Gearbox Borescope Inspection

Ventos Metodicos Warehouse

WTG 2

Author	Daniel Fuentes Moncayo
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1 Background

The company **Ventos Metodicos** contracts with **RES** to determine the present status of the different components which are part of the gearbox and the auxiliary equipment in the wind turbine.

Wind turbine definition:

- Situation: **Penamacor, Portugal**
- Wind farm: **Ventos Metodicos Warehouse**
- Designation: **2**
- Manufacturer: **Suzlon**
- Technology: **S88**
- Nominal Power: **2100 kW**
- Rotor Diameter: **88m**

2 Inspection Procedure

The inspection procedure consists in non-invasive inspection works in the wind turbine gearbox. Every element or system related to the gearbox operation are considered. This includes the main parts represented by the gears and the bearings among others and auxiliary elements (for instance filters, oil status…)
The first step in the work procedure is a visual inspection performed with a normal camera and it continues with a specific inspection focused on the gearbox bearings and gears throughout an endoscope. The endoscope characteristic is detailed below:

- Manufacturer: **KARL STORZ NDTec**
- Technology: **VTec Xplus420FM**
- Diameter probe: **3.9 mm**
- Serial number: **XHC2406121202**

The inspection was performed:

- **Manuel Ramiro Rey**
- **07/11/2025**

And revised:

- **Daniel Fuentes Moncayo**
- **11/11/2025**

3 Inspected Equipment

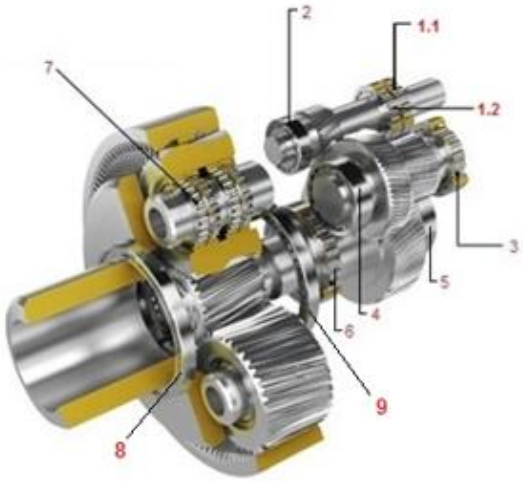
The inspected equipment consists in a gearbox detailed below:

- Manufacturer: **Winergy**
- Technology: **PEAB 4456.0**
- Serial number: **4807795-0020-3**
- Power: **2225 kW**
- Ratio: **98.828**

3.1 Gearbox description

This gearbox consists in one planetary stage and two parallel stages. The following pictures show a general view of the 3 stages, altogether with schemas with the different points where the inspection is carried out:

Point	Element	Label
A	High Speed Shaft Pinion	HSS
B	Intermediate Speed Shaft Wheel	IMS-HSS
C	Intermediate Speed Shaft Pinion	IMS-LSS
D	Low Speed Shaft Wheel	LSS
E	Ring Gear	RING
F	Sun Pinion	SUN
G	Satellites Gears	SAT-GEAR



Point	Element	Label
1.1	High Speed Shaft Bearing - Generator Side (Close to coupling)	HSS-GEN-GEN
1.2	High Speed Shaft Bearing - Generator Side (Close to pinion)	HSS-GEN-ROT
2	High Speed Shaft Bearing - Rotor Side	HSS-ROT
3	Intermediate Speed Shaft Bearing - Generator Side	IMS-GEN
4	Intermediate Speed Shaft Bearing - Rotor Side	IMS-ROT
5	Low Speed Shaft Bearing - Generator Side	LSS-GEN
6	Low Speed Shaft Bearing - Rotor Side	LSS-ROT
7	Satellites Bearings	SAT-BEAR
8	Planet Carrier Bearing - Rotor Side	PC-ROT
9	Planet Carrier Bearing - Generator Side	PC-GEN

4 Inspection

During this section, the results of the present inspection are shown. Firstly, the visual inspection general data are represented. Finally, the most significant elements of the gearbox or those which presents any defect are analysed.

4.1 Visual inspection

The following table summarize the conclusions of the visual inspection:

	CONCEPT	STATUS			
		C	MD	NC	OB
1	Oil temperature from control panel	X			
2	Bearing temperature	X			
3	Absence of temperature related alarms	X			
4	Cooler system engine check	X			
5	General condition Visual Check	X			
6	Optimum oil level 100%	X		X	X
7	Chip on magnet	X			
8	Chip on Oil Sump	X			
9	Gearbox leaks		X		X
10	Exterior gearbox case status	X			
11	Noises, Looseness	X			

*C: Correct / MD: Minor defect / NC: No correct / Ob: Observation

	REMARKS
6	Low oil level
9	Oil leaks

4.2 Borescope Inspection

The following table summarizes the conclusions of the borescope inspection:

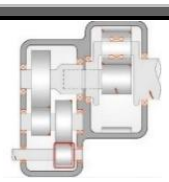
ETAPA	LOCALIZACIÓN		COMPONENTE		SEVERIDAD 0	SEVERIDAD 1	SEVERIDAD 2	SEVERIDAD 3	NIVEL*
PARALLEL 	HSS		A	Pinion		X			W1-C0-H1
			1	Bearing GEN	X				W0-C0-H0
			2	Bearing ROT		X			W1-C0-H0
	ISS		B	Wheel	X				W0-C0-H0
			C	Pinion		X			W1-C0-H1
			3	Bearing GEN		X			W1-C0-H0
			4	Bearing ROT		X			W1-C0-H0
	LSS		D	Wheel		X			W1-C0-H0
			5	Bearing GEN					No access
			6	Bearing ROT		X			W1-C0-H0
PLANETARY 	SUN PINION		F	Sun Pinion		X			W1-C0-H1
	PLANET CARRIER		8	Bearing ROT		X			W1-C0-H0
			9	Bearing GEN					No access
	RING		E	Ring Gear		X			W1-C0-H1
	SATELLITES		G	Gears		X			W1-C0-H0
			7	Bearings	X				W0-C0-H0

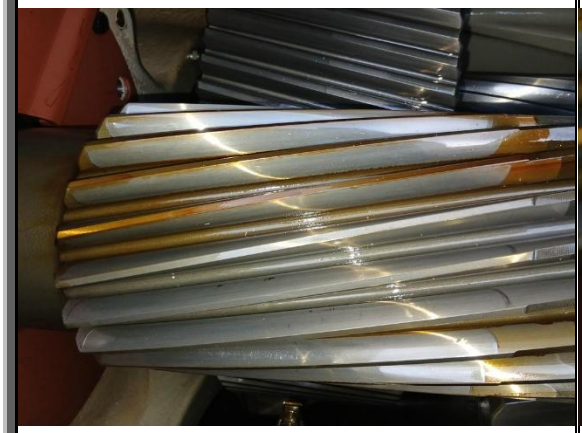
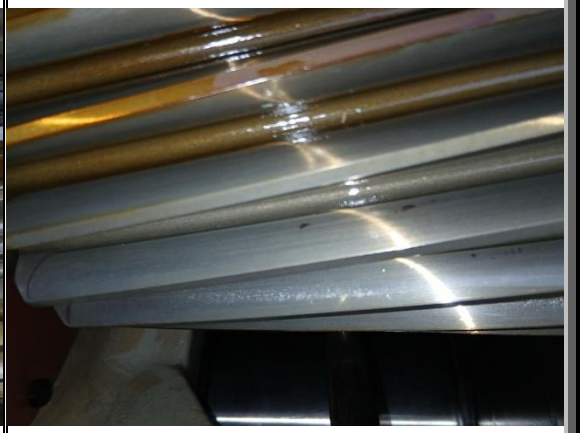
*On point 5, Appendix A, you could find all the information related with the diagnosis criteria.

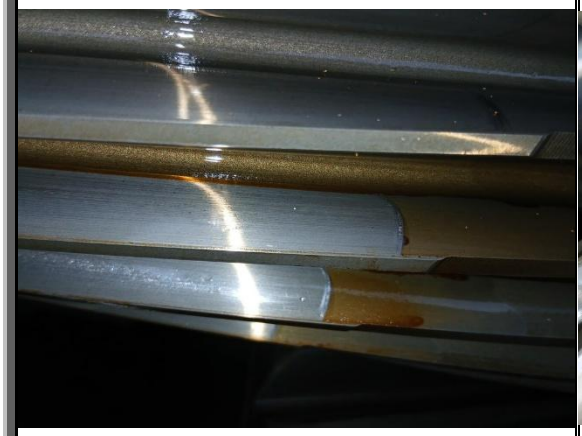
CONCLUSIONS AND PROPOSED ACTIONS	GEARBOX LEVEL
In summary, the defects that have been detected in the current inspection are catalogued as **minor defects and it is recommended to perform another inspection in 1 year to check the state of these defects.**	**1**

4.3 Inspection pictures

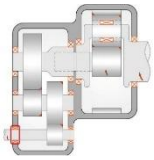
Position:	Visual Inspection		
			
Obs: Nameplate	C	**Obs:** Main view	C
			
Obs: Filter	C	**Obs:** Oil level	NC
			
Obs: Oil leaks	MD	**Obs:** Oil leaks	MD

Position:	A – HSS pinion	
Level:	W1-C0-H1	

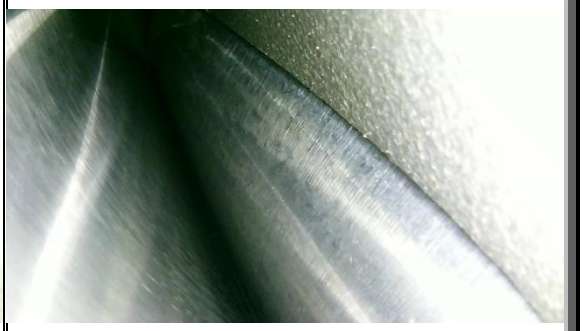
	
Obs: adhesion, abrasion and micropitting	**Obs:** adhesion, abrasion and micropitting

	
Obs: adhesion, abrasion and micropitting	**Obs:** adhesion, abrasion and micropitting

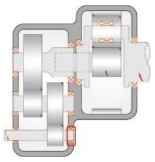
There is presence of adhesion, abrasion and micropitting signs in the teeth of the gear.

Position:	1 – HSS bearing GEN	
Level:	W0-C0-H0	

	
Obs: OK	**Obs:** OK

	
Obs: OK	**Obs:** OK

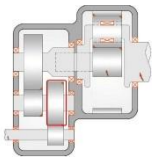
No defects have been found.

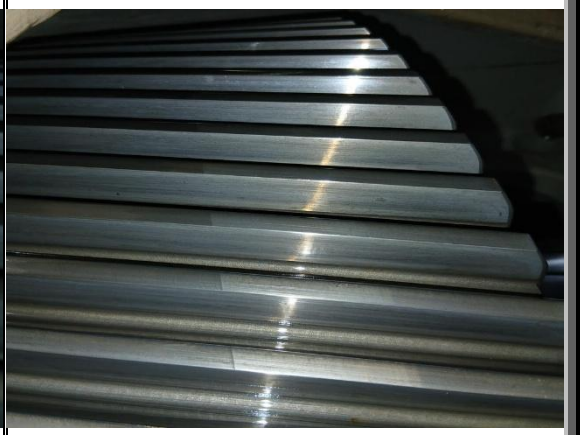
Position:	2 - HSS bearing ROT	
Level:	W1-C0-H0	

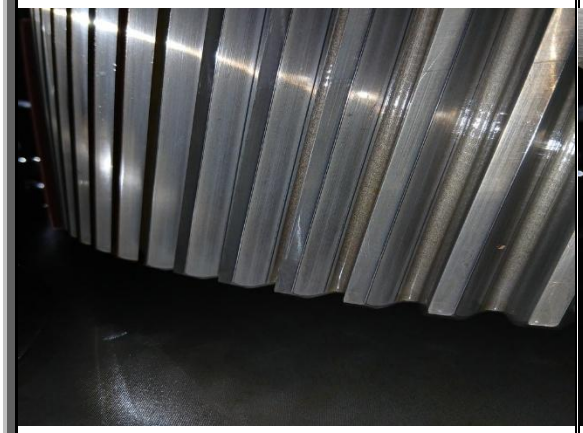
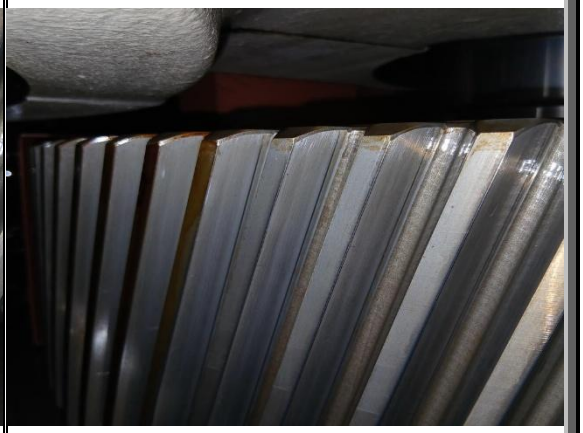
	
Obs: adhesion	**Obs:** adhesion

	
Obs: adhesion	**Obs:** adhesion

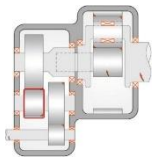
There is presence of adhesion signs in the surfaces of the bearing.

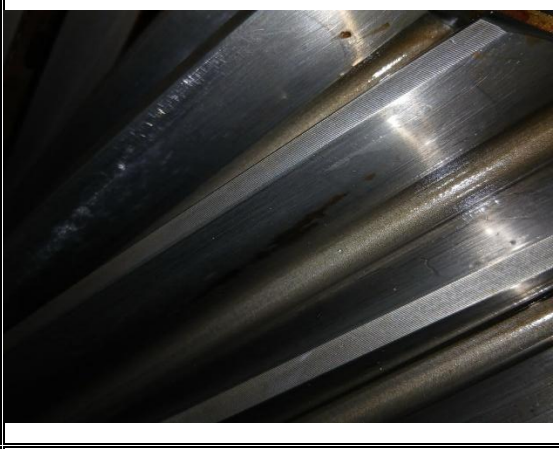
Position:	B - ISS wheel	
Level:	W0-C0-H0	

	
Obs: OK	**Obs:** OK

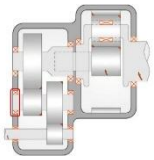
	
Obs: OK	**Obs:** OK

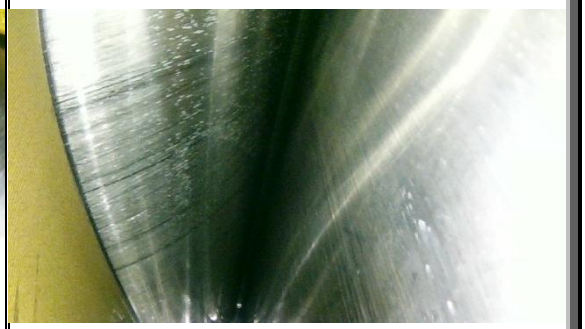
No defects have been found.

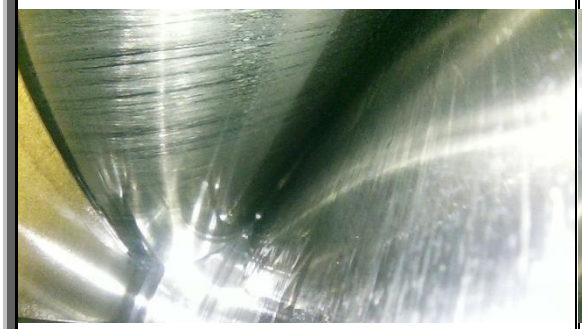
Position:	C – ISS pinion	
Level:	W1-C0-H1	

	
Obs: abrasion and micropitting	**Obs:** adhesion, abrasion and micropitting
	
Obs: adhesion, abrasion and micropitting	**Obs:** adhesion, abrasion and micropitting

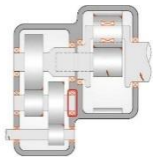
There is presence of adhesion, abrasion and micropitting in the teeth of the gear.

Position:	3 – IMS bearing GEN	
Level:	W1-C0-H0	

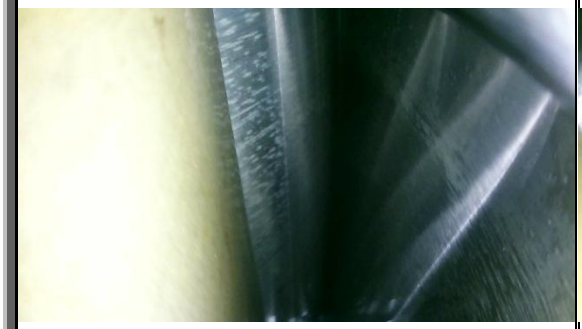
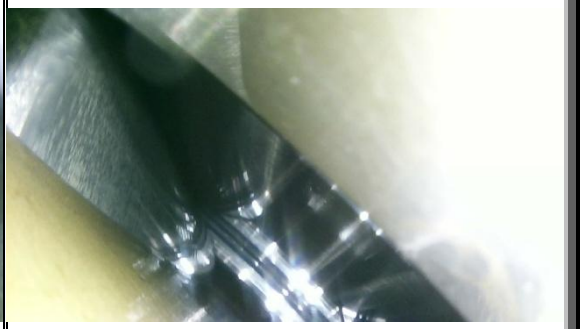
	
Obs: adhesion and scoring	**Obs:** adhesion and scoring

	
Obs: adhesion and scoring	**Obs:** adhesion and scoring

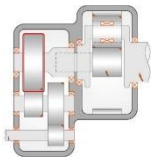
There is presence of adhesion and scoring signs in the surfaces of the bearing.

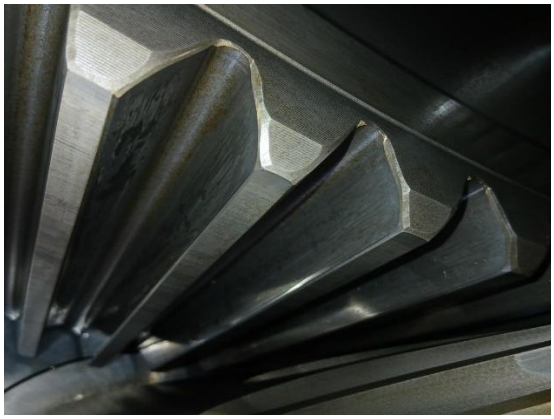
Position:	4 – IMS bearing ROT	
Level:	W1-C0-H0	

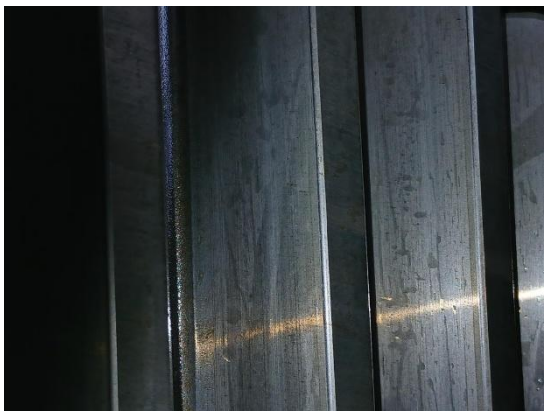
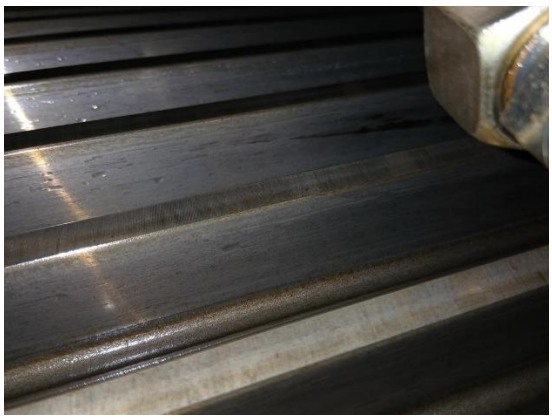
	
Obs: scoring	**Obs:** scoring

	
Obs: scoring	**Obs:** scoring

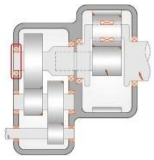
There is presence of scoring signs in the surfaces of the bearing.

Position:	D – LSS Wheel	
Level:	W1-C0-H0	

	
Obs: adhesion	**Obs:** adhesion

	
Obs: adhesion	**Obs:** adhesion

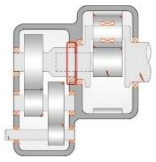
There is presence of adhesion signs in the teeth of the gear.

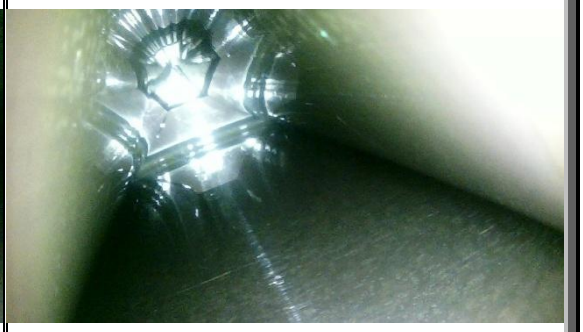
Position:	5 – LSS bearing GEN	
Level:	NO ACCESS	

	
Obs: Outside view	**Obs:** Outside view

	
Obs: Outside view	**Obs:** Outside view

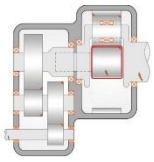
No access to the inside of the bearing.

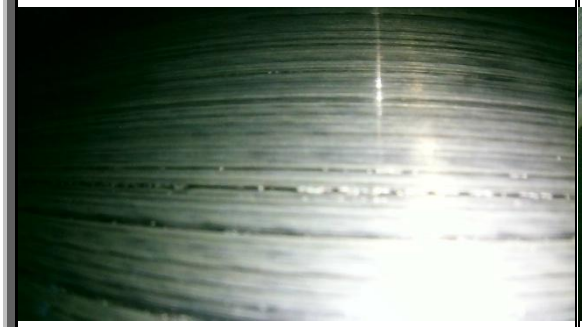
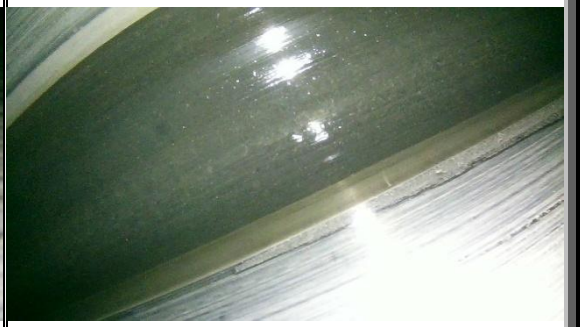
Position:	6 – LSS bearing ROT	
Level:	W1-C0-H0	

	
Obs: scoring	**Obs:** scoring

	
Obs: OK	**Obs:** OK

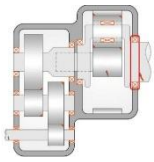
There is presence of scoring signs in the surfaces of the bearing.

Position:	F – SUN pinion	
Level:	W1-C0-H1	

	
Obs: micropitting	**Obs:** micropitting

	
Obs: adhesion and micropitting	**Obs:** abrasion and micropitting

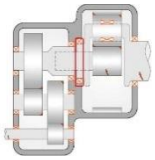
There is presence of adhesion, abrasion and micropitting signs in the teeth of the gear.

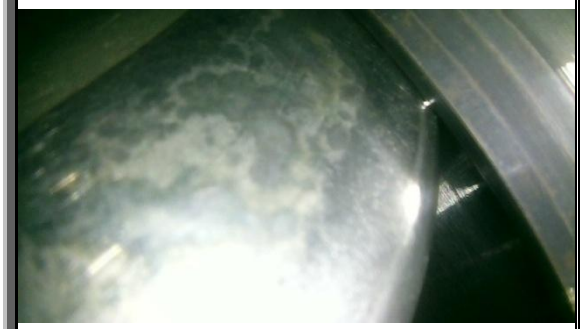
Position:	8 – PC bearing ROT	
Level:	W1-C0-H0	

	
Obs: scoring	**Obs:** scoring

	
Obs: scoring	**Obs:** scoring

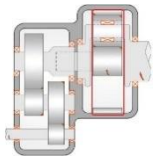
There is presence of scoring signs in the surfaces of the bearing.

Position:	9- PC bearing GEN	
Level:	NO ACCESS	

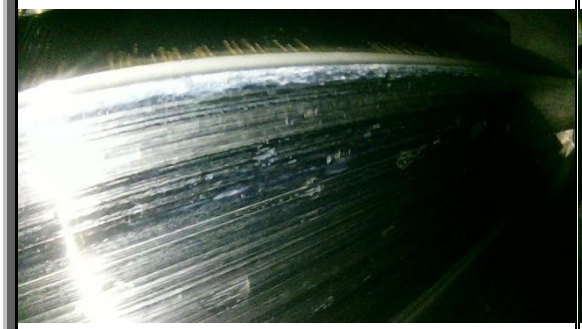
	
Obs: Outside view	**Obs:**

Obs:	**Obs:**

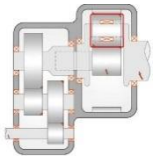
No access to the inside of the bearing because the rotor cannot be turned.

Position:	E – Ring gear	
Level:	W1-C0-H1	

	
Obs: abrasion and micropitting	**Obs:** abrasion and micropitting

	
Obs: abrasion and micropitting	**Obs:** adhesion

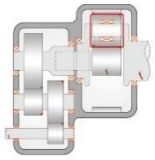
There is presence of adhesion, abrasion and micropitting signs in the teeth of the gear.

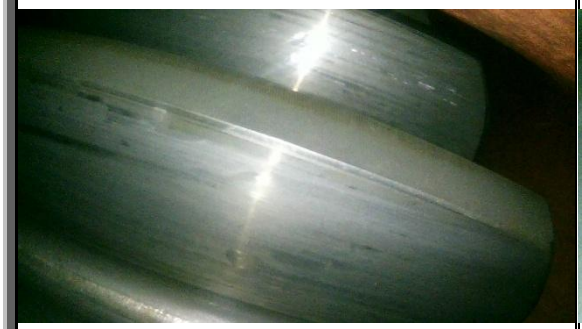
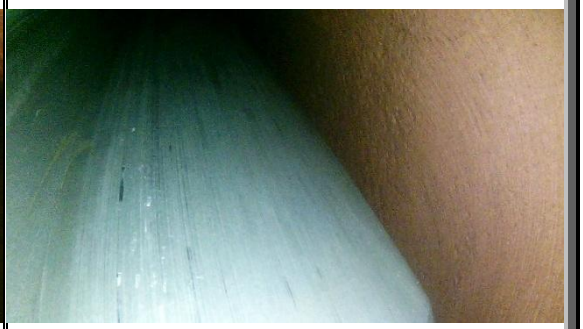
Position:	G.1 – Satellite gear 1	
Level:	W1-C0-H0	

	
Obs: abrasion and adhesion	**Obs:** abrasion

	
Obs: abrasion and standstill marks	**Obs:** abrasion and standstill marks

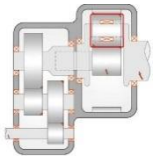
There is presence of standstill marks, abrasion and adhesion signs in the teeth of the gear.

Position:	G.2 Satellite gear 2	
Level:	W1-C0-H0	

	
Obs: adhesion and abrasion	**Obs:** adhesion and abrasion

	
Obs: adhesion and abrasion	**Obs:** adhesion and abrasion

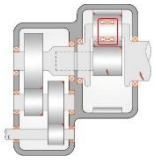
There is presence of adhesion and abrasion signs in the teeth of the gear.

Position:	G.3 – Satellite gear 3	
Level:	W1-C0-H0	

	
Obs: adhesion	**Obs:** adhesion and abrasion

	
Obs: adhesion and abrasion	**Obs:** adhesion

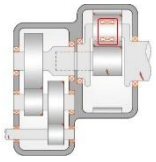
There is presence of adhesion and abrasion signs in the teeth of the gear.

Position:	7.1 – Satellite bearing 1	
Level:	W0-C0-H0	

	
Obs: OK	**Obs:** OK

	
Obs: OK	**Obs:** OK

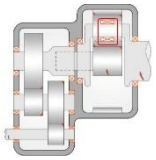
No defects have been found.

Position:	7.2 – Satellite bearing 2	
Level:	NO ACCESS	

NO ACCESS	
Obs:	**Obs:**

Obs:	**Obs:**

No access because the rotor cannot be turned.

Position:	7.3 – Satellite bearing 3	
Level:	W0-C0-H0	

	
Obs: OK	**Obs:** OK

	
Obs: OK	**Obs:** OK

No defects have been found.

5 Apendix A

5.1 Diagnostic criteria

The observed defects are going to be classified according to the next normative:

- ISO 10825: "Gears – Wear and damage to gear teeth – Terminology"
- ANSI/AGMA 1010-F14: "Appearance of Gear Teeth - Terminology of Wear and Failure"

  The next table summarises parts of the ANSI/AGMA 1010-F14 normative, focussing on the most common defects:

Class	General mode	Specific mode or degree	Non-preferred terminology
Wear	Adhesion	Mild Moderate Severe	Normal, running-in wear Tearing, Microwelding Scoring
	Abrasion	Mild, Moderate, Severe	Scratching Cutting
	Polishing Corrosion	Mild, Moderate, Severe	Burnishing
	Fretting	True brinelling False brinelling	
	Erosion	Fretting corrosion	Arcing
Scuffing	Scuffing	Mild, Moderate, Severe	Scoring Cold scuffing Hot scuffing Welding, Microwelding Galling Seizing
Plastic deformation	Plastic deformation	Indentation	Bruising Peening Denting True brinelling
		Cold flow	Permanent deformation
		Hot flow	Overheating
		Rolling Tooth hammer	
		Rippling	Fish scaling
Hertzian fatigue	Macropitting	Non-progressive Progressive Point-Surface-Origin Spall	Contact fatigue, initial Destructive Arrowhead
	Micropitting		Frosting Gray staining Peeling
	Subcase fatigue		Case crushing
Cracking	Cracking		
Fracture	Fracture		

The next manufacturer documentation is also considered as a support to the official normative:

- NSK Bearing Doctor: “Rapid Bearing Fault Diagnosis”
- SKF: “Bearing failures and their causes – Product information 401”
- FAG: “Rolling Bearing Damage”

5.1.1 Defect classification

In this subsection, the defects severity criteria and the corrective actions proposed according to the previous normative are going to be specified.

5.1.1.1 Wear

Level	Gears and bearings wear
W0	There is **no wear**.
W1	**Non-progressive wear** which usually suppose superficial wear in an area smaller than the 10% of the flank area. This includes defects like adhesion, mild scuffing, mild abrasion, mild polishing, false brinelling and erosion, among others.
W2	**Progressive defect** which requires supervision. It generally implies wear in an area between the 10% and the 70% in the flank area. This includes defects like moderate scuffing, moderate abrasion, moderate and severe polishing and some types of corrosion among others.
W3	**Severe defect that may suppose an important damage to the power train integrity**. The wear can be observed in large areas of the flank area. This includes defects like severe scuffing, severe abrasion and some types of corrosion among others.

5.1.1.2 Cracks, plastic deformation and/or fractures

Level	Gears and bearings cracks, deformation and/or fractures
C0	**There are no marks, cracks or deformations.**
C1	**None or slow progressive defect** which usually suppose small plastic deformations. This includes defects like indentations, some types of rolling, true brinelling, tooth hammer, rippling and some types of cold flow among others.
C2	**Progressive defect** which requires supervision. It is normally associated with considerable plastic deformation and cracks. This includes defects like some types of cold flow, rolling and some types of cracks among others.
C3	**Severe defect that may suppose an important damage to the power train integrity**. This defect usually involved severe plastic deformation, fractures and cracks. This includes defects like severe rolling and cold flow, severe cracks (which may suppose an immediate fracture) and every type of fracture.

5.1.1.3 Hertzian fatigue

Level	Gears and bearing Hertzian fatigue phenomenon
H0	There is **no defect**.
H1	**Non-progressive defect** which includes micropitting in an area smaller than the 10% of the flank area and non-progressive macropitting.
H2	**Progressive defect** which requires supervision. It is associated with micropitting in areas larger than the 10% of the active flank or with macropits in a significant portion of the tooth surface. This includes phenomenon like micropitting and some types of progressive macropitting and PSO macropitting among others.
H3	**Severe defect that may suppose an important damage to the power train integrity.** This includes defects like some types of progressive macropitting and PSO macropitting, spall macropitting and subcase fatigue among others.

5.2 Wear

Wear is a term describing change to a gear tooth surface involving the removal or displacement of material, due to mechanical, chemical, or electrical action.

5.2.1 Adhesion

Adhesion is caused by transfer of material from one tooth surface to another due to microwelding and tearing.
Adhesion can be categorized as mild or moderate if it is confined to surface films and oxide layers on the tooth surface. If, however, the oxide layers are disrupted and bare metal is exposed, the transition to severe adhesive wear (scuffing) may occur.

5.2.2 Abrasion

Abrasion is the removal or displacement of material due to the presence of hard particles: for example, metallic debris, scale, rust, sand, or abrasive powder, suspended in the lubricant or embedded in the flanks of the mating teeth.

5.2.2.1 Mild abrasion

Abrasion is classified as mild if it consists of fine scratches that are not numerous or deep enough to remove significant amounts of material from the tooth surface and some machining marks are visible on the tooth surface.

5.2.2.2 Moderate abrasion

Abrasion is classified as moderate if remnants of the original machining marks are visible on the tooth surface.

5.2.2.3 Severe abrasion

Severe abrasion removes all of the original machining marks from the active surface of the tooth. There may be wear steps at the ends of the active face and in the dedendum. The tooth thickness may be reduced significantly, and in some instances the tooth tip may be reduced to a sharp edge. See Figure 1

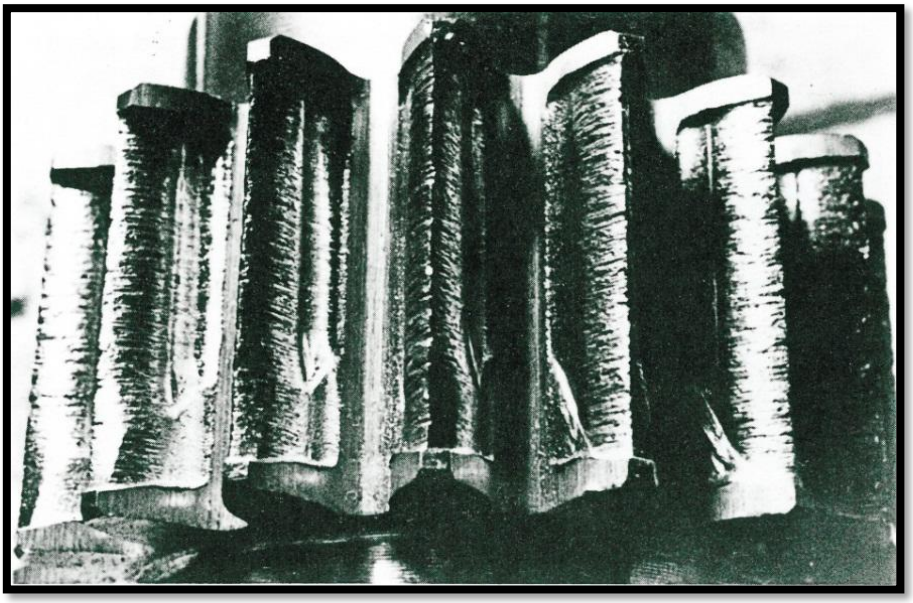


Figure 1 –Severe abrasion

5.2.3 Corrosion

Corrosion is the chemical or electrochemical reaction between the surface of a gear and its environment. The tooth surfaces may appear stained or rusty and there may be reddish-brown deposits of rust. Corrosion commonly attacks the entire tooth surface and it may proceed intergranularly by preferentially attacking the grain boundaries of the tooth surfaces.

5.3 Scuffing

Scuffing is severe adhesion that causes transfer of metal from one tooth surface to another due to welding and tearing. The damage typically occurs in the addendum, dedendum, or both, away from the operating pitch line, in narrow or broad bands that are oriented in the direction of sliding. Scuffing may occur in localized patches if it is due to load concentrations. The scuffed areas appear to have a rough or matte texture.

5.3.1 Mild scuffing

Scuffing is classified as mild if it occurs only on small areas of the teeth and is confined to the peaks of the surface asperities. It is generally non-progressive.

5.3.2 Moderate scuffing

Moderate scuffing occurs in patches that cover significant portions of the teeth. If the operating conditions do not change, moderate scuffing may be progressive. See Figure 2

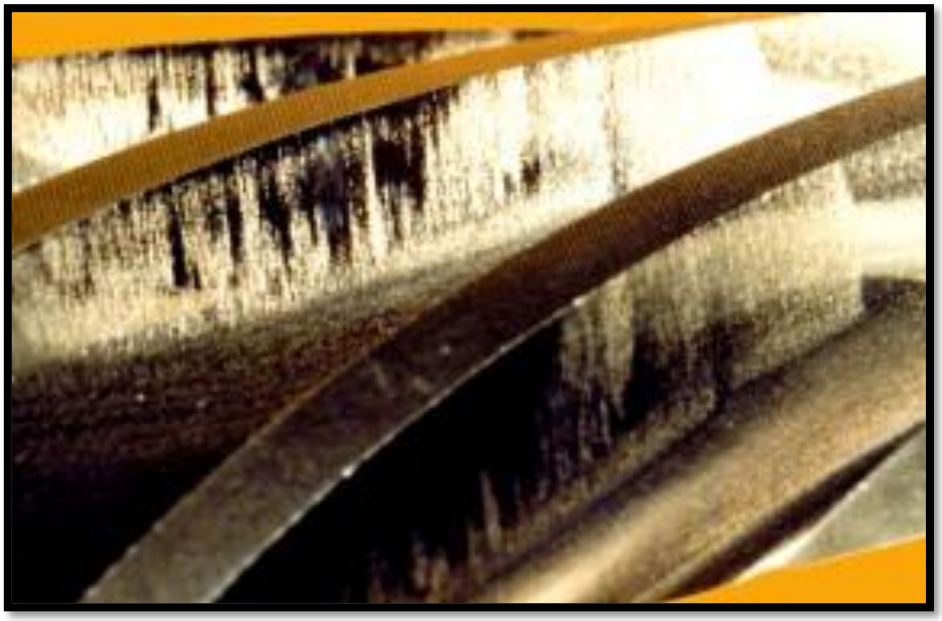


Figure 2- Moderate scuffing

5.3.3 Severe scuffing

Severe scuffing occurs on significant portions of the gear tooth (for example, the entire addendum, the entire dedendum, or both). In some cases, the surface material may be plastically deformed and displaced over the tip of the tooth or into the root of the tooth. Unless corrective measures are taken, severe scuffing is usually progressive.

5.4 Plastic deformation

Plastic deformation is permanent deformation that occurs when the stress exceeds the yield strength of the material.

5.4.1 Indentation

The active flanks of gear teeth may be damaged by indentations caused by foreign material that becomes trapped between mating teeth.

5.5 Hertzian fatigue

Repeated Hertzian stresses may cause surface or subsurface fatigue cracks and the detachment of material fragments from the gear tooth surface.

5.5.1 Macropitting

Macropitting may occur when fatigue cracks initiate either at the surface of the gear tooth or at a shallow depth below the surface. The crack usually propagates for a short distance in a direction roughly parallel to the tooth surface before turning or branching to the surface. When the cracks have grown long enough to separate a piece of the surface material, a macropit is formed.

5.5.1.1 Non-progressive macropitting

Nonprogressive macropitting normally consists of small macropits that occur in localized areas. They occur in localized areas and tend to redistribute the load by removing high asperities. When the load is more evenly distributed, the macropitting stops.

5.5.1.2 Progressive macropitting

Progressive macropitting normally consists of macropits that grow at an increasing rate until a significant portion of the tooth surface has macropits of various shapes and sizes. See
Figure 3.

5.5.1.3 Progressive macropitting

Point-surface-origin (PSO) macropitting consists of macropits that are relatively shallow but large in area. The fatigue crack extends from an origin at the surface of the tooth in a fan-shaped manner until thin flakes of material break out and form a triangular crater.

5.5.1.4 Spall macropitting

Spall macropitting is progressive macropitting that occurs when macropits coalesce and form irregular craters that cover a significant area of the tooth surface. See Figure 4.

5.5.2 Micropitting

Micropitting is Hertzian fatigue caused by cyclic Hertzian stresses and plastic flow on the asperity scale. It results in ultra-small cracks at the surface and formation of micropits, resulting in loss of material. See Figure 5.

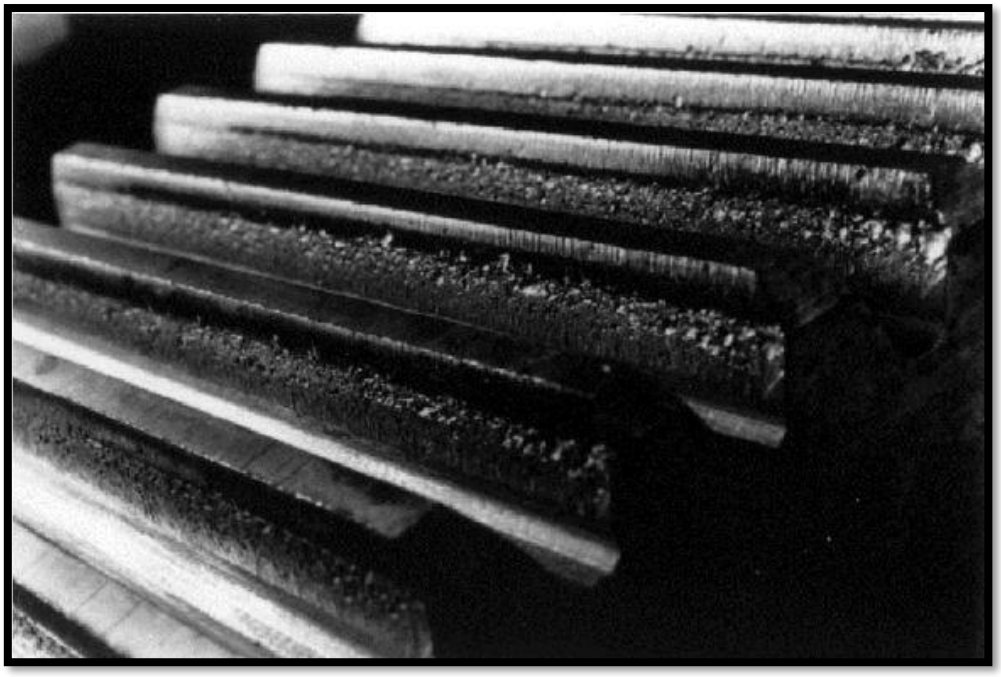


Figure 3- Progressive macropitting

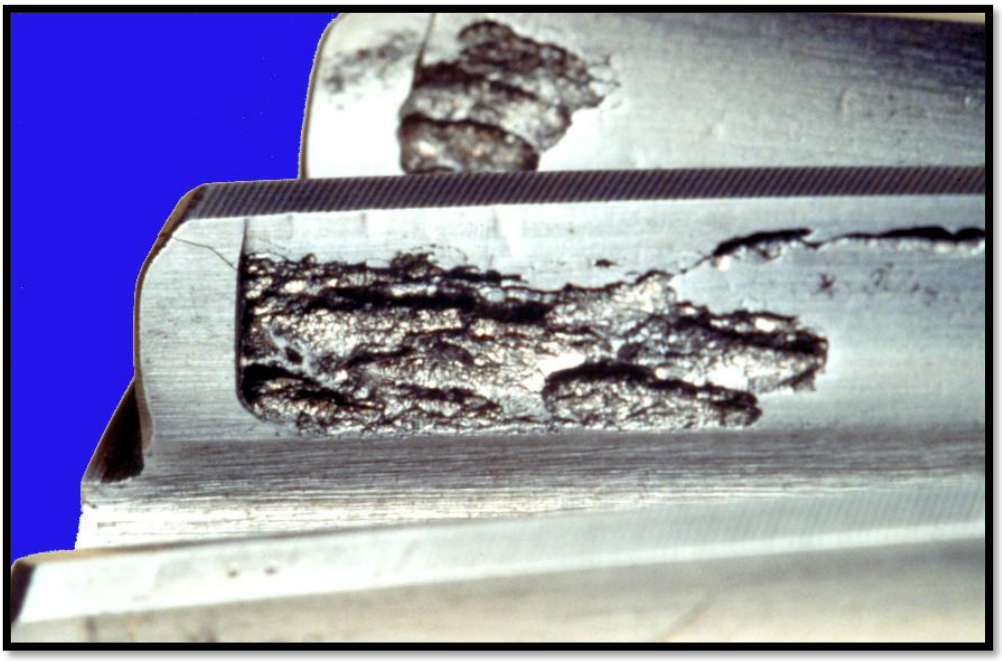


Figure 4- Spall macropitting

Figure 5- Micropitting

5.6 Cracks

Aside from cracks in the gear tooth root fillets caused by bending fatigue, cracks may occur elsewhere on the gear due to mechanical stress, thermal stress, material flaws or improper processing.

5.7 Fracture

When a gear tooth is overloaded because it is under-designed or the local load is too high, it may fail by plastically deforming or fracturing. If it fractures, the failure may be a ductile fracture preceded by appreciable plastic deformation, a brittle fracture with little prior plastic deformation, or a mixed mode fracture exhibiting both ductile and brittle characteristics.
Fatigue failures usually culminate in a fracture when the fatigue cracks grow to a size where the remaining tooth section can no longer support the load. In this sense, the remaining material is overloaded; however, the fracture is a secondary failure mode that is caused by the primary mode of fatigue cracking.