Avoiding major damage on a new hydrogenerator by monitoring air gap at Igarapava H.E.P.P.

Authors: *Raimundo Jorge Ivo Metzker*, CEMIG
Marc R. Bissonnette, VibroSystM
André Tétreault, VibroSystM
Jackson Lin, VibroSystM

Introduction

The Igarapava hydroelectric power plant comprises 5 x 42 MW bulb units on the Rio Grande River which borders the states of Minas Gerais and São Paulo in Brazil. The owner is the Igarapava Consortium which comprises five companies: Companhia Vale do Rio Doce – CVRD, Companhia Mineira de Metais – CMM, Companhia Siderúrgia Nacional – CSN, Companhia Energética de Minas Gerais – CEMIG and Mineração Morro Velho. The generators were designed by ABB Brazil and turbines were supplied by Voest-Alpine of Austria.

These are the first bulb units to be installed in Brazil. Thus, the owner insisted that they be fully equipped with a complete, on-line machine monitoring system which could monitor various generator parameters for condition-based maintenance purpose right from the units' commissioning. The monitored parameters are: rotor-stator air gap[1]; radial and axial shaft vibration at generator and turbine guide bearings; hydraulic pressure; generator MW; generator MVAR; generator voltage; stator current; exciter current; stator temperature; upstream and downstream water levels; upstream and downstream water pressures.

At Igarapava, the nominal rotor-stator clearance is 11 mm, therefore air gap monitoring becomes even more critical, especially since stator sag[2] leading to air gap distortion is common to many bulb units around the world. For bulb-type generators, the Igarapava units are considered large machines and air gap monitoring was judged to be indispensable.

Background

On July 27 1999, Igarapava Unit #2 had experienced rotor-stator contact within 5 months of unit commissioning. This led to a lengthy and costly outage to repair the unit. At the time, the machine monitoring system which was to be supplied by VibroSystM of Canada had not yet been installed. Due to project constraints, Units 1 and 2 did not have their monitoring systems commissioned in time for the start up of these two units. Upon occurrence of the rotor-stator damage, the commissioning of the ZOOM[3] system for all 5 units was accelerated while, concurrently, the main contractor was investigating the cause of the rotor-stator contact. From the contractor's perspective, the utility had purchased the monitoring system specifically to avoid such a problem. Thus, it was only logical to make the system fully operational as soon as possible and to use it for its intended purpose.

In September of 1999, while at the Igarapava site to complete system installation and commissioning on Units 1, 2 and 5, VibroSystM took the opportunity to perform test measurements on all five units. After reviewing polar plots and trends stored in the system database, VibroSystM noticed an irregularity on the previously commissioned Unit #4.

Rotor-Stator Air Gap Problem on Unit 4

A total of four air gap sensors are installed on the perimeter of the stator core approximately 25 cm (or 10 inches) from the edge of the stator iron. Sensors are installed at the 45°, 135°, 225° and 315° locations (see **Figure 1**).

During the tests of the ZOOM system on Unit 4, an anomaly was detected in the rotor-stator air gap at the 225º sensor location. Based upon data that was displayed with the ZOOM monitoring software, VibroSystM suspected the presence of a "bump"[4] on the rotor rim. Using the historical display capability of the ZOOM software, it was possible to isolate at a point in time the "signature"[5] (i.e. minimum air gap value of each pole measured over one rotor revolution) of each air gap sensor.

In order to facilitate the interpretation of air gap data, VibroSystM references air gap measurement to rotor poles rather than to time. Simplified, this means that a phase shift is performed on three of the four air gap sensors to align all four air gap traces according to their poles (for a detailed explanation, see **Appendix A**).

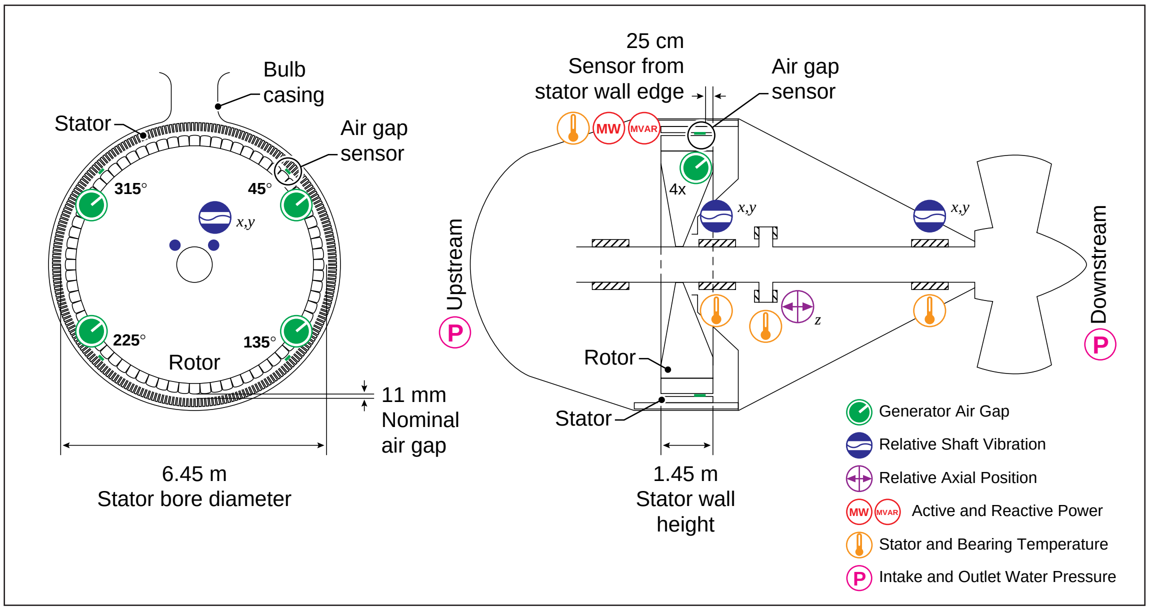


Figure 1: Cross-sections of bulb unit showing air gap sensor locations on stator wall plus other monitored parameters.

By isolating the signature of each of the four air gap sensors, it was possible to identify if the bump was permanent or transient (see **Figures 2 and 3**). A permanent bump would result in all four air gap sensors seeing the same signature trace. A transient bump would result in all four air gap signals showing a different trace. By using the ZOOM software, it was possible to determine that the bump amplitude varied depending upon the angle to which the rotor was turned. The maximum bump amplitude (or most critical air gap) occurred when rotor pole #39 passes in front of the 225° sensor.

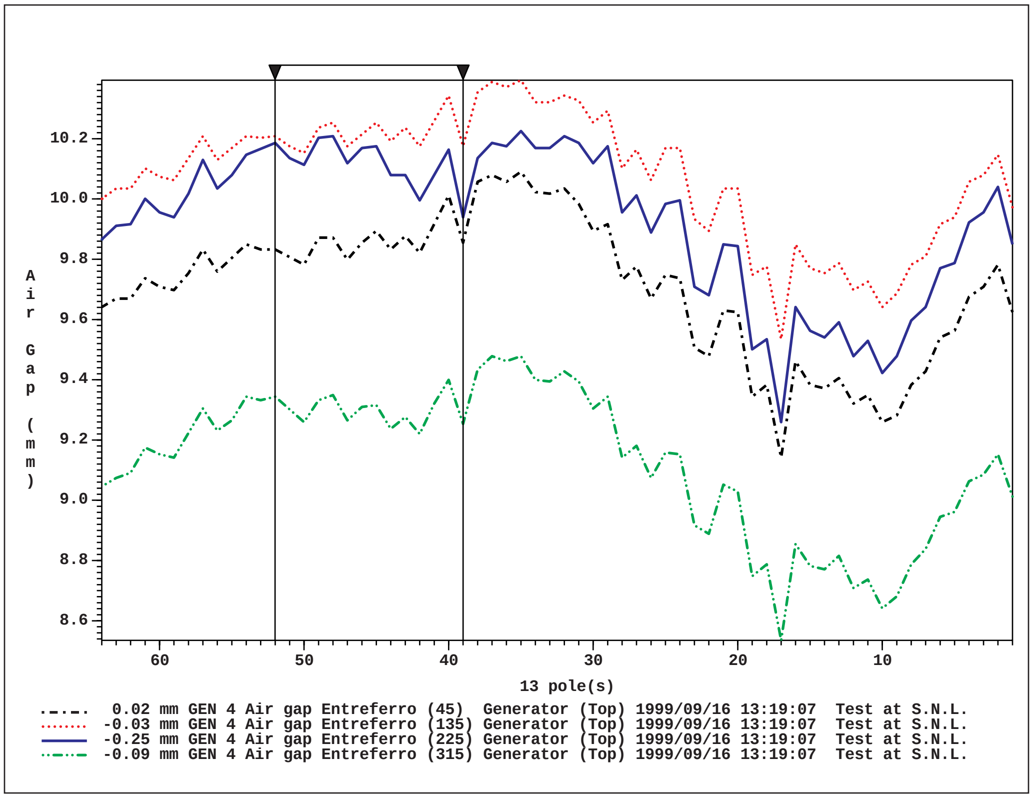


Figure 2: Air gap signature of all four sensors showing rotor profiles at Speed No Load (S.N.L.) In all figures, delta markers indicate variations between a stable rim location (pole 59) and the worst moving rim location (pole 39) along with numerical values for each curve displayed at bottom left.

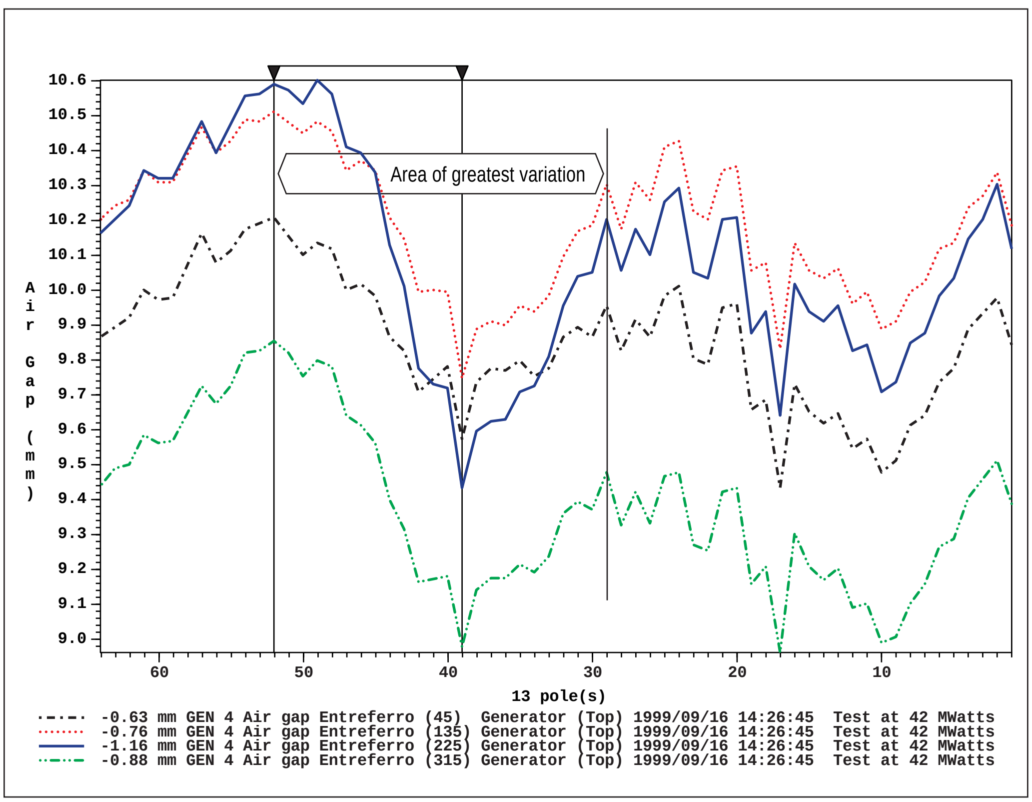


Figure 3: Air gap signatures of all four sensors at full load (42 MW). Note the dramatic shape variation for 225° sensor between poles 52 and 29 compared with other sensors and with Figure 2.

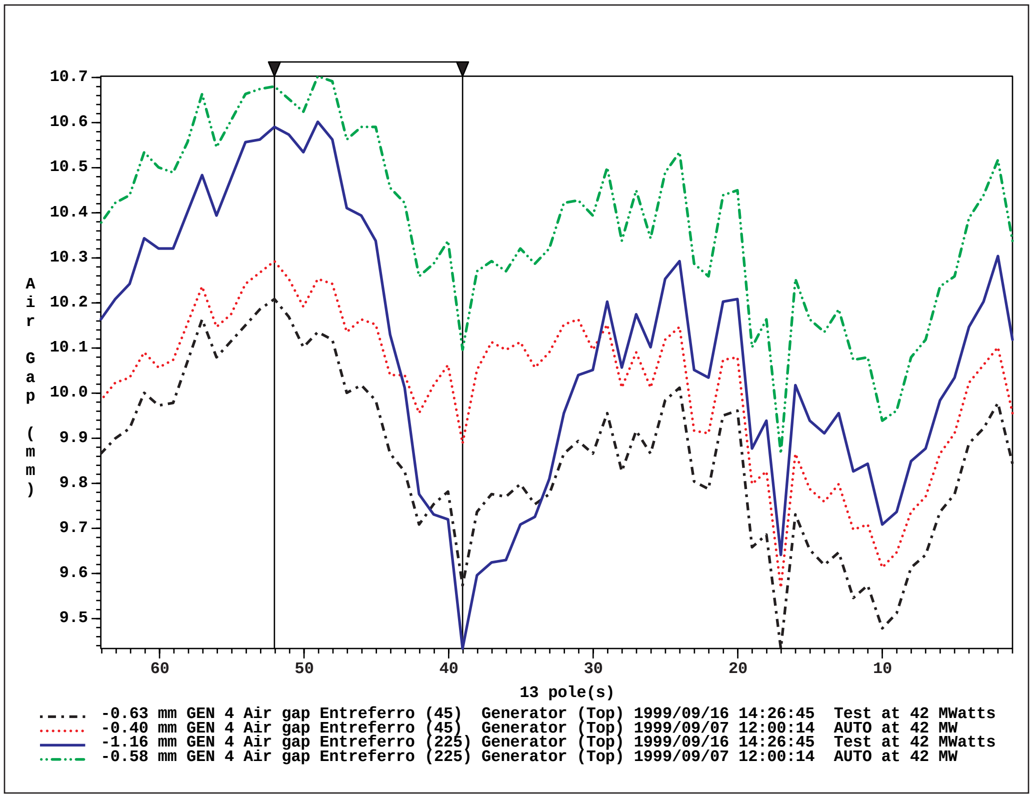


Figure 4: Air gap signature of opposite sensors at 45° and 225° showing rapid deterioration over a period of 9 days.

Table 1: Air gap differences for Pole 39 (location of greatest rotor rim movement) over a 9-day period

Sensor	***Pole 39 / 42 MW*** *(in mm)*		
	Sept. 7 1999	*Sept. 16 1999*	*Difference*
45 deg.	9.89	9.57	- 0.32
135 deg.	10.17	9.74	- 0.43
225 deg.	10.10	9.44	- 0.66
315 deg.	9.37	8.98	- 0.39

VibroSystM plotted the 225° and 45° sensors and compared these with the same data from a week earlier. From the signatures of **Figure 4** and data of **Table 1**, it was clear that even over the course of one week, there was significant deterioration of the air gap. Polar views of generator in **Figure 5** compares rotor rim profiles under two operating conditions (i.e. S.N.L. and full load) and in **Figure 6** compares rotor profiles at 42 MW load taken 9 days apart (September 7 and 16, 1999).

In studying the data, VibroSystM alerted CEMIG that the monitoring system clearly indicated a potential rotor-stator air gap failure could occur at any time.

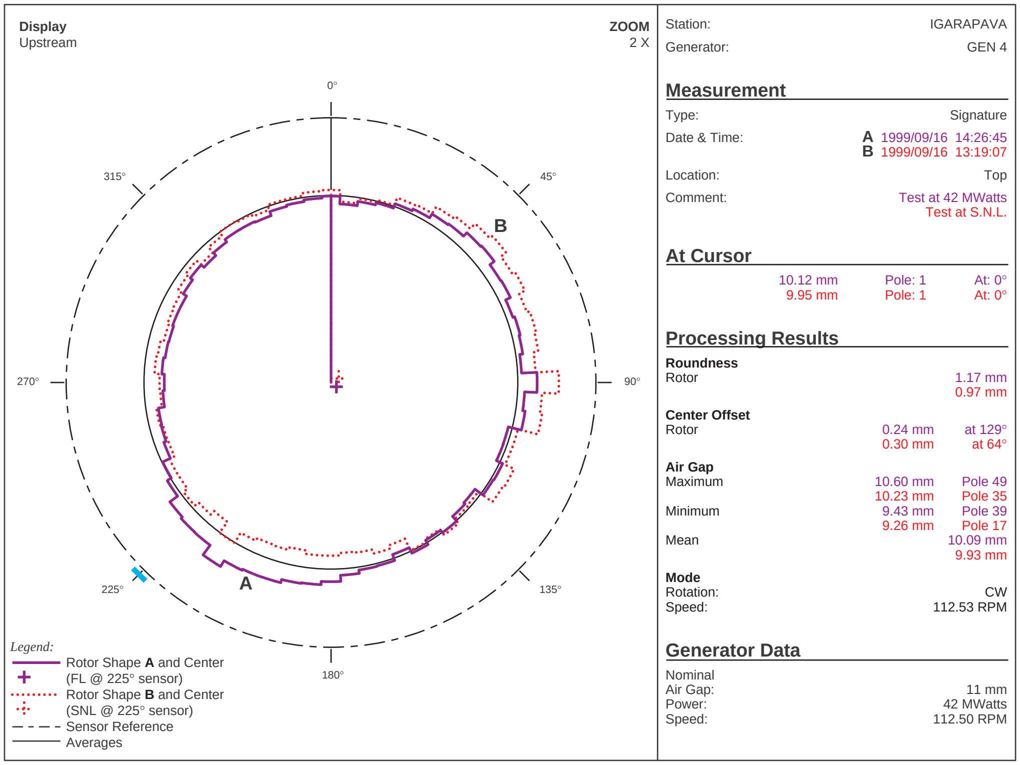


Figure 5: Polar view of generator comparing rotor shapes at S.N.L. (B) and Full Load (A) using 225° sensor. Numerical values at right stress the various changes in roundness, offset, angle, best/worst locations.

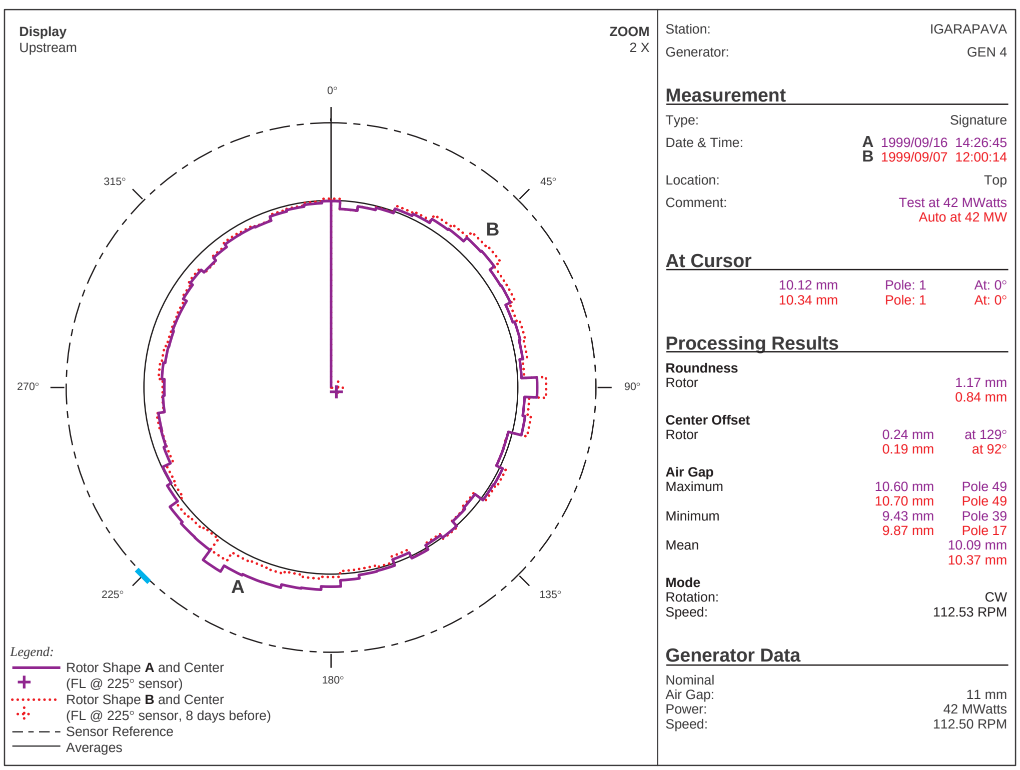


Figure 6: Polar view of generator comparing rotor shape deterioration over a period of 9 days (at full load of 42 MW).

Actions Taken

Realizing the gravity of the situation and the potential danger of the imminent rotor-stator contact, the CEMIG supervising engineer immediately contacted the CEMIG head office. From its Belo Horizonte headquarters, CEMIG engineers were able to remotely access the ZOOM data via their remote ZOOM controller and confirm that the danger of an imminent rub was real. The CEMIG engineers printed the relevant ZOOM plots showing the results and faxed them to the generator manufacturer's project office. Upon further study, CEMIG shut down the machine and requested the generator manufacturer to inspect the rotor rim.

Two days after the order was given to shut down the unit, the generator manufacturer visited the plant to conduct further investigations. It discovered that Unit 4 was in much worse condition than Unit 2 when its rotor had contacted the stator. Percussion tests were performed on the rotor rim bolts to the spider. Several bolts broke in the course of testing. It was evident that the rotor rim was loose on the spider and during machine rotation, this imbalance was overstressing the bolts and causing them to break. CEMIG and the generator manufacturer have performed a detailed generator design review to correct the problem and prevent its reoccurrence.

Conclusion

This is a clear case in which the air gap monitoring feature of the ZOOM system was able to predict an imminent rotor-to-stator contact in time that preventative action could be taken. CEMIG was very pleased that its investment in the ZOOM system had paid dividends. ***"With this one event, the full monitoring system investment for the entire plant had already paid for itself before all units had even been commissioned"***, commented one CEMIG Engineer. CEMIG is now closely monitoring the air gap and overall machine condition of all five generators to ensure the Igarapava Consortium's investment is fully protected. On-line monitoring (as opposed to periodic, off-line measurements) is particularly useful since this case has shown that a critical air gap change can occur over a period of weeks for which periodic, off-line measurements are insufficient to identify and correct a problem before it turns into a costly forced outage.

---

[1] Air Gap: Clearance between fixed (stator) and rotating (rotor) parts of a generator or motor.

[2] Stator Sag: Tendency of the stator shape on a horizontal machine to flatten (oval shape) under force of gravity.

[3] ZOOM System: Abbreviation for Zero Outage On-line Monitoring System. It is a multi-parameter, on-line machine condition monitoring system for hydroelectric generators/turbines. ZOOM incorporates in the base system an Air Gap Monitoring System (AGMS). ZOOM and AGMS are manufactured by VibroSystM of Longueuil, Canada.

[4] Rotor Bump: Area of the rotor rim shape that moves outward from a normal circle. It is synonymous with loss of clearance, thus critical air gap.

[5] Signature: Measurement of the minimum air gap value of each rotor pole over one machine rotation showing rotor shape profile as seen by each sensor.

APPENDIX A

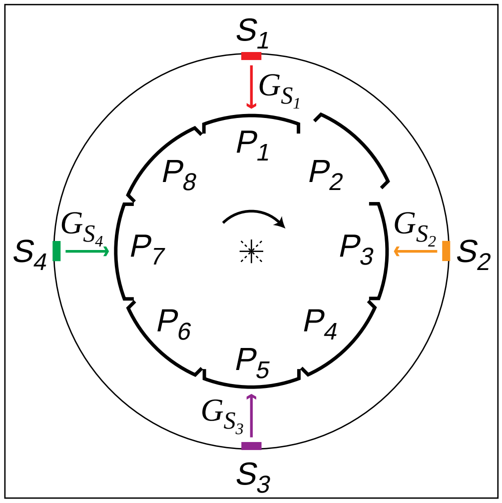
Introduction to Air Gap Results

1. Comparison of Reference Methods
2. Comparison of Generator Shapes

Air Gap Results Introduction

1. Comparison of Reference Method

As opposed to traditional time-referenced methods of monitoring, VibroSystM's AGMS is based on a pole-reference approach. The air gap being the smallest electro-mechanical step of the machine, the poles serve as physical references along the machine axis allowing for easy analysis by maintenance engineers.

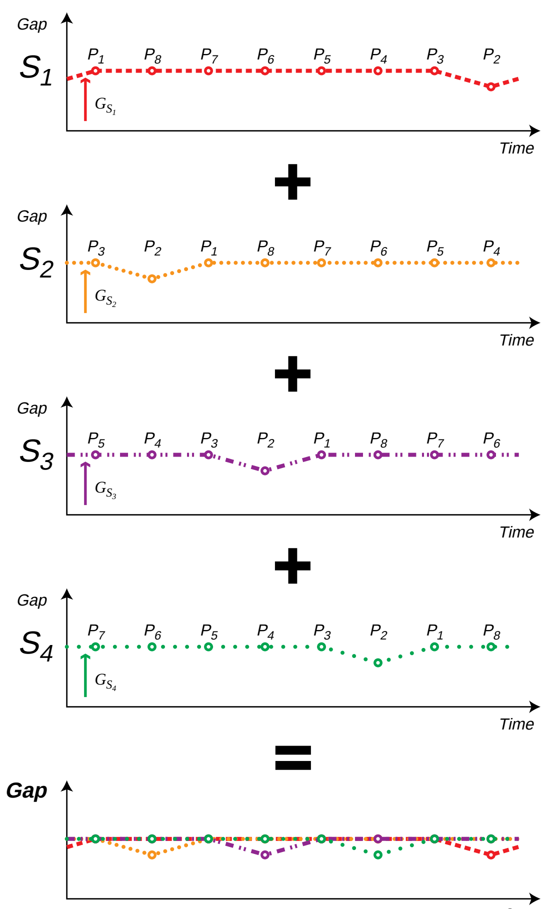


Example:

Top View of a Perfect stator perfectly centered with an almost perfect rotor

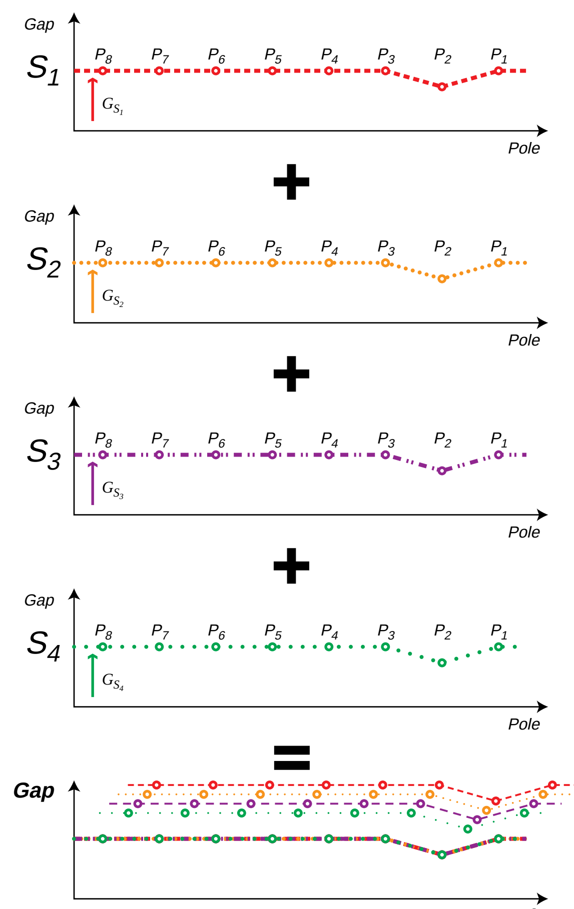
(one pole [P_2] is protruding to help in the comparison below)

Traditional Time-referenced Graph



Combined
(the curves are staggered)

AGMS Pole-referenced Graph

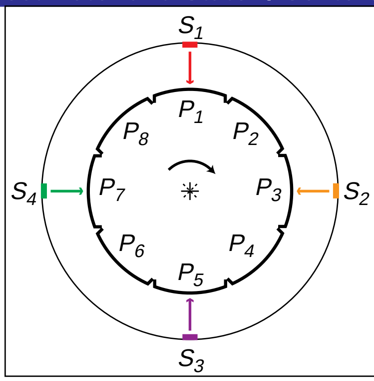


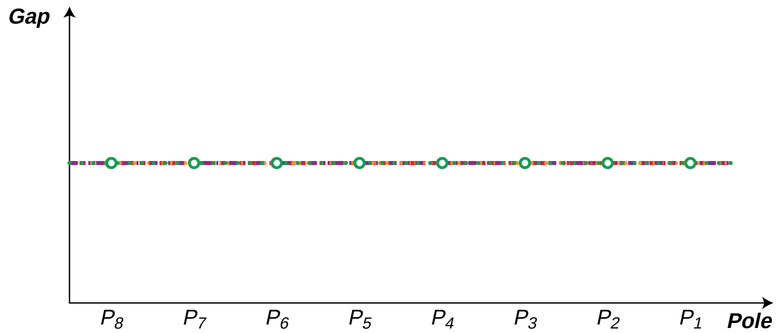
Combined
(all curves superimpose perfectly)

Air Gap Results Introduction

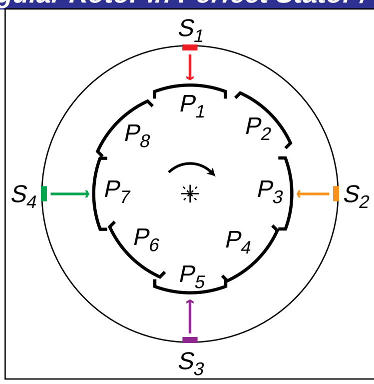
2. Comparison of Generator Shapes

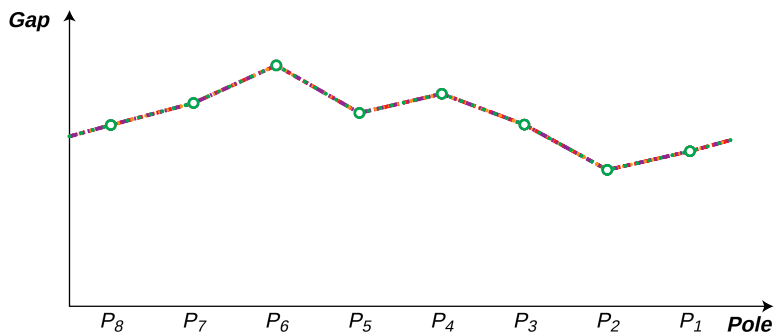
Perfect Rotor and Stator / Centered



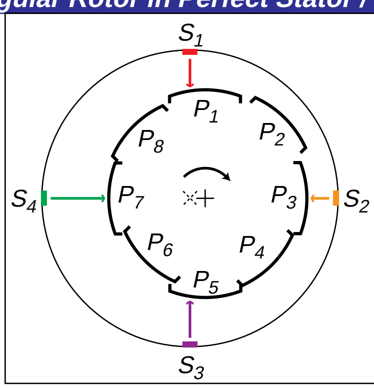


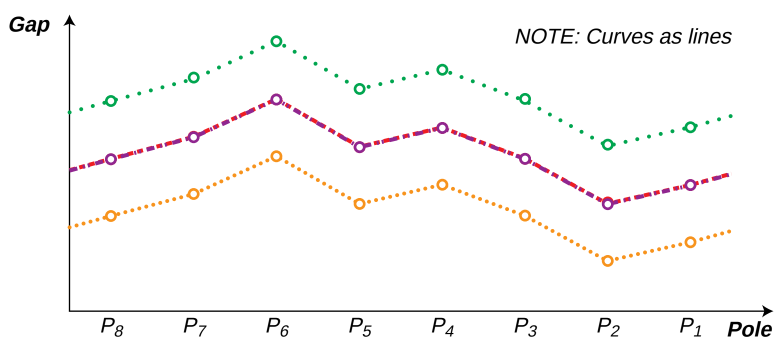
Irregular Rotor in Perfect Stator / Centered





Irregular Rotor in Perfect Stator / Off-centered





Irregular Rotor in Irregular Stator / Off-centered