Stress Decreasing at Water Turbine in AGC

Redukcja naprężeń występujących w trakcie pracy turbiny wodnej w trybie regulacji mocy

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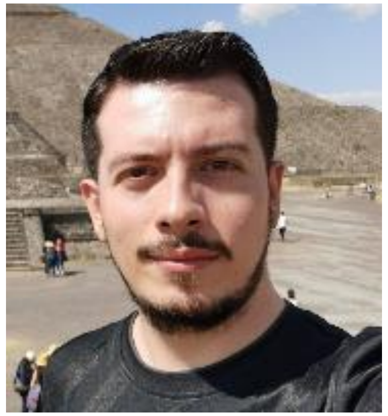
Stress Decreasing at Water Turbine in AGC

Ricardo Brenes
Engineering Regional Lead

Emerson, Power and Water Solutions
Multipark Office Center,
Tempisque Building ,
Guachipelin de Escazu
Costa Rica

ricardo.brenes@emerson.com



Jorge Fonseca
Senior Engineer

Emerson, Power and Water Solutions
Multipark Office Center,
Tempisque Building ,
Guachipelin 10201
Costa Rica

jorge.fonseca@emerson.com

Zoya Shavlovich
Manager Mechanical and Hydro Solutions Europe, PhD

Emerson, Power and Water Solutions
Konstruktorska 13
Warsaw PL 02-673
Poland

Work phone +48725850216
Zoya.Shavlovich@emerson.com

Speaker

Daniel Chowanski
Hydro Turbine SW Application Expert

Emerson, Power and Water Solutions
Konstruktorska 13
Warsaw PL 02-673
Poland

Work phone +48601551879
Daniel.Chowanski@emerson.com

Increased Water Turbine Stress as a Response to AGC/PFC

The Main Objective of the Governor's Retrofit

- To participate in Automatic Generation Control (AGC) and load frequency control (LFC) with flexible modes of operation
- To improve the primary frequency control (PFC) which purpose is to keep the frequency within required range
- To compliance with the PT9; IEEE-125; IEC 60308 standards (and similar)

Turbine's Negative Response

- Any change in the grid frequency will change power output to help maintain the desired grid frequency. This results in the turbine governor constantly adjusting the position of the actuators (wicket gate and runner blades)
- The number of movements in the regulating mechanism increases, especially if it is a **Kaplan turbine**

The first days after the Sayano-Shushenskaya HPP accident
Photo TASS

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Methods for Reducing Stress in Kaplan Turbines in AGC/PFC

Hybridization in Kaplan Turbines

Method is based on installing a battery in parallel with the unit which is in charge of infecting or subtracting power from the grid to provide AGC/PFC control [1]

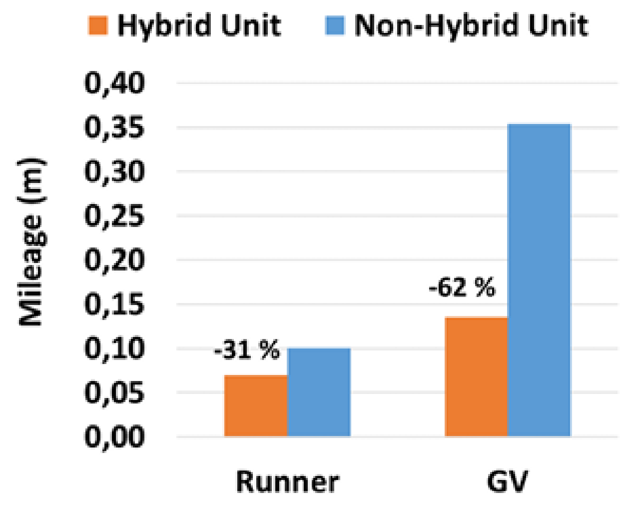
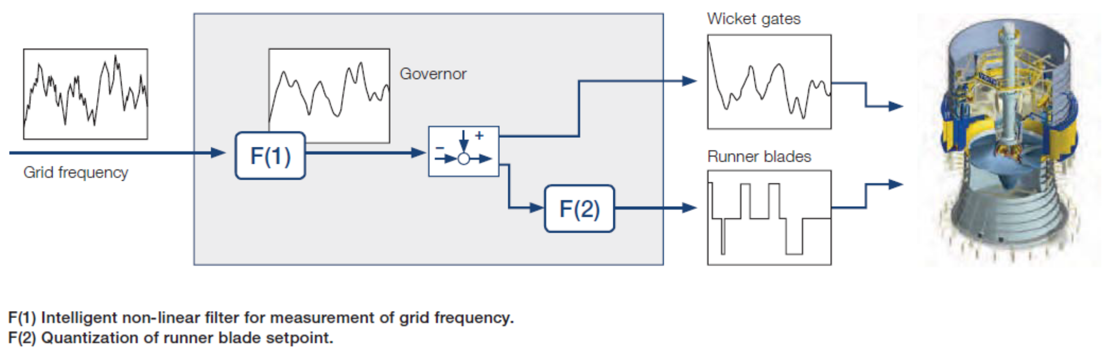


Figure 2. Servomotors mileage for the hybrid and non-hybrid units.

Program Methods for Reducing Loads on the Runner Blade

Publication [2]: Two digital filters in the Governor with decreasing optimal efficiency a bit and **increasing the load on the wicket gate** to meet the frequency requirements

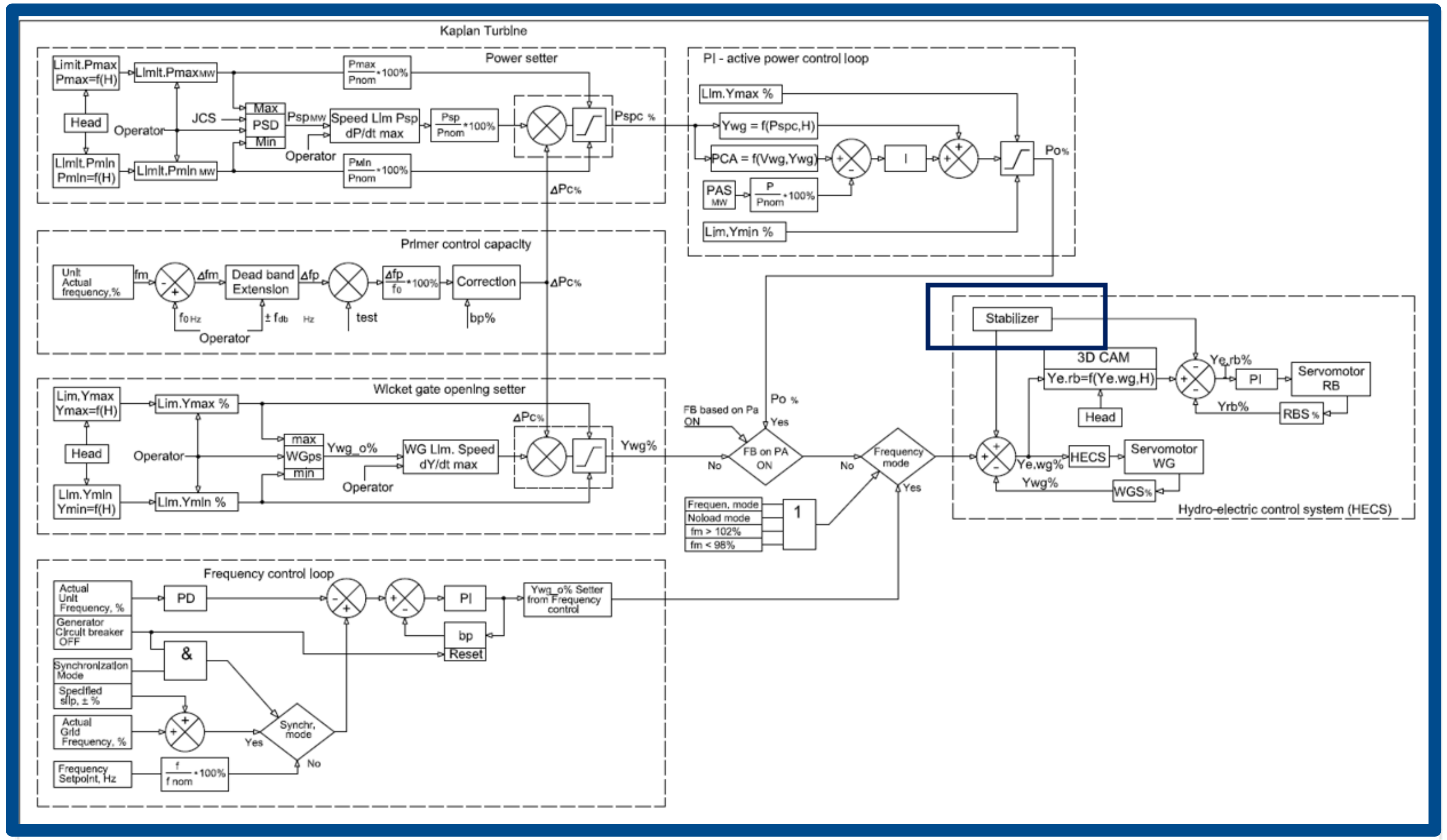


Emerson designed and uses since 2005 several program solutions in Ovation Governor:

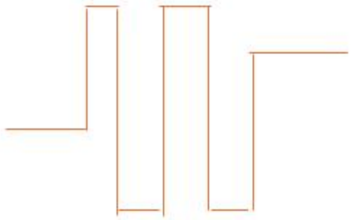
- "Stabilizer" with adjustable deadband
- Low-Pass filter
- "Balancing"

Program Methods for Reducing Stress on the Runner Blade

Stress Reduction Algorithm "Stabilizer"



RB



WG

The blades of the runner are set in optimum power point with dead zone -

Results: the runner blades make fewer movements

the wicket gate is responsible for frequency control

the movement of the **wicket gate** becomes **more frequent but with lower loads and pressure amplitudes**

the frequency control requirements are met with minimum stress on water turbine

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Program Methods for Reducing Loads on the Runner Blade

"Stabilizer" - Adjustable Deadband to Limit the Response During Blade Adjustment

The purpose of this feature is to limit the Runner Blade adjustment due to the ON-CAM correlation curve when the wicket gate changes its position. This means that for the Runner Blade to move, its reference, which comes from the correlation curve, must exceed a parameterizable deadband value.

Emerson recommends to follows the standard IEEE-std-125-2007, which states in section “4.7 Vane Control Deadband” that the RB deadband is typically 1% of the total range. Higher values imply reduced efficiency and may increase cavitation and vibration. Similarly, higher values may be specified by the customer if required. However, the customer can change the range if necessary.

The slides below provide an analysis that demonstrates the validity of this recommendation. This analysis was performed for three 135MW Kaplan turbines with upgraded regulators.

IEEE-std-125-2007

4.7 Blade control deadband

The blade control deadband is a measure of the smallest change in blade position setpoint that can be detected and to which the blade servomotor positioning system can respond. The blade control deadband determines the accuracy of the gate/blade relationship for an adjustable-blade turbine. The accuracy of the gate/blade relationship determines the efficiency of the turbine as well as the amount of vibration and cavitation produced by off-peak operation. Typically, a blade control deadband of 1.0% is achievable and is commonly specified for hydroelectric turbine governing systems. Increasing the amount of blade control deadband decreases the accuracy of positioning the blades as a function of gate position. The resulting deviation from the ideal blade position reduces the efficiency of the turbine. This reduction in turbine efficiency may result in loss of revenue due to the reduced efficiency; increased cavitation damage to the

VARIABLES DEL RODETE

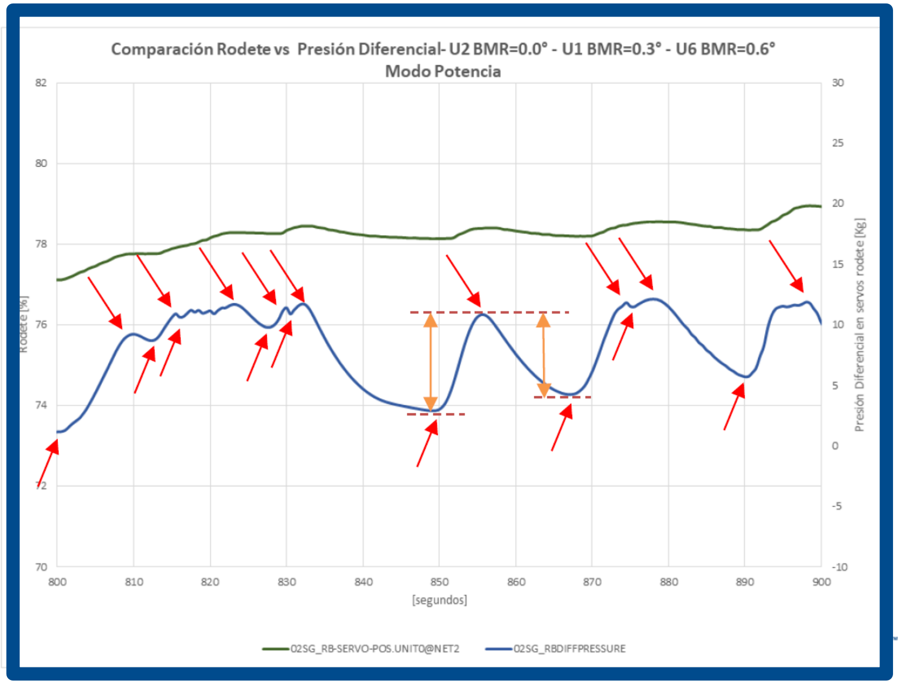
SELECCIÓN CURVAS COMBINAT :	A	B ✔	
LÍMITE DE ERROR [%]:	0.0		SET VALUE
BANDA MUERTA [°]:	0.0		SET VALUE
TASA DE CAMBIO LIMITE - ABRIEN [%/sec]:	10.0		SET VALUE
TASA DE CAMBIO LIMITE - CERRAN [%/sec]:	10.0		SET VALUE

Method of Analysis

To compare the impact of different blade angle deadband values on the cyclic loads of the wicket gate and runner blade, a rainflow count histogram was made using the differential pressures of servomotors that, when applied to the structures, are proportional to the loads.

The rainflow histrogram was created by recording the number of cycles (wave direction changes) and their magnitudes in the differential pressure curves for all tests.

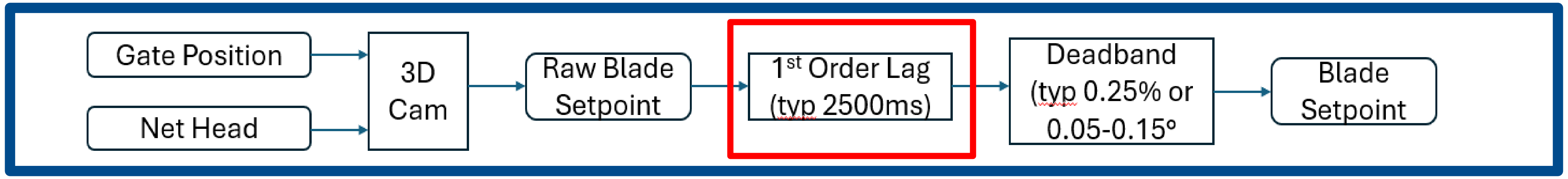
An example of how the cycles and their magnitudes are obtained



Low-Pass Filter

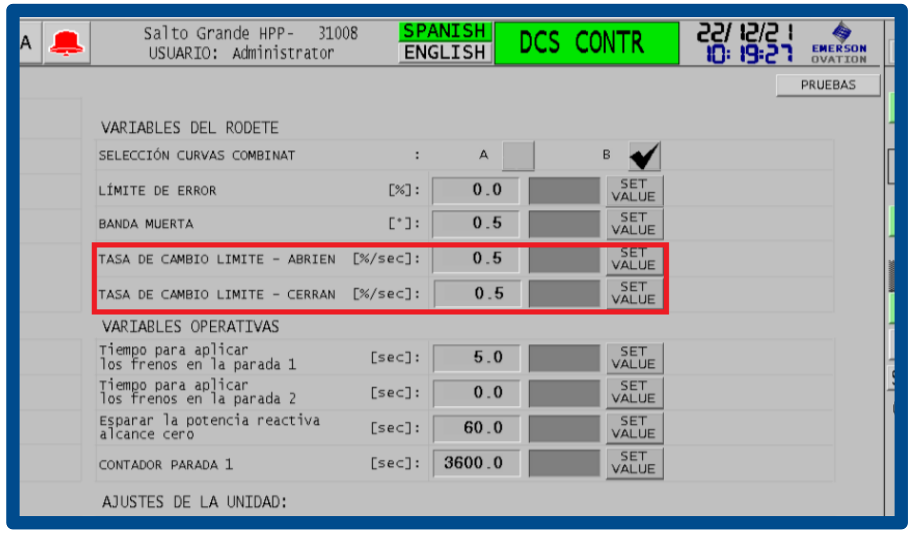
The purpose of this function is that there is a low-pass filter for the reference change ramp that would slow down the movements of the runnner blade while the error between the reference and the position is less than a configurable limit.

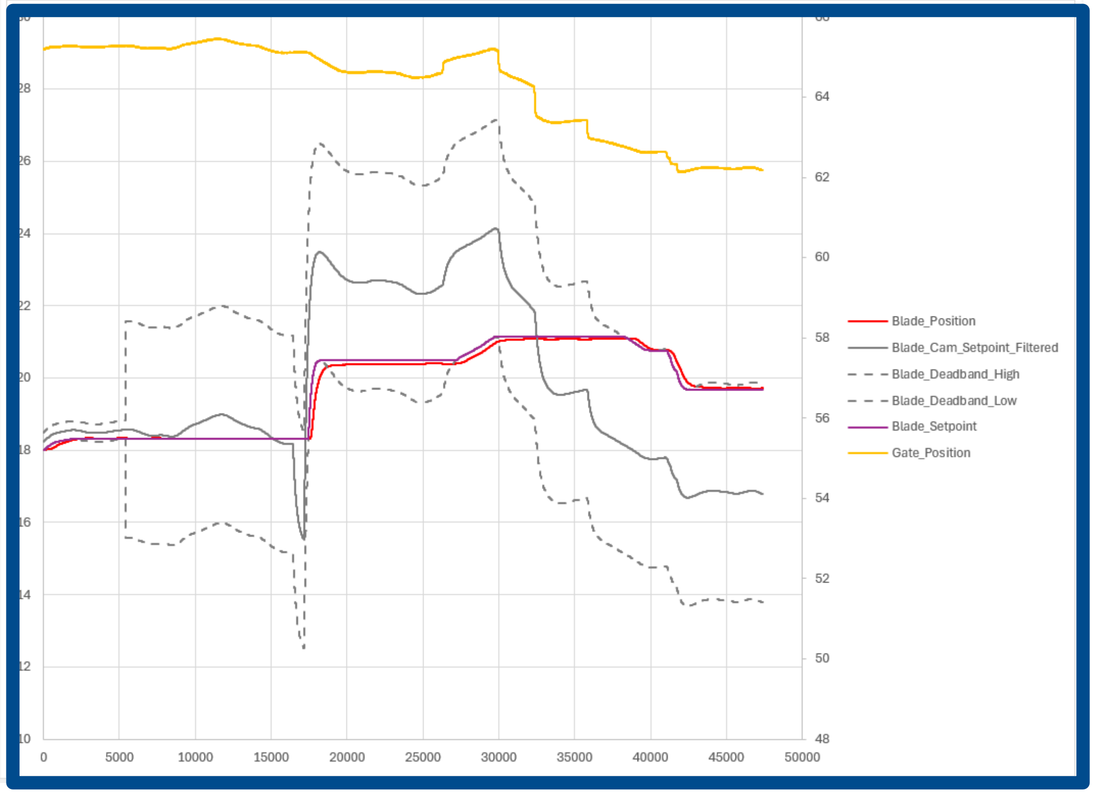
In other words, this algorithm provides a limitation of the runner blade speed within a certain zone, which is measured from the reference curve ON-CAM, with a minimum dead band on the runner blade.



Due to low dynamic of turbine, low-pass filter may be disabled due to grid requirements for efficient response in primary control, taking into account the recommendations of the IEEE-125 standard for the dead zone of the RB.

Selecting and setting up the low-pass filter function, as well as an example of its implementation for a hydraulic unit





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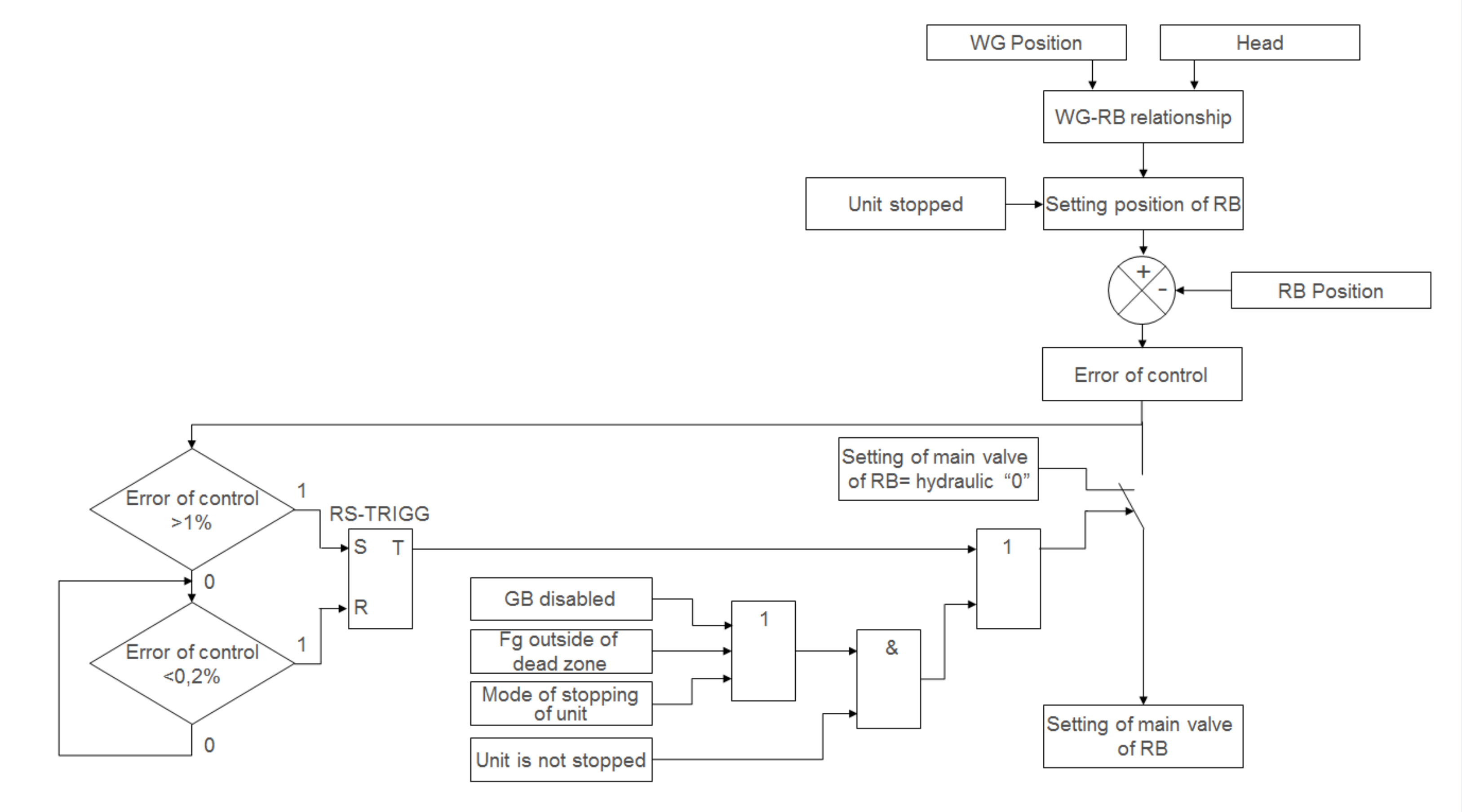
Algorithm "Balancing"

The purpose of this function is the forced centering of the main distribution valve in the "hydraulic zero" position to minimize the pressure drop on the servomotors in stationary or close to them modes of operation of the hydraulic unit, including when the turbine is stopped. Also is used to reduce the movements of the main distribution valves and the servomotors associated with them, due to increased internal leaks that increase when the turbine is operating in the AGC/PFC/LFC. As a result, the cyclic operation of the oil pressure unit deteriorates, and the temperature balance is disturbed.



For different MDVs, the hydraulic zero can vary from 5 to 30%

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RB and WG Stress Analyzing between two Governors

An analysis and comparison study were carried out between two Kaplan Units, **analyzing the oscillations and stresses caused in the wicked gate and runner blade**.

<u>Practical goals</u>

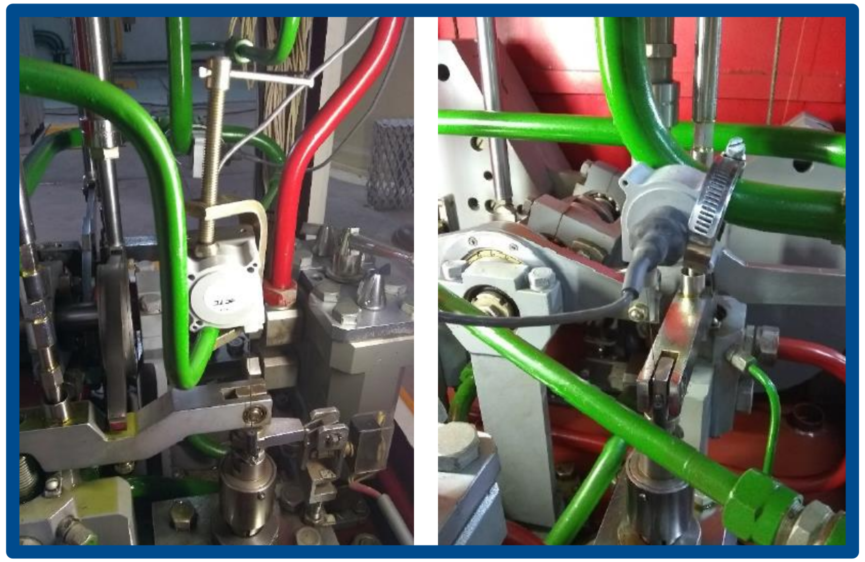
Determine whether the Unit with the new regulator places more or less demands on the turbine's regulation structure, comparing the load cycles due to the effect of pressure variations in the hydraulic system and network frequency using a rainflow methodology of pressures in servomotors, compared to the old regulator (which is emulated with a Unit with the new control).

<u>Methodology</u>

Four 60-minute tests were carried out on two Units working with the same grid frequency disturbance (at WG opening 58%, 61%, 70%; 74.5%). One Unit was in the current power control mode with PFC active, and the other Unit was in opening control adjusted with the parameters such as emulating the old regulator, also with PFC active. Tests were carried out at 3 load levels as was done during footprint tests of the old regulator. For each load level, previously in the turbine with opening control, the control logic was adjusted to find the settling time obtained in the mentioned study with the old regulator. This was checked by performing a frequency step and checking the settling time. A superposition of the curves obtained with those tested by Electrical Studies was made in the old regulator to observe that they are approved. Additionally, a test was carried out with higher power and with the parameters of the highest load level of the previous tests. The previous tests will also check whether there is a dead band between the wicked gate and the runner blade in the old regulator.

Footprint Tests of the Old Governor

Recorder Equipment



MDVs feedback transducers Installation

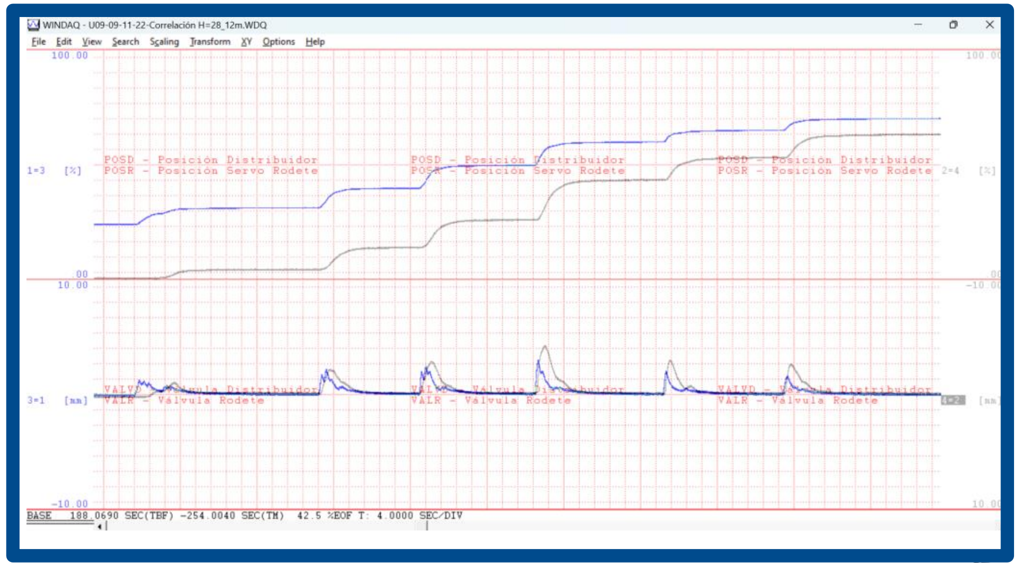
WG servomotor measurement

RB servomotor measurement

Measurement of opening and closing pressures of WG servomotors

Measurement of opening and closing pressures of RB servomotor

Measuring the movement of the WG ring



Recorded trends

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Analysis of Runner Blade Dead Band

"Stabilizer" tuning

The main objective of this study is to analyze the impact of the deadband on runner oscillations for different deadband values and, consequently, the increase or decrease in cyclic loads on the structures.

The initial conditions of the 3 Units:

<u>For all Units:</u>

- Power mode with frequency corrector
- Net head in manual mode H = 24 m
- Power reference P = 120 MW
- Low-pass filter OFF

<u>Unit 2</u>

- RB Dead Band = 0.0°

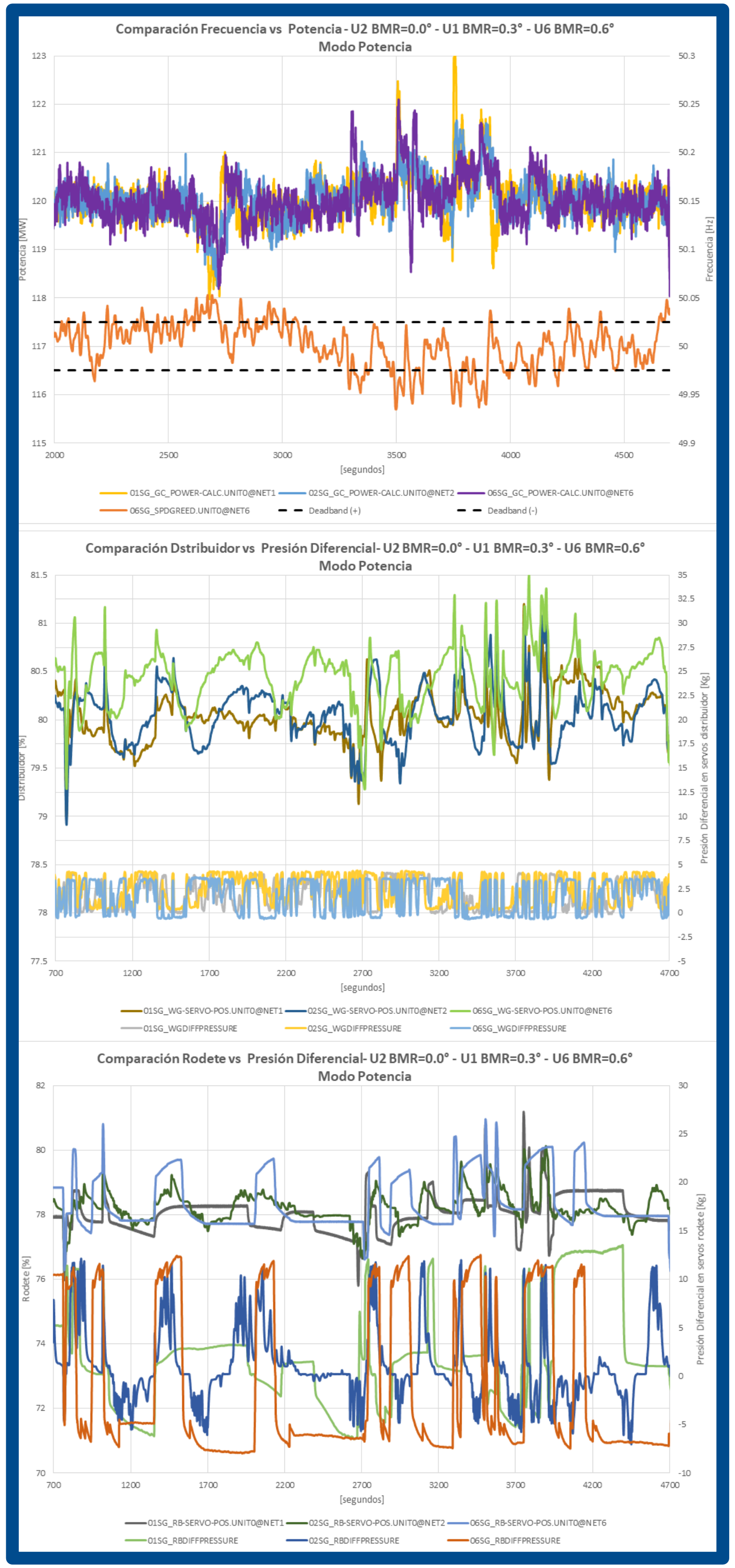
<u>Unit 1</u>

- RB Dead Band = 0.3°

<u>Unit 6</u>

- RB Dead Band = 0.6°

It is important to clarify that with the turbine operating in power control mode, as the runner will have a dead band, at times it will work outside the optimum indicated by the correlation curve and therefore there will be a small drop in efficiency causing the wicket gate to move more to reach the desired power.



An analysis is performed over a range of 4000 sec

The records show all the variables recorded in the three Units: Frequency, Power, WG, RB, and RB and WG differential pressure

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Analysis of Runner Blade Dead Band

Results

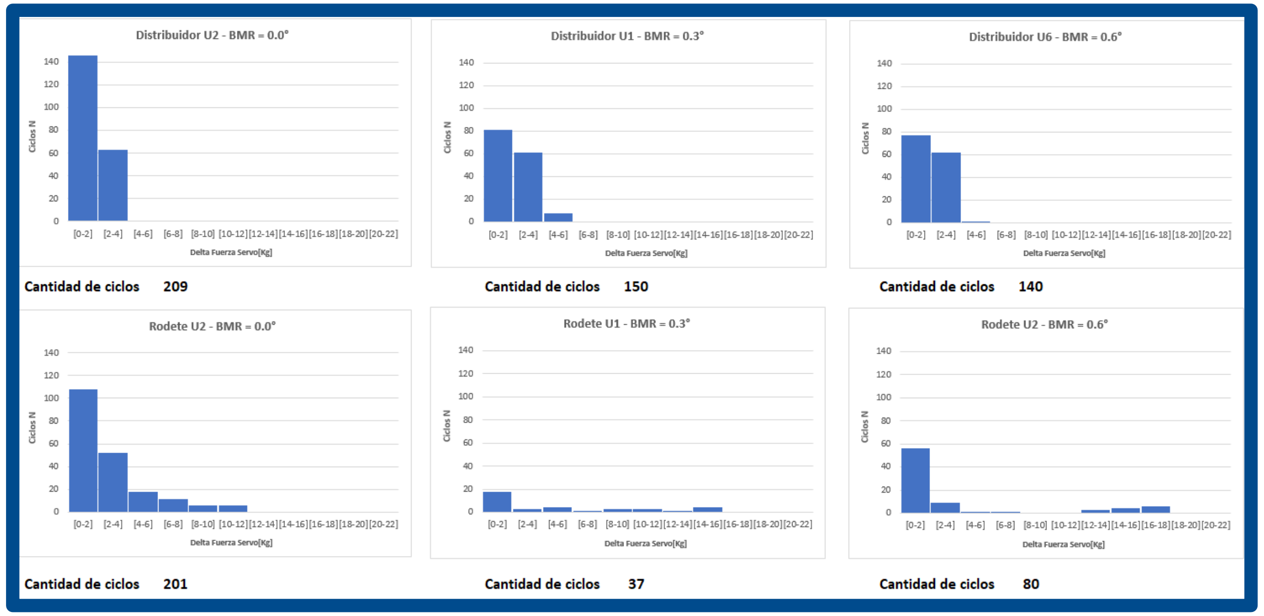
For rainflow counting, pressure fluctuations were classified into 2 kg ranges, and records were taken over 4000 seconds

The lowest number of cycles in the runner blade occurs for a dead band between 0.32 and 0.36 degrees (very similar to IEEE-125; (0.32° equal to 1%))

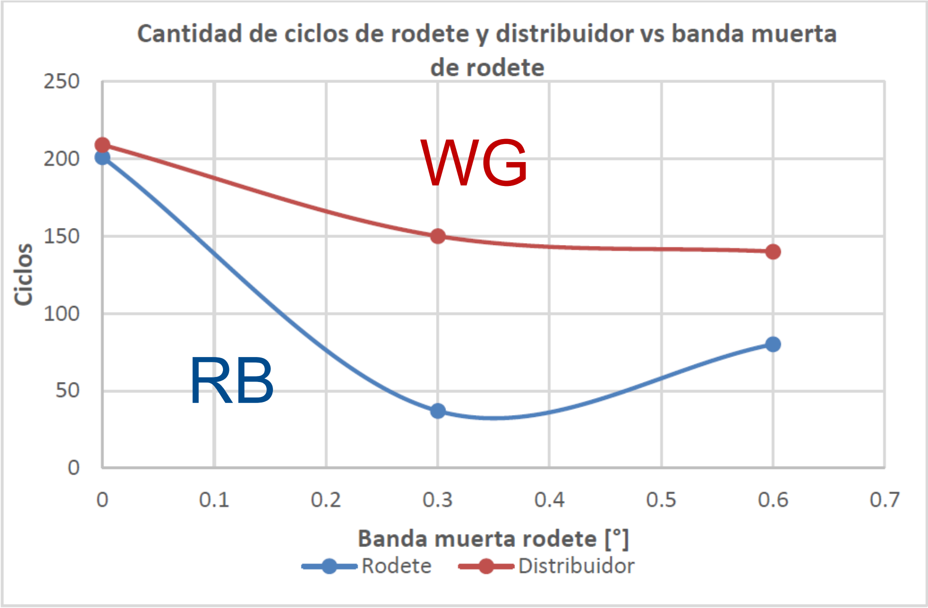
Ciclos en el distribuidor			
Presión [Kg]	Ciclos Unidad 2 BM rodete = 0.0	Ciclos Unidad 1 BM rodete =0.3	Ciclos Unidad 6 BM rodete =0.6
[0-2]	146	81	77
[2-4]	63	61	62
[4-6]	0	8	1
[6-8]	0	0	0
[8-10]	0	0	0
[10-12]	0	0	0
[12-14]	0	0	0
[14-16]	0	0	0
[16-18]	0	0	0
[18-20]	0	0	0
[20-22]	0	0	0
Total	**209**	**150**	**140**

Ciclos en el rodete			
Presión [Kg]	Ciclos Unidad 2 BM = 0.0	Ciclos Unidad 1 BM=0.3	Ciclos Unidad 6 BM=0.6
[0-2]	108	18	56
[2-4]	52	3	9
[4-6]	18	4	1
[6-8]	11	1	1
[8-10]	6	3	0
[10-12]	6	3	0
[12-14]	0	1	3
[14-16]	0	4	4
[16-18]	0	0	6
[18-20]	0	0	0
[20-22]	0	0	0
Total	**201**	**37**	**80**

WG

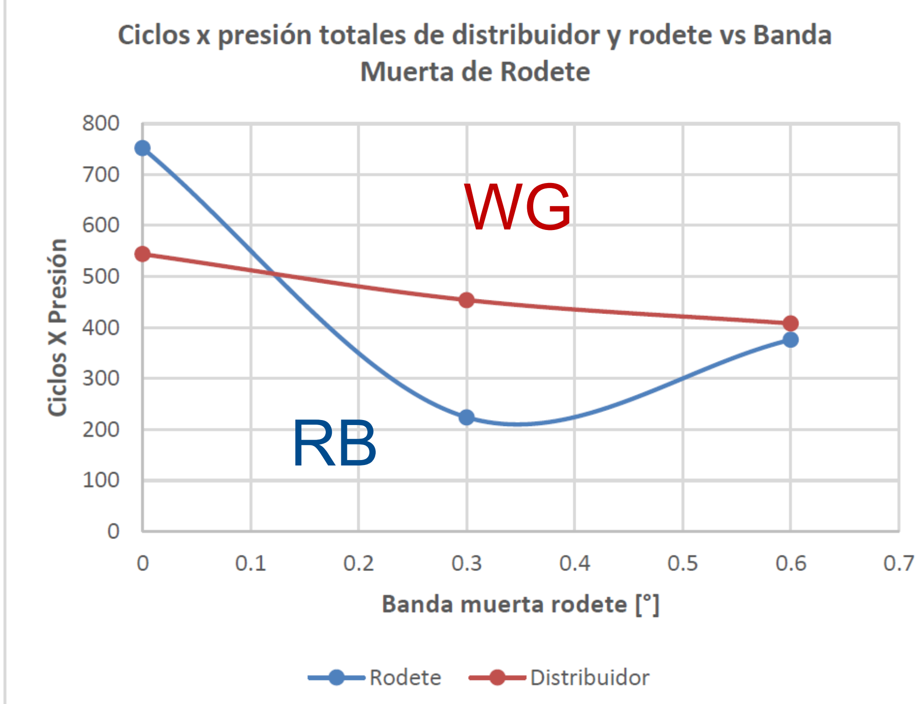


RB



BM [°]	0		0.3		0.6	
	Ciclos	%	Ciclos	%	Ciclos	%
Rodete	201	100%	37	18.41%	80	39.80%
Distribuidor	209	100%	150	71.77%	140	66.99%

The number of RB and WG cycles and RB dead band



BM [°]	0		0.3		0.6	
	Ciclos x P	%	Ciclos x P	%	Ciclos x P	%
Rodete	752	100%	224	29.79%	376	50.00%
Distirbuidor	544	100%	454	83.46%	408	75.00%

Sum of the product of the number of cycles by the maximum pressure value of each range

Governor tests

Wicked Gate Opened at 70%

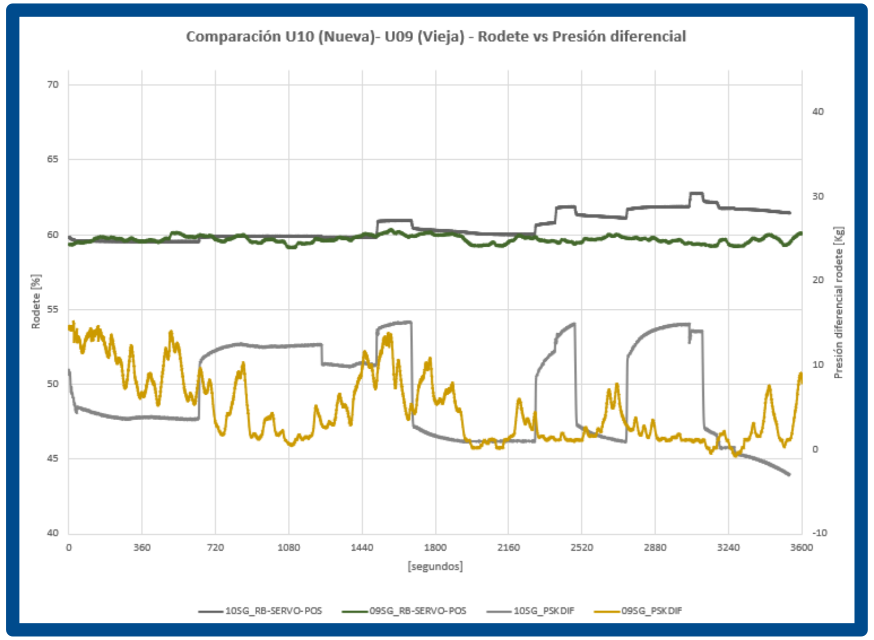
With the below settings, the two Units are placed at 70% opening, Unit 9 in opening mode with PFC and Unit 10 in power mode with PFC. This is recorded for 60 minutes and compared.

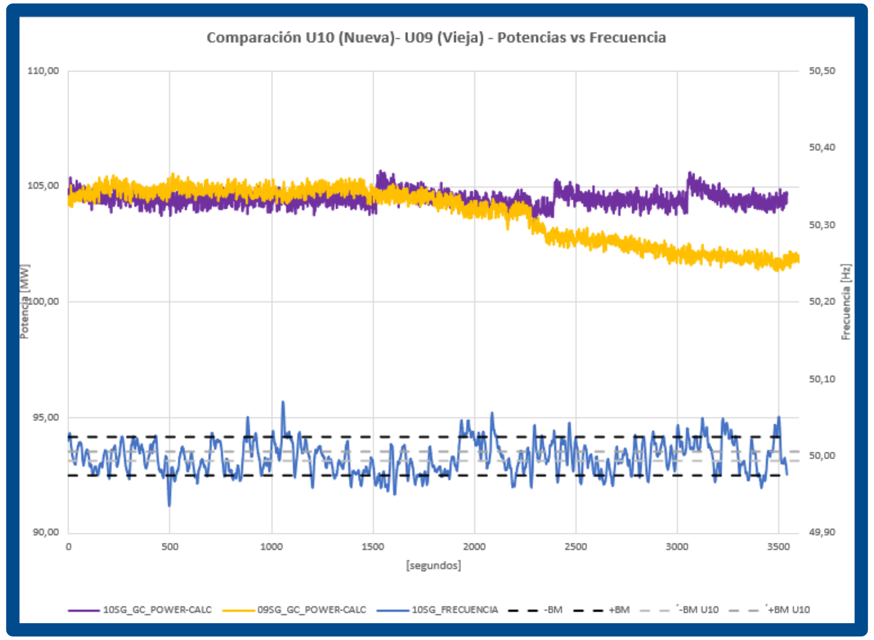
<u>U09</u>

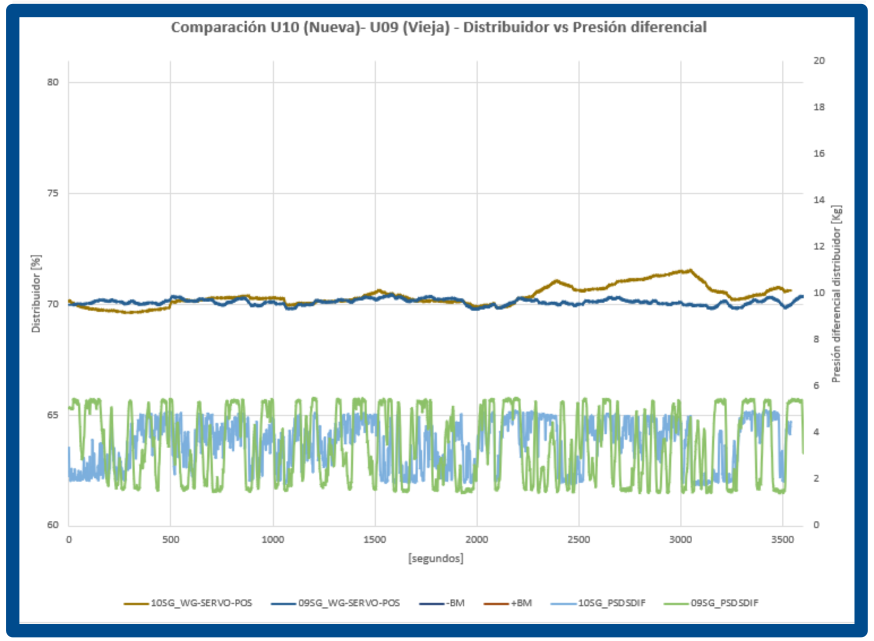
Open mode, PFC active, aperture reference 70%, Runner Blade deadband 0, frequency deadband +/- 6mHz, droop 15.2%. Stabilization time 70 seconds.

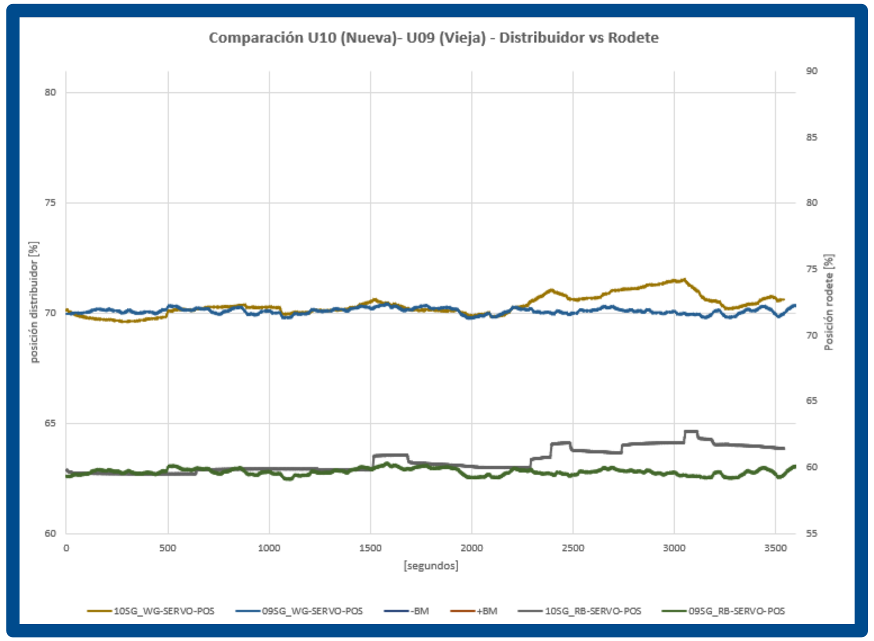
<u>U10</u>

Power mode with PFC active, power reference 104MW, with current settings. "Stabilizer" algorithm with RB dead zone of 1% and "Balancing" are working. Low-Pass filter is disabled.









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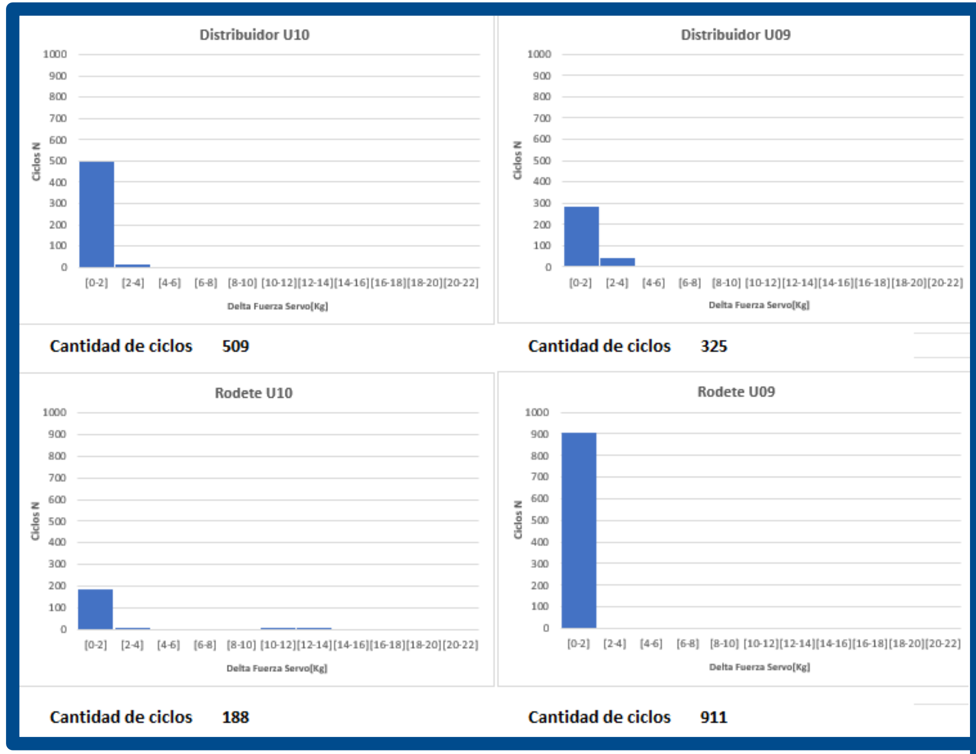
Governor tests

Wicked Gate Opened at 70%

In this opening it is observed that the load on the runner blade in the Unit with the new regulator is considerably lower than the Unit with the regulator that emulates the old regulator, for the wicked gate it is observed that there is an increase in the load of the new Unit.

Similar results were received for other tests (other WG opening).



U10 – Wicked Gate - Cycles x Pressure

Pressure Range	Fmax	Fmin	Cycles	F * N
[0-2]	2	0	496	992
[2-4]	4	2	13	52
[4-6]	6	4	0	0
[6-8]	8	6	0	0
[8-10]	10	8	0	0
[10-12]	12	10	0	0
[12-14]	14	12	0	0
[14-16]	16	14	0	0
[16-18]	18	16	0	0
[18-20]	20	18	0	0
[20-22]	22	20	0	0
			Total	1044

U10 – Runner Blade - Cycles x Pressure

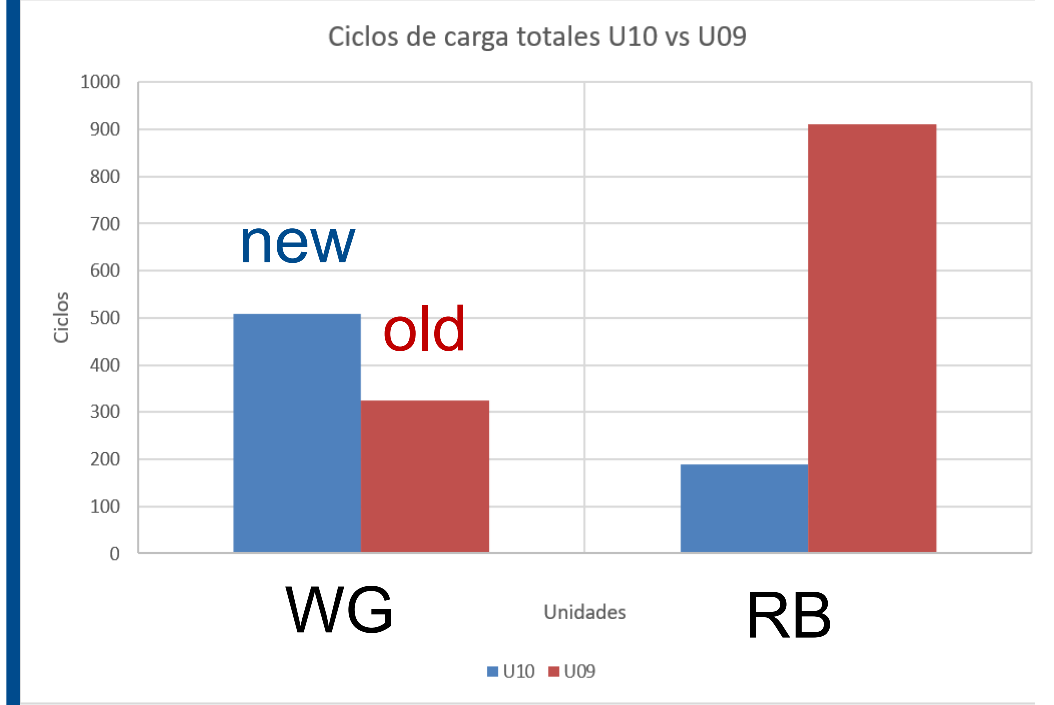
Pressure Range	Fmax	Fmin	Cycles	P * N
[0-2]	2	0	182	364
[2-4]	4	2	3	12
[4-6]	6	4	0	0
[6-8]	8	6	0	0
[8-10]	10	8	0	0
[10-12]	12	10	1	12
[12-14]	14	12	2	28
[14-16]	16	14	0	0
[16-18]	18	16	0	0
[18-20]	20	18	0	0
[20-22]	22	20	0	0
		Total		416

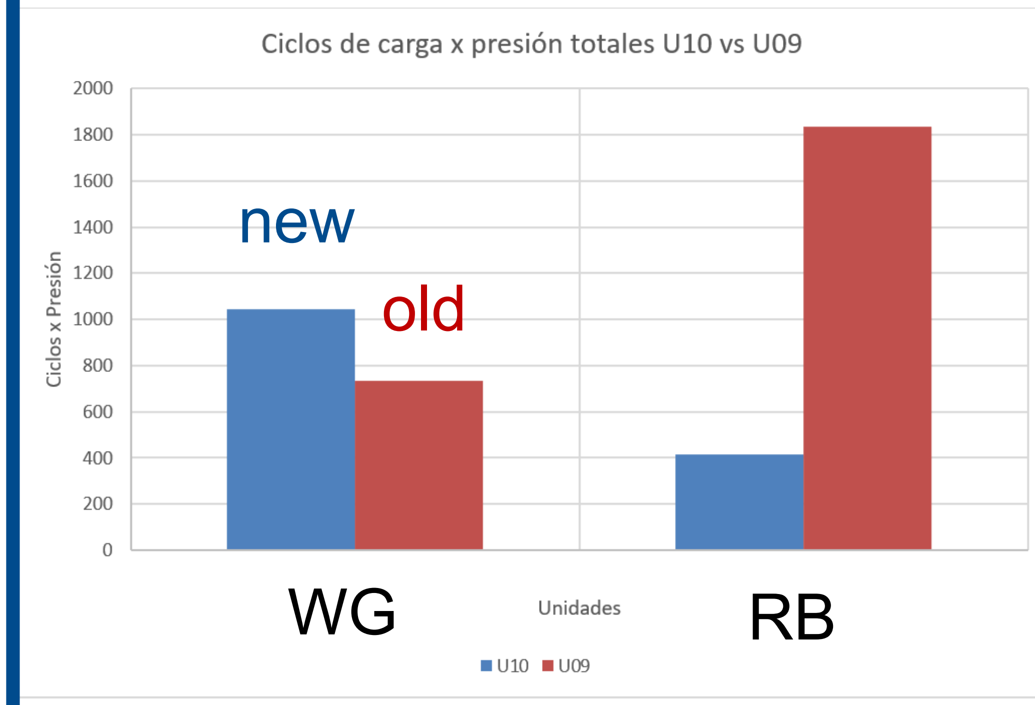
U09 - Wicked Gate - Cycles x Pressure

Pressure Range	Pmax	Pmin	Cycles	F * N
[0-2]	2	0	282	564
[2-4]	4	2	43	172
[4-6]	6	4	0	0
[6-8]	8	6	0	0
[8-10]	10	8	0	0
[10-12]	12	10	0	0
[12-14]	14	12	0	0
[14-16]	16	14	0	0
[16-18]	18	16	0	0
[18-20]	20	18	0	0
[20-22]	22	20	0	0
			Total	736

U09 - Runner Blade - Cycles x Pressure

Pressure Range	Fmax	Fmin	Cycles	F * N
[0-2]	2	0	905	1810
[2-4]	4	2	6	24
[4-6]	6	4	0	0
[6-8]	8	6	0	0
[8-10]	10	8	0	0
[10-12]	12	10	0	0
[12-14]	14	12	0	0
[14-16]	16	14	0	0
[16-18]	18	16	0	0
[18-20]	20	18	0	0
[20-22]	22	20	0	0
			Total	1834



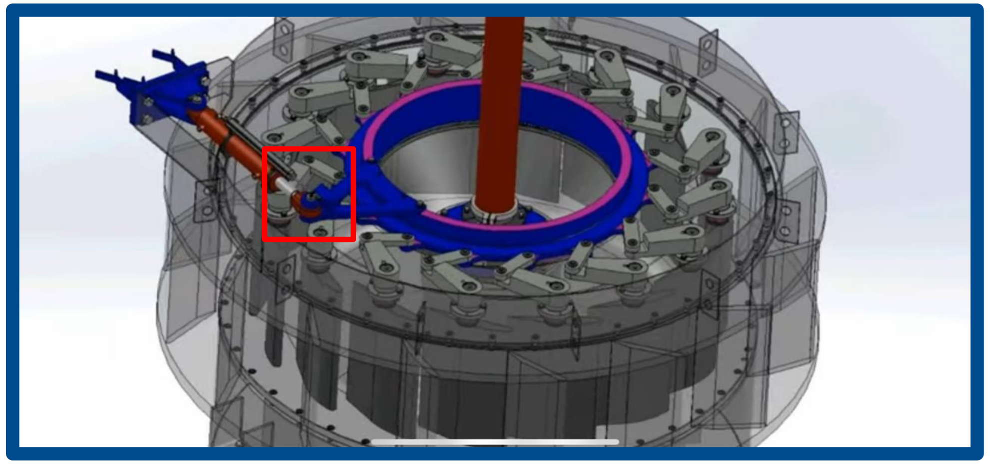


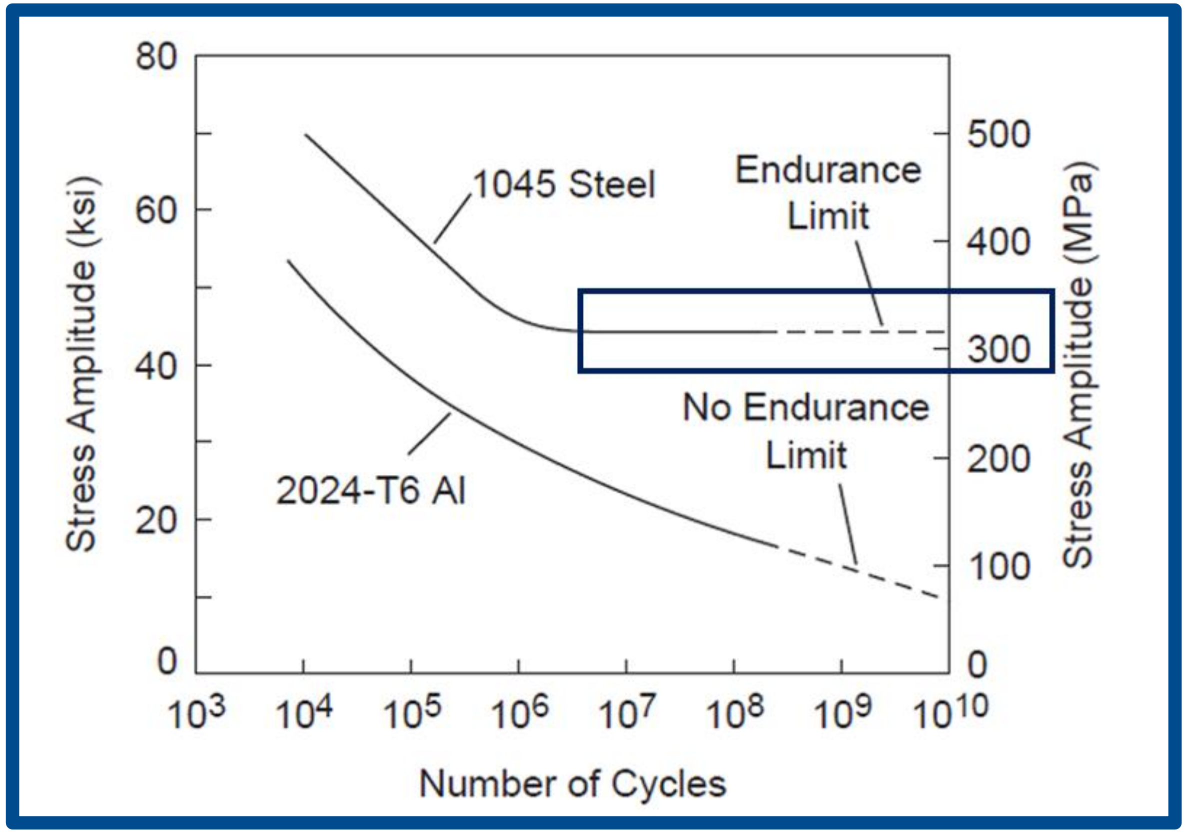
Stress Assessment on the Runner Blade and Wicket Gate

For water turbines, which are participate in AGC/PFC; according to the many publications: the larges stresses in the regulating mechanism are in the runner blade. In the wicket gate the largest stresses are in the connecting pin between the servomotor and the operating ring, however the stress amplitudes are small, therefore fatigue for these nodes is not considered.

That's why, after retrofit the control system, the stress on the runner blade should be no worse than before the upgrade.

In opposite of the runner blade, there are no criteria for the wicket gate. It is believed that some increase in stress in this unit is not critical. However, both when the Voith algorithm is running and when the "Stabilizer" algorithm is running, an increase in stress on the wicket gate is assumed. Here, the criterion for acceptable stress can be the curve of unlimited metal loading.





For some materials there will be an endurance limit, which means that if the stress amplitude is kept below the fatigue limit when the line has flattened out the material can withstand unlimited number of cycles [3]

The endurance limit is around 320 MPa for 1045 Steel or equivalent

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Stress Assessment on the Runner Blade and Wicket Gate

Final Results

1. The "Stabilizer" algorithm with RB's deadband 1%, with the "Balancing" algorithm enabled and the low-pass filter disabled, allowed to reduce the stress on the Runner Blades according to the following:
   a. 0-2 kgf/cm^2 : **77%**
   b. 2-4 kgf/cm^2 : **54%**
   c. 4-6 kgf/cm^2 : **33%**

2. The tension amplitude on the Wicket Gate servomotor decreased according to the following values:
   a. 2-4 kgf/cm^2 : **59%**
   b. 4-6 kgf/cm^2 : **100%**

3. Concentration tension below 2 kgf/cm^2 for wicket gate's servomotor is under of the unlimited number of cycles for Steel 45 or equivalent. Calculated tension much less than 320 MPa (around 55 MPa in the more critical part - the ring pin)

Distributor Opening 70%	WG U10	WG U9 (emulated)	Variation
Cycles	496	282	-76%
Amplitude (KgF)	2	2	
Cycles	13	43	70%
Amplitude (KgF)	4	4	
Cycles	0	0	
Amplitude (KgF)	6	6	

Distributor Opening 70%	RB U10	RB U9 (emulated)	Variation
Cycles	182	905	80%
Amplitude (KgF)	2	2	
Cycles	3	6	50%
Amplitude (KgF)	4	4	
Cycles	0	0	
Amplitude (KgF)	6	6	

Distributor Opening 74.5%	WG U10	WG U9 (emulated)	Variation
Cycles	504	292	-73%
Amplitude (KgF)	2	2	
Cycles	30	36	17%
Amplitude (KgF)	4	4	
Cycles	0	6	100%
Amplitude (KgF)	6	6	

Distributor Opening 74.5%	RB U10	RB U9 (emulated)	Variation
Cycles	195	820	76%
Amplitude (KgF)	2	2	
Cycles	5	5	0%
Amplitude (KgF)	4	4	
Cycles	0	2	100%
Amplitude (KgF)	6	6	

Distributor Opening 61%	WG U10	WG U9 (emulated)	Variation
Cycles	456	176	-159%
Amplitude (KgF)	2	2	
Cycles	14	61	77%
Amplitude (KgF)	4	4	
Cycles	0	0	
Amplitude (KgF)	6	6	

Distributor Opening 61%	RB U10	RB U9 (emulated)	Variation
Cycles	91	485	81%
Amplitude (KgF)	2	2	
Cycles	1	3	67%
Amplitude (KgF)	4	4	
Cycles	1	0	-100%
Amplitude (KgF)	6	6	

Distributor Opening 58%	WG U10	WG U9 (emulated)	Variation
Cycles	418	192	-118%
Amplitude (KgF)	2	2	
Cycles	16	59	73%
Amplitude (KgF)	4	4	
Cycles	0	0	
Amplitude (KgF)	6	6	

Distributor Opening 58%	RB U10	RB U9 (emulated)	Variation
Cycles	128	448	71%
Amplitude (KgF)	2	2	
Cycles	0	13	100%
Amplitude (KgF)	4	4	
Cycles	0	1	100%
Amplitude (KgF)	6	6	

Average 0-2	-106%
Average 2-4	59%
Average 4-6	100%

Average 0-2	77%
Average 2-4	54%
Average 4-6	33%

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Conclusions

- Emerson longterm experience in Governor tuning and flexibility to dynamic of the unit
- From the analysis presented investigation, it is concluded that the runner blade dead band of 1% (0.32 degrees) as suggested by the IEEE-125 standard and as shown with the comparison between 3 Units operating under the same conditions but with different dead bands, significantly reduces the oscillating loads on the runner blade when primary frequency regulation is performed.
- From the presented analysis, it is concluded that, comparing the two Units for different loads, the **effort on the runner blade decreases considerably** in the current operation with the Ovation system (more than 4 times).
- Regarding the **wicked gate**, an **increase in cycles is noted**, however, it is an expected result considering the compromise between different variables that are performance efficiency, AGC/PFC requirement and control stability.
- Making a relationship with the master's study by Aron Tapper “A fatigue investigation in a Kaplan hydropower station operating in frequency regulation mode”, where a fatigue analysis is made on a Kaplan turbine regulating frequency, it can be inferred that the effort in the wicked gate in terms of fatigue is 38 times less than in the Runner Blade.
- Concentration tension for wicket gate’s servomotor is under of the unlimited number of cycles for Steel 45.
- The results allow to rule out any oscillation harmful to the Unit components and confirm that the control parameters and their setting are optimal to continue operation under international and national standards related to AGC/PFC /LFC.

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Questions?

François Guermeur; francois.guermeur@emerson.com

Zoya Shavlovich; zoya.shavlovich@emerson.com