PROBLEMS DURING WORKING

Causes of damages

Introduction

The surrounding environment is a permanent source of troubling events, the majority of which cannot be easily predicted. In the case of bearings, the possible causes of damages and wrong-functioning are several.

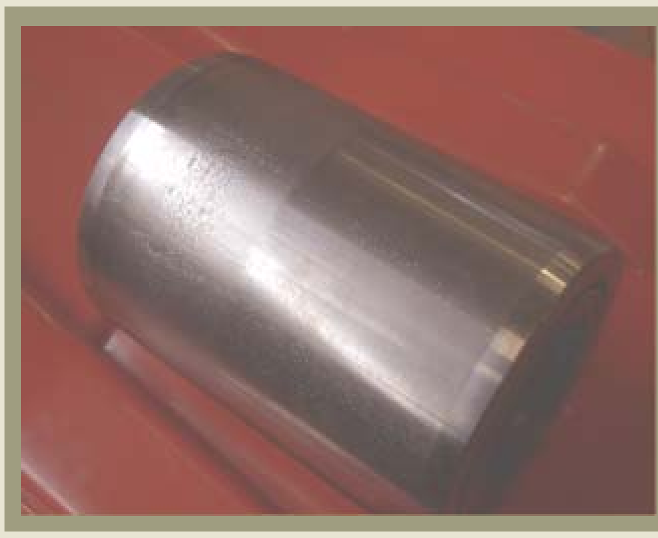
Causes

It is possible to detect the following causes of wrong-functioning:

working loads;
speed of rotation;
surrounding environment.

Working loads

The project phase foresees ideal load conditions; entity, direction and distribution of the load are supposed to be already known. Nevertheless, the real working conditions can lead to destabilizing factors which are completely different compared to those foreseen during the project phase.
But when the component is considered to be an integrating part of a machine or a plant, the bearing must bear: load not correctly distributed, shocks, vibrations...
It is not easy to find the causes of wrong-functioning, because of the complexity of production systems which the bearings are a part of. Nevertheless the visual analysis of wear marks can help detecting the causes.
The two following pictures show an example of simple radial load which, because of a non-correct alignment, is applied only to a reduced contact surface as regard to the one foreseen. As a result, the part of the surface which does not bear load is polished, whereas on one edge wear mark due to overload can be clearly seen.



Outer ring with evident marks of wrong functioning, due to a non correct alignment; the part of the outer ring which is still not damaged is still polished.

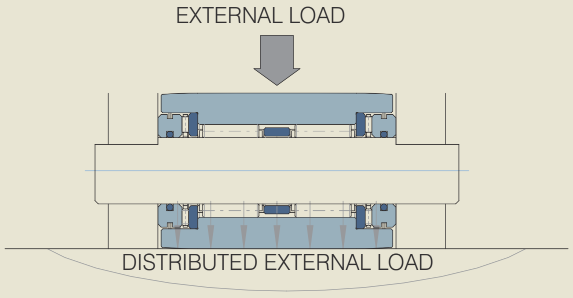
Pivot with marks of damages due to a non correct alignment; the part of the pivot which is not damaged is still polished.

Such a non correct alignment implies the onset of an unforeseen axial component, which cannot be easily quantified; the bearing cannot bear such component. This axial force implies the shearing of the rollers on the guiding shoulder and therefore the blocking of the bearing (see next picture).

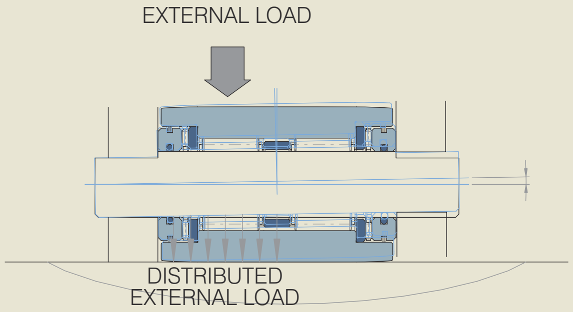
Bearing damaged on the guide brims and on the raceways of the outer ring, due to the axial thrusts.

The association of these two factors (axial thrust and shearing) generates a high wear in a short time, along with the separation of material and related contamination and degradation of the lubricant; the wear itself is linked to a considerable raise in temperature, until the tempering of the steel (hardness $<$ 40 HRC).
In order to make things clearer, a table is here below enclosed with a numerical example, in order to better understand the importance of the alignment.

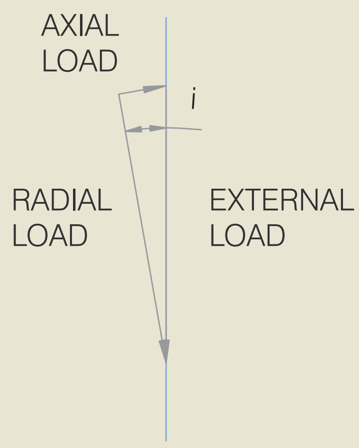
Configuration of load with perfect alignment: the load is distributed in adjusted way on all the contact surface; the bearing works in a correct way along the whole surface.



Configuration of load with incorrect alignment: the load is not distributed in adjusted way along the whole contact surface; the bearing works in an anomalous way along a part of the surface, which ends up to be overloaded in relation to the correct working.



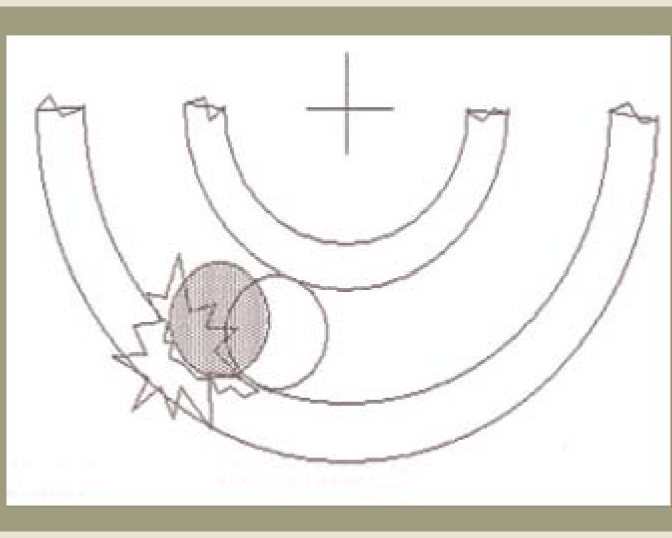
Vector scheme of configuration of load with incorrect alignment. It engenders an unforeseen axial component due to i corner.



Numerical example:
It is clear to see that, from light incorrect alignments, strong axial thrusts can derive, which increase in intensity along with the increase of the i corner of incorrect alignment.

i corner of incorrect alignment	=	**1°**
Project external load	=	**300kN**
Effective axial load	=	**300·sen(1°) ≅ 5kN**
Effective radial load	=	**300·cos(1°) ≅ 299.9kN**

Other causes of probable wrong functioning and reduction of the lifetime of the bearing are the shocks and/or vibrations.
There are shocks any time the changes of the load are applied impulsively, by generating high stresses in certain points; these stresses may cause marks and fillings on the sensitive parts of the bearing.
The above mentioned damages can arouse the formation of cracks and fissures that may bring to structural collapse.
The most worrying phenomenon is that of vibrations, as they represent a kind of stress which cannot be easily found, and which are often due to preceding damages caused by shocks.
In a specific case, the raise of vibration happens each time that a rotating element crosses a surface damage, or when the damage itself is on the rotating part. The reiterated shocks arouse series of impulsive forces, which are the source of vibrations, and therefore of noise.
The specific frequency of such vibrations is proportional to the speed of rotation of the bearing, to the geometry of the bearing, to the quantity of rotating elements and to the localization of the damage.



Scheme of rotating element that passes near to a lack on the raceway and causes an impulsive force.

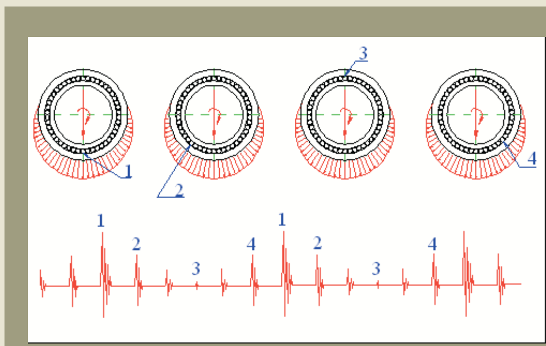
What has just been said can be easily verified by appraising the factors that influence the appearance of vibrations in two different working condition, you can find here below:

1st CONDITION OF WORKING

This situation shows the following characteristics

- Constant load;
- Inner ring/fixed pivot;
- Rotating outer ring;
- Lack found on the raceway of the outer ring or on the surface of the rotating part.

In the first condition of working, the load applied at the moment of the passage on the lack depends on the radial position of the lack itself, and therefore the intensity of the impulse is modulated.



1

1st condition of working: in this case we can find 4 situations:

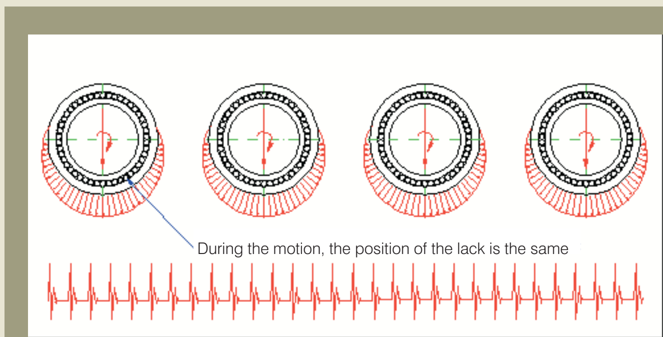
1. the lack is on the part of the outer ring that is mainly loaded; therefore an impulse of maximum breadth is generated;
2. the lack is on the part of the outer ring with medium load. therefore an impulse of medium breadth is generated;
3. the lack is on the part which is not loaded; the breadth of the impulse is negligible
4. the lack is once again on the part of the outer ring with medium load; the cycle of impulses starts to repeat itself.

2nd CONDITION OF WORKING

This situation shows the following characteristics:

- constant load;
- inner ring/fixed pivot;
- rotating outer ring;
- lack found on the raceway of rotation of the inner ring/pivot.

In the second working condition, the load applied on the lack is constant, and only determines the intensity of the impulse; no modulation is generated, which is the opposite of what happened in the first situation.



2

2nd condition of working:

in this case we point out that the breadth of the impulse is constant as the lack is still.

Independently from the condition of working, the vibrations are an important matter, as they work by overloading the bearing with toil stresses; moreover they cannot be easily determined, as they are influenced by several factors.

Rotation speed

An essential factor of the planning of the bearing is the speed of rotation, which is determined on the basis of dimensions ad of the execution, compatibly with the specific necessity of the customer.
This matter is extremely important, as the degradation of the lubricant and the lifetime of the bearing itself are directly linked to it.
In addition to these matters, the speed of rotation acts in indirect way on the bearing, as it strengthens the effects of vibrations and likely damages on the rotating elements and /or rotating raceways.

External environment

The environment in which the bearing works must be taken into consideration, as in it you can find:

- vibrations deriving from moving parts of the machine, which influence the bearing in indirect way; in this case, the worst situation can be noticed when the bearing submitted to those vibrations is unloaded and still.

- corrosive and/or contaminated environment; factor to be kept in mind since the phase of planning of the bearing, as there can be intrusions of fine dust in the bearing (if so, provide for more efficient than usual systems of seal), or there can be particularly corrosive atmospheres (if so, provide for suitable protective agents to safeguard the integrity of the bearing);

- high temperatures; in this case, the bearing must be planned according to the likely thermal expansions of its components, by foreseeing suitable clearances and tolerances; the heating treatment should be provided according to the range of temperature under which the bearing will work. Therefore a suitable stabilizing of the components should be provided, in order to prevent the tempering of the materials.

Events of damages

Introduction

Bearings represent one of the “critical” components in a plant where they work, as they have to fulfil the requirements of load projected by the designer of the plant and at the same time, they have to guarantee high levels of reliability and safety during working.
Unluckily, there are different causes that make the bearing no more suitable to its task, by reducing the theorical lifetime estimated during the project and concept development.
Each of these factors causes a typical structural damage, by leaving a particular mark.

Once considered this mark by testing a damaged bearing, the source of the inconvenient can be found, in order to take the necessary measures to avoid the reiteration of this problem.

Types of damages

The main cause of failure generates a typical damage which is called primary damage, which gives vent to another damage, called secondary damage, made of crumbling and cracks.
Usually, the damage of a bearing is due to a combination of both primary and secondary damage.
The classification of the types of damage is the following:

PRIMARY DAMAGES
- wear;
- marks;
- fillings;
- transfer of current;

SECONDARY DAMAGES
- crumbling;
- cracks.

PRIMARY DAMAGES: WEAR

General remarks

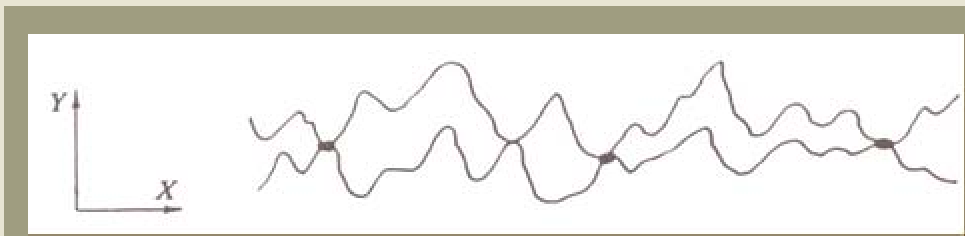
We can define as wear the surface loss of material that happens progressively on the surface of contact parts subject to relative motion.
Wear shows itself along with friction, but cannot be related to it in a simple and unambiguous way: there are couples of surfaces that show a low coefficient of friction and a high rate of wear and vice versa.
Wear can be classified according to four main types:

- adhesive wear;
- abrasive wear;
- corrosive wear;
- surface fatigue.

Adhesive wear

Adhesive wear happens when, in correspondence to the asperities of the surface of two parts pushed one against the other, there are some micro-joints or micro-welding, that break during the relative motion of the two parts.

One typical cause of wear is the lack of lubricant. Wear occurs also when the lubricant has lost its lubricating characteristic and therefore there is no suitable lubricating film which has enough load capacity: therefore there are direct contacts steel-against-steel between the rotating parts and the rolling raceways.

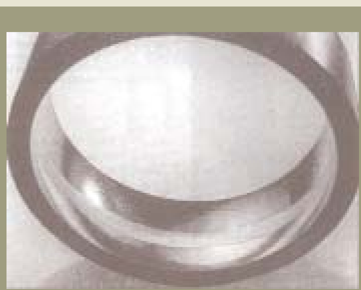


Adhesive wear: the contact starts among the blackest surface crests (in the picture, scale Y has been increased in comparison to scale X).

The crest of the microscopic asperities left by the mechanical process tear, whereas at the same time there is a certain rolling action on them; as a result, the surface is more or less polished.
When the bearing does not rotate, there is no lubrication film between the rotating elements and the raceways; so there is a contact between the metals.

As a result of the small relative movements generated by the vibrations, some small particles are removed from the surfaces; these particles form little tilts, and jags.

Obviously, the spheres produce spherical tilts, whereas the rollers produce longer tilts. In many cases we can find a rusty colour on the bottom of the tilts, which is due to the oxidation of the detached particles, which have a bigger surface in comparison to their volume. On the rotating parts there is no visible damage.



Outer ring of an adjustable roller bearing not adequately lubricated; the raceways are polished.

Cylindrical roller with polished surface, due to the scarcity of lubricant.

The bigger is the vibration, the bigger is the damage, whose evolution is also influenced by time and by the dimension of internal clearance of the bearing; it seems that the frequency of the vibrations does not produce any relevant effect. It has been proved that cylindrical roller bearings are more sensitive to this kind of damage than ball bearings;

the balls can rotate in all directions, whereas the rollers can rotate in one direction only around their axis; the other movements happen by shearing. The bearings who are the most subject to this event are the cylindrical roller bearings.
We usually find damages due to vibrations on the bearings of machines that lay still and are put near elements that produce vibrations.
When we can foresee the possibility of a constant presence of vibration, it is useful to find a solution at the moment of the project. Therefore ball bearing should be preferred in comparison to roller bearings. We can also increase the capability of the ball bearings to bear the vibrations without damages, by pre-loading them with springs. Also the lubrication in a bath of oil has proved to be a good solution, as the loaded parts of the rotating elements are always immersed. We can also provide for a base that can dampen the vibrations.
The bearings of the machines that have to be transported can be protected by keeping the shafts blocked, in order to prevent small movements, which are very harmful.

Outer ring of a tapered roller bearing damaged by the vibrations during functioning.

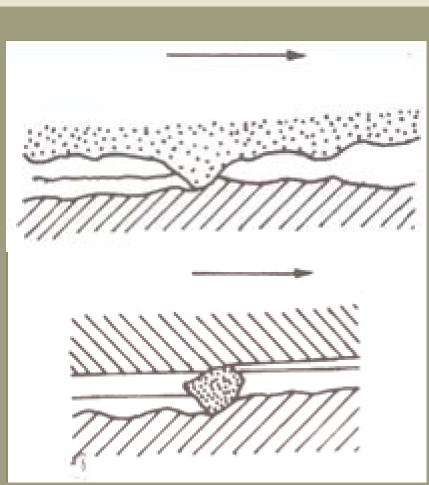
Inner ring of a cylindrical roller bearing damaged by vibrations. The damages occurred when the bearing was not rotating. It is clear, by seeing the littlest tracks between the more marked tilts (with corrosion on the bottom), that the ring has changed its position for small periods

Outer and inner ring of a cylindrical roller bearing subject to vibrations. The inner ring has changed its position.

ADHESIVE WEAR		
CHARACTERISTIC MARKS	CAUSES	POSSIBLE REMEDIES
Small marks along the raceway and on the rotating parts. Opaque and worn surfaces.	*Insufficient cleaning before and during the assembling process.*	*Remove the bearing from its packing only at the moment of its assembling/fixing. Keep the factory, the working table clean and use clean tools.*
Worn surfaces, often polished; as time goes by, the colour turns from blue to brown.	*The lubricant is now consumed or has lost its lubricant property.*	*Be sure that the lubricant is suitable to working conditions. Be sure that the lubricant reaches the bearing; re-lubricate with greater frequency.*
Little tilts in the raceways, with a rectangular shape in cylindrical roller bearings and round shape in ball bearings. The bottom of such tilts can be shiny or opaque and oxidized.	*The bearing has been subject to vibrations when motionless.*	*Pre-load the bearing during transportation. Provide for a base suitable to absorb vibrations. When possible, use ball bearings instead of roller bearings. If possible, lubricate in a bath of oil.*

Abrasive wear

This mechanism of wear is due to the action of grooving applied on a softer material, or by the ledges of the surface roughness of the hardest coupled element (this action is smaller just as much as the surface roughness of the hardest material is smaller), or by hard particles which are between the touching elements.
These particles can come form the surrounding environment or can be generated by other wear mechanisms (adhesive wear).



Abrasive wear: two different mechanisms of abrasive wear.

Outer ring of an revolving roller bearing with raceways worn by abrasive particles.
It is easy to see the border between worn part and entire part.

The little abrasive particles, such as sand and scraps, which somehow entered the bearing, produce wear of the raceways, the rotating parts and the cages. In this case, the surfaces become more or less opaque, according to the dimension and the nature of the particles. Sometimes some little fragments detach from the brass cage , they become in a copper-green colour and make the grease become greenish.
The quantity of abrasive particles increases gradually, as the material of the rolling surfaces and of the cage becomes weary. Wear is therefore a quick process, so much that in the end the surfaces become so weary that the bearing cannot be used anymore. Nevertheless it is not always necessary to discard a bearing that is only slightly damaged, as we can use it again once carefully cleaned.
In the bearing the abrasive particles can penetrate because of the inefficiency of the seals, but they can also be introduced by a contaminated lubricant or during the assembling process.

ABRASIVE WEAR

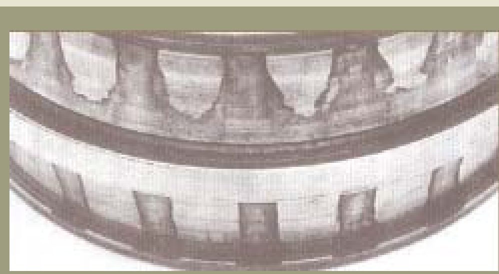
CHARACTERISTIC MARKS	CAUSES	POSSIBLE REMEDIES
Small marks along the raceway and on the rotating parts. *Opaque and worn surfaces.*	*Insufficient cleaning before and during the assembling process.*	*Remove the bearing from its packing only at the moment of its assembling/fixing..* *Keep the factory, the working table clean and use clean tools.*
	Inefficient seals	*Check and develop the system of seals, if necessary.* *Always use fresh and clean lubricant.* *Clean the greasers.*
Greenish grease	*Lubricant contaminated by particles that have moved from a brass cage.*	*Filter the grease* *Check the functioning of the lubrication plant: efficiency of the seals and of the filtering power of the filters.*

Corrosive wear

On the metal surfaces there are some layers of compounds, due to the chemical action of the substances in the environment. These surface films have a protective action on the metal underneath and if they are removed by the creeping, they are rapidly re-generated.
In a corrosive environment, the mechanical action and the chemical can strengthen their effects respectively: the superficial layers, chemically protective but easily removable, are continually removed and re-generated. Wearing process can become very quick.
The lubricants are usually a good protection against corrosive wear.
There is rust in the bearings when water or corrosive substances penetrate in it, in such a quantity that the lubricant cannot protect the surfaces any more and the is replaced by water. This process leads quickly to “deep rust”.

If there is a thin protective layer of oxide, which is impenetrable though,on the clean surfaces of the steel exhibited to the air, and, if water or corrosive substances touch those surfaces, there are some stains of a chemical attack, from which deep rust develops itself. Deep rust is very dangerous for bearings, as it can generate cleavages and cracks.

Deep rust on the outer ring of a cylindrical roller bearing.



Widespread chemical attack due to water on the inner ring of an adjustable roller bearing.

Acid liquids quickly corrode steel, whereas alkaline solutions are less harmful. The salts which are in water generate an electrolyte with it, which arouses a galvanic corrosion (“water etching”)
Sea water is therefore very harmful for bearings, as the aggressiveness of the chlorides in variable percentages in sea water is very well known.
Another kind of corrosion is the contact rust. If the thin oxide film is crossed and the oxidation proceeds deeper in the material, we can say we have contact rust.

Contact rust (“fretting corrosion”) on the outer ring of an adjustable bearing.

Widespread development of contact rust in the hole of an adjustable ball bearing.

A typical example of such an event is the corrosion that happens when there is a reciprocal movement between the ring of the bearing and its seat, when the coupling is too free.

This kind of damage can be called contact rust, or coupling rust or “fretting corrosion” and can be somehow quite deep. The reciprocal movement can also generate the detachment of small particles of material, which oxidise quickly once exposed to the oxygen of the atmosphere.

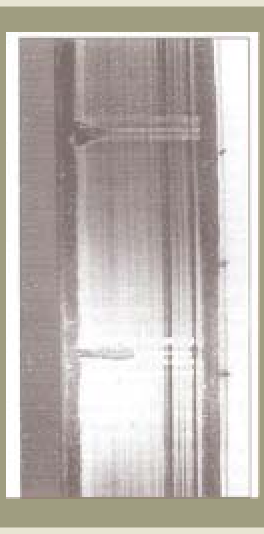
Because of the contact rust, the rings of the bearings can rest in an unjust way, which compromises the distribution of the load on the bearings themselves.
The rusty parts act also as a trigger for breaking.

CORROSIVE WEAR		
CHARACTERISTIC MARKS	CAUSES	POSSIBLE REMEDIES
Rusty parts on the outer surface of the outer ring or the hole of inner ring. Mark of working on the raceways deeply marked on the correspondent positions.	*Too free of a coupling. Seats on the joints or in the housing with mistakes in the shape.*	*Mend the seats.*

Primary damages: the marks

General remarks

During the functioning of the bearing, there can be some marks on the rolling raceways and on the rotating parts. This happens when the assembling stress is applied on the wrong ring and therefore passes through the rollers, or when the bearing is subject to abnormal loads when motionless. Also the foreign particles can cause marks.



Example of an unwise manipulation: the roller of a bearing with two rows of cylindrical rollers has been hit by a hammer.

Therefore we can see on it that there are two opposite marks, and in its turn the roller has created a mark on the outer ring.

In this situation the distance between the marks is the same as that between the rotating parts. In cylindrical roller bearings the damage has the shape of a material filling and, subsequently, if pressure increases, the shape of a mark.

Marks due to foreign particles

If the external particles, such as scraps and butts, penetrate into the bearing, they cause marks on the raceways when the rotating parts pass on them.
The particles do not have to be hard to generate such marks: thin pieces of paper or threads of the cloth can be enough.
Usually the marks are distributed along the whole rolling surface and have small dimensions.

MARKS		
CHARACTERISTIC MARKS	CAUSES	POSSIBLE REMEDIES
Marks on the raceways of both rings, at the same distance as the rotating parts.	*Assembling stress applied on the wrong ring.*	*Apply the assembling stress on the ring that must be stressed during assembling.*
	Overload applied on motionless bearing	*Avoid overload or prefer other bearings with higher Co value.*
Marks along the rolling Raceways and on the Surface of rotating parts.	*Entrance of foreign substances or particles in the bearing*	*Improve the cleaning of the assembling department, use a clean lubricant and improve the efficiency of seal systems.*

Primary damages: material fillings

General remarks

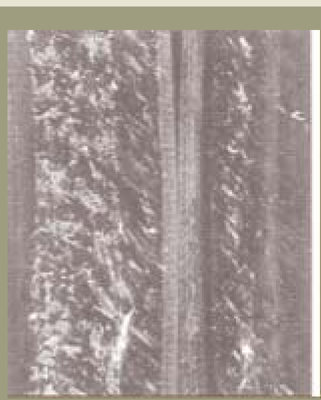
The material filling, better known as “smearing”, takes place when two contact surfaces that are not enough lubricated shear one against the other under applied load. The contact surfaces become rough.
Because of friction generated in the contact with shearing and with insufficient lubrication, the materials reach a temperature which is close to that of temper; this generates a strain that can lead to cracks and cleavages.
In the case of roller bearings, the shearing is mainly located in the part of contact between the head of the roller and the shoulders.
The material fillings may be generated when the rollers, which are subject to strong acceleration, pass in the loaded part of the bearing.

Material fillings on rollers and shoulders

The damage with material filling in cylindrical roller bearings is mainly located on the heads of the rollers that are into contact with the shoulders and on the faces of the shoulders themselves.

This fact is due to an insufficient lubrication between the surfaces that are into contact or to a strong axial load applied in the same direction for a long time. On the other hand, if the axial load was applied in both the directions, the problem would be of little importance, as the lubricant would have greater chance to go between the two surfaces. This kind of trouble can be partially avoided by using suitable lubricants with high oiliness/greasiness and higher stability towards viscosity.

Head of a cylindrical roller with evident signs of material filling, due to high axial loads and insufficient lubrication.



Magnification of a guide roller shoulder with damages due to material fillings

Material fillings on rolling raceways

Among the trouble related to the assembling process of cylindrical roller bearings we can find the situation in which the ring that bears the rollers and the cage are fixed sideways on the other ring and without rotating it. In this case, the rollers damage the ring and cause material filling in the shape of transverse streaks; the rollers themselves are damaged.

Cylindrical roller bearing with streaks on the rolling raceway of the inner ring and on the rollers due to wrong assembling operations.

This type of damage can be avoided by lubricating the bearing correctly and by rotating one of the rings.

FILLINGS		
CHARACTERISTIC MARKS	**CAUSES**	**POSSIBLE REMEDIES**
Coloured and rough had of rollers and faces of the shoulders	*Creeping when the loads are high and the lubrication is not enough*	*Use suitable lubricants*
Fillings on rolling raceways of cylindrical roller bearings with the shape of transverse streaks, located at the same distance as that of the rollers.	*During the operations of assembling, the ring with cage and rollers has been put obliquely in comparison to the other ring.*	*Rotate the inner ring and the outer ring during assembling.* *Lubricate the surfaces very well.*

Primary damages: transfer of electric current

This kind of damage is often neglected, as it is rarer that the previous ones, but it leads to serious consequences when it happens.

The transfer of electric current through a bearing happens when the electric current is transferred from a ring to another through the rotation parts; the damage occurs because we have a process similar to a welding arch where there is a contact.

The material is heated under a tempering temperature, until it comes closer to a melting temperature. In this kind of situation there are some coloured parts of different dimensions, where the material is tempered, re-hardened or melted. There are little craters where the material melts. The transfer of electric current leads to the forming of teeth on the raceways and on the rollers.

This kind of damage can be mistaken with that created by the vibrations; the difference lays in the fact that the hallows generated by electric current have a dark bottom, whereas those created by vibrations have a sparkly bottom, or a rusty one.

Both A/C and D/C are harmful for the bearing, as well as low-intensity current. The entity of damage depends on several factors:

- intensity of electric current;
- duration of electric transfer on the bearing;
- speed of rotation of the bearing;
- lubricant.

There are different solutions to prevent the transfer of electric current in the bearing; the easiest one seems to be the insulation of electric engines.

TRANSFER OF ELECTRIC CURRENT

CHARACTERISTIC MARKS	CAUSES	POSSIBLE RIMEDIES
Dark teeth or craters on the rolling raceways and on the rollers.	*Transfer of electric current through the rotating bearing.*	*Provide for preventing the electric current to be transferred through the bearing. Use insulated bearings.*
Burns located on the rolling raceways and on the rotating parts.	*Transfer of electric current through the motionless bearing.*	*Provide for preventing the electric current to be transferred through the bearing. Use insulated bearings.*

Secondary damages: cleavages

The cleavages (also known as “flaking” o “spalling”), classified as secondary damage, are the consequence of normal fatigue of the material once the bearing has reached his natural lifetime end, of rust, of transfer of current, of material fillings.
What said here above is not the usual cause of damage, as the cleavages seen on the bearings can be also due to other causes:

- external loads higher than foreseen;
- ovalization of the seats;
- axial dolly device (ex.: expansion of the joint)

Usually we realize that there is a cleavage when we perceive noise and vibrations in the bearing, which should therefore be replaced.

CLEAVAGES

CHARACTERISTIC MARKS	CAUSES	POSSIBLE RIMEDIES
Very evident working marks on the raceways of both rings.	*Pre-load due to excessive fatigue of the rings.*	*Change the coupling or choose bearings with higher internal clearance.*
Cleavages on the most loaded part	*Excessive difference of temperature between the inner and the outer ring.*	*Choose bearings with higher internal clearance.*
Very evident working marks on two opposite positions of the rings. Cleavages in those parts.	*Out of roundness seat on the joint or in the seat.*	*Manufacture a new joint or a new seat.*
Cleavages on the edge of the raceway	*Oblique fixing of the bearing.*	*Use a “button” with parallel faces*
Cleavages at the beginning on the loaded part on the raceway of the bearing.	*Material fillings due to sliding.*	
Cleavages at the same distance as the rotating parts and on the rolling raceways.	*Transverse material fillings due to wrong assembling operations.*	
Cleavages due to rust	*Deep rust*	
Cleavages on the raceway of one of the two rings. Corroded zone in the correspondent part of the outer diameter surface or of the hole of the bearing.	*Contact rust*	

Secondary damages: cracks

The forming of cracks in the rings of the bearings can have various causes:

- unwise manipulation during the assembling and disassembling process;
- hammer hits on the rings;
- forced assembling with heat of a ring on an out of tolerance joint;
- fillings, contact rust and cleavages.

CRACKS

CHARACTERISTIC MARKS	CAUSES	POSSIBLE RIMEDIES
Cracks or fragments that detach, usually on one face of the ring.	*Hammer or chisel hits on the ring during the assembling process.*	*Always interpose a soft material coupling bow. Do not hit the bearing directly.*
Cracks and material fillings on the ring. The ring can be broken in transverse direction. The filling cracks are usually formed in transverse direction in comparison to the trend of the fillings.	*Fillings*	