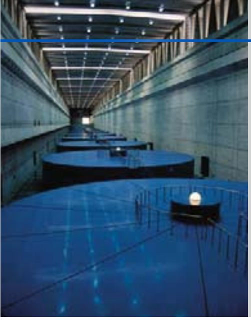

AN003

Air Gap Results Introduction – Pole vs. Time-reference Methods

VibroSystM AGMS and ZOOM systems are based on a *Pole*-reference (mechanical angle position) approach as opposed to the traditional *Time*-reference method of monitoring. The poles serve as physical references around the machine rotational axis allowing for easy analysis and quick diagnosis of machine behavior.

Introduction to Reference Methods

In order to introduce the *Pole*-reference method, comparison with the *Time*-reference method on a theoretical machine (see Figure 1) is used: perfectly round and well centered stator with perfectly round rotor except for pole P_2 protruding.

With a traditional *Time*-reference method, pole P_2 faces each sensor at different times and displays at different phases (Figure 2). This makes visual shape comparison more difficult.

In a *Pole*-reference method, pole P_2 still faces each sensor at different times. However, the system applies a phase shift – corresponding to the angle where each sensor is located on the stator plane – to all measuring chains except measuring chain #1 (normally upstream) . This ensures that pole P_1 is aligned on all curves (Figure 3). Comparison of the rotor shape and correlation of events to a specific position (angle) during the machine rotation becomes very easy and comprehensive.

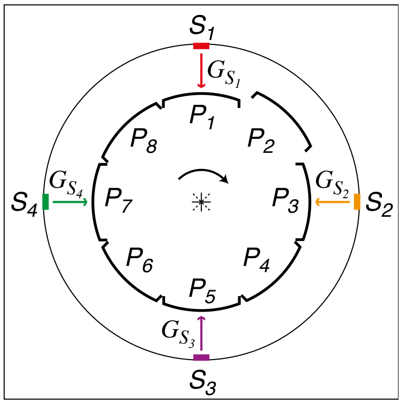

Figure 1: Example of a theoretically perfect generator with a round rotor inside a round stator. Pole [P_2] is deliberately protruding for comparison below.

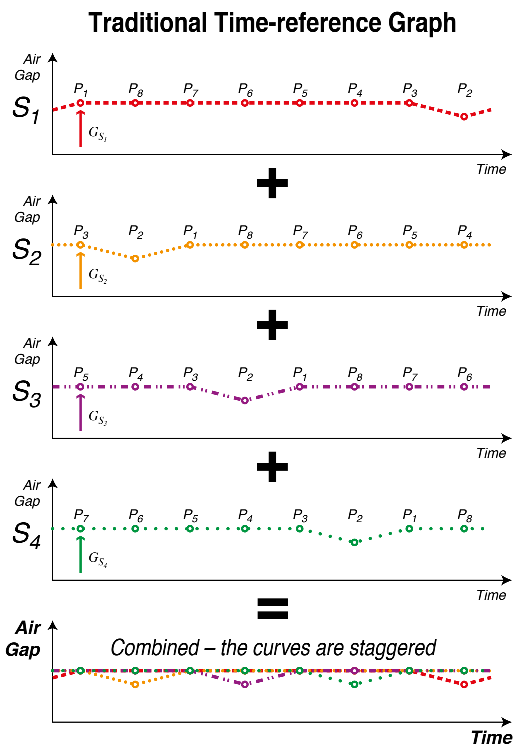

Figure 2: Graphs of traditional Time-reference method.

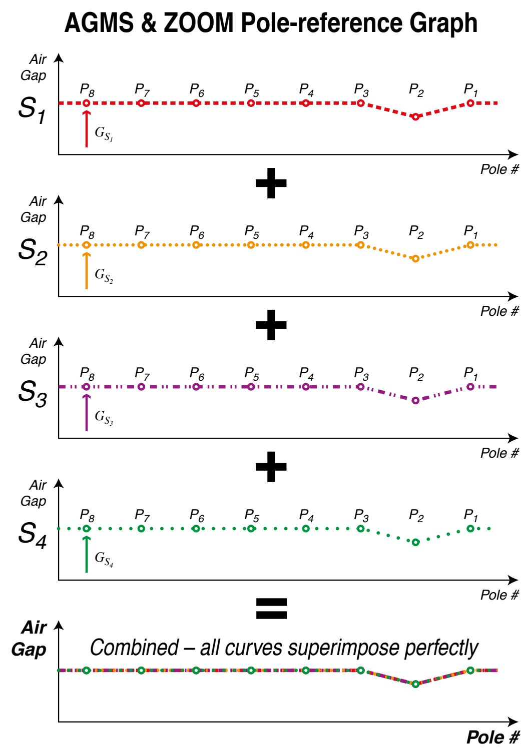

Figure 3: Graphs of AGMS & ZOOM Pole-reference method.

Basics of Air Gap Plots

The following theoretical examples, introducing graphic fundamentals, are based on air gap representation of: a perfectly round and centered rotor and stator, an out-of-round rotor, an out-of-round stator, and center offsets.

Perfectly Round and Centered Rotor and Stator

All four sensors measure identical air gaps for each rotor pole. On the graph, the curve from each sensor is straight and all curves superimpose perfectly (Figure 4).

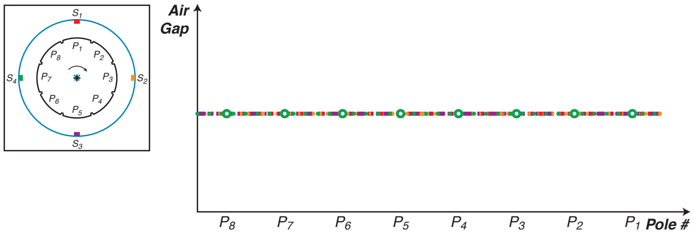

Figure 4: Graph of an ideal machine: the curves of all sensors superimpose.

Rotor Deformation

Here, each pole has a different air gap. Because the rotor is centered, the measurement of all sensors is the same. The curves still superimpose but no longer form straight lines. Instead, the curves now trace the shape of the rotor showing variations in air gap from pole to pole (Figure 5).

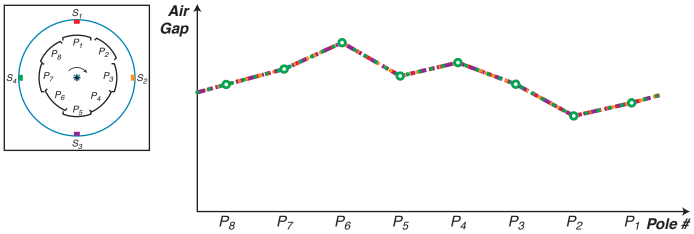

Figure 5: Graph of a deformed rotor: the curves are not straight.

Stator Deformation

In this case, the stator shape is deformed in two areas. Measurements of S_2 (farther) and S_3 (closer) are different than the ones of S_1 and S_4 (equal distance). On the graph, the round rotor produces straight lines again, but the lines are now apart (Figure 6).

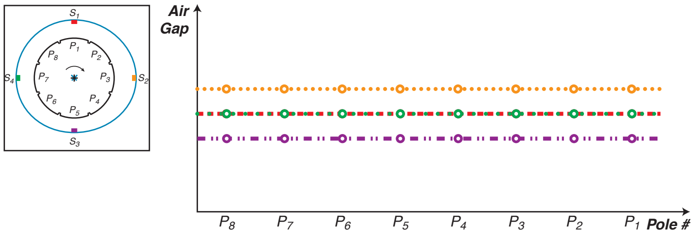

Figure 6: Graph of a deformed stator: the curves are apart.

Center Offset (non-concentric)

Finally, the offset of the stator center vs. rotor center means that all sensors are at a different distance from the rotor. The graph (Figure 7) displays both the rotor shape and the position of each sensor.

In summary, rotor deformation produces a non-linear trace, whereas stator deformation and center offsets plot curves that are apart.

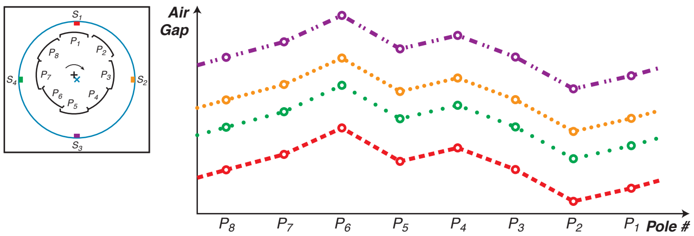

Figure 7: Graph of non-concentric rotor and stator: all curves are apart again.

When evaluating air gap results, VibroSystM makes three assumptions by default: 1) rotor radius is constant over one rotation (i.e. rotor shape does not change), 2) rotational axis is stable over one rotation (i.e. shaft is not moving and vibration is negligible), and 3) stator is stable over one rotation (i.e. stator core is not moving and vibration is negligible). Variations from these conditions still provide valuable information about a generator.

Mechanical Condition and Dynamic Behavior

In day-to-day situations, generators display a combination of the previous fundamentals. Various shaft behaviors and rotor rim conditions will now be represented.

Only one type of X-Y graph has been used so far: *Signature*[1]. In this section, a second type of graph is introduced: *Pole*[1]. The *Signature* graph is a snapshot of the generator for one machine rotation whereas the *Pole* graph displays consecutive signature graphs taken over multiple rotations. Tracking the evolution of the machine over longer periods of time provides greater analysis possibilities for diagnostic purposes.

Shaft Runout — Mechanical Imbalance Displacement

Shaft mechanical runout is characterized by rotational axis displacement of significant amplitude describing orbits of one cycle or less per turn. The orbit follows a distinctive, somewhat circular path. In this situation, each sensor measures a different rotor shape that is not exactly representative of the true shape. The curves are not uniformly spaced and may cross each other. Peak-to-peak values as well as minimum and maximum may correspond to different poles from one sensor to another (Figure 8).

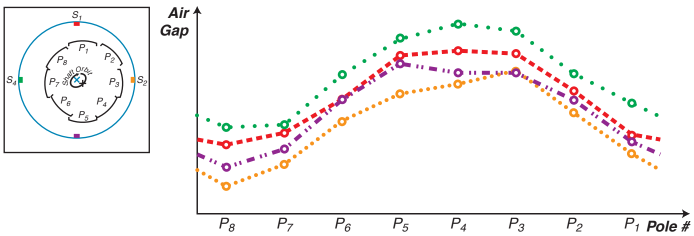

Figure 8: Graph reflecting shaft runout: peak-peak values as well as minimum and maximum poles are different from one curve to another.

Shaft Vibration — Small Rotational Axis Displacement

As opposed to shaft runout, shaft vibration is characterized by small, high frequency and random movements of rotational axis describing no particular circular path (orbit). In this situation, the rotor shape measured by each sensor varies very little, providing a good picture of the real shape. The graph displays curves that are quite similar except for small variations observed on some of the poles here and there. Minimum and maximum poles are usually the same and variation between peak-peak value for each curve is small.

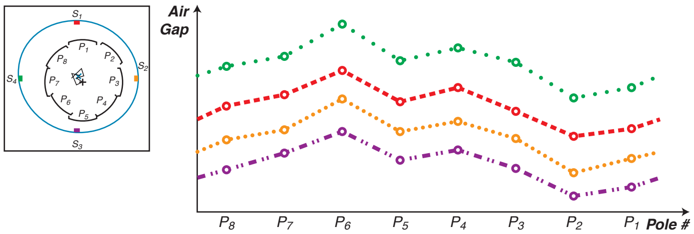

Figure 9: Graph reflecting shaft vibration: the curves are not perfectly parallel. There is some degree of variation for each pole, usually within acceptable tolerance and bearing play.

1 *Signature and Pole measurements/graphs: for information, see Application Note AN002: "ZOOM Measurement & Graphs Types".*

Shaft Displacement during Transient Conditions

Shaft displacement (i.e. rotor rotational axis) usually occurs during transitory conditions such as: start-up, field excitation, load rejection, overspeed, and shutdown. It can be described as a change of rotor center axis created by magnetic pull, centrifugal force, or an unbalanced rotor (change of shape). Such movement normally takes a few rotations to complete. It is visible from a Pole measurement or by comparing Signature measurements.

In a Pole measurement graph, there is a change in the curves, more or less sudden, corresponding to the shaft changing position (Figure 10).

In comparing two Signature measurement graphs presenting different operating conditions, the air gap variation of a given pole measured by each sensor is not uniform. The order in which the curves appear can also change (Figure 11).

As a general rule, radially opposed sensors in line with or close to the displacement axis show inverse air gap variations, while lateral sensors may show no variation. Often, the closest sensor displays an air gap reduction whereas the farthest sensor shows an air gap increase. Radially opposed sensors may not measure the same movement amplitude as they may also be affected by inward or outward stator movement from magnetic pull or release.

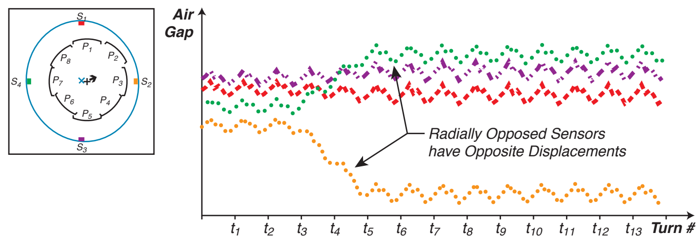

Figure 10: Graph of a Pole measurement during field excitation: radially opposed sensors display inverse behavior.

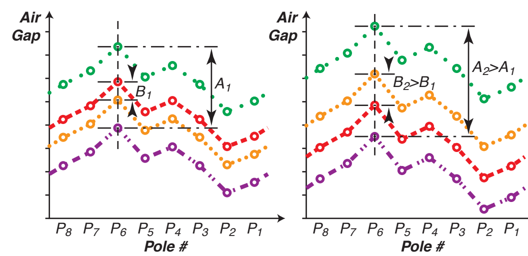

Figure 11: Comparison of Signature measurement graphs at two operating conditions: variations between two points from one graph to another are not the same; order of curve appearance can change.

Loose Rotor Rim

A loose rim is visible by comparing the curves – rotor shapes – on graphs from Signature or Pole measurements, for all sensors in a given measurement or at different operating conditions. It can affect a portion or the entire rotor circumference, and can last the entire rotation or be cyclic during part of the turn. On the graph, the loose section will display rotor shape variations from curve to curve while the solid section will be almost identical (Figure 12). A completely loose rim may display changing shapes from one turn to another.

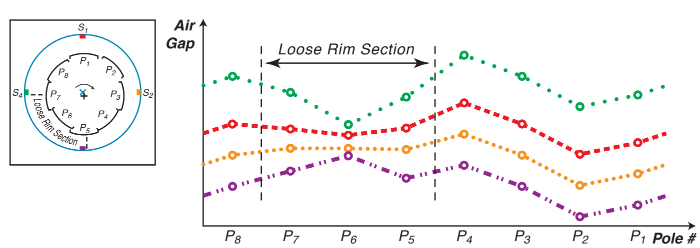

Figure 12: Graphs showing a loose rotor rim section: an area of the rotor rim is not consistent with the rest of the rotor profiles.

Overshrunk Rotor Rim

An overshrunk rotor rim reveals itself as a series of waves on the graph corresponding to the number of arms on the rotor spider (Figure 13). On the polar graph, it usually plots as a geometric shape where the junctions – smaller gaps – are located at the end of the arms. It is more evident on rotor spiders with eight arms rather than fourteen.

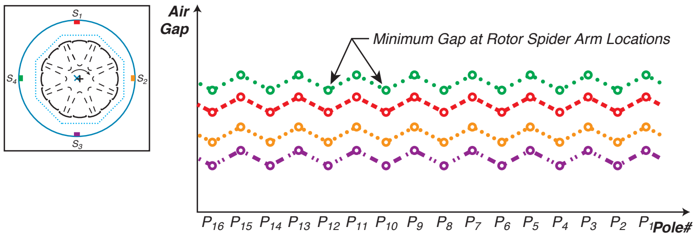

Figure 13: Graph of an overshrunk rotor rim: typically plots as waves of the same number as spider arms with valleys at end of arm locations; on polar graph (left), it often traces a distinctive geometric shape.

Oval Rotor Rim

An oval rim is usually associated with a floating rim design. As it tends to adopt an oval shape, it creates a magnetic imbalance generating a stress on the stator at twice the rotational frequency. On a Signature measurement graph, it plots as two waves per rotation. (Figure 14).

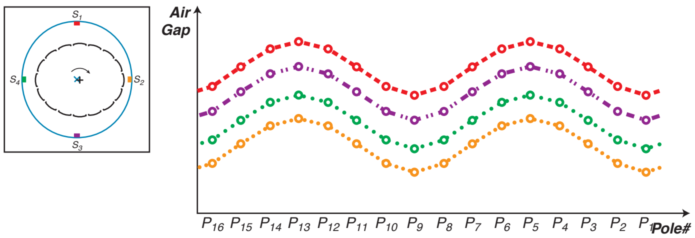

Figure 14: Graph of an oval rotor rim often associated with floating rim design.

Rotor Rim Expansion (Circularity)

The greatest rim expansion comes from increasing centrifugal force during start-up (Figure 15) and load rejection. If the rim is not tight enough, it may deform creating a mechanical imbalance and subsequent problems. On a smaller scale, additional expansion also occurs at field application and from raising operating temperature.

Rim expansion is assessed by studying the difference between minimum and maximum gaps (i.e. minimum and maximum rotor radiuses) of each turn on Pole measurements during transient conditions (Figure 15) or by comparing Signature measurements from different operating conditions (Figure 16).

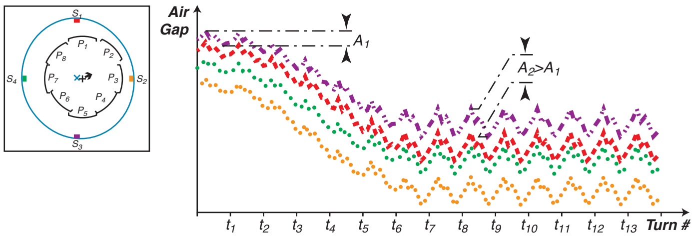

Figure 15: Graph of a Pole measurement during start-up: variation between minimum and maximum gaps per turn represents the rotor rim expansion.

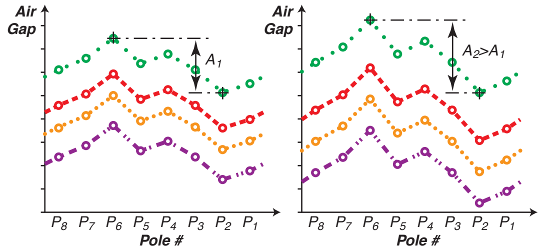

Figure 16: Comparison of Signature measurement graphs at two operating conditions such as Speed No Load with Field Applied or Full Load.

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