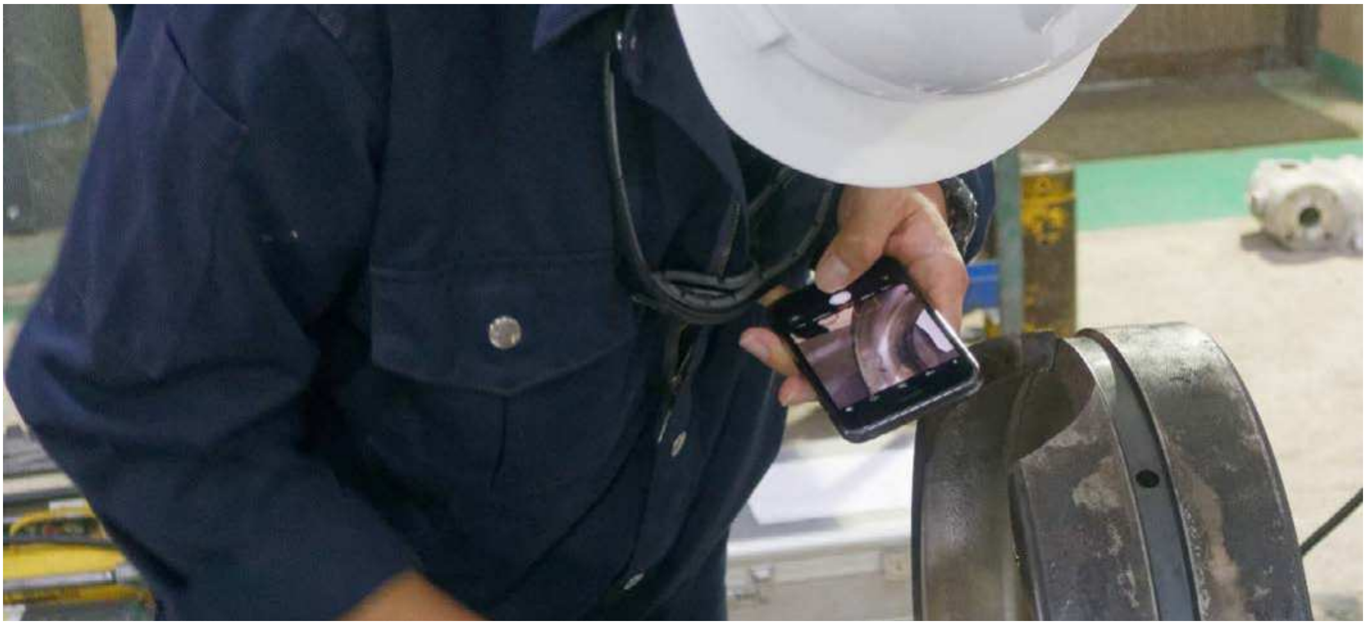
SKF Pulp & Paper Practices
SKF Global Pulp & Paper Segment | No. 24 | September 2018



How to take correct photos of damaged bearings

This issue of Pulp & Paper Practice is about taking photos of damaged bearings. Some would comment that this is odd and question why?

Since the early years of the XXI century there has been a constant increase in the exchange of photos taken with digital cameras. This includes photos of damaged bearings. In the 1990s an SKF application engineer would, most of the time, travel to meet customers and carry out visual inspections or be sent the damaged bearing. Today, most of the time, we receive pictures of the damaged bearing first. As a global application engineer, supporting local colleagues where necessary, I receive photos from all over the world. Unfortunately, communication is so easy and fast, that I can receive an SMS with photos from the other side of the world at 3 o'clock in the morning, requesting an answer a.s.a.p. It is even worse when the photo is of such bad quality that it is not even possible to differentiate grease from a spall on the raceway or the rolling element.

The fact that more and more pictures are taken with smartphones or tablets doesn't help at all. In 2010, about 40% of the photos around the world were taken with smartphones, now, the figure is around 90%, including tablets. This is an issue since smartphones are designed for point and shoot, are handheld, and have a picture quality that is good enough for 99.9% of consumers. For a landscape photo, with plenty of light behind the photographer, it is hard to see the difference between a premium smartphone and a professional camera. However, the gap in image quality is huge in low light, as can be the case in workshops. It is the low light that creates issues. This issue of Pulp & Paper Practices will help you to understand the issues and how to avoid them.

Regards,
Philippe Gachet
Senior Application Engineer
SKF Application Competence Centre

How to take correct photos of damaged bearings

1. Introduction

This article is not intended to make you into a professional photographer. It is just designed to help you take good enough pictures of damaged bearings. Good enough to see the damage sharply enough to find clues for RCFA (Root Cause Failure Analysis). Good enough for reports or training.

Some of the pictures shown in this article need to be viewed in a bigger size when reading, so do not hesitate to zoom in if you cannot see what I am writing about in the picture.

The article is based on today's camera technology. Technology changes quickly nowadays, but photography basics don't change much.

Just a reminder before starting. Do not focus exclusively on the most important damage. Often the most important damage is a consequential damage that "hides" the initial damage. For example, heavy spall and ring fracture have replaced the surface distress (surface micro spalling) created by inadequate lubrication.

A bearing consists of two rings (sometimes more), rolling elements and cages (not always), not just one unique element which is damaged. Clues can be found on the other elements and bearing history and operating conditions. So, do not forget to take pictures of the other elements as well.

Fig. 1: My current devices for taking photos

Which camera to use?

This is always the first question that I get asked, which is why I have put it at the beginning of this document.

My experience is based on nearly 30 years of taking pictures of damaged bearings with the cameras and smartphone shown in → **fig 1**, some are missing, have been given away, or are broken. From film to digital SLRs (Single Lens Reflex) through different compact cameras to a smartphone.

The first conclusion from my experience is that there is no need for an expensive professional SLR camera and lens. Of course, they are nice to have, but they are expensive, bulky and heavy.

Good compact cameras can do the job with sufficient image quality. They are easier to transport and you are not as anxious about damaging them in a workshop or outside. Mine is small enough to keep in my jacket pocket. I will not recommend any brand, neither will I offer a best buy. The first reason is that new models come on to the market every year and my recommendation would be quickly outdated. The second reason is that we do not all have the same priorities, and as no camera achieves best performance across all features, you have to choose a compromise.

However, I will list the minimum specifications that I recommend. But it will be at the end of this article since you need to understand the specifications first.

2. Some basics that you need to know

Noise

- All electrical or electronic devices create noise, which is an unwanted disturbance in an electrical signal. **Fig 2** shows the complete picture and → **fig 3, 4** and **5**, just a small cropped version. They are the same pictures, but with different camera settings.
- **Fig 3** shows a small part of a picture in which the electrical signal containing the picture information is much bigger than the noise. Noise cannot be seen and the picture looks sharp and detailed.
- **Fig 4** shows a small part of a picture in which the noise has increased relative to the signal. Information about picture colours and light intensity are disturbed. Sharpness and detail are decreased.
- **Fig 5** is the same picture as → **fig 4** but "noise reduction" has been applied to make the full picture look better for the average consumer. Noise reduction generally "smooths out" the picture and details are lost.

On a smartphone screen, without zooming in on the picture, the complete pictures used for → **fig 3, 4** and → **fig 5** look very similar and have the same quality. You need to zoom in or view them on a monitor to see the differences. For bearing failure investigations, you may need to increase picture size to see details and find clues for a RCFA.

Noise should be avoided when taking pictures of a damaged bearing.

Fig. 2: Large spall on a deep groove in a bearing inner ring. Application: industrial electrical motor

Fig. 3: No noise reduction, ISO 125, shutter speed 1/5 second

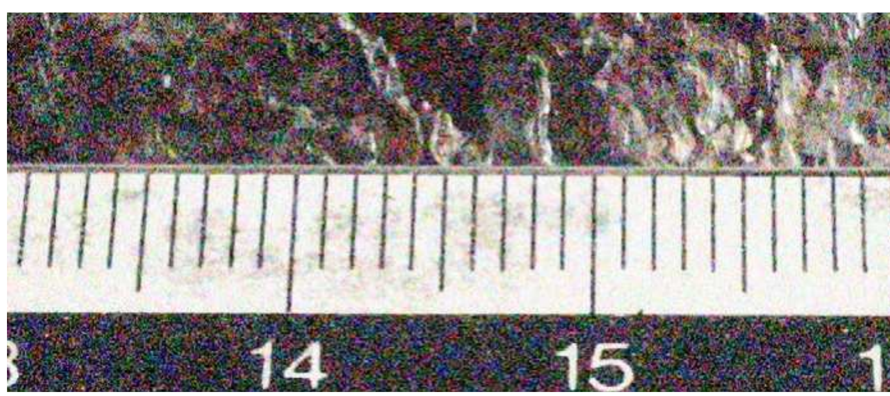


Fig. 4: No noise reduction, ISO 12800, Shutter speed 1/500s

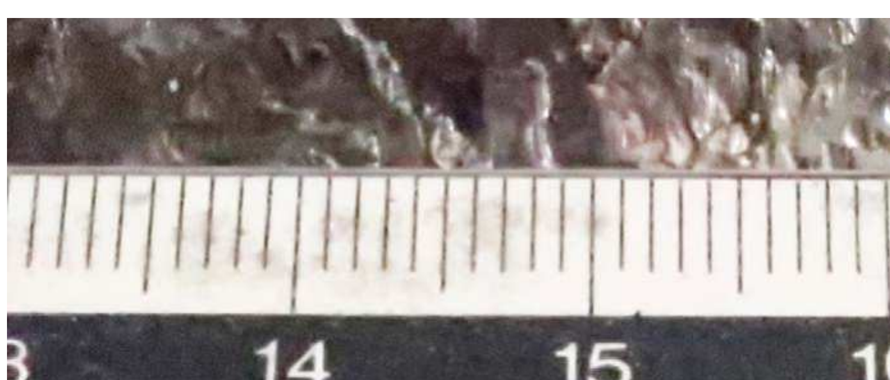


Fig. 5: Maximum noise reduction, ISO 12800, shutter speed 1/500s

Sensor

The sensor is the element that captures the light and transforms it into an electrical signal. The sensor uses several million tiny light cavities, also called photosites, that capture the photons. It is very similar to the retina of a human eye.

A 20-megapixel camera has a sensor containing many more cavities (photosites) than a camera which has 10 megapixels.

The larger the photosite, the more photons it can capture, and the more information about light intensity can be recorded. The sensor will be more capable of distinguishing colour shades. The signal will also be less influenced by the electronic noise. The photosite density, or in common photography language, the pixel density, is the number of pixels per unit of sensor surface.

My smartphone (year 2014) has 8 megapixels on a sensor surface of 15 mm^2. Density is 0.533 megapixels/mm^2.

My SLR (Single Lens Reflex) camera (year 2015) with full frame sensor has 24 megapixels on 860 mm^2. Density is 0.028 megapixels/mm^2.

There are about twenty more and much smaller photosites, per unit of surface, in my smartphone than in my SLR camera. My smartphone will be less able to distinguish colour shades and light, and will be much more sensitive to noise.

Note that the density on the compact camera (year 2017) that I use for taking pictures of damaged bearings during customer visits is 0.17 megapixels/mm^2.

The average consumer has assumed the bad habit of thinking that the more megapixels there are, the better the quality of the pictures, and the more details that are captured, but he forgets the sensor size influence.

Fig. 7: Camera at ISO 125, the lowest for that camera, on a tripod, and self-timer

Exposure

“Exposure” is the act of exposing the sensor to light.

The correct exposure is when the picture, or the detail that is considered as important, is not too dark or too bright. **Fig 6** shows the correct exposure in the middle, underexposure (too dark) on the left and overexposure (too bright) on the right. This will depend on the sensor’s sensitivity to light and the amount of light reaching the sensor.

The exposure can be automatic, the camera decides, or you can adjust some parameters to control the exposure. Chapter 8 will explain why you should learn to adjust exposure and not just rely on the camera program.

ISO number

The ISO number was created to give an indication of the sensitivity of the photographic film to light. A low ISO (such as ISO 100) means low sensitivity, and a high ISO (such as ISO 3200) means higher sensitivity to light, so you need less light to obtain the correct exposure. The ISO number has been kept for digital cameras to provide information about the sensor’s sensitivity to light using an equivalence to film sensitivity to make it easy for “older” photographers.

In digital cameras, sensors are designed to perform best at one ISO number, the lowest ISO number. **Fig 7** shows a camera set to the lowest ISO number. Increasing the sensitivity of the sensor, thus increasing the ISO number, is achieved by amplifying the signal. The drawback is that amplifying the signal means also amplifying the noise. **Fig 3** was taken with an ISO 125 while → **fig 4** was taken with an ISO 12800.

Fig. 6: The picture in the middle is the correct exposure

Fig. 8: f/3.5 on the left (wide open), f/22 on the right (closed as far as possible)

Shutter speed

The shutter speed is, to make it simple, the time the sensor is exposed to light.

Diaphragm or aperture

The quantity of light that is captured by the sensor can be controlled by adjusting the size of the hole that the light goes through. It is similar to the pupil of the human eye, which gets wider in the dark and narrower in light. **Fig 8** shows a camera lens with aperture wide open (f/3.5) on the left and closed to its smallest position on the right (f/22).

In camera information on how wide the hole is specified in f/N, such as f/2.8, f/8, etc., beginners are often puzzled when they learn that the smaller the value of N, the wider the hole. An aperture of f/2.8 lets more light reach the sensor than f/8! But in fact, f is the focal length (see below), and the focal length is divided by a number to give the diameter of the hole. Example: for a 50 mm focal length, 50/2.8 = 17.85 mm is bigger than 50/8 = 6.25 mm.

Important: Smartphones have just one aperture value. You cannot adjust the “hole” size. Exposure is only controlled by adjusting shutter speed and ISO.

Focal length

For the average consumer using a camera, focal length doesn’t mean much. They don’t know that zooming in (to make an object bigger in the picture) or zooming out (to have more of a landscape on the picture) changes the focal length. The focal length is specified in mm and is the distance between the lens and the sensor when the subject is in focus.

Zooming in increases the focal length.

Zooming out decreases the focal length.

Fig 9 and **10** are two pictures of the same subject, taken from the same distance, but with two different focal lengths. **Fig 11** explains why the picture seems closer.

It isn’t much of an issue that the focal length affects the perspective and deforms shapes (makes a line look like a curve) when performing an RCFA for a damaged bearing. But the focal length has an important effect on the depth of field and the aperture and should therefore be taken in consideration when taking pictures of damaged bearings.

Important: Smartphones, except premium ones, have one unique focal length. When zooming in to take a “closer” picture, the smartphone just crops the picture delivered by the sensor. When zooming in, you reduce the number of pixels in the final picture. You will not obtain a final picture with a more detailed subject by zooming in. The only way to obtain a more detailed subject, such as damage on the bearing surface, is to reduce the distance between the damage and the smartphone. Just a few smartphones have optical zoom.

Fig. 9: 60 mm focal length

Fig. 10: 105 mm focal length

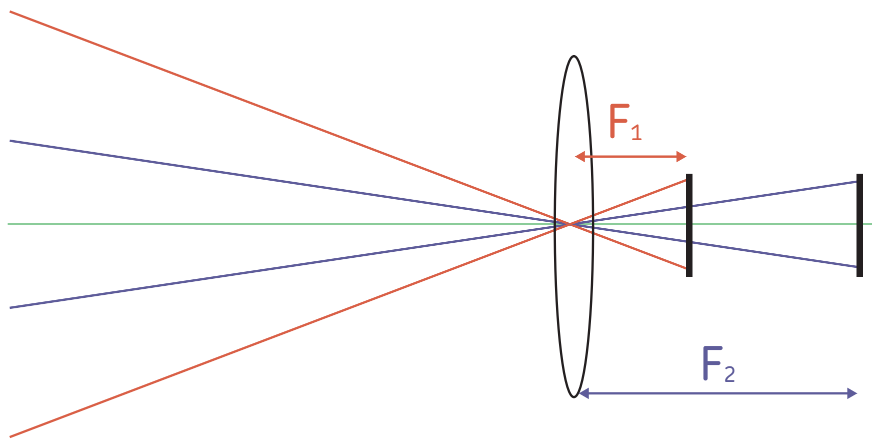


Fig. 11: The sensor placed at a focal length of F1 will have a wider view of what is in front of the lens than if the sensor were placed at a focal length of F2

Fig. 12: 105 mm lens, aperture at f/3.5

Fig. 13: 105 mm lens, aperture f/32

Depth of field

The depth of field is a distance within which objects appear acceptably sharp on an image. **Fig 12** shows a picture with small depth of field, while → **fig 13** shows the same subject with an extended depth of field.

Having a good depth of field allowing you to see all the damage and possible clues on a bearing is crucial.

For a camera, depth of field depends on focal length and aperture.

Opening the aperture (decreasing the f-number) decreases the depth of field, as in → **fig 12** and **13**. The reason for this is explained in → **fig 14**, in which a subject (a point) in front of the lens is slightly out of focus relative to the sensor. If the diaphragm is wide open the point will make a large dot on the sensor. If the diaphragm is almost closed, the dot on the sensor will be smaller and human eyes will see it as in focus.

Increasing the focal length decreases the depth of field. **Fig 9** and **10,** above, show two pictures with two different focal lengths, but the same aperture, which was set at f/3.5.

Note that on most smartphones, aperture and focal length are fixed. However, the focal length is very small, which gives a large depth of field. On my smartphone, the focal length is 3.9 mm, but because the sensor is very small, the picture looks like it has a 30 mm focal length lens on my full frame sensor SLR camera.

This is explained in → **fig 15**. To help consumers, camera specifications also give focal length for a camera as the equivalence of a full frame sensor, 24x36 mm. My compact camera is a 10.2 to 30.6 mm, which is equivalent to 28 to 84 mm.

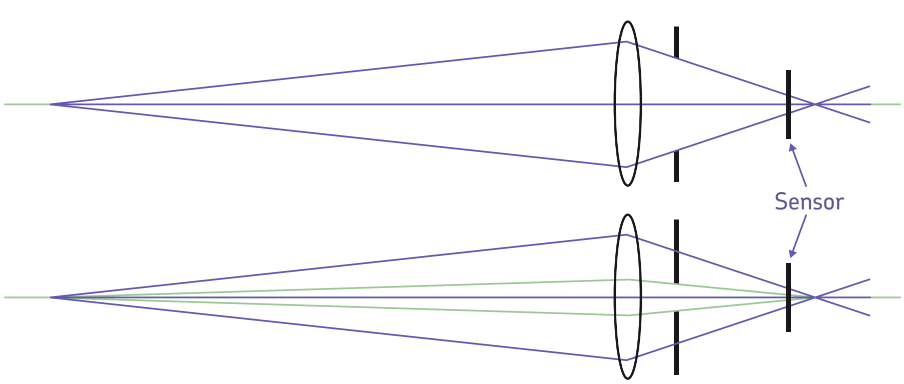


Fig. 14: Influence of the diaphragm (aperture) on image size of a point out of focus

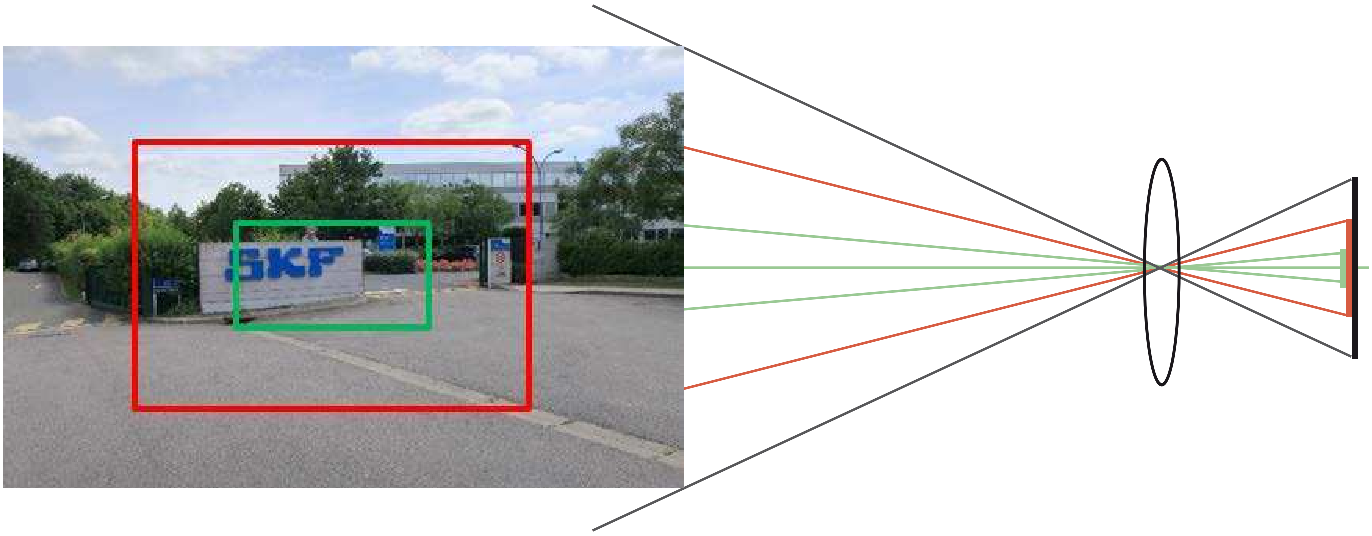


Fig. 15: With the same focal length, a smaller sensor only records a smaller portion of the picture, just as though it was zoomed in

3. It is all about light and the capacity of the camera sensor to distinguish subtle difference in colours

Light is the most important factor for photography. Artists play with the light or wait for the crucial moment when the sunlight will give the best results, often at dawn, never at noon. It is the same when taking pictures of damaged bearings, particularly because steel can be highly reflective.

Fig 16 shows the case of a half spherical roller bearing outer ring that suffered from abrasive wear. Placed in a direct light source, here the sun, the picture cannot be used to see the condition of the full surface of the raceway. Instead of the sun, the light source could be a lamp in the workshop or office. In addition, surrounding objects are also reflected. One solution, for example, is to place the ring in the shadow to avoid direct light sources and add a white sheet of paper to prevent any disturbance from reflections **(→ fig 17)**. In the old days, using tracing paper was quite common. It was a good accessory for diffusing light when placed between the light source and bearing. You can also just place your hand, or ask somebody to stand, between the light source and bearing as was done in **→ fig 18**.

Fig. 16: Bearing steel is reflective, so try to hide the light source and reflections of the surroundings

Fig. 17: A sheet of white paper helps prevent unwanted reflections

Light has to be captured by the sensor, but the sensor isn't able to reproduce the whole light scale, from full dark to very intense bright light that exists in nature. On → **fig 19** there are two bands of shades of grey. The top one represents the shade of grey that can be found in nature, the bottom one is what the sensor can deliver as feedback. Black on the final photo is in fact dark grey in reality, and white on the photo is light grey in reality. Depending on the camera setting for exposure, or in other words, depending on ISO, aperture and shutter speed, the below band will move to the left or to the right. The width of the bottom band is called the dynamic range. **Fig 20** shows two pictures. The top one has a large dynamic range, the bottom one has a lower dynamic range.

Important for bearing damage analysis:

1. The camera should be able to capture and restore the widest dynamic range possible. As a rule of thumb, between sensors of the same generation and technology, the one with the lowest pixel density has the widest dynamic range.
2. The camera should be able to deliver a picture file without too much information loss from what the sensor delivers. This will be explained in chapter 12.

Fig. 18: Left hand picture, light from a window was reflecting on the bearing raceway. Right hand picture, my wife stood between the bearing and window

Fig. 19

Fig. 20: The top picture has a wider dynamic range than the bottom one, some details are lost in the bottom picture

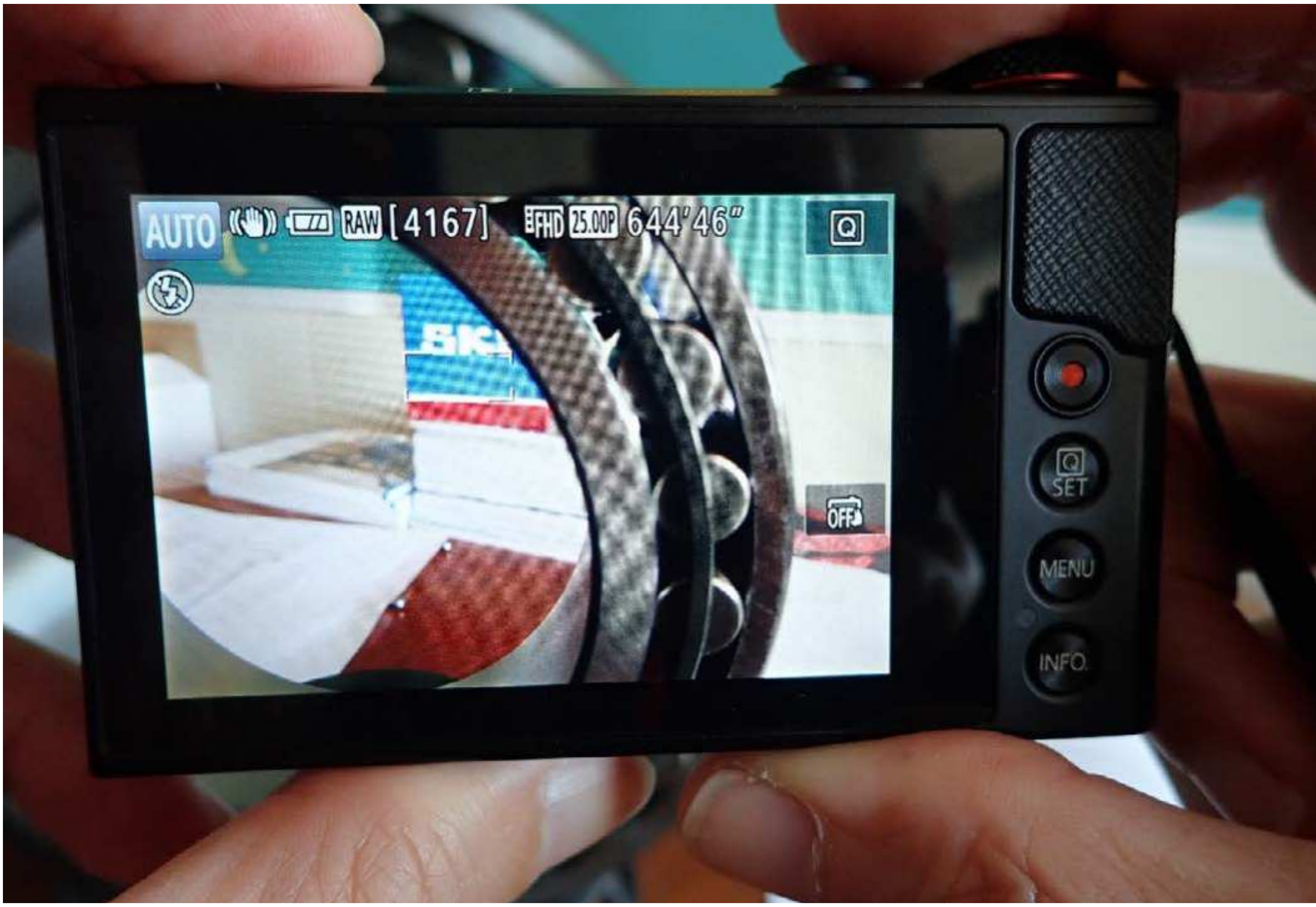


Fig. 21: Fully automatic mode, the focus icon (white rectangle corners) moves directly onto the background as soon as the bearing is moved slightly away from the middle of the screen

4. Avoid blur

Blur due to the camera being out of focus

When you do not adjust the focus manually, you rely on the camera's autofocus system. In some cases the autofocus has difficulties or is not able to focus correctly, or focuses on another subject. The main reasons for this are:

1 The user relies completely on the fully automatic mode of the camera.
2 There isn't enough contrast on the subject
3 User tries to take a close up picture but hasn't activated the macro mode
4 There isn't enough light

Fully automatic mode is primarily designed for average consumer use, such as taking pictures of friends, family or while on holiday. If a modern camera can choose where to focus, it will focus on a person, or subjects that are neither too far away nor too close, if there are several subjects at different distances. **Fig 21** shows my camera, in fully automatic mode, able to switch from normal focus to macro, but wanting to focus on the SKF box behind the bearing ring, when the ring should be the focal point. As the image on the camera screen is small, the ring could appear to be in focus. But on a computer monitor, where the picture is much larger, the box will be in focus and the ring blurred. Note that while taking the picture, if the bearing was more or less centred, with the box mostly hidden, the compact camera focused on the bearing designation for a few seconds, but then suddenly focused on the books behind.

First important rule: Do not rely on the fully automatic mode on your camera

Select the modes in which you choose the subject on which the camera focuses.

When a surface is only one colour, like a clean car body or the outer diameter of a new bearing, the camera will have difficulties focusing. The amount of light is also important. If a single-colour surface has a small visible scratch, thus giving a variation of colour, the camera may be able to focus on the scratch or not depending of the amount of light and the extent of the variation in colour created by the scratch.

One way to help the camera is to add a thin object of a different colour close to the bearing damage, where the camera will focus on the object edge.

Fig. 22: A ruler helps to focus and gives an indication of dimensions

Fig. 23: A business card can give a strong contrast and help the camera to focus

Fig 22 shows a ruler giving a black grey contrast and → **fig 23** shows a business card giving a white/grey contrast, both on a bearing raceway with surface distress. The ruler can be left in place when the picture is taken to give an idea of the size of the damage. The business card can be removed before taking the picture. On most cameras, you can press slightly on the shutter button to allow the camera to focus without taking the picture. Once the camera has focused, keep the shutter button in the same position, don't move the camera. Remove the business card and press the shutter button fully to take the picture.

Blur due to photographer movements when holding the camera by hand

Blur due to photographer movements is caused by the fact that the shutter speed is too low relative to the photographer's ability to hold the camera still. Cameras in fully automatic mode or ISO Auto mode and all smartphones/tablets will increase ISO or activate in-built flash if the calculated shutter speed is considered to be too low.

This also depends on the focal length used. The higher the focal length, the higher the speed needs to be. If you have any experience of binoculars, you know that a highly magnified image is less stable when holding the binoculars by hand than when you have less magnification. It also depends on sensor size and number of photosites. Hopefully, the camera's integrated image stabilizer helps you use lower shutter speeds without blur. The old rules for avoiding blur, such as that minimum speed should be the inverse of the focal length (i.e. a 50 mm focal length gives 1/50 s minimum shutter speed) are now obsolete.

Use of a tripod and self-timer is recommended, see chapter 11. But taking pictures with a handheld camera is much quicker, so I recommend checking the slowest shutter speed you can use without blur. The checking procedure is quite simple and gives a good estimation for modern compact cameras:

1 Take a piece of paper with printed text on it, like a newspaper, and pin it on a wall in a room without too much light.
2 The amount of light must be sufficient for you to be able to take several photos, starting at 1/60 second and decreasing the shutter speed in steps down to 1/8 seconds, with a correct exposure, without changing ISO number, which is at the lowest setting, and maximum focal length. Use the shutter speed priority mode on your camera. The aperture will be chosen automatically. The surrounding light must be such that the camera is still in the aperture range and giving the same exposure at 1/60s and at 1/8s.
3 Take five pictures of the text at 1/60s, five at 1/30s, five at 1/15s and five at 1/8s, without your arms or any part of your body resting on a support to make it more difficult.
4 You can repeat for lower focal lengths, but the results at the maximum focal length will put you on the safe side.
5 The shutter speed at which the five pictures do not give any sign of blur due to camera movement will be your minimum shutter speed for handheld situations.

Important 1: for the same person, minimum shutter speed will vary depending on the camera.

Important 2: SLR cameras and bridge cameras can be equipped with a lens that has a long focal length, and a higher shutter speed than 1/60s could be needed.

Blur due to the camera

SLR cameras have a mirror that moves upwards before the shutter opens to let light reach the sensor, and then moves back downwards after the shutter closes. The mirror can create small internal vibrations that will create blur, even if the camera is on a heavy tripod. This can happen when the shutter speed is somewhere around 1 second to 1/20 second. If a picture has to be taken using these speeds, use the mirror lock-up feature (read the owner's manual…).

5. Avoid electronic noise

With electronic noise, details that could give a clue on the root cause of the damage vanish. Pictures of damaged bearings should be taken with camera set at its lowest ISO value. Depending on the camera, exceptions can be permitted as loss of detail can be considered acceptable up to a certain ISO value.

With my SLR camera, I know that I can work up to ISO 800.

With my compact camera, I try to keep ISO below 250.

With my smartphone, I just avoid using it.

These maximum ISO values that I have fixed are done after some tests.

For those who just have a smartphone and consider it sufficient, please note that in general the OEM camera App doesn't allow you to control speed and ISO. It just keeps to the lowest ISO value until it considers that the shutter speed is too low for an average user and that there is a risk of blur due to camera movement. In the majority of cases, there isn't enough light in workshops, so the ISO value increases rapidly without any warning.

Aftermarket Apps like the one shown in → **fig 24** allow you to know the ISO and shutter speed at which the picture will be taken (shown in the red box on the left), and even set an ISO value or a shutter speed value (shown in the red box on the right).

Setting the camera at the lowest ISO value in low light conditions will either make it necessary to open the aperture or/and decrease the speed, with the risk of losing depth of field and/or having blur when holding the camera by hand.

It is best to use a tripod so you can set the camera at the lowest ISO value and set the aperture that you want, without low shutter speed being an issue any more.

Fig. 24: Smartphone with aftermarket camera App giving information and control over ISO and shutter speed

6. Increase depth of field

The depth of field will depend on:

1 The focal length: the depth of field increases as the focal length decreases. Note that small sensors will give the same picture as big sensors but with a smaller focal length. So, as a short cut, smartphones have a larger depth of field than an SLR camera with full frame sensors.
2 The aperture: the depth of field increases as the hole created by the diaphragm decreases (the aperture number increases)
3 The distance between the camera and the subject: the depth of field increases as the distance increases.

To get the maximum details of a bearing damage, we tend to position the camera as close as possible to the damage and zoom in (increase the focal length), so we reduce the depth of field.

The only way to have a decent depth of field, if needed, is to close the diaphragm (increase aperture number), and this will of course reduce the amount of light and make it necessary to reduce the shutter speed. Remember that we do not want to increase the ISO number.

In most cases, a tripod and/or additional light would be recommended.

Some could argue that smartphones have a large depth of field, so they would be a good choice in this case. But in my opinion, they are too sensitive to electronic noise and don't have as wide a dynamic range.

One interesting technology that I first saw on an electron microscope, and more recently on a compact camera, is taking several pictures with different focal points and then merging the sharp parts of each picture into one unique picture. I bought such a camera this year.

7. Macro mode

When taking close up pictures, the camera should have its autofocus set in the macro mode. The macro mode is generally an icon that looks like a flower, → **fig 25**. But this is not true all the time. My second compact camera has a microscope as an icon.

One trap when choosing a camera is to rely on commercial brochures or reviews that give only the minimum focus distance in macro mode without any other information. Cameras that have the same minimum focus distance at all focal ranges are rare. In general, the minimum focus distance is given at the smaller focal length. Most cameras, but not all, have a minimum focus distance that increases with the focal length. My second compact camera has the same minimum distance focus across the full focal range.

This means that if you want to zoom in to make the subject bigger on the screen, you have to move the camera away from the subject to allow the camera to focus.

With the camera shown in → **fig 25**, the minimum distance is 5 cm at minimum focal length, producing the picture in → **fig 26**. Zooming in to maximum focal length means positioning the camera at a distance of 35 cm, producing the picture in → **fig 27**. In this case, the roller face is bigger on the picture without zoom! In other words, if you want maximum details when putting the camera as close as possible to the subject, you must not zoom in, but keep the lower focal length. This is not a general rule.

Setting the camera at small focal length (wide angle) can make the edge of the picture look blurred while the centre is sharp. This is the case with my two compact cameras. **Fig 28** shows the case for one camera and → **fig 29** shows the case for the second camera, which has a better macro mode.

Fig. 25: Macro mode (little flower top right), ISO 125, the lowest for this camera to avoid noise, aperture close to its maximum for maximum depth of field, self-timer and tripod. Note that depth of field is smaller on the camera screen than it is on the final picture (fig 26) because the aperture is wide open during setting and will close only when pressing the shutter button

Fig. 26: Focal length: 10.2 mm: focus distance 5 cm

Fig. 27: Focal length: 30 mm: focus distance 35 cm

Fig. 28: Compact camera 1: maximum close up, sharp in centre, blurred on the edges

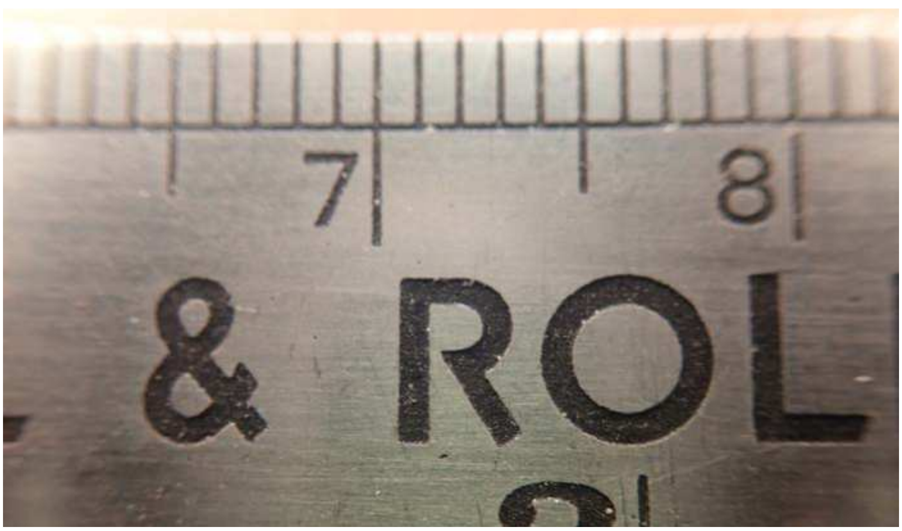


Fig. 29: Compact camera 2: maximum close up, normal mode, sharp in centre, blurred on the edges

Fig. 30

Fig. 31:

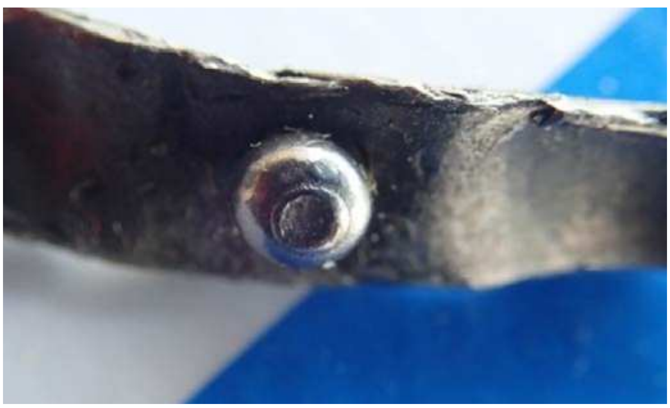


Fig. 32: Picture taken with just one picture, the depth of field is short

Fig. 33: Picture created by merging different pictures with different focus distances

Increasing the focal length reduces the optical deformation, but, unless you have expensive professional lenses on an SLR, the aperture decreases, so for the same ISO, the shutter speed needs to be decreased to obtain the same exposure. My recommendation is to use a tripod and increase the focal length a bit; there is no need to use maximum focal length.

Taking pictures with an extreme close up gives very short depth of field.

Fig 30 shows a piece from a cage coming from a deep groove ball bearing, taken with my camera 1 which has “poor macro mode”. The piece of cage has no blurring. But with my second camera “2”, that has a good macro mode, only the rivet head is sharp (→ **fig 31**), even with the diaphragm closed to its maximum.

One way to avoid blurring in close ups is to take several pictures with different focus distances and let a software merge the pictures, keeping only the sharp part of each.

Fig 32 is a picture taken with just one picture, the depth of field is short.

Fig 33 is a picture made up of several pictures merged together. The pictures are merged by internal camera software.

Is macro mode with outstanding close up necessary?

For damaged bearings, in more than 95% of all cases (my estimation), the answer is no. For the rest, with some exceptions, it isn't outstanding camera macro performances that will help, but electronic microscopes. This is my humble opinion and I can already hear colleagues who will not agree.

Let's look at one example, the spall from a CARB toroidal bearing, paper machine drying cylinder application, outer ring raceway. The ring is used as subject for several pictures in this document. We want to focus on one part of the spall that can give a clue to the root cause of the damage.

Camera 1 with poor macro mode gives its maximum close up as shown in → **fig 34**. As camera 2 has a better macro mode, it is possible to get the part of the spall that we want to focus on as the whole picture, → **fig 35**.

Note that → **fig 35** is a picture created by merging several pictures to have good depth of field, unfortunately the result is only a jpeg file, so white balance wasn't corrected. **Fig 35** seems great, and it is, as it shows clearly how the subsurface fatigue developed axially and not in the rolling direction as for normal rolling contact fatigue.

But if you zoom in on → **fig 34**, the picture from camera 1 with poor macro mode, and crop the picture, you come to the same conclusions as shown in → **fig 35**. See → **fig 36**. The camera with poor macro mode just needs to have enough megapixels.

Fig. 34: Maximum close up with camera 1

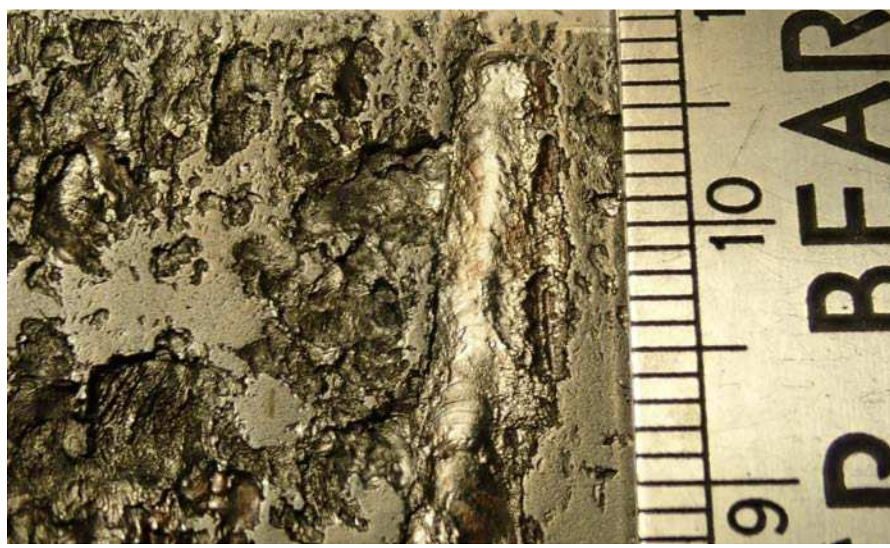


Fig. 35

Fig. 36: Fig 35 on the right and cropped version of fig 34 on the left

8. Exposure: the traps of the full auto mode

The exposure, that is the choice of aperture and shutter speed for a given ISO number by the camera, is set to give an average mid-tone or average brightness if the picture were in black and white.

Taking a picture of snow in fully automatic mode will make the snow appear to be an average grey in the picture. Taking a picture of a black wall in the same mode will give a grey, not a black, wall.

Here are two pictures of a bearing ring, bright colour, and a V-ring, dark colour. The two pictures are taken with exposure in automatic mode.

Fig 37, the background is a white piece of paper. As the white background covers most of the picture, the final picture will be darker than reality, the paper looks light grey, not white. The V-ring, which is dark, appears darker, and the markings are more difficult to read.

Fig 38, the background is black tissue. As the black background covers most of the picture, the final picture will be brighter than reality, the tissue looks dark grey, not black. The V-ring, which is dark, gets brighter, and all marking is easy to read while the ring surface is too bright with loss of some information.

In conclusion, if you do not want to set exposure manually or take time to modify your picture afterwards, i.e. you just want to point and shoot in fully automatic mode follow this rule:

Dark subjects should be on a dark background if the background covers most of the picture.

Bright subjects should be on a bright background if the background covers most of the picture.

It is important to have the correct exposure for the damage in order to provide a clue of the root cause.

You cannot always take a macro photo showing just the damage on the picture. You will often have to take a picture with the surroundings, like → **fig 26 and 27**, and then zoom in for the final picture. If I had just relied on the automatic exposure, the roller face would be too dark as the surrounding is quite bright.

Fig. 37

Fig. 38

Three potential solutions are to:

- modify the exposure setting on the camera
- modify the exposure mode setting on the camera
- modify the picture on your computer. In this last case the exposure should not be too different between the picture taken by the camera, and the one that should give a clear view of the damage. More explanations in chapter 12.

With my compact camera, it is faster to change the exposure setting, to either underexpose or overexpose the picture. But I often make a final adjustment on the computer.

On my SLR, changing the setting (ISO, Speed, aperture, focus mode, exposure mode, etc.) is quite quick, and there is no need to go into a menu or look at the rear screen. Most often I would change the exposure mode, moving from full picture exposure metering, to central or spot metering, where the exposure is calculated just for the detail that I'm focusing on.

9. Use of the camera's integrated flash

Main rule: do not use the camera's integrated flash on a bearing as steel will reflect the light.

Exception: If there is very bright light source, like the sun (→ **fig 39**), and the part you want to show is in the shadow:

- either adjust the camera to expose the part in the shadow correctly, which will overexpose the part in the sun
- or use the flash to remove the shadow (→ **fig 40**)

Note that I have never tried the annular lightning that is an option on my camera 2 with good macro mode. It is an interesting option for taking macros with the camera very close to the subject as the camera hides surrounding light. I do not know how the light reflects off the bearing steel. I will have to buy one and test it.

Fig. 39: Bearing ring in the sun, spall in the shadow

Fig. 40: Same picture as fig 39, but with use of flash

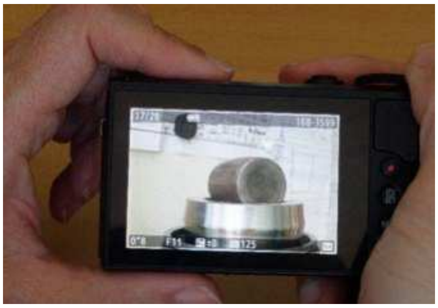


Fig. 41

Fig. 42

10. Check your picture quality

As a camera screen is small, parts of a picture which are out of focus (blurred), may appear to be in focus (sharp). If ambient light is too bright, it will make it more difficult to see if the picture is in focus or not.

Once in front of your computer, with the picture at full size, you discover that the picture of the details that you wanted to show are out of focus.

Make it a habit to always look at the pictures you have taken. Zoom in on the picture to check the quality, → **fig 41**, full picture on the camera after it has been taken, → **fig 42** shows that zooming in on the picture helps to check its quality (no blurring).

Be aware that the picture on the camera's rear screen is a low quality copy of the final picture. In time, you will be able to estimate whether a picture really has a small blur or if it is just the low quality of the copy on the screen. In case of doubt, take another picture, double checking focus and shutter speed.

11. Your best friend is a tripod

Use a tripod so you can reduce the shutter speed and keep a low ISO, even in low light. Tripods are also available for smartphones.

Fig 43 shows my colleague taking a picture holding his smartphone by hand. To avoid blur, since there was not enough light, the smartphone automatically increased the ISO number, which created noise. Noise reduction created smoothing on the final picture.

Fig 44 shows my camera on its articulated tripod, keeping its lowest ISO number and a shutter speed of 0.3 seconds. The final image is sharp without noise and smoothing.

If there is no tripod, and there is a risk of blur due to camera movement, if possible, try to stand the camera/or smartphone in a fixed position in front of the subject.

Fig 45 shows the smartphone held still, set at its lowest ISO, which is ISO 32, with self-timer in operation.

When the camera is on a tripod or standing on another support, always use the self-timer, set for five seconds or more, to avoid any camera movement, or blur, when pressing the shutter button. I usually set the self-timer for 10 seconds, so if the camera moves after I press the shutter button, I still have enough time to reposition it before the photo is taken.

Fig. 43

Fig. 44

Fig. 45

Fig. 46

Fig. 47

Fig. 48: If you do not see any differences between the two pictures, increase the size of the document!

12. Why use RAW instead of jpeg?

I now always take pictures in RAW file format after I had an issue with a lens on my SLR 11 years ago. The diaphragm was stuck wide open leading to overexposure. Luckily, I managed to save the picture which I thought I would never be able to do. **Fig 46** was the original overexposed picture, → **fig 47** is the picture after rescue with a special software. I would not have been able to save the picture if it were a jpeg.

RAW is a picture file with no or minimal changes, directly from the sensor. The RAW file is like the negative of a film.

A jpeg is a picture file from the sensor that the camera has internally transformed and compressed. A jpeg is like the photo on paper, created by a lab from the film negative.

There is one main difference, which is important when taking pictures of damaged bearings, and that is the number of bits of the files. In computer science a bit is a 0 or a 1. A sensor receives light and transforms it into information composed of zeros and ones. If the information given by each photosite is coded as just one bit, the information can only be a 0 or a 1, so only two tones like black and white. If there are two bits, the information can be 00, 01, 10 or 11, so four tones such as black, dark grey, light grey and white.

Jpeg files out of the camera or smartphones are coded in 8 bits, so 256 possible tones.

Cameras can deliver different quality jpeg pictures. You can choose the size of the final picture and its compression. By default, the camera generally delivers a fine jpeg with low compression, and if the picture is for damage analysis, it should stay in fine quality with minimal compression as there is less loss of information.

Note that a jpeg is already a compressed file, even at its maximum quality settings.

RAW files can be coded in 12 bits, 14 bits or even more depending on the camera. My compact camera delivers a 14 bit RAW file, so 16384 possible tones per photosite. A RAW file contains much more information and is more able to differentiate two very close colours in the grey shade.

Essentially, if a landscape has two stones next to each other with very similar colours, the RAW file will record the two different colours and you can see that there are two stones in the final picture. The jpeg file will record the two colours as being the same colour and you will not be able to see that there are two stones. The more the jpeg is compressed, the more two similar colours are considered as one. → **Fig 48** shows what happens when compressing a picture file. On the left is the fine jpeg of 396 kB and the same picture compressed to be only 40 kB. The pixels between the 6 and the 3, and between the 9 and the 12, have very similar colours and once compressed the information is lost.

A RAW file has drawbacks: RAW files are quite heavy files. Pictures taken with my compact camera to illustrate this issue of Pulp & Paper Practices are between 25 and 40 MB each.

RAW files need special software to be read. Each camera OEM, with some exceptions, has its own type of RAW file. RAW files cannot be read by colleagues, suppliers or customers if they do not have the correct software. Additional time is needed, after taking a picture to transform it into a jpeg file/photo that everybody can read/see.

If the subject or the damage is well exposed when taking the picture, a RAW file isn't really necessary. I use RAW files when possible because I want to be able to change the exposure afterwards.

In some cases, I underexpose on purpose, when I use take the picture with a handheld camera, in order to have a higher shutter speed and avoid blur. For example, when I see that I'm already at ISO 300 with my compact camera and have a 1/8s shutter speed. I know that I will have a blurred picture because 1/8s is too slow for me. By reducing the exposure, I can move into the speed range I'm comfortable with, like 1/30s. The picture is dark, but once the picture file is on my computer, I will change the exposure.

Fig 49 shows the picture as exposed when the photo was taken.

Fig 50 is the result of the exposure change from the RAW file.

Fig 51 is the result of the exposure change from the jpeg file.

Fig. 49: Picture underexposed on purpose to increase shutter speed and avoid blur

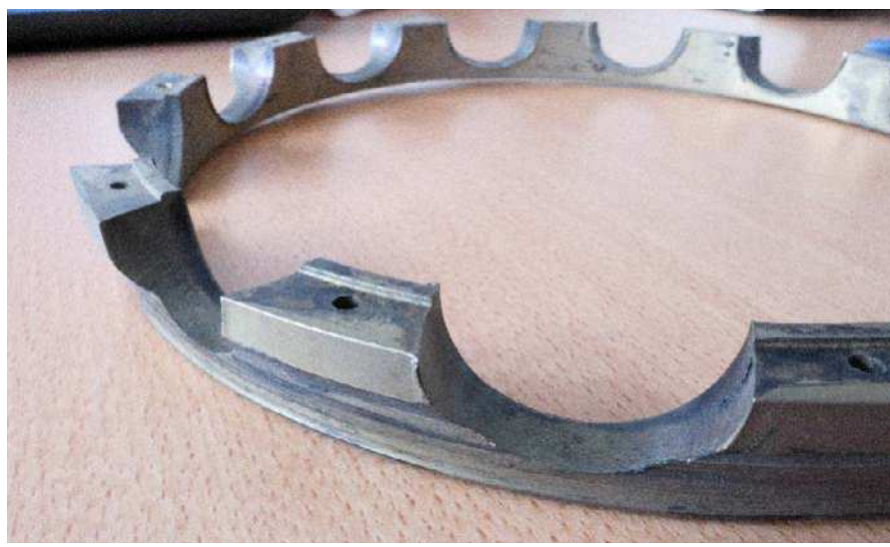


Fig. 50: Fig 49 with exposure increase, from a RAW file

Fig. 51: Fig 49 with exposure increase from a jpeg file: due to less information, dynamic range is reduced compared to fig 50, details are lost in the bright zones at this new exposure

Fig. 52: The picture on the left is the original picture of the bottom of a digester in a pulp mill, with orange light from the artificial lighting, in the picture on the right, the white balance is adjusted using the white paper located on the bottom right

13. White balance

Adjusting white balance gives back the realistic colour of the subject, as if it were in normal daylight. A picture taken in the shadow will tend to be bluer than in reality. A picture taken near a candle will look more orange than in reality. By reality, I mean what our brain sees. Our brain makes some white balance adjustment. If you concentrate you will be able to see the colour changes depending on the light source (direct sun, indirect sun, etc).

Taking care of white balance isn't always necessary when taking pictures of damaged bearings. It could be interesting when, for example, taking pictures of a grease lubricated bearing where the colour of the grease could give a clue. Automatic white balance modes do quite a good job on modern cameras, but they do make errors, especially in artificial lighting depending on the subject.

I always leave my camera set to automatic white balance and correct it on my computer. You need to use RAW, not jpeg. I will not explain how I adjust it using elements in the picture that have neutral colour (piece of white paper, clean bearing steel), but I will show one example, → **fig 52**.

Be aware that nearly all computer monitors for office and family use are adjusted to be too bright and too blue. For real colours, you must adjust the colour settings for the monitor.

Fig. 53

14. Minimum camera specifications

Smartphones have a great depth of field, and nearly everyone has one. But the sensor is too sensitive to noise and the dynamic range is limited. I do not recommend relying on smartphones.

SLRs with specific macro lenses take very nice pictures and are nice to use, but they are expensive, heavy and need a heavy tripod. If you have one in your office and do not need to travel with it, then why not.

I recommend a compact camera, with a light articulated tripod.

1. The camera should be able to deliver RAW picture files
2. Concerning sensor size and number of megapixels, I'm quite uncomfortable recommending anything, as a small sensor gives a wider depth of field than a larger one, but larger ones (with same number of pixels) are less sensitive to noise. I would tend to state that if it is your only compact camera and you could also use it for taking pictures of friends/family during the evening, go for a sensor with a pixel density below 0.25 megapixels/mm^2. If you need the camera to take pictures of still subjects such as damaged bearings using a tripod to keep low ISO in low light, then you can opt for a sensor with higher density, but try to stay below around 0.40 megapixels/mm^2.
3. A tough camera, shockproof, waterproof (to a certain extent), that can be easily cleaned.
4. Offers full manual control allowing you to set ISO, aperture and shutter speed as you want.
5. For the macro mode, do not make a decision solely on the basis of the minimum focus distance. Focal length and sensor number of photosites are also important. Try to get your hands on the camera and take pictures before buying it. Search reviews online.
6. An articulated rear screen is an advantage in some situations, but it makes the camera thicker

As result, I have two compact cameras. I couldn't find a tough camera with good macro mode and full manual control with top performance for noise reduction at high ISO.

My choice is an expert compact camera without articulated screen, so it fits in my pocket, even though it isn't tough and doesn't have a very good macro mode.

My colleague, head of SKF France's application engineering service, prefers a compact camera with articulated screen and good macro mode. He still uses his old 5.1 megapixel camera to take pictures of bearing damage, → **fig 53**. Between my expert camera with poor macro mode or my tough camera with good macro mode, his choice is the tough one because of its macro mode.

One of my former colleagues, now working for one of the main pulp & paper OEMs, had other priorities in addition to a good macro mode. He wanted a simple point and shoot camera with the option of taking slow motion and/or 4K video. He bought the same camera as my tough camera.

15. Sending pictures

Sending full pictures without compression can be an issue since picture weight could be 10 MB or even more for compact cameras. Ten pictures of a damaged bearing attached to an email, so around 100 MB, can be problematic.

Compressing the picture to reduce weight isn't always the best idea as quality decreases and clues can vanish.

It is best to compress the pictures giving an overall view.

For the details, just crop the original picture and do not reduce quality when saving the cropped version. For example, → **fig 34** is 20.8 MB, but the cropped version of that picture, seen on the left of → **fig 36** is 0.54 MB without reduction in quality, 40 times less in weight.

Philippe Gachet, Senior Application Expert, SKF Application Competence Centre, philippe.gachet@skf.com

16. Conclusions and main recommendations

I hope that this Pulp & Paper Practice has provided you with knowledge on what is important when taking pictures of a damaged bearing. Wide depth of field, no blur due to camera movement, correct exposure of the detail that might provide a clue and no electronic noise are the main points that you want to observe.

Finally, my top recommendations:

- Never set your camera to fully automatic mode.
- Avoid built-in flash. Avoid light reflection off the bearing steel.
- Set your camera to the lowest ISO number
- Always check the shutter speed when holding the camera to take a picture.
- Close the diaphragm for maximum depth of field. It does not always need to close to its maximum.
- Always have a small articulated tripod in your bag, just in case the shutter speed is too low.
- Always zoom in on the picture that you have taken to check quality.
- And read the manual for your camera

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PUB 11147/23 EN · September 2018