	0.086
6	225°	0.086
7	270°	0.065
8	315°	0.089
	Verticality Y:	0.011 mm/m
	Verticality X:	0.042 mm/m
	Resultant:	0.044 at 75°

Here are the formulas to calculate the verticality when using 8 readings, where the constant 0.707 is equivalent to sine 45°. These formulas are entered in two cells of a spreadsheet to obtain the results directly.

Y = (R1 + 0.707*R2 - 0.707*R4 - R5 - 0.707*R6 + 0.707*R8) / 4
X = (0.707*R2 + R3 + 0.707*R4 - 0.707*R6 - R7 - 0.707*R8) / 4

The same results would be obtained if we would calculate first the verticality from the 4 readings in the main axes, using the difference of the readings divided by two as shown earlier, and calculate the verticality from the 4 readings at 45 degrees (R2, R4, R6 and R8), convert the result in the X and Y axes, and then make the average of these two calculations to obtain the verticality in the X and Y axes based on 8 readings.

It is interesting to note that these formulas give the same results as if we would have used the best center formulas given in a document titled “Hydroelectric Turbine-Generator Units – Guide for Erection Tolerances and Shaft System Alignment” published by the Canadian Electrical Association. These formulas can also be used for more than 8 readings.

3.4 Setting-up of a boring bar or a compass

The electronic level can be used to measure and adjust the verticality of a boring bar, used for machining of the bottom ring or the runner seals. It can also be used to set-up the verticality of a compass being used to measure the circularity of a rotor.

In the following example, a level is mounted on a boring bar used for machining of the stationary runner seals. In addition to be centered, the boring bar must be set vertical. As seen on the picture, the level is mounted on the center post of the boring machine and is maintained firmly with a nylon strap. It could also be mounted on one of the horizontal surfaces but the option of strapping it to the shaft is better because it offers a firm set-up unlikely to be disturbed during the rotations. Then, the boring machine is rotated manually and stopped at intervals of 90 degrees to record the following level values.

	Initial readings (arcsec)	Second readings (arcsec)	After first correction (arcsec)	After final correction (arcsec)
Upstream	41.8	44.0	4.6	5.0
3 o'clock	40.8	41.8	10.4	6.8
Downstream	-28.4	-28.4	8.4	7.4
9 o'clock	-25.2	-25.4	4.2	7.2
Sum Y axis	13.4	15.6	13.0	12.4
Sum X axis	15.6	16.4	14.6	14.0
Verticality Y	35.1	36.2	-1.9	-1.2
Verticality X	33.0	33.6	3.1	-0.2

From the initial readings, we first look at the sums in both axes. It varies by 2.2 arcsec which is not bad but an attempt to improve on that is done by marking more precisely the 90 degrees positions for the subsequent rotations of the bar. Then four new readings at 90 degrees intervals are taken in only 5 minutes, and the sums in both axes are within 1 arcsec this time.

The verticality in one axis is calculated by taking the value in one axis less the value on the opposite side and dividing the result by two:

Verticality in the Y axis = (44.0 - (-28.4)) / 2 = 36.2 arcsec = 2.10mil/ft (36.2x 0.058)
Verticality in the X axis = (41.8 - (-25.4)) / 2 = 33.6 arcsec = 1.96 mil/ft

Since the boring bar had already been centered at the elevation of the bottom bearing, the verticality of the bar is corrected by moving the top bearing. The distance between the two bearings is 10 feet; therefore a movement of the top bearing of 21 mils (0.021 in) and 19 mils is required in the direction of upstream and 3 o'clock.

After this correction, the verticality values in Y and X axes are calculated at -1.9 and 3.1 arcsec, requiring movement at the bearing of the order of 1 and 2 mils. After that final correction, the remaining verticality error is only 1.2 arcsec in the Y axis, which corresponds to 0.07 mil/ft or 0.006 mm/m.

For this example, the use of an electronic level provided an accurate verticality measurement and helped to make accurate corrections. The time to set-up this boring bar was reduced by at least two or three hours, and the installer and the customer had good data in hands to be confident about the set-up.

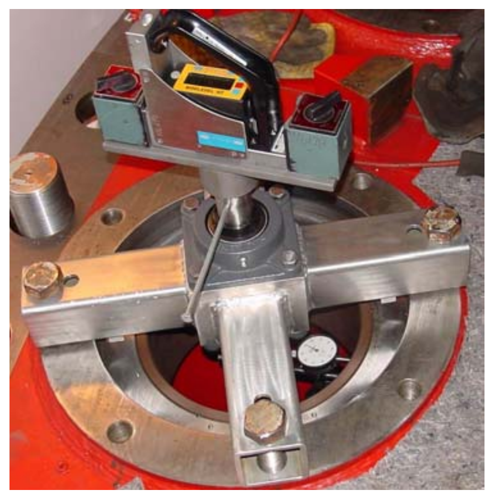
One valuable alternative to this example of setting the boring bar would have been to make no calculation for the movement of the upper bearing but instead using the level to monitor the movement and advise when to stop. Right from the first set of readings, we could have calculated that the average of the four readings is equal to approximately 7 arcsec. Then when making an adjustment in one axis, the level can be watched and the movement is stopped when the average value is reached. After adjusting both axes, four new readings are taken and the average is recalculated and a new correction is made if necessary.

3.5 Bore alignment device

On hydrogenerator plants, vertical bore alignment is required when the turbine head cover is aligned with respect to the bottom ring. The wicket gate bores need to be concentric. We also need to measure the bore alignment when line boring is done on the wicket gate bores.

The simplest method is to use a plumb wire and take four radial readings at each bore, but it is time consuming and is sometimes subject to reading errors. Another traditional method is to use a reference system like optics or laser and use reference targets mounted on different bores.

Using a bar equipped with dial indicators, and using an electronic level to accurately correct the verticality of the bar represents an innovative method to verify the bore alignment. It has been used successfully in a few occasions so far.



In the first picture, a bar is equipped with seven dial indicators, but not all visible, and was used to verify the alignment of the bores before and after the line boring operations. The results compared very well with those obtained with an optical system and centering targets, which were used by the machining contractor. The results were repeatable within 0.001 inch, and the time to take the readings was approximately twenty minutes for each gate location which was slightly better than the optical system, for a fraction of the cost.

The principle is simple. A vertical bar is supported on the head cover and dial indicators are mounted on this bar to indicate the surfaces of the wicket gate bushings or bore. The verticality of the axis of rotation of this bar is measured accurately and corrected using an electronic level mounted at the top end of the bar. Then dial indicator readings are recorded with the bar rotated at four positions, and the concentricity of the bores or bushings at each elevation are calculated from these readings.

In the second picture, this bore alignment device was used to align a head cover using the readings from four wicket gates located 90 degrees apart. At each wicket gate, the bar axis of rotation was set vertical and three dial indicators were used to obtain the concentricity of the wicket gate bushings. The rule for adjusting the verticality of the axis of rotation was that the difference on the readings from opposite sides should not exceed 0.03 mil/in. Therefore the verticality error being less than 0.015 mils/in, with a distance of 40 inches between the bushings, the maximum error on the concentricity calculations would be only 0.6 mils which is acceptable.

4. LEVEL MEASUREMENTS

Typically in the hydrogenerator plant, the components that need to be leveled precisely and for which the use of the electronic level is appropriate are the thrust bracket, the shaft coupling flange, the thrust block, and any shell bearing seating flange.

When reading on a flat horizontal surface, we have the option of taking a reverse reading for every reading. If the zero setting is accurate, every reverse reading should be approximately the same value as the first reading but with opposite sign. For each pair of readings, we take the normal reading less the reverse reading and divide by two to obtain the absolute slope of the surface. The use of reverse readings is an option to obtain higher accuracy but is not needed for every application.

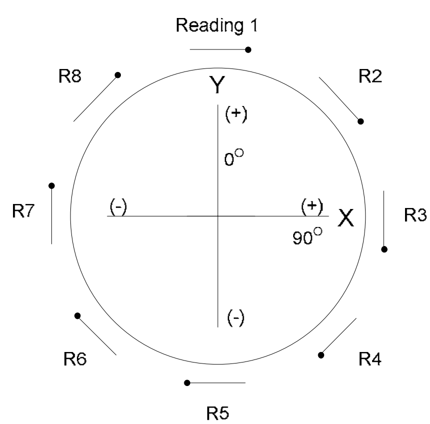
For level readings, the surface should be clean and stoning is sometimes required to remove irregularities on the surface. The level is put down on the surface and slid into position. Then the contour of the level should be marked in order to be able to recheck the reading or for optionally taking the reading with the level in the reverse position.

4.1 Method with level in radial axis

Four readings can often be sufficient to confirm the inclination of one component, but more accurate results can be obtained with 8 readings. The calculations with 8 readings can be done in the same way it was done in the example of section 3.3 for the shat verticality. It is important that the level instrument always have the same side towards the center of the component.

4.2 Method with level in tangential axis

Here is an example with 8 readings taken on a circle with the level in the tangential axis. Sometimes the machined surface is not wide enough to set the level in the radial axis but it can be used in the tangential axis. The level should be positioned the same way for all readings as indicated by the dot on the figure below.



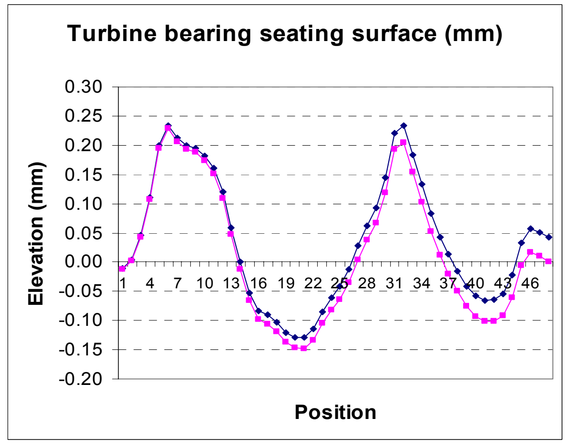
Reading No.	Reading (mm/m)
1	-0.020
2	0.014
3	0.040
4	0.042
5	0.020
6	-0.014
7	-0.040
8	-0.042
Verticality Y: 0.040 mm/m Verticality X: 0.020 mm/m Resultant: 0.044 at 27°	

It can be demonstrated that the following formulas apply for the case with 8 tangential readings.

$$Y = (0.707*R2 + R3 + 0.707*R4 - 0.707*R6 - R7 - 0.707*R8) / 4$$
$$X = (-R1 - 0.707*R2 + 0.707*R4 + R5 + 0.707*R6 - 0.707*R8) / 4$$

4.3 Checking the level and the flatness of a bearing seating flange

The readings are taken in the tangential axis of a circle, as shown above but with additional readings in order to evaluate the flatness of the component.



Flatness of the seating surface of any shell bearing is an important characteristic for the quality of the bearing installation. A flatness error or distortion of the seating surface can affect the durability of the bearing.

In that example taken on a large turbine bearing seating flange, 24 readings were taken, plus a reading in reverse position for each reading, to obtain 24 slope values. Then 24 other slope values were interpolated between the 24 measured values, to obtain 48 slope values to work with. Then a change of elevation for each point is calculated by taking the slope multiplied by the distance or arc length between each point. The elevation for each point is the elevation from the preceding point plus the change of elevation. The mismatch between the starting point and the 48th point was only 0.05 mm shown by the first trace on the graph (blue), and this error is cancelled by making a correction to each value by the amount of the cumulative error (0.05) divided by the number of points, as shown by the second trace in pink color. That bearing seating flange needed to be corrected by shimming or grinding. The electronic level provided very accurate measurements in a relatively short time.

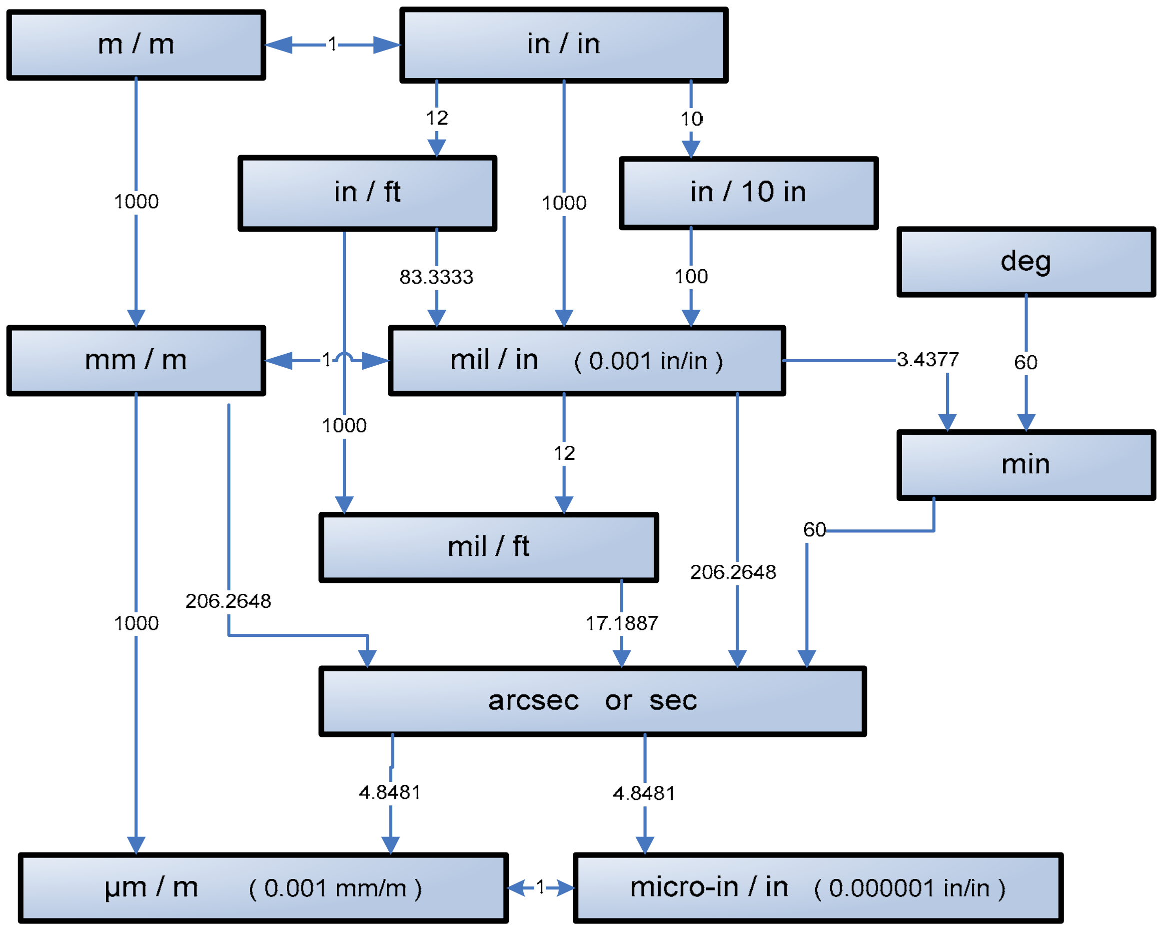
5. CONCLUSION

The electronic level can be used for a variety of applications in a hydrogenerator plant. One of the most useful applications is to measure the verticality of the axis of rotation of a vertical unit. Using an electronic level for that application has become a well-proven method. The verticality can be measured with an accuracy of 0.005 mm/m or better. Although there is nothing wrong with the four wires technique for the alignment of hydrogenerators, the use of an electronic level is an interesting alternative, normally leading to significant time and cost saving.

AUTHOR

Dany Lessard obtained a BSc from Laval University (Quebec) in 1981, and an MSc in Mechanical Engineering from the Ecole Polytechnique (Montreal) in 1985. He has 19 years of experience in the hydrogeneration business, mostly involved on installation projects, site technical direction, site management, technical support, unit alignment, balancing and commissioning. He is the founder of Hydro Expertise DL Inc. and is located in Montreal, Canada. Tel: (514)-422-9161, e-mail: dany.lessard@hydroexpertise.com

APPENDIX - Slope and verticality units



Conversion rule: multiply when going with the arrow and divide when going against the arrow.

Example: 0.25 mil/ft = 0.25*17.1887 arcsec
0.25 mil/ft = 4.3 arcsec
0.25 mil/ft = 0.25/12 mm/m = 0.02 mm/m

Prefered units for alignment are:
mm/m or mil/ft
Frequently used conversion:
1 arcsec = 0.0582 mil / ft

Note: Conversion between angle and slope values can be considered as linear only for small angle values. For angle values less than 1 degree, the error is less than 0.01% when using the constants given above.