Stator Winding Wedge Tightness Evaluation on Large Hydro Generators

2022 IRIS Rotating Machines Conference

June 14, 2022

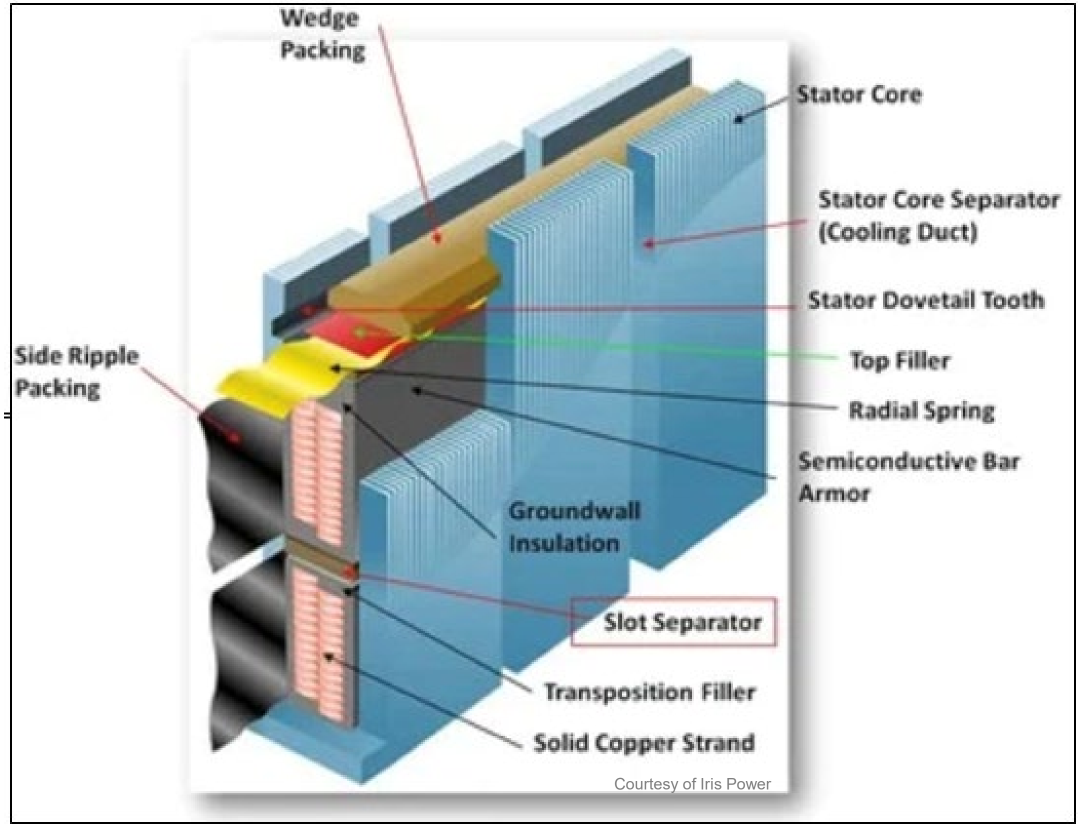
Presented by:

Igor Chichkin, P.Eng

BC Hydro, Canada

BC Hydro
Power smart

Concept of Stator Core slot packing



Courtesy of Iris Power

There are many different winding systems utilized by different manufactures. However, all have the common purpose to keep the stator bars /or coils tight in the slot.

Shall the stator winding be tight in the slots ?

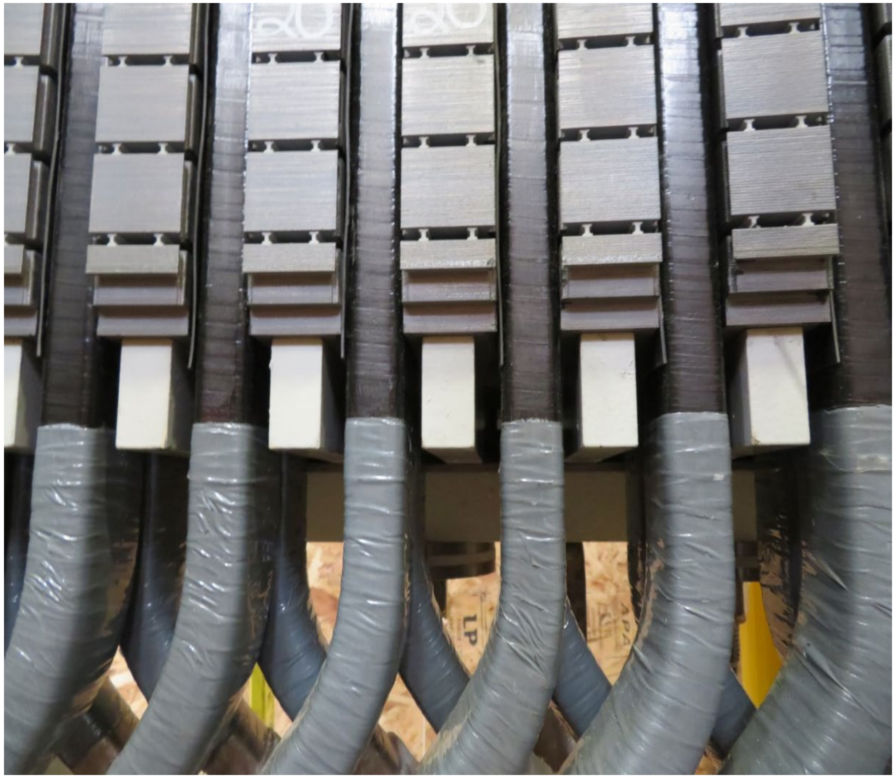
Several factors which influence Stator Wedge System relaxation :

1. Winding crew experience
2. Rate of Thermal Cycling Wedge System experiences
3. Percent of depth packing used in total slot
4. Wedge system used
5. Total slot coil side force

- Thermoplastic and Thermoset stator winding
- Semi-conductive side- packing and its installation
- “Twintone ®” winding doesn’t need separate side-packing

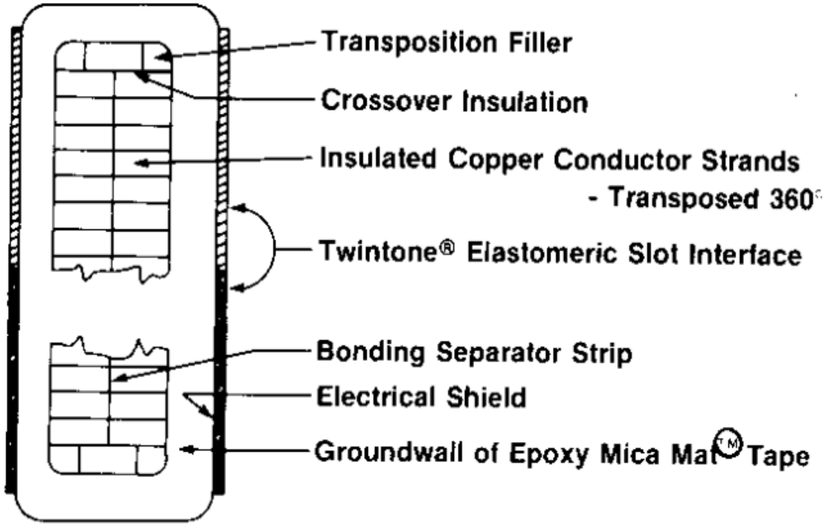
Stator winding side packing

Side packing (trailing side of the bar)



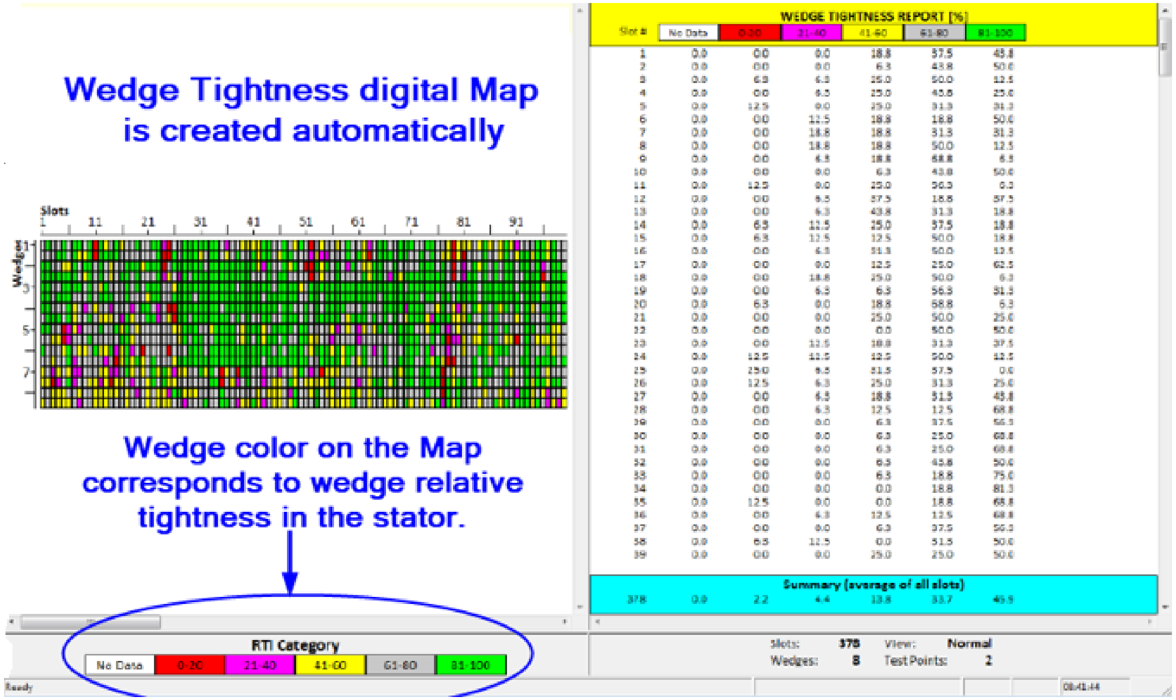
Twintone® bar design

(no side packing is necessary)



Stator Wedge Tightness testing (electronic)

Iris Power
SWA (Stator
Wedge
Analizer)



Wedge Tightness digital Map
is created automatically

Wedge color on the Map
corresponds to wedge relative
tightness in the stator.

WEDGE TIGHTNESS REPORT [%]

Slot #	No Data 🟥	0-20 🟥	21-40 🟪	41-60 🟨	61-80 ▨	81-100 🟩
1	0.0	0.0	0.0	18.8	37.5	43.8
2	0.0	0.0	0.0	6.3	43.8	50.0
3	0.0	6.3	6.3	25.0	50.0	12.5
4	0.0	0.0	6.3	25.0	43.8	25.0
5	0.0	12.5	0.0	25.0	31.3	31.3
6	0.0	0.0	12.5	18.8	18.8	50.0
7	0.0	0.0	18.8	18.8	31.3	31.3
8	0.0	0.0	18.8	18.8	50.0	12.5
9	0.0	0.0	6.3	18.8	68.8	6.3
10	0.0	0.0	0.0	6.3	43.8	50.0
11	0.0	12.5	0.0	25.0	56.3	6.3
12	0.0	0.0	6.3	37.5	18.8	37.5
13	0.0	0.0	6.3	43.8	31.3	18.8
14	0.0	6.3	12.5	25.0	37.5	18.8
15	0.0	6.3	12.5	12.5	50.0	18.8
16	0.0	0.0	6.3	31.3	50.0	12.5
17	0.0	0.0	0.0	12.5	25.0	62.5
18	0.0	0.0	18.8	25.0	50.0	6.3
19	0.0	0.0	6.3	6.3	56.3	31.3
20	0.0	6.3	0.0	18.8	68.8	6.3
21	0.0	0.0	0.0	25.0	50.0	25.0
22	0.0	0.0	0.0	0.0	50.0	50.0
23	0.0	0.0	12.5	18.8	31.3	37.5
24	0.0	12.5	12.5	12.5	50.0	12.5
25	0.0	25.0	6.3	31.3	37.5	0.0
26	0.0	12.5	6.3	25.0	31.3	25.0
27	0.0	0.0	6.3	18.8	31.3	43.8
28	0.0	0.0	6.3	12.5	12.5	68.8
29	0.0	0.0	0.0	6.3	37.5	56.3
30	0.0	0.0	0.0	6.3	25.0	68.8
31	0.0	0.0	0.0	6.3	25.0	68.8
32	0.0	0.0	0.0	6.3	43.8	50.0
33	0.0	0.0	0.0	6.3	18.8	75.0
34	0.0	0.0	0.0	0.0	18.8	81.3
35	0.0	12.5	0.0	0.0	18.8	68.8
36	0.0	0.0	6.3	12.5	12.5	68.8
37	0.0	0.0	0.0	6.3	37.5	56.3
38	0.0	6.3	12.5	0.0	31.3	50.0
39	0.0	0.0	0.0	25.0	25.0	50.0

Summary (average of all slots)

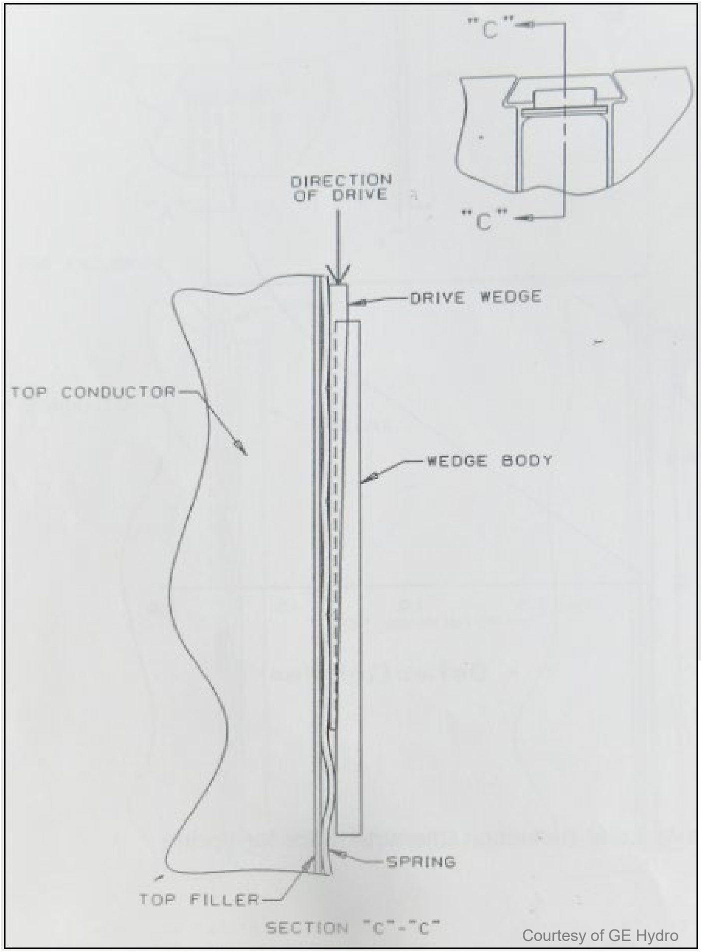
378	0.0	2.2	4.4	13.8	33.7	45.9

Slots: 378 View: Normal
Wedges: 8 Test Points: 2

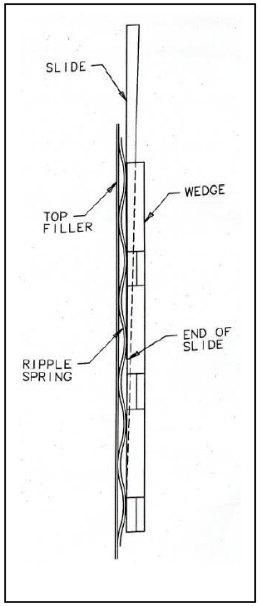
Proceq Equotip
SVP 40

Wedging Systems Assembly

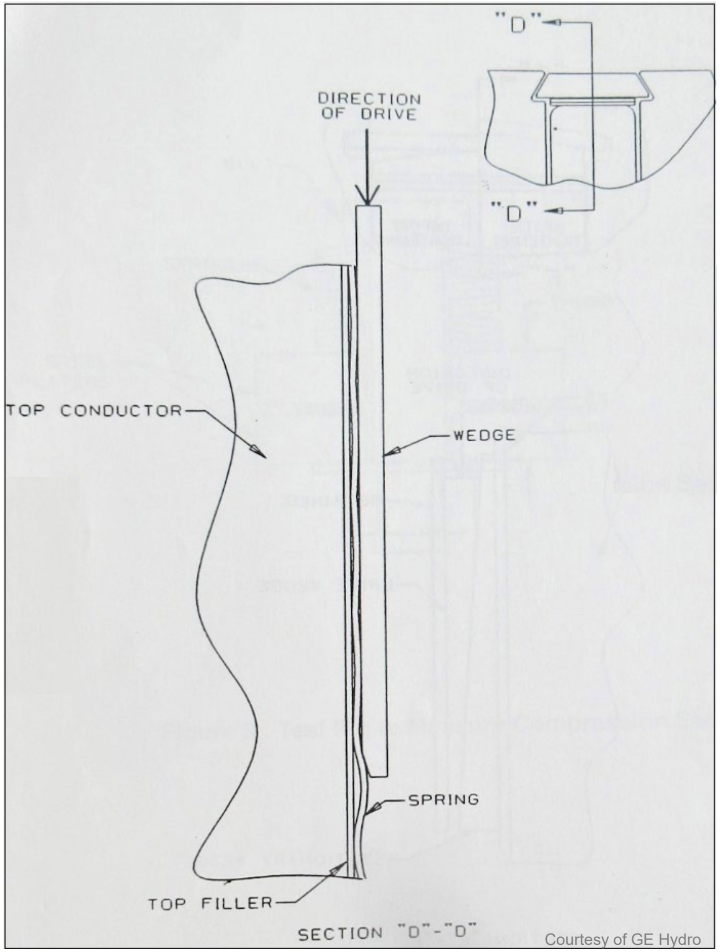
Radial wedge and spring - “Piggy-back”



Courtesy of GE Hydro



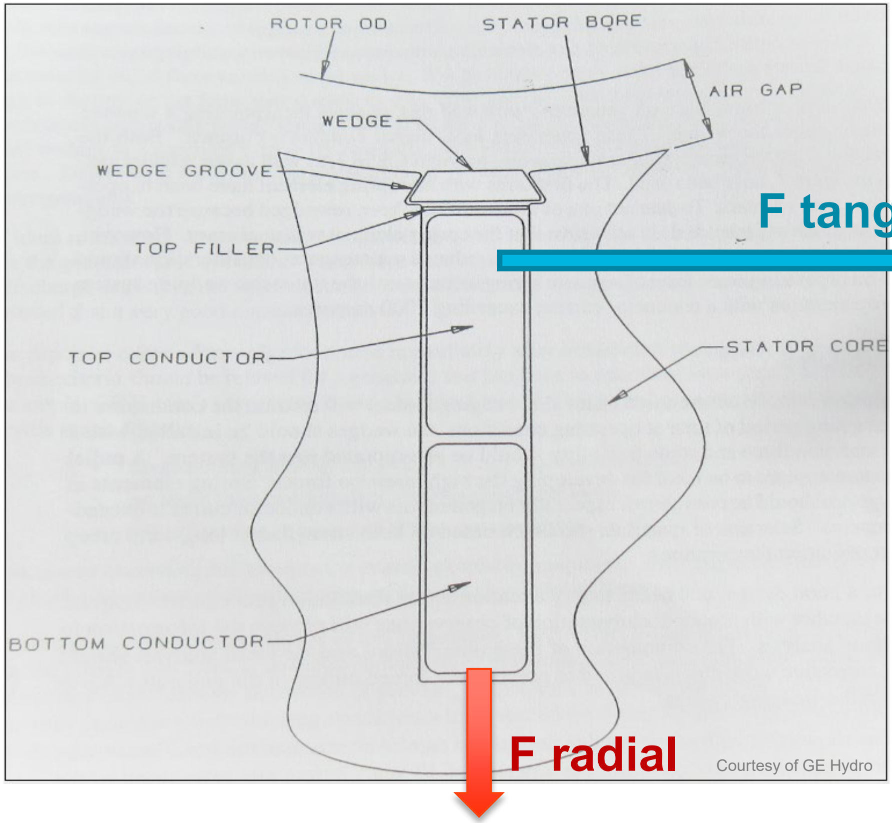
Slab wedge and spring



Courtesy of GE Hydro

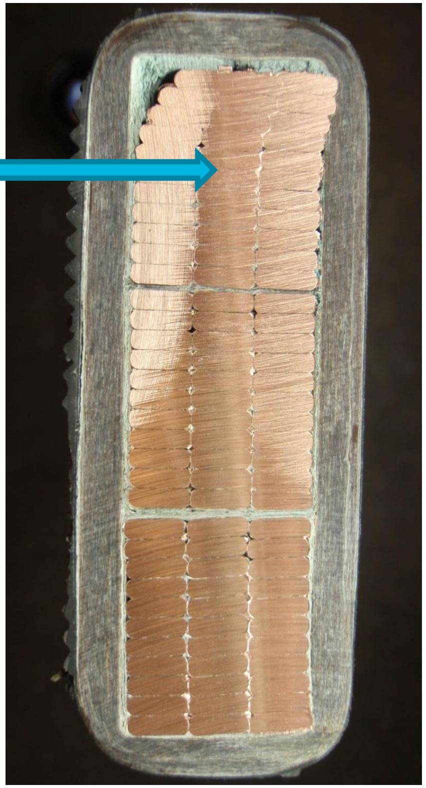
Mechanical Stress

Effects of radial and tangential forces.



Courtesy of GE Hydro

Air gap row is 10% narrower than other rows



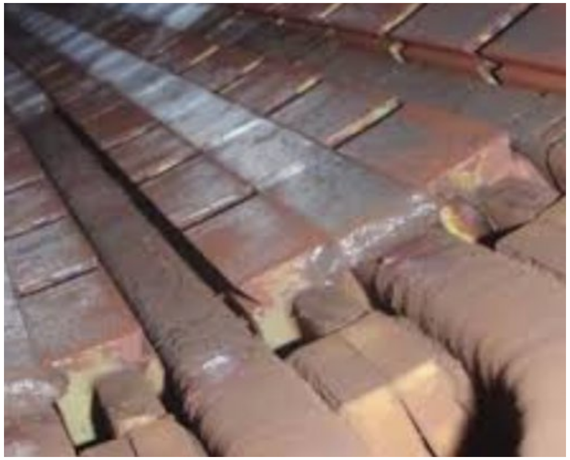
Two major current related stressors

Radial and **tangential** forces acting on the conductors

- Radial 10X larger than tangential
- Both due to current in the conductors
- Tangential forces highest at the air gap

BC Hydro
Power smart

Thermal stress



Thermal Expansion (axial & radial directions)

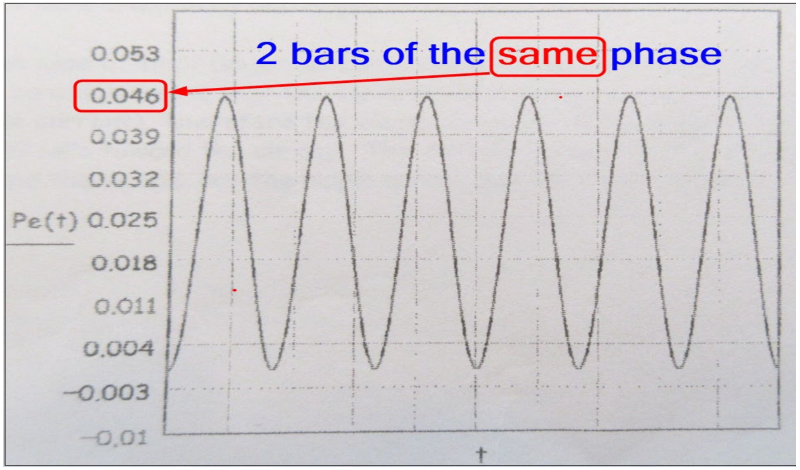
- ➢ Considerable heat is generated in the stator bar or coil creating thermal expansion, contraction and insulation shrinkage:
  - ✓ *Can easily loosen bars/coils in the slot, if not wedged properly.*
- ➢ Increase in copper conductor temperature causes increase in coil/bar length:
  - ✓ *Axial grow could be ~ 1-2 mm*
  - ✓ *Different thermal coefficient of expansion for copper conductor and core lamination steel* → *causes relative movement between conductor and the slot occurs and needs a slip plane.*
- ➢ Bar/coil not properly bottomed in the slot when wedged plus insulation shrinkage and *vibration* → *causes coil/bar looseness.*

Thermal/chemical deterioration followed by conductor forces and voltage stress appears to be the predominate ageing mechanism.

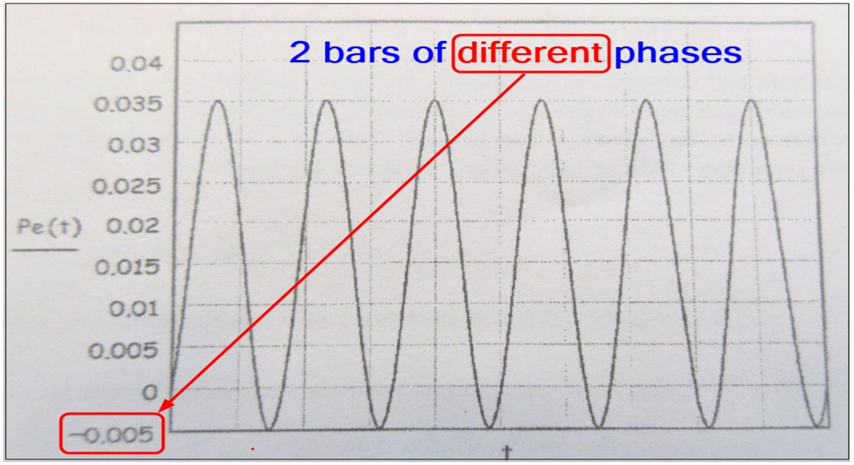
Forces acting on the Stator bars

Electromagnetic pressures (**Pe**) acting on the stator bar

For 275 MVA machine **Pe** [MPa] was calculated considering dimensions of the stator slot / copper bar, and 2176 A current per circuit :



Maximum **Pe** pressure on the top bar (in the same phase) applied towards the bottom of the slot : 0.046 MPa



Maximum **Pe** pressure applied towards the ripple spring is 0.005 MPa and it occurs in slots with bars of different phases.

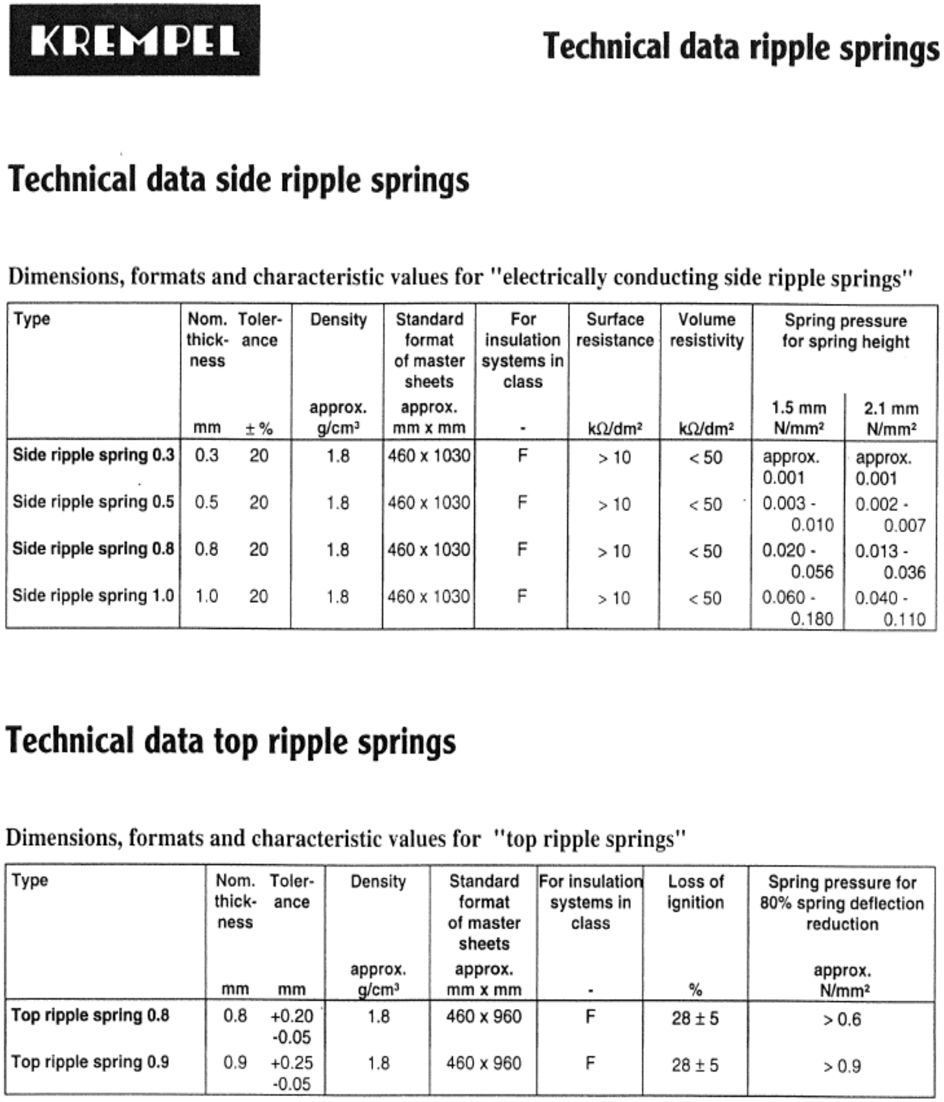
Under the fault (short-circuit conditions) :

Sub-transient currents 1/xd"=5.76 pu → Pe= 0.005 MPa x (5.67^2)= 0.1609 MPa towards the air gap.

Some "settling" of slot content over time → remaining spring compression 0.53 MPa – 1.86 MPa

Safety Factor under this condition 0.53/0.1609 = **3.3** → even if the spring is compressed <70% ,still the margins would be available.

Top and Side Ripple Springs



KREMPEL

Technical data ripple springs

Technical data side ripple springs

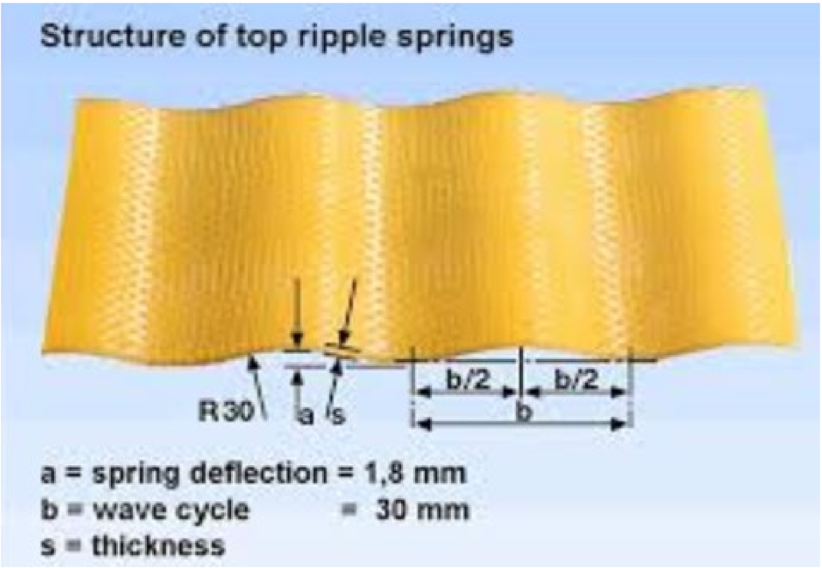
Dimensions, formats and characteristic values for "electrically conducting side ripple springs"

Type	Nom. thickness	Tolerance	Density	Standard format of master sheets	For insulation systems in class	Surface resistance	Volume resistivity	Spring pressure for spring height	
	mm	± %	approx. g/cm³	approx. mm x mm	-	kΩ/dm²	kΩ/dm²	1.5 mm N/mm²	2.1 mm N/mm²
Side ripple spring 0.3	0.3	20	1.8	460 x 1030	F	> 10	< 50	approx. 0.001	approx. 0.001
Side ripple spring 0.5	0.5	20	1.8	460 x 1030	F	> 10	< 50	0.003 - 0.010	0.002 - 0.007
Side ripple spring 0.8	0.8	20	1.8	460 x 1030	F	> 10	< 50	0.020 - 0.056	0.013 - 0.036
Side ripple spring 1.0	1.0	20	1.8	460 x 1030	F	> 10	< 50	0.060 - 0.180	0.040 - 0.110

Technical data top ripple springs

Dimensions, formats and characteristic values for "top ripple springs"

Type	Nom. thickness	Tolerance	Density	Standard format of master sheets	For insulation systems in class	Loss of ignition	Spring pressure for 80% spring deflection reduction
	mm	mm	approx. g/cm³	approx. mm x mm	-	%	approx. N/mm²
Top ripple spring 0.8	0.8	+0.20 -0.05	1.8	460 x 960	F	28 ± 5	> 0.6
Top ripple spring 0.9	0.9	+0.25 -0.05	1.8	460 x 960	F	28 ± 5	> 0.9

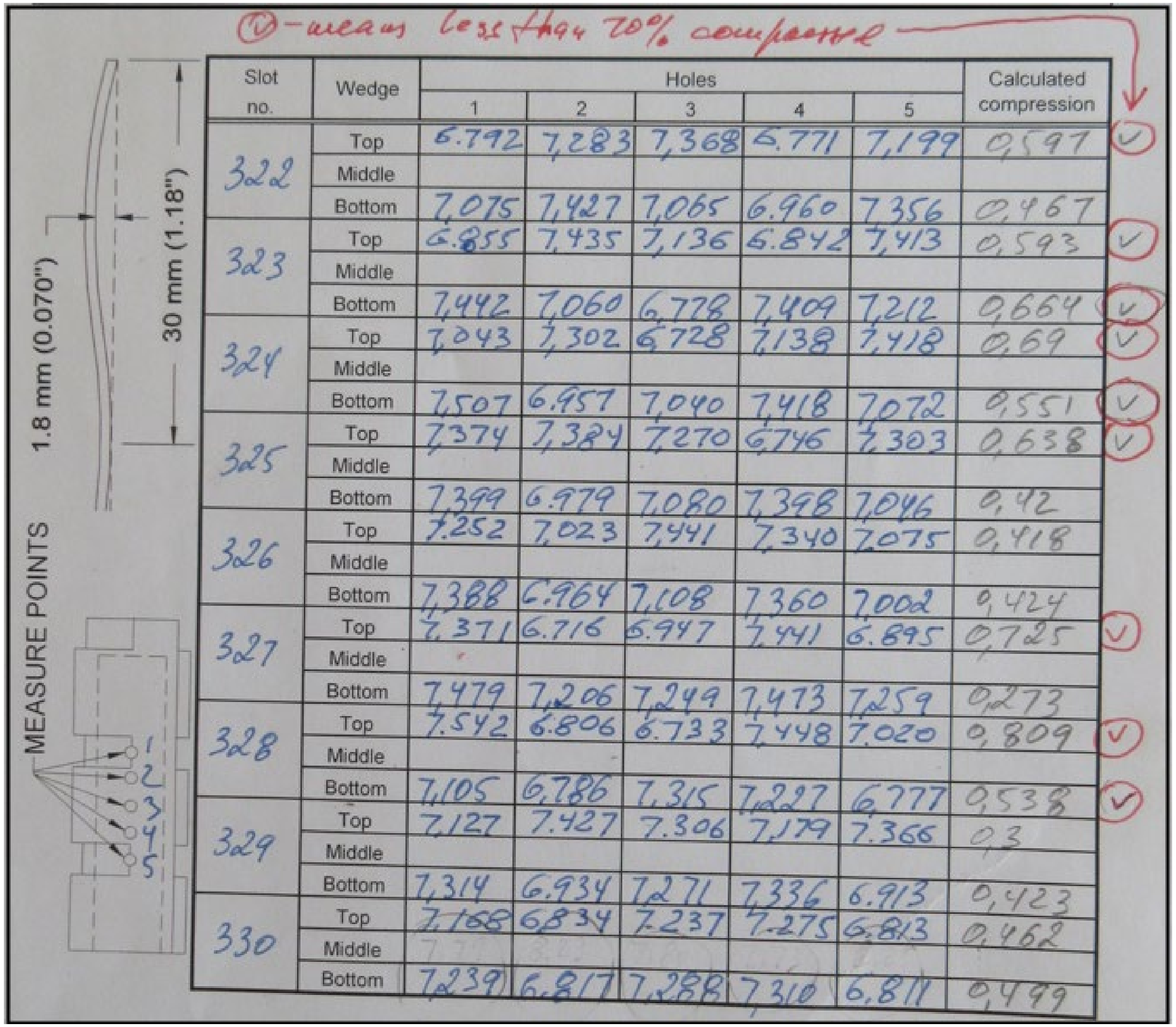


Structure of top ripple springs

a = spring deflection = 1,8 mm
b = wave cycle = 30 mm
s = thickness

Ripple Spring Deflection measurements

Wedge to be considered “ loose” (i.e. < 70% compressed)
if spring deflection measured is > 0.533 mm

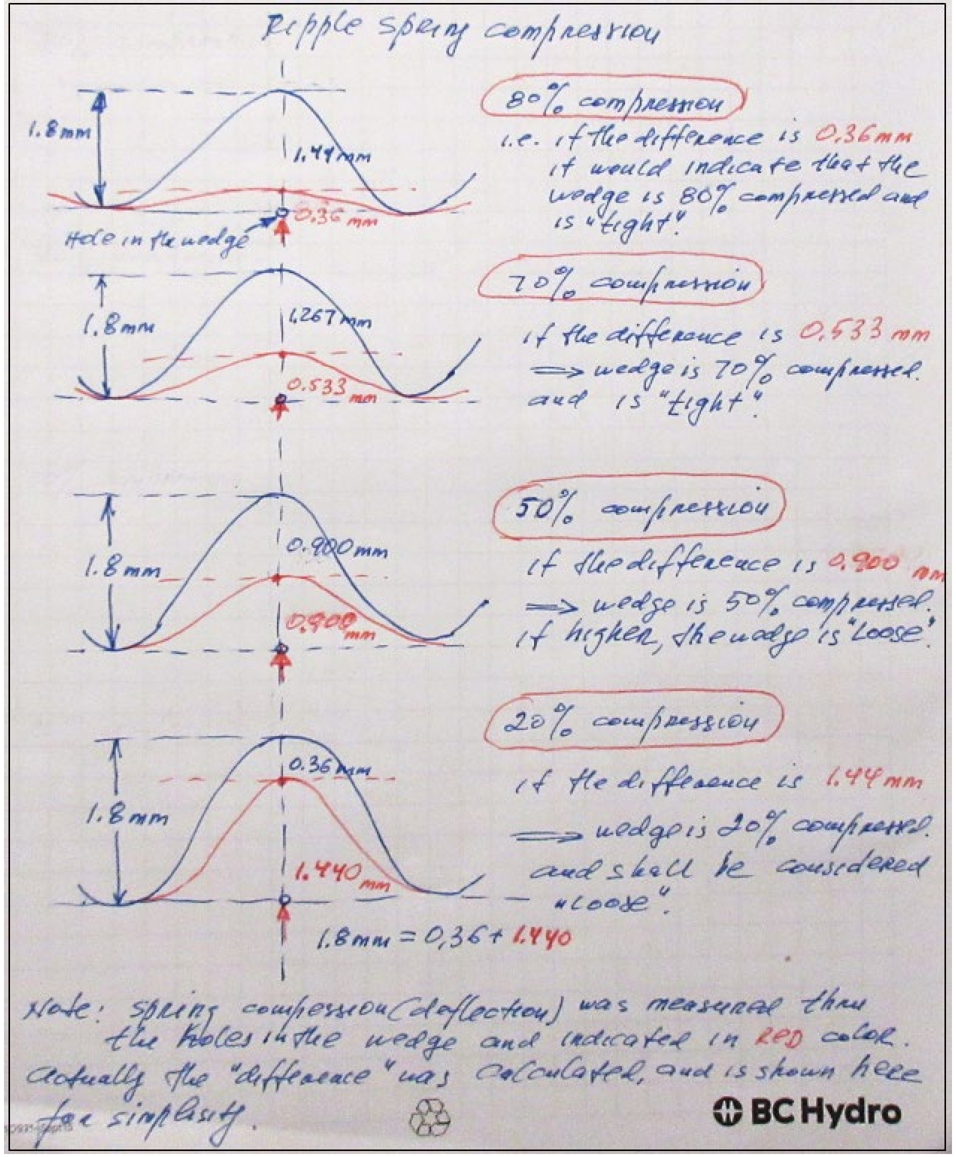


(✓) - means less than 70% compressed

Slot no.	Wedge	Holes 1	2	3	4	5	Calculated compression	
322	Top	6.792	7,283	7,368	6.771	7,199	0,597	(✓)
	Middle							
	Bottom	7,075	7,427	7,065	6.960	7,356	0,467	
323	Top	6.855	7,435	7,136	6.842	7,413	0,593	(✓)
	Middle							
	Bottom	7,442	7,060	6,778	7,409	7,212	0,664	(✓)
324	Top	7,043	7,302	6,728	7,138	7,418	0,69	(✓)
	Middle							
	Bottom	7,507	6.957	7,040	7,418	7,072	0,551	(✓)
325	Top	7,374	7,384	7,270	6,746	7,303	0,638	(✓)
	Middle							
	Bottom	7,399	6.979	7,080	7,398	7,046	0,42	
326	Top	7.252	7,023	7,441	7,340	7,075	0,418	
	Middle							
	Bottom	7,388	6.964	7,108	7,360	7,002	0,424	
327	Top	7,371	6.716	6.947	7,441	6.895	0,725	(✓)
	Middle							
	Bottom	7,479	7,206	7,249	7,473	7,259	0,273	
328	Top	7.542	6.806	6.733	7,448	7,020	0,809	(✓)
	Middle							
	Bottom	7,105	6,786	7,315	7,227	6,777	0,538	(✓)
329	Top	7,127	7.427	7.306	7,179	7.366	0,3	
	Middle							
	Bottom	7,314	6.934	7,271	7,336	6.913	0,423	
330	Top	7,168	6,834	7.237	7.275	6,813	0,462	
	Middle							
	Bottom	7,239	6,817	7,288	7,310	6,811	0,499	

Mitutoyo ID-S112MX
electronic Depth Gauge

KREMPEL Ripple Spring Deflection



Ripple spring compression

80% compression

i.e. if the difference is 0,36mm it would indicate that the wedge is 80% compressed and is "tight".

70% compression

if the difference is 0,533 mm ⟹ wedge is 70% compressed. and is "tight".

50% compression

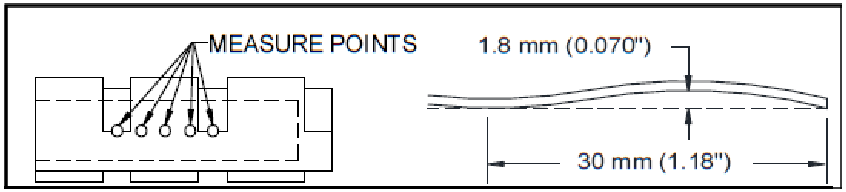
if the difference is 0.900 mm ⟹ wedge is 50% compressed. if higher, the wedge is "Loose".

20% compression

if the difference is 1.44mm ⟹ wedge is 20% compressed. and shall be considered "Loose".

1.8mm = 0,36 + 1.440

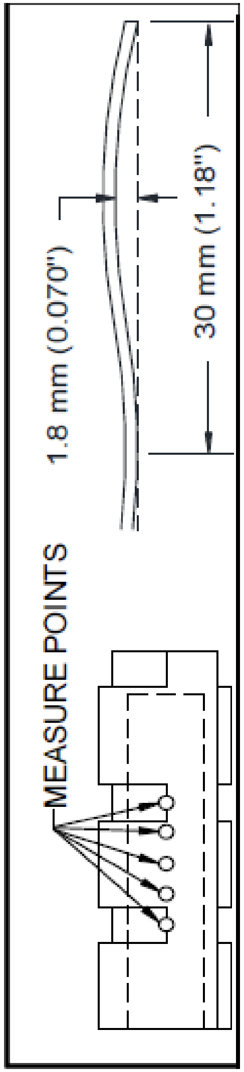
Note: spring compression (deflection) was measured thru the holes in the wedge and indicated in RED color. Actually the "difference" was calculated, and is shown here for simplisity.



When the wedge is **70%** compressed the spring deflection would be 1.267 mm (= 70 % x 1.8 mm) and depth measured thru the hole. = 0.533 mm

When the wedge is **20%** compressed the spring deflection would be 0.36 mm (= 20% x 1.8 mm) and measured 1.440 mm thru the hole.

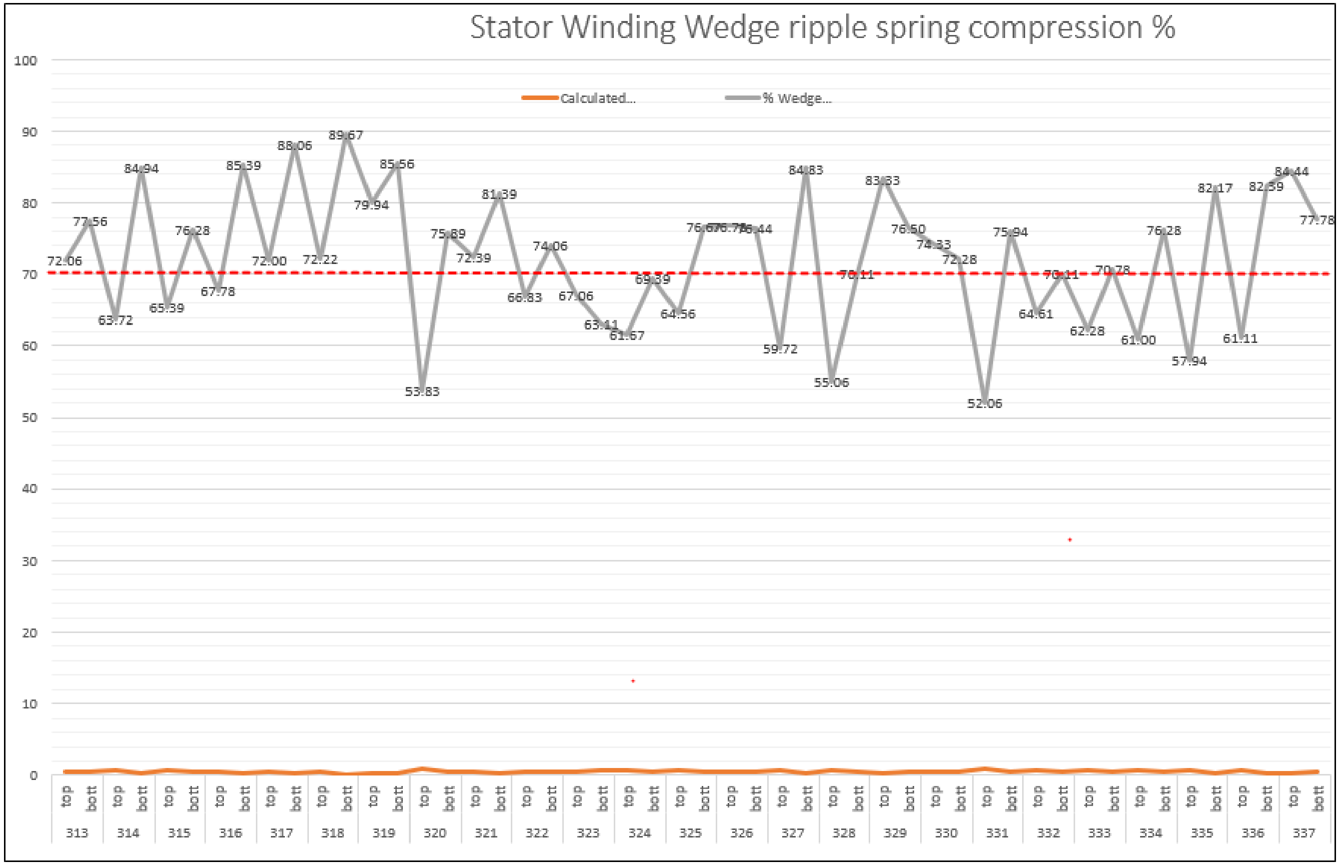
Ripple Spring Deflection measurements



50 wedges tested through their holes using

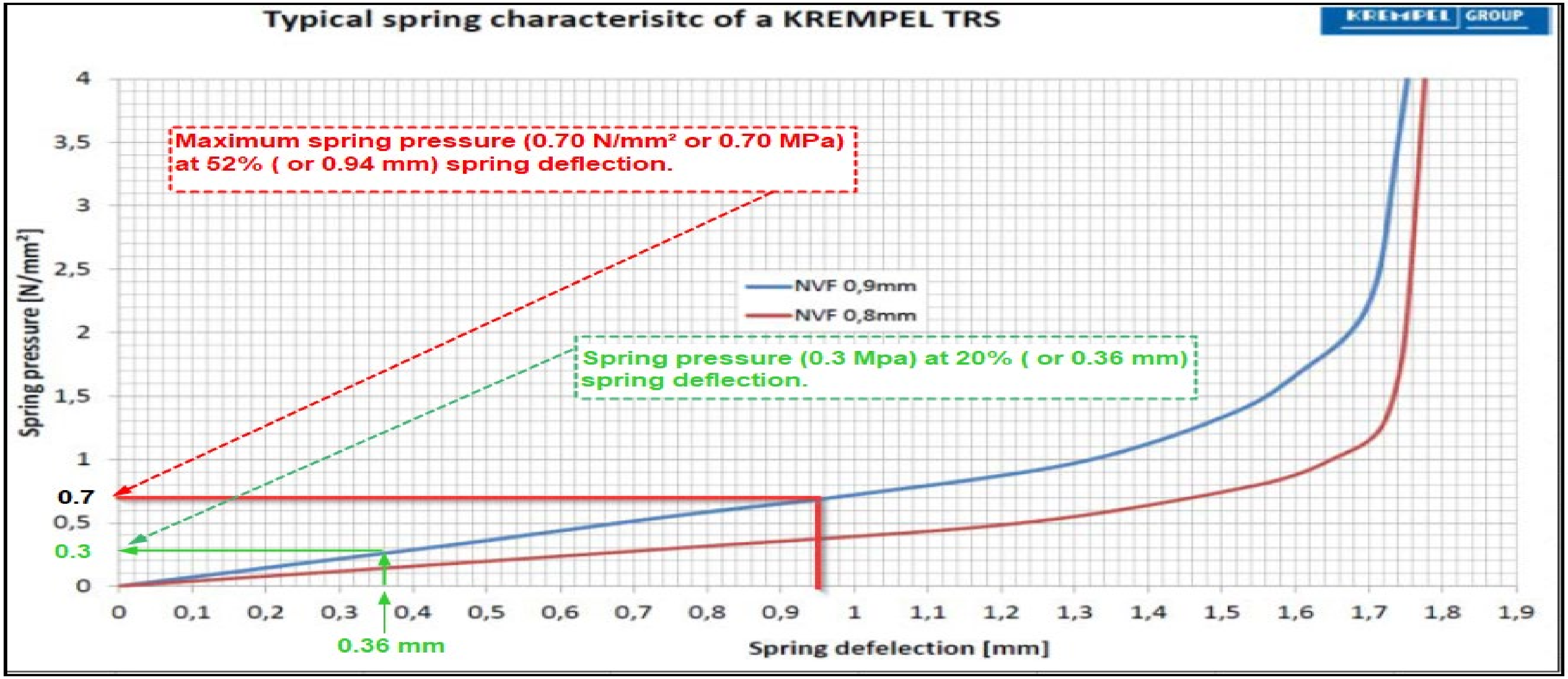
Mitutoyo ID-S112MX electronic Depth Gauge

(acceptance criteria > 70% spring compression)



BC Hydro
Power smart

KREMPEL Ripple Spring Pressure vs Spring Deflection



Typical spring characterisitc of a KREMPEL TRS

Maximum spring pressure (0.70 N/mm² or 0.70 MPa) at 52% (or 0.94 mm) spring deflection.

Spring pressure (0.3 Mpa) at 20% (or 0.36 mm) spring deflection.

Maximum inward pressure from the top bar is 0.005 MPa during normal operating conditions.

- With the lowest measured ripple spring compression 0.94 mm (or 52%), the spring pressure is **140** (=0.70/0.005) times greater than the maximum inward pressure of 0.005 MPa from the top bar, i.e. the Safety Factor (SF)=140 during normal operating conditions.

- When the wedge is 20% compressed , the spring deflection would be 0.36 mm (= 20% x 1.8 mm) and the pressure is ~ 0.3 MPa compared to minimum required pressure of 0.005 MPa ⇨ the SF is 60 (= 0.3 /0.005).

Slot Support System, including Wedges

- All the slot packing materials in contact with the bars shall be semi-conductive throughout their volume and to be rated to Class F.

- The slot packing design (both circumferential and radial) shall ensure follow-up action on the stator coil/bar that will compensate for insulating material shrinkage. In the circumferential direction, to maintain continuous contact between the stator winding and core, a service-proven, resilient packing system is preferred.

- The force exerted by the side packing system shall be sufficient to prevent the stator coil/bar vibration caused by electromagnetic forces during normal generator operation.

- The slot wedge shall have a “piggy back” wedge design.

- The slot wedging materials shall have properties equivalent to or better than NEMA G11 for Class F winding.

- Some type of “ spring follow-up “system (a top ripple spring) to maintain continuous pressure on the winding shall be used.

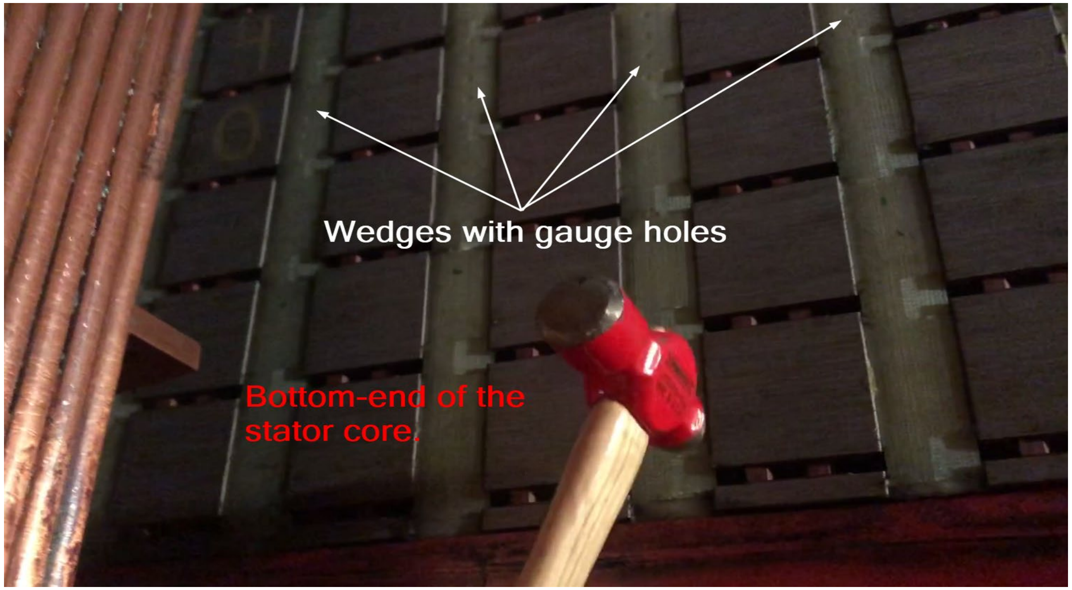
- Alternative systems to secure bars in the slots will be considered.

- A procedure to measure the integrity of the wedging system shall be included in the Insulation Manual.

- A tap test shall be performed using an accepted electronic wedge tapper on 100% wedges. During the tap test ,there shall be no movement of wedges in any direction and the wedges shall sound solid and firm.

- Drawing with the details and dimensions of the slot content shall be included in the proposal documentation.
- Complete description of the installation procedure shall also be included.

Possible acceptance criteria for wedge tightness verification



Immediately after installation:

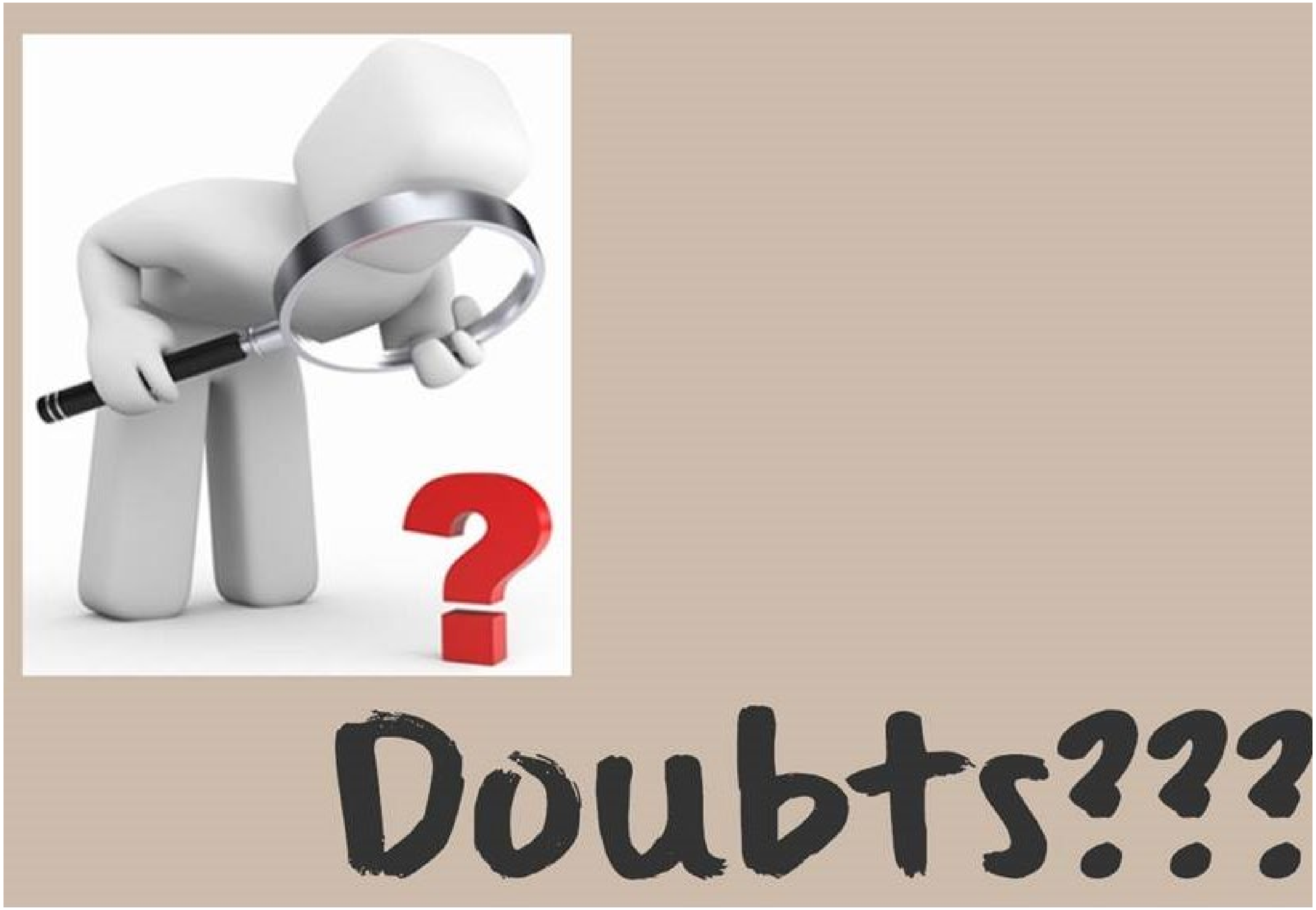
1. No more than 2 wedges in any slot should be loose.
2. No two adjacent wedges in any slot should be loose.
3. Neither of two wedge at each end of the core should be loose.

In-service machine :

1. No more than 25% of wedges in any slot should be loose.
2. No more than two adjacent wedges in any slot should be loose.
3. Neither wedge at each end of the core should be loose.

Verify the percentage of compression of the ripple spring using deflection with a suitable dial depth gauge and confirm with approved “tap” test.

BC Hydro
Power smart


Doubts???